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LITTER BIOMASS AND CARBON STORAGE IN PRIA LAOT WATERFALL TOURISM AREA, BATEE SHOEK VILLAGE, SABANG

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ABSTRACT

Differences in climate and human activities, such as deforestation and intensive agriculture, can increase litter carbon emissions, thereby contributing to global warming. Waterfall tourism areas possess vegetation characteristics that differ from those of natural forests, making it essential to analyze litter biomass and carbon storage in Pria Laot Waterfall Tourism Area, Sabang City. This study employed a purposive sampling method using transect lines and plots to determine litter biomass, carbon storage, and the environmental parameters influencing these factors. The results showed that the total litter biomass in Pria Laot Waterfall Area, Batee Shoek, Sabang, reached 6.47 kg, with an average of 1.32 kg per transect. Transect 3 exhibited the highest litter biomass (3.52 kg), while Transect 1 recorded the lowest (0.99 kg). The total stored litter carbon in the area was 0.253 kg, with an average of 0.084 kg per transect. Transect 3 also had the highest litter carbon (0.138 kg), whereas Transect 1 had the lowest (0.039 kg). The litter carbon storage in the area amounted to 2.53 tons/ha, with Transect 3 showing the highest value (1.38 tons/ha) and Transect 1 the lowest (0.39 tons/ha). The study concludes that variations exist in litter biomass and carbon storage across transects, where transects located near settlements exhibited higher biomass and carbon storage. These findings indicate that environmental factors play a crucial role in determining litter and carbon distribution.

Keywords: Litter biomass, Carbon storage, Pria laot waterfall

ABSTRAK

Perbedaan iklim dan aktivitas manusia, seperti deforestasi dan pertanian intensif dapat menyebabkan peningkatan emisi karbon serasah yang berkontribusi terhadap pemanasan global. Kawasan wisata air terjun memiliki karakteristik vegetasi yang berbeda dari hutan alami, sehingga penelitian ini bertujuan untuk menganalisis simpanan biomassa dan karbon serasah di Kawasan Wisata Air Terjun Pria Laot, Kota Sabang. Metode yang digunakan adalah purposive sampling dengan jalur stasiun dan plot untuk mengetahui jumlah biomassa serasah, simpanan karbon dan parameter lingkungan yang mempengaruhi jumlah biomassa serasah dan simpanan karbon. Hasil penelitian menunjukkan bahwa total biomassa serasah di Kawasan Air Terjun Pria Laot, Batee Shoek, Sabang, mencapai 6,47 kg, dengan rata-rata 1,32 kg per stasiun. Stasiun 3 memiliki biomassa serasah tertinggi sebesar 3,52 kg, sedangkan stasiun 1 memiliki biomassa serasah terendah sebesar 0,99 kg. Total karbon serasah yang tersimpan di kawasan ini adalah 0,253 kg, dengan rata-rata 0,084 kg per stasiun. Stasiun 3 memiliki karbon serasah tertinggi sebesar 0,138 kg, sedangkan stasiun 1 memiliki nilai terendah sebesar 0,039 kg. Simpanan karbon *serasah di kawasan ini mencapai 2,53 ton/ha, dengan stasiun 3 menunjukkan nilai tertinggi sebesar 1,38 ton/ha dan stasiun 1 nilai terendah sebesar 0,39 ton/ha. Penelitian ini menyimpulkan bahwa terdapat perbedaan dalam jumlah biomassa dan karbon serasah di setiap stasiun, di mana stasiun yang berdekatan dengan pemukiman memiliki simpanan biomassa dan karbonn Hal ini menunjukkan bahwa faktor lingkungan berperan dalam menentukan distribusi serasah dan karbon.*

Kata Kunci : *Biomassa serasah, Simpanan karbon, Air terjun pria laot*

Introduction

Climate variations can differ significantly across regions worldwide, influenced by factors such as geographical location, topography, and atmospheric circulation patterns that determine a region's climatic characteristics (Asdak, 2023). Moreover, climate conditions may change naturally over time, including seasonal fluctuations, El Niño and La Niña cycles, as well as long-term climate changes such as global warming. Human activities, particularly the combustion of fossil fuels, have increased greenhouse gas emissions, which in turn have affected the global climate by raising the Earth's average temperature, a phenomenon commonly known as global warming (Susilo, 2021).

One strategy to mitigate the impacts of climate change involves enhancing carbon sequestration and reducing carbon emissions that contribute to global warming. These measures aim to maintain and strengthen existing carbon reserves across various ecosystems (Mahardika, 2022). The enhancement of carbon stocks can be achieved through multiple approaches, such as the cultivation of more woody plants capable of absorbing atmospheric carbon and the replacement of fossil fuels with renewable energy sources like solar or geothermal power (Ratag, 2017).

Increased litter carbon emissions, also referred to as soil organic carbon emissions, have become an environmental concern in recent years (Safitri, 2019). This phenomenon occurs when organic carbon stored in the soil is released into the atmosphere as carbon dioxide (CO_2) or methane (CH_4) due to human activities and natural environmental changes (Rahmadania, 2022). One of the primary causes of increased litter carbon emissions is deforestation, which removes vegetation cover and disrupts soil ecosystems, thereby reducing the soil's ability to store carbon (Baderan, 2017). Climate change, which leads to higher temperatures and unstable rainfall patterns, can also disturb the soil carbon balance, resulting in greater litter carbon emissions (Dinilhulda et al., 2018).

A study conducted by Huda et al. (2022) revealed that biomass and organic carbon stocks in the Iboih Mountain region reached 0.021 g/cm² for biomass and 0.00987 g/cm² for organic carbon stock. Within the study area, plots 1 and 2 exhibited the lowest values, recording 0.018 g/cm² for biomass and 0.00846 g/cm² for organic carbon stock. In contrast, the highest average litter carbon biomass was observed at Station 5, with 0.0195 g/cm² for biomass and 0.009165 g/cm² for litter organic carbon. These findings provide detailed insights into the distribution of biomass and organic carbon stock in the Iboih Mountain area.

Another study by Andaliani et al. (2022) indicated that soil carbon stock is influenced by various physical and chemical factors, such as soil acidity levels, as reflected in pH values. A decrease in pH indicates a tendency toward more acidic soil

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conditions, while an increase reflects a shift toward alkalinity. In addition, biological factors also play a significant role in determining the amount of carbon stored in soil components.

Elvina et al. (2019) ound substantial differences in the estimated litter biomass and carbon content among transects in the secondary forest of Pulau Nasi, Aceh. Data collection involved sampling using 1×1 m quadrats at nine points per transect, focusing on litter carbon biomass. The results showed that the highest total litter carbon biomass occurred at Transect II (mosque area), point 3, with 4,864,098.931 g, while the lowest was recorded at Transect I (field area), point 3, with 1,077,245.213 g. These findings indicate significant variation in litter biomass and carbon distribution across different areas of the secondary forest in Pulau Nasi.

This study differs from previous research in that waterfall tourism areas typically exhibit distinct vegetation structures and compositions compared to natural forests. Such areas often include ornamental plants, shrubs, and other vegetation planted for aesthetic purposes, which generally have lower biomass than natural forest vegetation. Consequently, biomass storage in waterfall tourism areas tends to be lower. Moreover, litter in these areas is often managed or removed to maintain aesthetics and accessibility, leading to lower potential litter carbon accumulation than in natural forests, where organic material accumulates naturally (Abidin & Candra, 2020).

Based on field observations conducted on October 9, 2023, at Pria Laot Waterfall Area in Sabang, diverse vegetation was identified, including tall trees such as Casuarina equisetifolia and coconut palms, epiphytic plants like forest orchids and ferns attached to tree trunks, and aquatic plants such as water hyacinth and water fern along the stream. Additionally, shrubs and grasses were also found throughout the area. This rich biodiversity reflects the adaptive responses of local flora, such as strong root systems and thick leaves.

The observed litter composition near the waterfall consisted of dry leaves, twigs, bark fragments, and other small organic debris originating from nearby trees. The litter tended to accumulate along the edges and areas not directly exposed to water flow. The environment surrounding the waterfall was characterized by humidity, shade, and cool temperatures due to dense tree canopies. Such conditions support higher litter biomass accumulation and slower decomposition rates. Therefore, this study was conducted to investigate “Litter Biomass and Carbon Storage in Pria Laot Waterfall Tourism Area, Batee Shoek Village, Sabang.” The primary objective of this study is to determine the total litter biomass and carbon storage in Pria Laot Waterfall Tourism Area in Sabang City.

Methods

The research area consisted of three stations. The first station was selected due to its proximity to the waterfall, the second because of its dense tree coverage, and the third due to its location near residential areas. The distance between each station was approximately 300 meters. Each station contained 12 plots measuring 1 × 1 meters, resulting in a total of 36 plots across the three stations.

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The tools used in this study included raffia rope, GPS, measuring tape, camera, stationery, calculator, machete, pH meter, thermohygrometer, soil tester, and soil meter. The materials used consisted of litter samples and gloves.

This study utilized quantitative data analysis, encompassing calculations of litter biomass and total carbon. The quantitative approach involved collecting numerical data and analyzing it statistically (Sugiyono, 2017). The value of organic material in litter for each plot was determined using the following formula:

$$\text{Total Biomass} = \frac{\text{Dry Sample Weight} \times \text{Total Wet Weight}}{\text{Sample Wet Weight}}$$

Litter biomass observation was conducted by weighing the samples at a constant dry weight. The total dry weight was calculated using the established equation (Rif'ah et al., 2021).

Results and Discussion

The litter biomass in Pria Laot Waterfall Area, Batee Shoek, Sabang, varied across the different stations and sampling plots. From the three analyzed stations, the total litter biomass obtained was 6,468.97 g (6.47 kg), with an average of 1,322.99 g (1.32 kg) per station. Station 3 exhibited the highest litter biomass, totaling 3,524.12 g (3.52 kg) with an average of 293.68 g (0.29 kg). The highest biomass point within this station was observed at Point 2, Plot 2 (469.70 g), while the lowest occurred at Point 3, Plot 3 (155.15 g). Station 2 recorded a total litter biomass of 1,952.60 g (1.95 kg) with an average of 162.72 g (0.16 kg), where the highest biomass was found at Point 1, Plot 3 (259.00 g) and the lowest at Point 3, Plot 1 (68.25 g). Station 1 had the lowest litter biomass, totaling 992.25 g (0.99 kg) with an average of 82.69 g (0.08 kg); the highest value was recorded at Point 4, Plot 1 (145.50 g), while the lowest was observed at Point 1, Plot 1 (27.03 g).

The total litter carbon in Pria Laot Waterfall Area varied across stations. Station 3 recorded the highest value at 138.03 g (0.138 kg or 1.38 tons/ha), followed by Station 2 with 76.48 g (0.076 kg or 0.76 tons/ha), and Station 1 with 38.86 g (0.039 kg or 0.39 tons/ha). The total carbon content in the area was 0.253 kg (2.53 tons/ha), with an average of 0.084 kg (0.84 tons/ha) per station. These variations indicate that environmental conditions and proximity to settlements influence the accumulation of litter and stored carbon.

The environmental parameters recorded at the three stations varied slightly. Air temperature ranged between 28°C and 29°C, with the highest temperature at Station 1 (29°C) and the lowest at Station 3 (28°C). The soil pH decreased progressively from Station 1 (pH 6) to Station 3 (pH 4.5), indicating increasing acidity toward the residential area. Air humidity ranged between 70% and 81%, and soil moisture varied between 70% and 82%, with the highest recorded at Station 1 and the lowest at Station 3. Light intensity was relatively stable across stations, ranging from 91 to 92 cd.

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1. Litter Biomass

The analysis of litter biomass in Pria Laot Waterfall Area revealed notable differences among the three stations, with a total of 6.47 kg and an average of 1.32 kg per station. Station 3, located near settlements, exhibited the highest biomass (3.52 kg), while Station 1, closest to the waterfall, recorded the lowest (0.99 kg). According to Marindra et al. (2024), litter biomass is influenced by several environmental factors, including soil moisture, air humidity, and soil pH.

The temperature among the stations ranged between 28°C and 29°C, with Station 3, the site with the highest biomass, showing the lowest temperature. This suggests that lower air temperature contributes to greater litter accumulation, likely due to a slower decomposition rate compared to higher-temperature areas. These findings align with Karina et al. (2022), who noted that lower temperatures enhance air humidity, influencing litter decomposition dynamics.

The soil pH decreased from Station 1 (pH 6) to Station 3 (pH 4.5). Kusuma & Yentiana (2021) reported that higher soil acidity tends to reduce microbial activity involved in decomposition, leading to greater litter accumulation. Soil acidity significantly affects microbial decomposition rates (Octaprama et al., 2023). According to Susanti et al. (2024), neutral to slightly acidic soils generally promote optimal microbial activity, while extremely acidic or alkaline conditions hinder decomposition, increasing litter buildup (Nopriani et al., 2023). These findings are consistent with Thalib et al. (2021) who found that lower pH in Ceriops tagal forests in the Tanjung Panjang Nature Reserve slowed down litter decomposition.

Station 1 exhibited the highest soil and air humidity (82% and 80%, respectively), while Station 3 had the lowest (70%). Lower humidity at Station 3 likely reduced microbial activity, slowing decomposition and allowing litter to accumulate. In contrast, higher humidity at Station 1 likely enhanced decomposition rates, resulting in lower litter biomass. Kusmana & Yestiana (2021) emphasized that soil and air humidity significantly influence both litter production and decomposition rates.

Rendy et al. (2024) also noted that excessive humidity could slow decomposition due to reduced microbial activity, while Hamawi & Akhiriana (2022) found that very low humidity limits decomposer activity, thereby reducing decomposition rates. Kusmana & Yentiana (2021), in their study at the Dramaga Forest Research Area, Bogor, confirmed that temperature and humidity affect litterfall rates, with higher temperatures reducing air humidity, increasing transpiration, and accelerating leaf fall.

Light intensity remained stable (91–92 cd) across stations, likely having limited direct influence on litter biomass differences. However, it may indirectly affect vegetation growth and litter production through photosynthesis. Jayanthi & Arico (2017) similarly reported that light intensity influences vegetation growth and litter production via canopy photosynthetic activity.

Maulidya et al. (2019) reported that litter carbon biomass in the Gampong Deudap Forest Area, Pulau Nasi, Pulo Aceh Subdistrict, varied across observation stations. Among six analyzed stations, the average litter carbon biomass was 12,719 g, while the average total biomass across the entire forest area was 2,119.83 g/ha. Station 2 had the highest litter carbon biomass, averaging 254 g, while medium and low categories were recorded at 234 g and 221.66 g, respectively. These findings demonstrate that litter carbon biomass distribution is influenced by local environmental conditions and natural decomposition processes.

Susanty & Halwany (2017) examined the decomposition rate of litter and the diversity of soil macrofauna in Nyawai (Ficus variegata) industrial plantations. Their findings showed that soil and air humidity significantly influence litter decomposition processes, which in turn affect nutrient cycling. Additionally, Karina et al. (2022) investigated the influence of soil pH on leaf litter decomposition rates in forest areas, revealing that lower pH levels tend to slow decomposition because soil microbial activity is optimal at pH 6.5–7. Similarly, Tiffara (2023) studied litter productivity and decomposition rates in peat protection forests and found that soil pH strongly affects microbial activity during decomposition; extremely acidic or alkaline conditions hinder microbial function. Kanti et al. (2019) also studied nitrogen and phosphorus release from mangrove leaf litter decomposition in sediments and concluded that sediment pH affects both decomposition rate and nutrient release, with optimal pH supporting active microbial decomposition.

Previous studies consistently show that litter biomass is affected by environmental factors such as soil moisture, air humidity, temperature, and soil pH. Pasaribu et al. (2024) stated that litter biomass is influenced by soil and air humidity as well as soil acidity. Similarly, Tijau et al. (2024) found that the average carbon content in mangrove litter was 43.03 tons/ha/year, with an average daily carbon percentage of 12.48%, influenced by mangrove species type and local environmental conditions. Arif et al. (2024) examined aboveground biomass, belowground (root) biomass, deadwood biomass, litter biomass, and soil organic biomass in teak (Tectona grandis) stands, showing that trees with larger diameters store greater amounts of carbon.

Thus, this study demonstrates that litter biomass in Pria Laot Waterfall Area, Batee Shoek, Sabang, is influenced by environmental factors such as temperature, soil pH, soil and air humidity, and light intensity, consistent with the findings of previous studies. Karina et al. (2022) and Thalib et al. (2021) concluded that lower temperature and soil pH can slow down litter decomposition and increase biomass accumulation, while Kusmana & Yentiana (2021) emphasized the role of humidity in accelerating or decelerating the decomposition process.

Furthermore, earlier research by Susanty & Halwany (2017) and Kanti et al. (2019) confirmed that soil and microclimatic conditions play a key role in determining litter decomposition rates and nutrient release, supporting the findings of this study. However, this research found that light intensity had no direct effect on litter biomass, although it may influence vegetation growth, consistent with Jayanthi & Arico (2017), who observed that denser canopies can enhance litter production through higher photosynthetic activity. A comparison with Maulidya et al. (2019) on Pulau Nasi also indicates that location and environmental differences affect litter biomass quantity and distribution, where the total biomass recorded in this study was lower than their findings (12,719 g/ha).

2. Litter Carbon

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The litter biomass in Pria Laot Waterfall Area, Batee Shoek, Sabang, exhibited varied distribution across stations, with a total biomass of 253.37 g and a carbon content of 0.253 kg or 2.53 tons/ha. Station 3 had the highest biomass and carbon content (293.68 g and 1.38 tons/ha, respectively), likely influenced by environmental factors such as lower temperature (28°C) and more acidic soil (pH 4.5), which may slow decomposition processes and promote litter accumulation. These findings align with Karina et al. (2022) and Susanti et al. (2024), who stated that lower soil pH can reduce microbial activity in litter decomposition, resulting in higher biomass accumulation.

Furthermore, Kusmana & Yentiana (2021) found that higher soil moisture accelerates litter decomposition, consistent with this study's findings that Station 1, having the highest soil moisture (82%), had less litter accumulation compared to other stations. Similarly, Maulidya et al. (2019), in their study of the Gampong Deudap Forest on Pulau Nasi, reported that variations in litter carbon biomass are influenced by local environmental factors and natural decomposition processes, with higher average litter biomass carbon than that observed in this study. Additionally, Tijau et al. (2024) demonstrated that carbon content in mangrove litter varies depending on environmental conditions and dominant vegetation types, consistent with the current study, where vegetation density at each station likely influenced litter and stored carbon accumulation.

Litter carbon storage is affected by various environmental factors, including climate, topography, soil type, and vegetation characteristics (Azzahra et al., 2022). Soil and air humidity, soil pH, and light intensity are key parameters influencing litter production and decomposition (Wasis & Sajadad, 2024). Optimal soil moisture supports microbial activity during decomposition, thereby influencing the amount of carbon stored in litter (Suswana & Maulana, 2023). Additionally, appropriate soil pH enhances nutrient availability for plants, which subsequently affects litter production (Mendrofa et al., 2024).

This study is consistent with the findings of Hartati et al. (2021), conducted in the Education and Research Forest of the Faculty of Forestry, Mulawarman University, Samarinda, where the total carbon reserve in understory vegetation and litter reached 933.4 tons, with 95.9% stored in litter. This highlights the significant role of litter in forest carbon storage. Moreover, Farhaby et al. (2023), in the Kurau Timur Mangrove Forest, Central Bangka Regency, found that litter carbon production was influenced by environmental factors such as dissolved oxygen (DO) and pH, with higher pH values correlating with increased litter carbon production.

Tijow et al. (2024), in a mangrove forest in Bulo Village, Wori Subdistrict, North Minahasa Regency, estimated an average litter carbon content of 43.03 tons/ha/year, with an average daily carbon percentage of 12.48%. Similarly, Komul & Hitipeuw (2022), in the Soya State Forest, Ambon City, found that litter carbon biomass ranged between 0.7459 tons/ha and 1.36803 tons/ha. Factors such as vegetation density and environmental conditions were shown to influence the amount of litter and stored carbon.

Conclusion

The total litter biomass in Pria Laot Waterfall Area, Batee Shoek, Sabang, was 6,468.97 g (6.47 kg), with an average of 1,322.99 g (1.32 kg) per station. The total litter carbon in the area was 0.253 kg, with an average of 0.084 kg per station. Litter carbon storage in the area reached 2.53 tons/ha, with an average of 0.84 tons/ha, where Station 3 showed the highest carbon storage (1.38 tons/ha) and Station 1 the lowest (0.39 tons/ha).

It is recommended that future research expand the spatial coverage to obtain a more representative understanding of litter biomass and carbon distribution across different forest ecosystems in Sabang City. Further studies should include additional environmental factors such as vegetation type, rainfall, and anthropogenic activities that influence litter dynamics. The use of humidity sensors and satellite imagery is also recommended to improve data accuracy and deepen understanding of litter decomposition patterns and their role in the forest carbon cycle.

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