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RESEARCH ARTICLE

Annual litterfall Production in the Medium-high Tides Mangrove Area of Angke Kapuk Protected Forest

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ABSTRACT

Litterfall production in the mangrove ecosystem is essential for the mangrove community. It also has an essential role in contributing carbon to estuaries in the tropics. This study aimed to determine the mangrove litterfall production in the Angke Kapuk Protected Forest area, Indonesia, which has a medium-high tide tidal type, and how environmental factors affect the litterfall production. The method used to catch litterfall in the forest for a certain period was the litter-trap method with 34 litter-traps size 1 x 1 meter each and a mesh size of 1 mm spread out systematically and suspended above the maximum tidal height. The trapped litterfall was sorted into leaves, twigs, and reproductive components. Litterfall was baked in an oven at 105 °C for 24 hours, and the dry weight was weighed. The annual production of mangrove litterfall in the medium-high tides area is 761.37 g m^{-2}. Leaves were the most dominant component of mangrove litterfall. There is no significant correlation between litterfall production and monthly rainfall, while the correlation between litterfall production and wind speed only affects reproductive parts significantly affected by wind speed.

Introduction

Mangrove forests are the most productive ecosystems and also a unique wetland ecosystems in the intertidal coastal regions of the tropics and subtropics [1,2]. Mangrove forests are very important as a protector for coastal areas from abrasion, wind, storms, and other disturbances. Approximately 75% of the coastline in tropical and subtropical areas is covered by mangroves, and 23 to 24% is found in Indonesia [3]. Mangroves cover over 13,760,000 ha of world coastal areas [4]. Plants that grow in mangrove forests are able to grow well in tropical to subtropical tidal zones and have unique physiomorphological characteristics of adaptation and tolerance to hypersaline environments, tidal cycles, and soil chemistry. Mangrove ecosystems play a crucial role in the global carbon cycle. Mangroves store 10 to 15% of the organic carbon found in coastal sediments [5]. Mangroves also contribute significant nutrients to estuarine and coastal productivity through litterfall. Mangrove plants absorb all important nutrients from the sediment and are then carried through litterfall and accumulated into the sediment. Nutrients are returned to soils through litter decomposition, and will absorbed again by trees for growth. That is make the litter as a valuable indicator of productivity and the most easily measured component for total net primary productivity measurement [6,7].

Litterfall, a collection of dead organic matter that covers the forest floor, consists mainly of dead plant parts including leaves, twigs, and reproductive parts. Litterfall is a source of nutrients and food for organisms living in the mangrove ecosystem; therefore, estimating the amount and composition of litterfall is essential for studying nutrient cycling [8], primary production [9,10], and ecosystem structure and function. Litterfall, especially leaf litterfall, transports nutrients back to the sediment [11]. More than 50% of the carbon in sediments comes from litterfall [12,13]. Nitrogen and phosphorus are known to be limiting factors for mangrove trees due to the lack of nutrient sources. Litterfall, such as leaves, twigs, and fruits, is a significant

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source of nitrogen and phosphorus [14]. Litterfall depends on many factors, including mangrove species, geomorphology, climatic factors, salinity, and pollution [6]. Stand age, stand density, and several climate variables, such as wind speed, temperature, rainfall, and evaporation, as the responsible factor of the litterfall production variability of in forest ecosystems [15,16].

The Angke Kapuk Protected Forest is the conservation area in the Jakarta that has important function for protects the Jakarta area from abrasion and seawater intrusion from north beach of Jakarta. This area has 44.76 ha and is supervised by the DKI Jakarta Forestry Service. This area is located in an area that has a high level of disturbance due to abrasion and sedimentation [17]. The existence of mangrove forests in urban areas in Indonesia, including mangroves in the Angke Kapuk Protected Forest, often faces pressure from deforestation and degradation [18]. The existence of land use activities such as fisheries cultivation and urban development has had an impact on mangrove forests, which can affect the carbon and nutrient accumulation capacity of the ecosystem [19]. This also affects the productivity of mangrove litterfall. Therefore, this study was conducted to explore the species and temporal patterns of litterfall production against climate variables in the Angke Kapuk Protected Forest area, especially in areas with medium-high tide types. This study aims to understand the productive role of mangrove forests in the research location, which has medium-high tides that can be beneficial for conservation and sustainable management in the future.

Materials and Methods

Research Site

This research turned into carried out from July 2020 to June 2021 in the Angke Kapuk Protected Forest, North Jakarta, especially in medium-high tide area. This area has moderate tides and sometimes not hit by the tide. weighing and baking the sampel was conducted at the Forest Ecology Laboratory of the Faculty of Forestry and Environmental IPB University, whereas soil and litterfall content analysis was conducted at the Soil Laboratory of the Department of Soil Science and Land Resources at IPB University. A map of the research locations is shown in Figure 1.

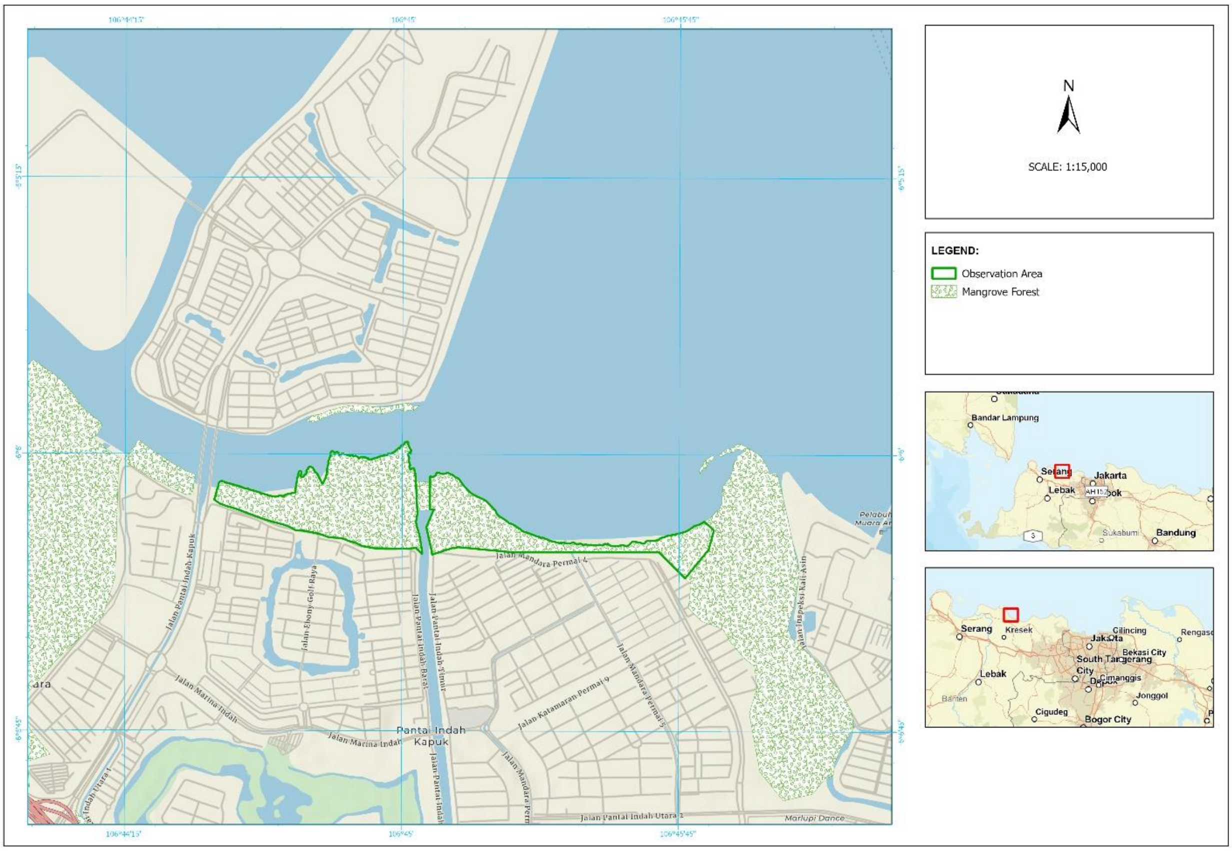
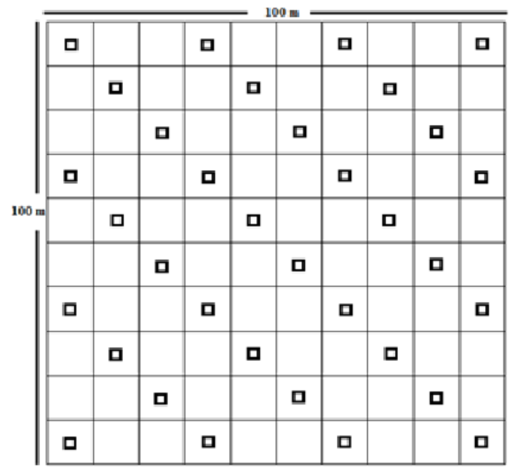


Figure 1. Map of research area (medium-high tides area of Angke Kapuk Protected Forest).

Procedure

The method used to catch litterfall in the forest for a certain period was the litter trap method (litter trapped with nets). The size of litter trap was 1 × 1 meter and the size of mesh was 1 mm. The litter trap that number 34 litter traps were installed systematically in 1 ha permanent plot. The litter traps installed above the maximum tidal height. The layout of litter trap placement is shown in Figure 2. Litterfall that traped into litter trap was collected for one year with an interval of 15 days. The collected litterfall was separated on the basis of its parts (leaves, twigs, and reproductive parts). The litterfall was placed in a paper envelope bag, labelled, and dried in an oven at 105 ^oC for 24 h [20]. Dried litterfall was weighed to obtain the dry weight. All tree species within the permanent plot were inventoried, including the stem diameter at breast height (DBH) or 10 cm above the still root, as well as height.



□ Litter trap with size 1 × 1 meters

Figure 2. Layout of litter traps placement in permanent plot.

Data Analysis

Estimates of litterfall rates of various components (leaf, twig, reproductive parts, and insect body) were calculated using the following equation:

$$Xj = \sum_{j=1}^{n} \frac{Xi}{n} \quad (1)$$

where Xj is the average litterfall production per replicate in a specific period (g m^{-2}), Xi is litterfall production per repetition in each repetition in a particular period (g), and n is the total plot (m^{-2}). To explain the forest structure, density (N), mean of stem diameter at breast height (DBH), and mean of tree height. The tree density (N) was calculated using a formula as follows [21].

$$\text{Density (ind/ha)} = \frac{\text{Number of trees (ind)}}{\text{area of sample plot (ha)}} \quad (2)$$

Results

Physic-Chemical Condition of The Research Environmental

Mangrove soil results from deposited sediment, usually characterized as hydromorphic alluvial soil or marine clay. The physical-chemical analysis of the soil at the research site is presented in Table 1. The soil condition in the research area dominated clay texture (61.98%). Furthermore, the soil chemical condition results show that the soil condition in the research location was acid with pH under 6.6. The organic carbon content was very high (>5%), and the total nitrogen content was moderate (0.21–0.5%).

The location of this area that situated at the interface between land and sea, mangrove forests are closely linked to the around hydrology condition more than any other forest type in structure and function. The results of the physical and chemical analysis of water in the research area are presented in Table 2. Based on Table 2, the water analysis results at the research location are still in accordance with the quality standards for water conditions for marine biota, except for turbidity values of more than 5. Furthermore, based on Table 2 the water conditions at the research location fall into the brackish water category with salinity 11‰.

Table 1. The physical-chemical condition of the soil at the research location.

Soil properties		Unit	Value	Category*)
I	Physic			
	Texture:			
	Sand	%	10.55	
	Silt	%	27.47	Clay
	Clay	%	61.98	
II	Chemistry			
	pH	-	6.18	Slightly acidic
	C-org	%	5.46	Very high
	N-Total	%	0.41	Moderate

Note: *) criteria based on Guideline of *Balai Penelitian Tanah* [22].

Table 2. The physical-chemical condition of the water at the research location.

Parameter		Unit	Quality Standard *)	Value
I	Physic			
	Turbidity	NTU	< 5	7.78
	Water temperature	ºC	Natural (28–32)	29.80
II	Chemistry			
	pH	-	7–8.5	7.48
	Salinity	‰	Mangrove: s.d. 34	11.00
	Dissolved oxygen (DO)	mg/L	> 5	7.50

Note: *) Quality standard based on Ministerial Decree of Environmental Ministry number 51-year 2004 (for marine biota).

The climate condition for this research taken from the nearest BMKG (*Badan Meteorologi, Klimatologi, dan Geofisika*) station data and the results is presented in Figure 3. The climate change maybe have a substantial impact on mangrove ecosystems by the processes like increased storminess, increased temperature, and changes in precipitation. In this research, we also observed how climatic factors influence litterfall productivity. Based on Schmidt and Ferguson's climate classification, the Angke Kapuk Protected Forest area has a climate type B with an annual rainfall of around 2,217.3 mm. The lowest monthly rainfall occurred in August 2020 (77.9 mm), and the highest in February 2021 (466.8 mm).

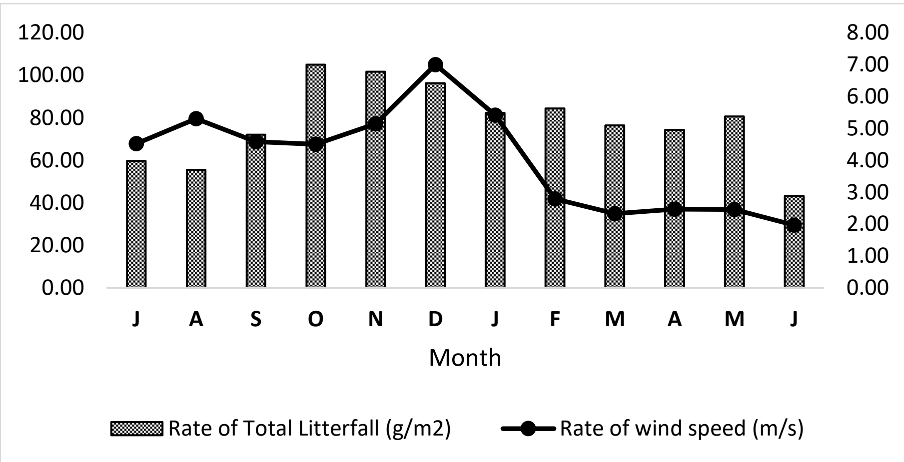


Figure 3. Monthly rainfall and average monthly wind speed, Angke Kapuk Protected Forest, Jakarta, July 2020 to June 2021.

Vegetation Condition

The major mangrove species found in the research site are *api-api* (*Avicennia marina*) and *bakau* (*Rhizophora mucronata*), the minor mangrove species found is *buta-buta* (*Excoecaria agallocha*), and the associate mangrove species found are *ketapang* (*Terminalia catappa*), *flamboyan* (*Delonix regia*), and *nyamplung* (*Calophyllum inophyllum*). The tree density, mean of DBH, and mean of tree height of all species are shown in Table 3.

Table 3. The tree density, mean of DBH and mean of tree height of all species found in the research location.

Tree species	N (ind/ha)	Mean of DBH (cm)	Mean of tree height (m)	Group of mangrove element*)
Avicennia marina	126	30.86	15.07	Major/true mangrove
Excoecaria agallocha	21	17.03	9.19	Minor mangrove
Rhizophora mucronata	11	16.62	13.45	Major/true mangrove
Delonix regia	8	21.50	18.19	Mangrove associate
Calophyllum inophyllum	5	10.83	14.40	Mangrove associate
Terminalia catappa	4	22.85	17.50	Mangrove associate
Total	175			
Mean		19.95	14.63	

Note: *) criteria based on Tomlinson's book [23].

Litterfall Production

Leaf litterfall production in the mangrove ecosystem is significant for the mangrove community as a source of nutrients and food for organisms living there. The estimation of annual production of every litterfall components (leaf, twig, reproductive parts, and body insect) at the research location is shown in Table 4. The annual litterfall production in the research location was estimated at 761.37 g m^{-2} or 7.61 ton ha^{-1} and the dominated component of litterfall is leaf. The annual production of leaf litterfall is more than 62% of the total litter (470.43 g m^{-2} $year^{-1}$). While the twig becomes the second most component of the total litterfall (19% of the total litterfall or 147.73 g m^{-2} $year^{-1}$), the reproductive parts are 17% of the total litterfall production (126.34 g m^{-2} $year^{-1}$ and the most minor component is insect body (2%) to the total litterfall or 16.87 g m^{-2} $year^{-1}$).

Table 4. Estimated annual litterfall production and its components at the research location.

No	Litterfall components	Litterfall production (g m^{-2} $year^{-1}$) Quantity	%
1.	Leaf	470.43 ± 11.50	62
2.	Twig	147.73 ± 7.62	19
3.	Reproductive parts	126.34 ± 10.88	17
4.	Insect body	16.87 ± 1.12	2
Total		761.37 ± 18.05	100

The fluctuation of monthly total litterfall production and monthly litterfall production of each component shown in Figure 4 and Figure 5. Total monthly litterfall during the sampling period ranged from 43.05 g m^{-2} in January 2021 to 111.99 g m^{-2} in October 2020. The peak of leaf litterfall production occurs in May 2021 (58.99 g m^{-2}), while the peak of twig and reproductive parts production occurs in October 2020 (32.37 and 28.74 g m^{-2}), and for insect body, the peak of the production occurs on August 2020 (4.48 g m^{-2}).

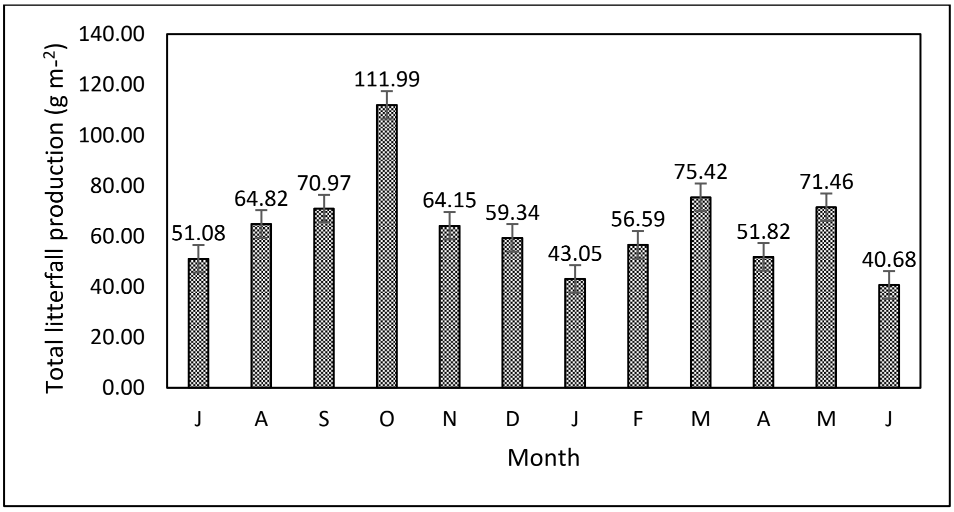


Figure 4. Monthly rates of total litterfall at the research location in the period of July 2020 to June 2021.

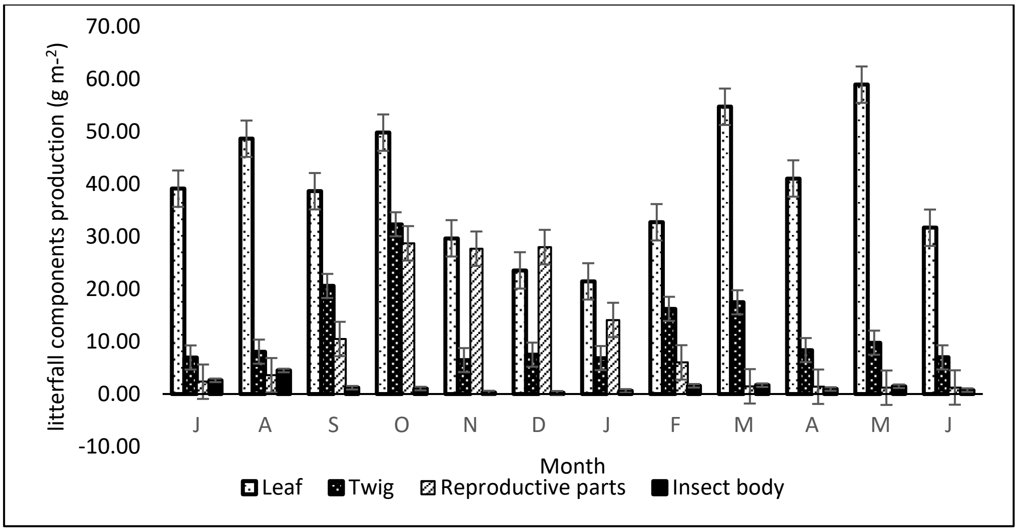


Figure 5. Monthly rates pattern of litterfall components at the research location in the period of July 2020 to June 2021.

The Correlation between litterfall production (total litterfall and litterfall components production) in the research location is shown in Table 5. Based on Table 5, all the litterfall components correlate negatively with monthly rainfall, although there was no significant correlation. As for the correlation with the average wind speed, the reproductive parts have a significant positive correlation at the 0.05 level.

Table 5. Correlation value between litterfall production and climate parameter (rainfall and wind speed).

No	Litterfall components	Correlation value	
		Monthly rainfall (mm)	Average of wind speed (m s^{-2})
1	Total	–0.23	0.07
2	Leaf	–0.31	–0.48
3	Twig	–0.02	–0.11
4	Reproductive parts	–0.02	0.71*
5	Insect body	–0.24	–0.02

Noted: *) Correlation is significant at the 0.05 level (2-tailed).

Discussion

The mangrove in Angke Kapuk Protected Forest area consists of 13 tree and 12 non-tree plant species. This number is around 12% of the total mangrove plants found in Indonesia, namely 202 species [24]. For the medium-high tides, 6 of 13 mangrove species is found; the dominant species is *Avicennia marina*. *Avicennia marina* is one of the important species in mangrove forest. This is because the *Avicennia marina* is a pioneer species in mangrove forest areas that have a wide salinity tolerance range [25]. The condition of the research site with sediment with a clay texture was one of the factors that supported the *Avicennia marina* to grow and develop well [26,27]. The results of another study by Budiadi et al. [28] stated that a salinity level of 5 to 15 ppt is the optimal salinity condition for the growth of *Avicennia marina* seedlings. In addition to suitable sediment and salinity conditions, *Avicennia marina* is also a species with a bimodal distribution, and it spreads in locations close to land and sea [29]. This condition relates to litterfall production, where the dominant organ trapped in the litter trap comes from *Avicennia marina*'s organ.

Mangroves play an important role as contributors of nutrients that support the productivity of estuarine and coastal waters through the release of organic matter from litter. The release of nutrients and organic matter from mangrove litter during leaching and decomposition plays an important role in the biogeochemical cycle of the mangrove ecosystem [30]. Nutrients released during the leaching and decomposition process also seep into the surrounding waters, increasing the productivity of the surrounding aquatic ecosystem, including the habitat of fish, crustaceans, and other aquatic organisms that depend on the nutrient content produced by the mangrove ecosystem. Therefore, optimal litter production will increase carbon stocks in the mangrove ecosystem, which in turn supports climate change mitigation. In addition, the increase in organic matter produced by litter in estuarine waters also affects the aquatic food chain, from plankton to top predators such as fish and water birds. The organic matter contained in this litter goes through a decomposition process, creating a substrate that is rich in nutrients and very supportive for the life of aquatic biota [31].

The comparison of litterfall production at the research location with other locations that have the same vegetation conditions is presented in Table 6. Based on Table 6, the annual litterfall production in the research location (716.37 g m^{-2}) compared to litterfall production in other mangrove areas is still in the moderate category. The difference can be caused by the differences in vegetation forest structure, soil fertility, hydrological and climatic conditions in the research area and other areas [8,10,32,33]. Previous studies have shown that litter production is directly proportional to vegetation density. The higher the tree density in an area, the more litter material is produced, because there are more leaves, twigs, and reproductive parts that can be shed periodically [34,35]. Differences in soil fertility and hydrology are also important factors in litter production. In areas with fertile soil and supportive hydrological conditions, mangrove tree growth is more optimal, which then results in higher litter production [32]. Conversely, this study location may have lower soil fertility or less than optimal hydrological conditions, which limit the productivity of mangrove vegetation and the litter produced.

Table 6. Productivity of *Avicennia marina* litterfall in several mangrove ecosystem locations.

No	Location	Litter-fall Productivity (g m^{-2} $year^{-1}$)	Source
1.	Medium-High Tide Mangrove Area of Angke Kapuk Protected Forest, Jakarta	761.37	Current research
2.	All-High Tide Mangrove Area of Angke Kapuk Protected Forest, Jakarta	918.02	[34]
3.	Sundarbans Mangrove Forest, Bangladesh	1,005.9	[36]
4.	Tropical Mangrove of Sarawak, Malaysia	1,640.82	[15]
5.	Tangerang Coast, Banten	1,259.25	[37]
6.	Surabaya East Coast, Indonesia	784.75–1,197.2	[38]
7.	Peninsular Mangrove Ecosystem, Malaysia	2,405.35	[39]
8.	Mangrove Forest of Whangamata Harbor, New Zealand	324–538	[40]
9.	Mangrove on the Northern Coast of Aceh Besar District, Aceh Province, Indonesia	255.5	[41]

Litterfall is organic material from dead trees consisting of leaves, twigs and reproductive organs that fall to the ground. Litterfall productivity is the weight of all dead material deposited on the surface of the soil at one time. The high and low litterfall productivity is influenced by the diameter of the tree, the growth of new leaves, and the frequency of ebb and flow [42]. Litterfall functions as a valuable source of organic material in the mangrove ecosystem, supporting soil fertility and providing nutrients for other vegetation around it. Leaf, as the dominant component of litterfall, decompose faster than other components, such as twigs or reproductive organs, thus providing more immediate nutrients for the soil and decomposing microorganisms [43,44]. This cycle is very important for the sustainability of the mangrove ecosystem, because nutrients that return to the soil support the growth of new vegetation, maintain ecosystem stability and tree resistance to environmental changes.

Seasonal changes, especially rainfall and temperature, have an impact on litter production patterns in the mangrove ecosystem. The highest total litter production occurs in October. This result is in line with the research results of Farooqui and Siddiqui [45] in an area that has the same conditions as the research area, namely dominant litter from *Avicennia marina* litter in Pakistan, where the highest productivity occurs in October to November. The most dominant litter component of the total litter production is leaf litter, which is around 62%. Leaf litter production reaches its highest production in May. This result is in line with the research results of Azad et al. [32] which states that the dominant litter component is leaves, and the highest production is in the range of March to May. This is thought to be related to decreased rainfall which causes a shortage of fresh water supply and increases salinity. Under these conditions, mangrove trees respond to stress by shedding leaves to reduce water loss through transpiration [46,47]. Thus, seasonal patterns affect the adaptive response of trees to harsh environmental conditions, which are then seen in litter production patterns.

Low monthly rainfall in climate type B, according to Schmidt and Ferguson's classification, indicates that this area is relatively wet with tropical rainforest vegetation, although it is not classified as an area with high rainfall [48]. This observation is supported by data from Santoso [49] which shows that the Angke Kapuk area has a total annual rainfall of 2,217.3 mm, which is lower than other areas around it. This relatively stable and low rainfall may not be significant enough to be a determining factor in litterfall production patterns, so the resulting correlation is negative. This may be related to the adaptation of mangrove trees that have been adapted to grow in environments with minimal variations in water supply and are able to manage water stress, including tolerance to high salinity in coastal environments. On the other hand, the average wind speed shows a positive and significant correlation to litter production, especially for reproductive components such as flowers and fruits. Strong wind gusts or storms can increase litterfall production by shedding unripe flowers or fruits from trees. This is because the reproductive components of trees are usually more susceptible to mechanical stress from wind. Strong winds, or even storms, can affect litterfall productivity levels by increasing the amount of reproductive material that falls, especially during periods or seasons of strong winds [50].

Litter productivity trends vary from one area to another. Deviations in this pattern can be caused by habitat-specific stress, such as drought or nutrient deficiency, and it is possible that litter production patterns are endogenous rhythms of the trees themselves [51,52]. For example, trees in areas experiencing environmental stress such as drought or nutrient deficiency tend to have different litter production patterns than trees in more stable habitats. This litter production pattern, which is influenced by wind speed and does not depend significantly on rainfall, has important implications for the management and conservation of mangrove ecosystems in the Angke Kapuk area. Given the important role of litter as a source of nutrients for soil and microorganisms, understanding the factors that drive or inhibit litter production can help in managing mangrove ecosystems more effectively. Area management by considering external factors, such as wind speed and other local factors, can balance the ecosystem and also contribute to climate change mitigation in coastal areas.

Conclusions

The mangrove area are dominated by the species of *Avicennia marina*, and it is in line with the dominant litterfall was litterfall from the part of *Avicennia marina*. The result of annual litterfall estimation for the medium-high tides mangrove of Angke Kapuk Protected Forest was 761.37 g m^{-2}, and it is categorized as moderate compared to other mangrove forest locations. Leaf is the dominant component of litterfall that found in this research, accounting for 62% of the total. The peak of monthly total litterfall rate occurs in October and the lowest in January. While for the leaf, the peak of litterfal rate occurs in May, and for twig and reproductive components occurs in October. The correlation between litterfall production and monthly rainfall are not significant, and for wind effect, only the correlation between reproductive parts production and wind speed are significant.

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