Litter Productivity Dynamics in Segara Anakan Mangrove Forest, Cilacap, Indonesia

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Abstract

Mangrove litter is a critical component of the nutrient cycle, reflecting soil fertility and water quality within the mangrove ecosystem. This study investigates the dynamics of litter productivity in the Segara Anakan mangrove forest in Cilacap. The study area is divided into two locations with three points, with five litter traps installed at each point. Sonneratia caseolaris dominates vegetation characteristics at Station 1, while Station 2 has more diverse vegetation, including Sonneratia caseolaris, Aegiceras corniculatum, Acanthus ilicifolius, Derris trifoliata, Rhizophora mucronata, Avicennia alba, and Avicennia marina. Sampling follows seasonal changes in Indonesia, covering June 2023 to March 2024. The primary data for this study include aboveground litterfall production, estimated using litter traps, and the litter layer on the forest floor collected through soil transects. Secondary data comprise weather measurements, including air temperature, rainfall, wind speed, and humidity. Litterfall and litter layer were collected four times: June (dry season), September (transition from dry to rainy season), December (rainy season), and March (transition from rainy to dry season). The results indicate a total litter productivity of 18.99 tonnes ha^{-1} yr^{-1}. The lowest litter production was observed in September, while the highest was in March. Leaf litter contributed the most, accounting for 71.49%, followed by twigs at 19.19%, flowers/fruits at 8.31%, stipules at 0.62%, and the lowest portion from other unidentified materials at 0.39%. Litter productivity shows a strong correlation (0.99) with rainfall. The main factors influencing litter productivity include environmental factors, primarily rainfall, and physiological factors, such as flowering and fruiting phenology.

Keywords: *annual life cycle; litter; mangrove; rainfall; Segara Anakan*

Introduction

The mangrove ecosystem is a unique environment situated at the transition between land and sea. It serves multiple functions that benefit human life and the various species inhabiting its surroundings. Ecologically, mangrove ecosystems function as nursery grounds, feeding grounds, and spawning grounds for numerous marine species (Marlianingrum *et al*., 2021; Bimrah *et al*., 2022). Mangrove forests protect coastal areas by minimizing the adverse effects of natural disasters, such as floods, storms, and tsunamis, and reducing erosion (Akram *et al*., 2023). Additionally, mangroves play an essential role in capturing atmospheric carbon dioxide (CO_2) through photosynthesis, storing it in biomass both above ground (in trunks and leaves) and below ground (in roots and soil) (Rovai *et al*., 2021; Arifanti *et al*., 2022; Paul *et al*., 2022;). Due to its essential function, mangroves are critical for climate change mitigation through long-term carbon storage, called blue carbon. Globally, mangrove forests store approximately 11.7 Pg of carbon (1.6 Pg C in aboveground biomass and 10.2 Pg C in below-ground biomass) (Kauffman *et al*., 2020). The important function of mangroves in storing carbon and supporting their ecosystem cannot be separated from the role of litter, which is the main source of organic material for the energy and nutrient cycles within them.

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Litterfall is an integral component of the mangrove ecosystem. Mangrove leaf litter provides the primary source of organic matter for energy and nutrient cycling within mangrove areas (Lin *et al.*, 2023; Hernandez and Park, 2024). This leaf litter plays a crucial role in maintaining ecosystem productivity by supplying nutrients to microorganisms and macrofauna, thus supporting the food web within the ecosystem. Through decomposition by microbes and detritivores, mangrove leaf litter breaks down into more straightforward organic matter, releasing nutrients like nitrogen (Mandal *et al.*, 2013), phosphorus, and carbon (Sánchez-Andrés *et al.*, 2010; Kamruzzaman *et al.*, 2019). This process helps maintain soil and water fertility in mangrove regions, promotes mangrove growth, and provides an essential nutrient source for marine organisms.

Indonesia's mangrove forests experienced a loss of 261.141 ha, with 70% of this damage due to deforestation and 30% to degradation between 2009–2019 (Arifanti *et al.*, 2022). The highest deforestation rates occurred in Kalimantan, Sulawesi, Sumatra, Bali Nusa Tenggara, Papua, Java, and the Maluku Islands. One of the most extensive mangrove forests on Java Island, the Segara Anakan Mangrove Forest in Cilacap, has also undergone significant changes due to land conversion and sedimentation (Dewi *et al.*, 2016). The balance between litter production and decomposition rate plays a crucial role in determining the extent to which an ecosystem functions as an energy flow. Research on litter productivity in the Segara Anakan mangrove forest was previously conducted in 2002, yielding an average total litter production of 1.08 tonnes ha^{-1} mo^{-1} (Siswanto, 2003). In a different location, a study in Mempawah, West Kalimantan, estimated litter productivity at 8.07 tonnes ha^{-1} yr^{-1} (Rafdinal *et al.*, 2021). Meanwhile, the estimated productivity in Laguna El Soldado, California Bay, was 14.8±3.6 $g.m^{-2}$ mo^{-1} (Torres *et al.*, 2022). Factors influencing litter productivity include forest-type (Arreola-Lizárraga *et al.*, 2004), vegetation structure patterns (Dewiyanti *et al.*, 2019; Muliawan *et al.*, 2020), tree age (Purnobasuki *et al.*, 2022; Dali, 2023), herbivorous activity (Giweta, 2020), phenology (Sharma *et al.*, 2012; Mchenga and Ali, 2017; Kamruzzaman *et al.*, 2019), anthropogenic activities (such as deforestation and agriculture) (Rudianto *et al.*, 2020), and environmental conditions (temperature, rainfall, wind speed, and humidity levels) (Imgraben and Dittmann, 2008; Mukherjee *et al.*, 2019; Azad *et al.*, 2021; Hernandez and Park, 2024), as well as nutrient availability (Zhu *et al.*, 2019; Qiu *et al.*, 2023). This study aims to assess litter productivity in relation to seasonal dynamics in Indonesia. A deeper understanding of these processes will provide essential insights into litter's contribution to the nutrient cycle and the overall balance of the mangrove ecosystem, which is particularly critical given the increasing impacts of climate change and human activity on coastal regions.

Materials and Methods

The research was conducted from June 2023 to March 2024 at the Segara Anakan mangrove forest, Cilacap, Indonesia. The Segara Anakan mangrove forest is a natural mangrove forest with various mangrove species. The water conditions are influenced by tidal movements and the confluence of several rivers, resulting in low salinity levels at the research location, ranging from 4‰ to 8‰ (Kresnasari and Gitarama, 2021; Cahyo *et al.*, 2024). As a reference, in 2022, the highest rainfall occurred in November at 799.60 $mm.yr^{-1}$, and the lowest was in May at 0.201 $mm.yr^{-1}$. The highest humidity was recorded in November at 87%, while the lowest was in January at 81.9%. The highest temperature was recorded in May at 28.3°C and the lowest in October at 26.5°C. The average highest wind speed was recorded in August at 5.9 knots, and the lowest was in February and November at 2.3 knots (BPS Kabupaten Cilacap, 2023).

There are two research locations, namely the eastern (St 1) and western (St 2) parts of the Segara Anakan lagoon (Figure 1). Each station has three points, and each point has five litter traps installed. The stations are named St 1.1 (7°39'57.9" S – 108°51'14.1" E), St 1.2 (7°40'50.2" S – 108°52'16.5" E), St 1.3 (7°41'54.4" S – 108°52'46.3" E) for Station 1 and St 2.1 (7°39'34.3" S – 108°50'18.1" E), St 2.2 (7°40'11.0" S – 108°50'28.9" E), St 2.3(7°40'49.9" S – 108°48'39.7" E) for Station 2. Based on a preliminary survey, the dominant vegetation at St 1.1, St 1.2, and St 1.3 is *Sonneratia caseolaris*, while St 2 has more diverse vegetation. The dominant tree vegetation at St 2.1 includes *S. caseolaris* and *Aegiceras corniculatum*, along with highly dominant associated mangroves such as *Acanthus ilicifolius* and *Derris trifoliata*. At St 2.2, the dominant vegetation is *S. caseolaris* and *Rhizophora mucronata*. At St 2.3, the dominant vegetation is *Avicennia alba* and *Avicennia marina*. Litter trap are placed on tree vegetation species that dominate at one point and are in good condition.

The sampling method was conducted using purposive random sampling. The primary research materials were mangrove litter collected from litter traps and the mangrove forest floor (*litter layers*) (Brown, 1984; Pribadi, 1998). The collected litter was categorized as leaves, wood or stems, flowers/fruits, stipules, and others (unidentified). Supporting data, including weather conditions, including air temperature measured in situ, wind speed, humidity,

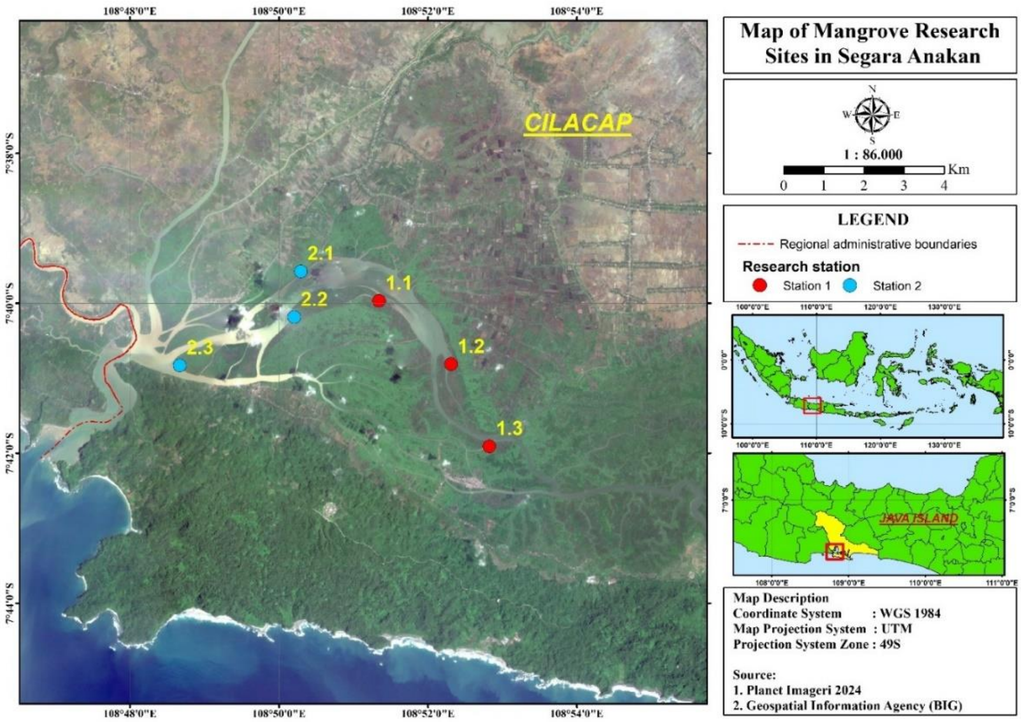

Figure 1. Research Location Map

and rainfall were obtained from government agencies (Meteorology, Climatology, and Geophysics Agency/BMKG).

Litter was collected using traps made of 1 x 1 m nylon nets with a 2 mm mesh size (litter traps). Each trap was hung with string from mangrove trees at a height of 1,5 m above Mean High Water Springs (MHWS). Litter layer collection was conducted by gathering litter from the mangrove forest floor in a 1 x 1 m transect. Transects were randomly selected around litter traps at the research site. The collection of the litter layer was done simultaneously with the litter fall collection. The collected samples were cleaned of attached mud and then sorted by category. Litterfall and litter layer were collected four times according to the seasonal changes in Indonesia throughout the year: June (T1) (dry season/east monsoon), September (T2) (transition from dry to the rainy season), December (T3) (rainy season/west monsoon), and March (T4) (transition from rainy to dry season) (Muskananfola *et al*., 2021). The collected litter is separated according to type and then dried in an oven at 80°C for 24–48 h or until the sample has a constant weight to evaporate water and bound water.

Data analysis

Litter productivity was calculated from the average litter production in the litter traps and on the mangrove forest floor at each research location. A correlation test was conducted between litter production and weather conditions (air temperature, humidity, wind speed, and rainfall). The monthly litter production rate was calculated per litter trap (surface area 1 m^{-2}), for each observation point using the following formula:

$$monthly\ litter\ production\ (gm^{-2}mo^{-1}) = \frac{Dry\ weight\ of\ monthly\ litter\ (g)}{1m^2}$$

Results and Discussion

The total litter production recorded during the study in Segara Anakan was 18.99 tonnes $ha^{-1}\ yr^{-1}$ (Table 1). The highest litter production occurred in March 2024 and the lowest was in September 2023. The result of the correlation analysis between litter and weather are shown in Tabel 2. The highest correlation is between litter and rainfall, and the lowest is between litter and humidity.

Fluctuations in litter productivity during the study were influenced by water availability. Strengthened by the results of correlation analysis showed that litter productivity was closely related to weather factors, particularly rainfall. The increase in litter productivity during the rainy season is due to high rainfall, which saturates the soil, prompting plants to expel excess water through guttation to maintain water balance in plant tissues. Continuous water absorption by the root system leads to water accumulation in the roots and low transpiration, creating hydrostatic pressure. This pressure can drive water upward toward the leaves through the xylem vessels in the stem, forcing some water out through hydathodes on the leaf surface in the form of water droplets (Zheng *et al*., 2022). Guttation droplets formed at the tips and edges of leaves can add physical weight to them. Under certain conditions, especially in plants with thin or fragile leaves, this additional weight can cause physical damage or even lead to leaf breakage and shedding. Additionally, the accumulation of salts, minerals, and some chemicals on the leaf surface due to guttation can damage leaf tissues, hinder photosynthesis, and ultimately contribute to leaf fall. In addition, high rainfall can provide direct physical pressure, damaging old or weak leaves, twigs or plant parts, thereby increasing litter productivity. The Segara Anakan mangrove area has high air humidity of 81-85%. The high humidity is caused by the surrounding area of water bodies (rivers) and mangrove soil containing water. High rainfall and humidity can reduce transpiration, so plants respond by shedding leaves to balance water intake. Very high wind speeds (storms and typhoons) can cause physical damage to plants, producing large amounts of litter but disrupting the balance of the ecosystem. Environmental stress such as temperatures that are too high (hot) or too low (cold) cause the photosynthesis process to not run optimally and leaves experience tissue damage and even vegetation death. Thus, causing litter productivity to increase. According to Chen *et al*. (2017), in winter in China, *S. caseolaris* shows a high level of sensitivity to causing serious leaf tissue damage and even vegetation death.

Humidity has a low correlation with litter productivity because during the study the humidity value ranged from 81-85%. This does not show a significant difference during the dry season and rainy season. So that air humidity has a weak correlation with litter production. Wind speed during the study ranged from 3-5 knots. According to the Beaufort Scale, the wind speed is classified as a weak breeze, the leaves sway lightly, felt on the face. The difference in wind speed in the dry season and the rainy season does not show a significant difference. Therefore, wind speed has a weak correlation with litter production. Previous research in 2002, litter productivity was influenced by rainfall (Siswanto, 2003). However, no analysis was carried out for the variables of air humidity and wind speed.

Based on Figure 2, the rainfall type in Segara Anakan is unimodal. The highest peak of the rainy season occurs in one season, after which it tends to be dry or the rainfall is much lower. The figure shows that the lowest litter productivity occurs in September 2023 with low rainfall conditions. Likewise, in March 2024 high rainfall will get high litter productivity. Litter production after June decreased significantly along with decreasing rainfall in August and September. Then rainfall increased slowly and there was an increase in litter production. A similar phenomenon occurs in tropical forests in China, where litter peaks

Table 1. Monthly Distribution of Litter Production (tonnes $ha^{-1}yr^{-1}$) in June, September, December 2023, and March 2024 in Segara Anakan, Cilacap

Month	Leaves	Branches	Flowers/Fruits	Stipules	Others	Total
June 2023	4.68	0.73	0.35	0.05	0.02	5.83
September 2023	1.30	0.54	0.21	0.02	0.02	2.08
December 2023	2.14	1.12	0.23	0.02	0.00	3.52
March 2024	5.46	1.25	0.78	0.03	0.04	7.56
Total	13.58	3.65	1.58	0.12	0.07	18.99

Table 2. Correlation Between Litter Productivity and Weather

	Litter (tonnes $ha^{-1}.yr^{-1}$)	Rainfall ($mm.yr^{-1}$)	Humidity (%)	Wind speed (Knot)	Air temperature (^0C)
Litter (tonnes $ha^{-1}.yr^{-1}$)	1,00				
Rainfall ($mm.yr^{-1}$)	0,99	1,00			
Humidity (%)	0,08	-0,04	1,00		
Wind speed (Knot)	-0,38	-0,48	0,89	1,00	
Air temperature (^0C)	0,25	0,40	-0,80	-0,87	1,00

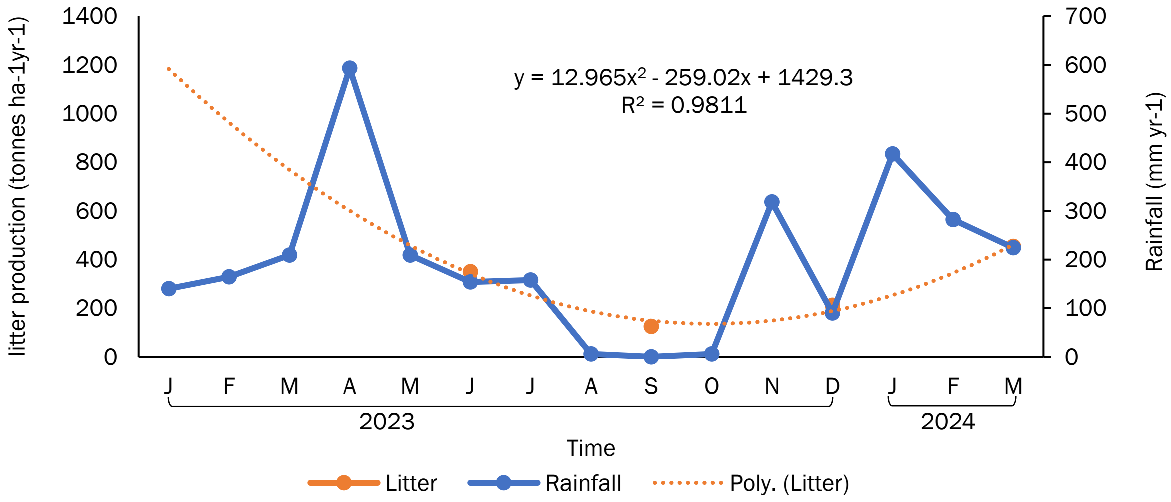

Figure 2. Graph of the relationship between litter production and rainfall

between January and April during the rainy season and is low between July and October during the dry season (Zhu *et al*., 2019). In another location, Guayas Estuary, the highest litter production occurs in September during the rainy season (Wafar *et al*., 1997). The decrease in litter productivity observed in September and December 2023 was due to high air temperatures with little rainfall. Vegetation adapts by shedding leaves to reduce transpiration (Lin *et al*., 2023). Litterfall was suspected in the previous month (August) due to the dry season, causing some vegetation to experience drought and death. According to Gomes *et al*. (2021), prolonged dry seasons can decrease litter productivity by up to 25% due to physiological stress. The extended El Niño effect causes vegetation mortality. This situation occurred at St 1.2 and St 2.1 in September, November, and March, where there was a decrease in leaf litter production and an increase in twig litter production. The dominant vegetation at stations 1.2 and 2.1 is *S. caseolaris*. This species lacks a hypodermis (water storage tissue), making it more susceptible to leaf shedding and death (Tihurua *et al*., 2020). Observations in March 2024 showed the emergence of leaf buds and small leaves after rain. According to Queiroz *et al.* (2019), flowering and fruiting occur after leaf buds appear in the rainy season. The dynamics of litter productivity at the research site are determined by the physiological mechanisms of vegetation (evaporation) and environmental variables, such as rainfall. Increased shedding of leaves, branches, and other vegetation parts is a natural response to metabolic stress due to excess water supply. This condition increases the availability of litter as a source of nutrients for microorganisms and basic fauna such as mangrove macrozoobenthos. In the rainy season, the decomposition process is faster because high humidity and rainfall are ideal conditions for the activity of microorganisms and fauna that destroy litter, such as bacteria, fungi, and mangrove crabs. Rainwater dissolves water-soluble compounds such as sugars, tannins, and proteins in litter, thereby accelerating initial decomposition.

The distribution of falling litter and the litter layer can be seen in Tables 3 and 4. All locations showed higher litter fall than the litter layer. However, locations 1.2 and 2.1 had lower litter falls than litter layers when taking T3 and T4. Fruits and stipules at all locations and observation times experienced fluctuations. The study results showed that leaves were the largest contributor to litter, followed by twigs, flowers/fruits, stipules, and lastly, other unidentified components. Similar results were obtained in the mangrove forest area of Mempawah, West Kalimantan, where leaf litter production was 76.26-78.53%, twigs 9.43-13.27%, and reproductive parts 8.20-14.31% (Purnobasuki *et al*., 2022). However, twigs contributed the most to litterfall in St 1.2 in December 2023, March 2024, and St 2.1 in September 2023 in March 2023, and March 2024. This was due to some *S. caseolaris* vegetation experiencing leaflessness. Leaf litter on St 1.2 was influenced by tidal flows from the Banyu Segara River, located next to the sampling area. Leaf litter on St 2.1 originated from the vegetation *Acanthus ilicifolius* and *Derris trifoliata*, which dominate the area. A similar event occurred in the mangrove forest of Zanzibar, Tanzania, where maximum twig litter occurred in the summer, specifically in January and February, when temperatures were high (Mchenga and Ali, 2017). Changes in evapotranspiration due to drought can affect the hydrological cycle and decrease soil moisture. Extremely dry soil at the beginning of the rainy season makes it difficult for rainwater to infiltrate the soil, increasing surface runoff. This runoff can result in the loss or deposition of organic matter, including litter.

The variation in litter production from leaves, fruits, flowers, and stipules is due to the phenology of vegetation. Phenology refers to the annual changes in plants, such as the emergence of leaf buds, young leaves, and old leaves, influenced by climate dynamics, including solar radiation, rainfall, and temperature (Songsom *et al.*, 2019). Phenology varies depending on the mangrove species and its ecological adaptation to specific environmental conditions. During the rainy season, groundwater availability increases, which supports physiological processes such as photosynthesis, vegetative growth, and reproduction. The development of mangrove fruits in tropical areas typically occurs at the end of the rainy season when the soil is more humid, nutrients are more abundant, and sunlight is sufficient. Some mangrove species begin to flower at the start of the rainy season and reach maturity at the end of the rainy season or the beginning of the dry season. This happens with *A. marina, A. alba* (at location 2.3), which reach peak fruiting in March 2024. Therefore, *Avicennia* flower/fruit litter is often found in litter traps and on the mangrove forest floor. While during the dry season reproductive activity slows down, stomata are smaller and salt builds up in the leaves allowing this species to survive during the dry season. If there is excessive salt buildup, leaf shedding will occur. The relationship between leaves and fruit development is vital, as leaves are the primary source of photosynthates, the products of photosynthesis that support various growth processes, including fruit development. Healthy leaves actively use photosynthesis, providing energy and carbon for fruit development. During the transition from the end of the rainy season to the beginning of the dry season, the products of photosynthesis are primarily allocated to flower/fruit development. This condition can cause some leaves to age more rapidly (*senescence*) due to reduced nutrients reaching the leaves, triggering leaf fall as an

Table 3. Litterfall distribution ($g.m^{-1}.mo^{-1}$)

Station	Composition	Time			
		June (T1)	September (T2)	December (T3)	March (T4)
1.1	leaves	121.13	5.50	17.21	125.65
	branches	10.38	2.65	9.91	20.85
	fruits	2.26	1.76	6.09	3.22
	stipules	0.16	0.28	0.79	0.18
	others	0.09	0	0.13	2.31
1.2	leaves	28.83	3.00	5.22	1.90
	branches	3.34	1.29	8.02	5.49
	fruits	2.34	1.00	0.74	0.18
	stipules	0.63	0	0	0
	others	0.05	0	0	0
1.3	leaves	37.16	14.94	29.44	97.53
	branches	4.75	5.46	9.68	9.25
	fruits	9.98	3.84	4.23	2.29
	stipules	1.14	0.52	0.21	0
	others	0.60	0.80	0	0.32
2.1	leaves	38.70	0.510	2.34	10.30
	branches	10.61	0.65	11.02	18.29
	fruits	2.00	0.33	0.43	0
	stipules	0.44	0	0	0
	others	0	0	0	0
2.2	leaves	89.34	25.03	34.70	74.37
	branches	10.70	5.04	7.99	15.23
	fruits	6.87	3.62	2.80	14.31
	stipules	1.83	0.97	0.06	0.32
	others	0.56	0.75	0	1.04
2.3	leaves	71.52	24.13	30.58	62.43
	branches	4.84	13.66	22.16	15.61
	fruits	38.37	1.82	1.42	4.56
	stipules	1.58	0.23	0.46	0.14
	others	0.152	0	0.27	0.28

Table 4. Litter layer distribution ($g.m^{-1}.mo^{-1}$)

Station	Composition	Time			
		June (T1)	September (T2)	December (T3)	March (T4)
1.1	leaves	27.56	2.77	7.80	37.13
	branches	0.42	1.32	4.23	17.75
	fruits	0.45	0.50	1.76	0.69
	stipules	0.05	0	0.14	0
	others	0	0	0	0
1.2	leaves	4.87	10.18	11.33	8.10
	branches	1.24	2.43	16.85	7.07
	fruits	0.47	1.70	2.68	0
	stipules	0	0	0	0
	others	0	0	0	0
1.3	leaves	6.71	9.68	12.41	21.43
	branches	1.75	3.09	3.15	4.09
	fruits	1.84	2.88	1.51	0.31
	stipules	0.27	0.01	0	0
	others	0	0	0	0
2.1	leaves	5.28	5.80	24.11	18.72
	branches	2.27	10.57	11.21	7.03
	fruits	0.72	0.28	0.006	0
	stipules	0.07	0	0	0
	others	0	0	0	0
2.2	leaves	26.29	15.79	18.99	50.20
	branches	5.44	3.04	3.98	12.54
	fruits	3.65	2.12	0.15	2.34
	stipules	0.43	0.13	0	0.14
	others	0	0	0	0
2.3	leaves	19.30	12.27	20.36	29.27
	branches	6.64	5.13	4.02	2.41
	fruits	0.26	0.98	1.69	16.39
	stipules	0	0	0.012	0.63
	others	0	0	0	0

energy-saving measure. In contrast to *S. caseolaris*, vegetative development occurred in March 2024, namely the growth of leaf buds and small leaves. Especially *S. caseolaris* which is at St 1.2 and 2.1 which previously experienced severe shedding in the dry season. According to Ryan *et al.* (2018), increased generative production (fruit) inversely correlates with vegetative growth (leaves and stems), making fruit development a priority in carbohydrate allocation.

Tidal variables can affect litter layer production. The Segara Anakan mangrove area has a mixed tidal type with a double diurnal tendency. When the tide rises, litter that has fallen to the forest floor can be lifted and carried by the water flow. Lighter litter such as leaves is often carried out of the mangrove system into rivers or open water. The effect of high tides can reduce litter accumulation on the mangrove floor, especially in mangrove areas that are often submerged by high tides. When the tide recedes, the mangrove floor dries out, allowing litter to remain in place. Litter accumulation at low tide mostly comes from litter fall. Leaves and other organic materials have time to decompose, which support by the present of microorganism, supporting the return of nutrients to the soil. Therefore, the litter layer at the research location mostly comes from litterfall. In accordance with the statement of

Table 5. Litter production in various regions.

Litter Production	Location	Reference
The total litter productivity in the Segara Anakan Cilacap mangrove forest is 18.99 tons ha^{-1} yr^{-1}. The lowest litter production occurs in September, while the highest occurs in March.	Segara Anakan Mangrove Forest, Cilacap	This research
Avicennia officinalis 10.2 tonne ha^{-1} yr^{-1}, *Rhizophora apiculata* and *Rhizophora mucronata* 11.8 tonne ha^{-1} yr^{-1}, *Sonneratia alba* 17 tonne ha^{-1} yr^{-1}.	Mangrove ecosystem along the Mandovi–Zuari estuary on the Central West Coast of India	Wafar *et al*. (1997)
The productivity of litter in the Segara Anakan mangrove forest, Cilacap is 1.08 tons $ha^{-1}mo^{-1}$	Segara Anakan Mangrove Forest, Cilacap	Siswanto (2003)
Annual litter production in restored mangroves was 13.96 Mg ha^{-1} yr^{-1} and 10.18 Mg ha^{-1} yr^{-1} in intact mangroves.	Restored mangroves in Perancak Estuary, Bali, Indonesia	Pradisty *et al*. (2022)
Average leaf litter production rate in Sukamandi Village was 258.81 g m^{-2} mo^{-1}.	Mangrove forest in Sukamandi Village, East Belitung Regency, Indonesia	Farhaby *et al*. (2023)
Litter production of *Avicennia marina* over 2 years in the northern part of the Red Sea (Yanbu) was 142-539.5 kg ha^{-1} and in the southern part (Shuaiba) was 87.7-543.1 kg ha^{-1}.	Mangroves in the Red Sea coast, north (Yanbu) and south (Shuaiba)	Abohassan (2023)
Total litter production in Muara Pagatan was 1.568,21 g m^{-2} 45 day^{-1}. The highest litter productivity was in *Rhizophora mucronata* at 858,28 g m^{-2} 45 $days^{-1}$, followed by *Bruguiera gymnorrhiza* at 268,52 g m^{-2} 45 $days^{-1}$, *Avicennia marina* at 222,9 g m^{-2} 45 $days^{-1}$ and finally *Sonneratia alba* at 218,51 g m^{-2}45 $days^{-1}$.	Analysis of Mangrove Leaf Litter Decomposition Rate in Mangrove Ecosystem of Muara Pagatan, South Kalimantan	Selviani *et al.* (2024)

Sukardjo *et al.* (2013), litter accumulation occurs more due to litterfall than the influence of tides. Litter production in mangrove areas in various regions is listed in Table 5.

Based on Table 5, it can be seen that the litter productivity obtained from this study is higher than in 2003. However, the Segara Anakan mangrove forest has the lowest litter productivity compared to other regions. This difference is due to geographical location, which influences by climate, mangrove density, different mangrove species characteristics, and plant phenology. According to Farhaby *et al*. (2023) and Rafdinal *et al*. (2021), mangrove litter productivity is affected by mangrove density. The leaf structure of mangroves also influences litter productivity. The leaves of *A. marina*, *A. alba*, and *Aegiceras corniculatum* have salt glands, allowing them to survive in high salinity conditions (Reef and Lovelock, 2015; Sudhir *et al*., 2022). In contrast, *S. caseolaris* leaves are thin, easily damaged, lack water storage organs, and do not have salt glands. To adapt to high salinity, *S. caseolaris* leaves shed. Meanwhile, the leaves of *R. mucronata* are thick due to having water-storage organs (Lechthaler *et al.*, 2016), making them more resistant to drought.

Conclusion

The total litter productivity in the Segara Anakan Cilacap mangrove forest is 18.99 tons ha^{-1} yr^{-1}. The lowest litter production occurs in September, while the highest occurs in March. Litter productivity is influenced by rainfall and physiological adaptation of mangrove plants to water availability. This condition will also impact the efficacity of photosynthetic process, and by the end will also affect the plant phenology, litter components and nutrients availability.

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