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Nitrate and Phosphate Content in Mangrove Leaf Litter of *Rhizophora apiculata* and *Sonneratia alba* in Passo Village, Ambon Bay, Indonesia

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ABSTRACT

The mangrove ecosystem plays a crucial role in the coastal nutrient cycle, particularly through litter production and decomposition. This study aimed to analyze nitrate and phosphate content in the litter of *Rhizophora apiculata* and *Sonneratia alba* in Negeri Passo, Ambon Bay. Sampling was conducted at three stations over three periods using 1 × 1m litter traps. Physicochemical parameters of the water were measured *in situ*, while nutrient analysis was performed in the laboratory. The results showed that litter production of *R. apiculata* ranged from 1.98 to 2.75 g/m²/day, which was higher than *S. alba*, ranging from 2.36 to 2.67 g/m²/day. Leaf fractions were the dominant component, contributing 1.52–2.07 g/m²/day in *R. apiculata* and 1.70–1.87 g/m²/day in *S. alba*. The nitrate content in *R. apiculata* litter ranged from 0.2159 to 0.5367 mg/L, while *S. alba* exhibited higher values, ranging from 0.2207 to 0.6468 mg/L. A similar pattern was observed for phosphate content, with *R. apiculata* ranging from 0.2159 to 0.5367 mg/L and *S. alba* from 0.2207 to 0.6468 mg/L. The release of nitrate and phosphate from litter contributes to the primary productivity of coastal ecosystems; however, excessive accumulation may lead to eutrophication. Therefore, monitoring nutrient dynamics is essential for the sustainable management of mangrove ecosystems.

INTRODUCTION

Mangrove ecosystems play a crucial role in maintaining coastal environmental balance **(Rahman *et al*., 2024a)**. One of the key components of mangrove ecosystems is litterfall, produced by mangrove trees, which contributes to biogeochemical cycles and serves as a food source for various organisms. Research on the nutrient content of mangrove litter, particularly essential nutrients such as nitrate and phosphate, is becoming increasingly important in understanding the contribution of this ecosystem to environmental balance and coastal water quality. Nitrate and phosphate, as primary nutrients, play a vital role in plant growth and ecosystem health; however, excessive concentrations can lead to eutrophication **(Alongi, 2009)**.

Mangrove litter consists of fallen leaves, twigs, and other decaying plant parts, which undergo decomposition at the mangrove forest floor **(Rahman *et al*., 2023a, b)**. This decomposition process releases various compounds that are essential for biogeochemical cycles and serve as nutrient sources for decomposer organisms. Several studies have examined nutrient content in mangrove litter; however, most have focused on specific species or measured only one type of nutrient (e.g., nitrate or phosphate) without considering the relationship between them **(Thaillardat *et al*., 2019)**.

Rhizophora apiculata and *Sonneratia alba* are two common mangrove species found along the Indonesian coast, including in Passo Village, Ambon Bay **(Peitersz *et al*., 2024)**. These species play a significant ecological role in maintaining coastal stability and supporting biodiversity **(Bengen *et al*., 2022; Rahman *et al*., 2024b)**. However, studies on nitrate and phosphate content in the litter of these species in Ambon Bay remain limited, particularly in relation to their impact on water quality and overall mangrove ecosystem productivity.

The nitrate and phosphate content in mangrove litter largely depends on environmental conditions and mangrove species. Some studies indicate that soil conditions, water salinity, and water availability influence the concentration of these nutrients in litter **(Singh *et al*., 2005)**. Research by **McKee (1993)** also showed that nitrate and phosphate concentrations in litter can vary between mangrove species and are influenced by factors such as seasonal changes and water quality. Therefore, exploring nutrient content in mangrove litter in specific locations, such as Passo Village, is essential to understand species-specific variations.

The novelty of this study lies in its comprehensive analysis of nitrate and phosphate content in the litter of *Rhizophora apiculata* and *Sonneratia alba* in the coastal area of Ambon Bay. Previous studies in this region have predominantly focused on the biological aspects and diversity of mangrove species **(Latumahina *et al*., 2024)** without considering the role of litter nutrients in water quality or the sustainability of the mangrove ecosystem itself. Thus, this research aimed to provide deeper insights into the role of mangrove litter in nutrient cycling within coastal ecosystems, particularly concerning nitrate and phosphate content.

This study is also expected to provide insights into the potential use of mangrove litter as an environmental quality indicator and for improved coastal ecosystem management. For instance, **Alongi (2018)** suggested that mangrove litter can be used to monitor environmental quality changes and guide more effective conservation efforts. By obtaining more comprehensive data on nutrient content in mangrove litter, the management of mangrove areas in Passo Village can be conducted more sustainably.

Additionally, the findings of this study will be valuable for policy development related to mangrove management in Indonesia, a country with the largest mangrove ecosystems in the world. A better understanding of the role of mangrove litter in nutrient cycling can contribute to designing more effective management strategies to ensure the sustainability of mangrove ecosystems and their benefits to coastal communities.

Overall, this research is expected to contribute to the advancement of mangrove ecology and coastal management by focusing on the relationship between nitrate and phosphate content in mangrove litter and its impact on coastal environmental quality in Passo Village, Ambon Bay.

MATERIALS AND METHODS

1. Description of the study sites

The study was conducted from June to August 2024, focusing on the mangrove ecosystem in Passo Village, located in the waters of Ambon Bay, Ambon City, Maluku Province. Astronomically, the study area is positioned at coordinates 128° 14’ 25.26” – 128° 14’ 57.71” E and 3° 38’ 7.28” – 3° 37’ 59.13” S (Fig. 1). Sampling was carried out at several designated stations within the mangrove area of Passo Village, with the specific locations of each station listed in Table (1).

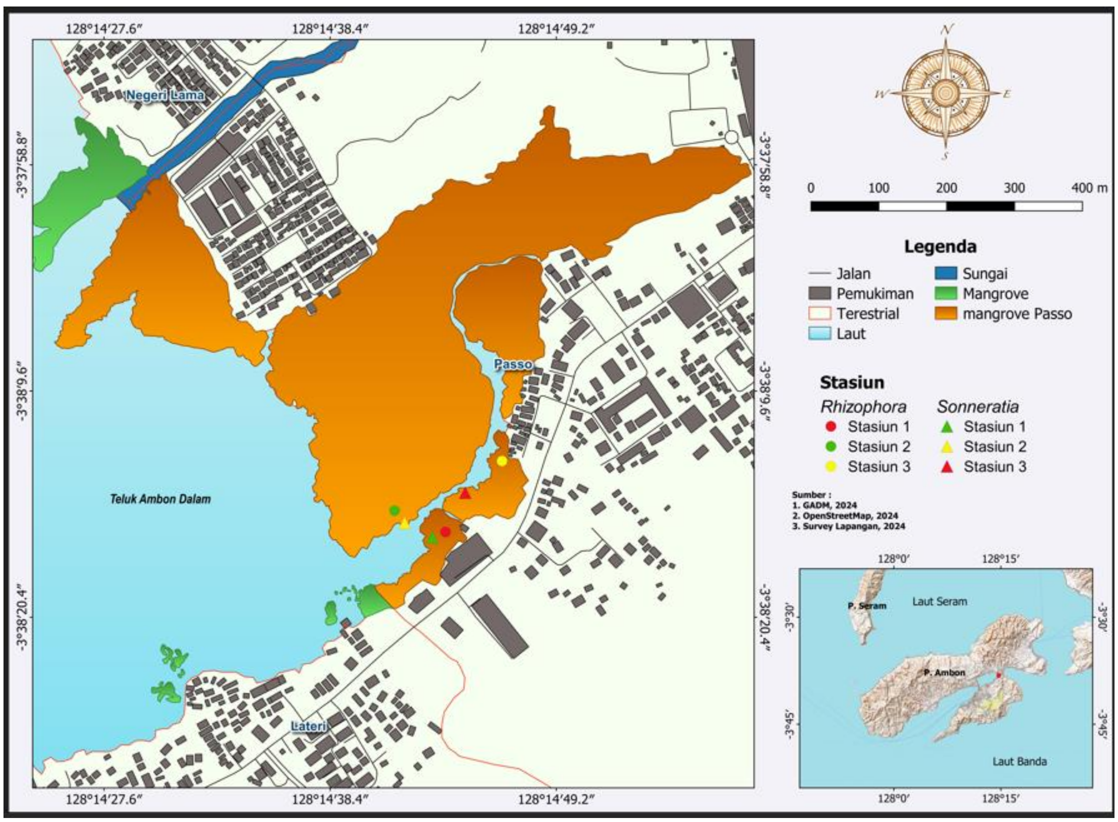

Fig. 1. Map of the study sites

Table 1. Station position in the mangrove area of Passo Village

Station	Longitude	Latitude
Rhizophora apiculata		
ST 1	03° 38' 16,33"	128° 14' 43,91"
ST 2	03° 38' 15,31"	128° 14' 41,48"
ST 3	03° 38' 12,94"	128° 14' 46,61"
Sonneratia alba		
ST 1	03° 38' 16,58"	128° 14' 43,29"
ST 2	03° 38' 15,89"	128° 14' 41,96"
ST 3	03° 38' 14,16"	128° 14' 44,93"

2. Litter sampling and nutrient analysis

Litterfall sampling was conducted using a commonly applied method for capturing falling litter in mangrove forests, employing six 1 × 1m litter traps. Three litter traps were installed at each station (Station 1, Station 2, and Station 3) for *Rhizophora apiculata*, while the other three were placed at the same stations for *Sonneratia alba*. Litterfall collection was performed every 14 days over three sampling periods (Period 1, Period 2, and Period 3).

After collecting, the accumulated litter was separated into leaves, twigs, and flowers/fruits. The samples were then dried and weighed. The collected data included the dry weight of mangrove leaf litter from *Rhizophora apiculata* and *Sonneratia alba* over the three sampling periods.

The analysis focused on nitrate (NO_3^-) and phosphate (PO_4^{3-}) content in mangrove leaf litter. The dried leaf samples were ground into fine powder, and 10 grams from each species were extracted and processed. Nutrient analysis was conducted using spectrophotometric methods based on the Standard Methods for the Examination of Water and Wastewater **(APHA, 2017)**, in the Marine Science Laboratory, FPIK, Pattimura University.

Data analysis

Litter production analysis

Mangrove litter that falls into the litter trap was collected and placed into plastic bags. Components such as leaves, twigs, flowers, and fruits are separated and then weighed using a scale with an accuracy of 0.001 grams. The measured data were then calculated in units of grams/m²/day. The results of the litter production calculations are presented in tables and graphs, followed by a descriptive discussion.

Litterfall production estimation

Litter production at each station was analyzed according to **Mahmudi *et al*. (2008)**:

$$Xj = \sum_{j=1}^{n} \frac{xi}{n} (g/m^2)$$

Where, Xj is the average litter production of each repeat over a given period of time; Xi is the litter production of each repeat at a certain period of time (to i = 1, 2, 3); and N is the number of observation litter traps.

Potential nutrient production from mangrove litter

The potential nutrient production of the litter (litter/all nutrient accession) was calculated using the equation from **Djamaludin (1995)**:

$$NA = N \times P$$

Where, NA = Nutrient accession of nutrients produced (g/m^2/day); N = Nutrient content; and P = Production of wet weight litter (g/m^2/day).

RESULTS AND DISCUSSION

1. Litterfall production

Litterfall production of R. apiculata

Litterfall production plays a crucial role in the ecological functioning of mangrove ecosystems, primarily serving as a major source of organic matter and nutrients for coastal waters and sediments **(Alongi, 2014)**. The litterfall production of *Rhizophora apiculata* observed in Negeri Passo, Ambon Bay, exhibited variations among stations, with total values ranging from 1.98 to 2.75 g/m^2/day (Table 2). Station 3 recorded the highest average litterfall production (2.75 g/m^2/day), while Station 2 had the lowest (1.98 g/m^2/day). These variations may be influenced by specific environmental factors such as tree density, tidal inundation frequency, and nutrient availability **(Twilley *et al*., 1992)**.

The dominant fraction of total litterfall production across all stations was leaves, contributing an average of 1.52 to 2.07 g/m^2/day. These results are consistent with previous studies indicating that mangrove litterfall is predominantly composed of leaves, followed by twigs, flowers, and fruits **(Kristensen *et al*., 2008)**. The higher leaf production at Station 3 suggests a more favorable growth environment, possibly due to optimal hydrodynamic conditions and lower anthropogenic disturbances. In contrast, the lower leaf production at Station 1 may indicate environmental stressors, such as increased salinity or sedimentation, which could affect tree physiology and productivity **(Clough, 1992)**.

The presence of twigs, flowers, and fruits in litterfall production provides additional insights into the phenological patterns of *Rhizophora apiculata* in this region. Twigs contributed significantly to the total litterfall production at Station 1 (0.89 g/m^2/day), which may be attributed to natural pruning processes or branch shedding caused by storms **(Duke *et al*., 1998)**. Meanwhile, flower and fruit productions exhibited the lowest outcome across all stations, ranging from 0.23 to 0.64 g/m^2/day. This suggests that *R.*

apiculata in Negeri Passo is in a moderate reproductive phase, potentially influenced by seasonal variations and local climatic factors **(Lovelock *et al*., 2010)**.

Table 2. Litterfall production of *Rhizophora apiculata* in Negeri Passo, Ambon Bay

Station	Period	Leaves (g/m²/day)	Flowers & Fruits (g/m²/day)	Twigs (g/m²/day)	Total (g/m²/day)
1	1	0.50	0.29	1.64	2.43
	2	1.50	0.71	0.14	2.36
	3	2.55	0.00	-	2.55
Average		1.52	0.64	0.89	2.45
	1	1.08	0.14	0.36	1.58
2	2	1.71	0.20	0.36	2.27
	3	1.96	0.13	-	2.09
Average		1.59	0.23	0.36	1.98
	1	0.63	0.21	0.36	1.20
3	2	1.86	0.27	0.36	2.48
	3	3.74	0.11	0.72	4.56
Average		2.07	0.29	0.48	2.75

Compared to mangrove litterfall production in other regions of Indonesia and Southeast Asia, the values observed in Negeri Passo remain within the general range of 1.5 to 6.0 g/m²/day **(Clough, 1992)**. However, local differences in hydrology, sediment characteristics, and nutrient input can significantly influence these values. Mangrove litterfall plays a crucial role in the carbon cycle, supporting detritus-based food chains and enhancing organic matter accumulation in sediments **(Bouillon *et al*., 2008)**. Therefore, understanding litterfall production dynamics is essential for assessing the health and productivity of the mangrove ecosystem in Ambon Bay.

Litterfall production of S. alba

The litterfall production of *Sonneratia alba* in Negeri Passo, Ambon Bay, exhibited variations among stations, with total production ranging from 2.36 to 2.67 g/m²/day. Stations 1 and 3 recorded the highest average litterfall production (2.67 g/m²/day), while Station 2 had the lowest value (2.36 g/m²/day) (Table 3). These variations may be influenced by environmental factors such as canopy openness, wave intensity, and tidal dynamics, which can affect litterfall shedding **(Alongi, 2014)**. The relatively uniform litterfall production suggests that *S. alba* follows a stable leaf-shedding pattern, which is commonly observed in fast-growing mangrove species with high tolerance to extreme environmental conditions **(Robertson & Alongi, 1992)**.

Leaves dominated the litterfall fraction across all stations, with average values ranging from 1.70 to 1.87 g/m²/day. This aligns with the general characteristics of mangroves, where leaves constitute the primary component of litterfall, while flowers, fruits, and twigs contribute less **(Kristensen *et al*., 2008)**. Although *S. alba* is well adapted to low-oxygen environments, the higher leaf production at Stations 1 and 3 suggests that trees in these locations experience better growth conditions compared to

Station 2, which may be subjected to higher environmental stress, such as sedimentation or anthropogenic disturbances **(Lovelock *et al*., 2010)**.

Table 3. Litterfall production of *S. alba* in Negeri Passo, Ambon Bay

Station	Period	Leaves (g/m²/day)	Flowers & Fruits (g/m²/day)	Twigs (g/m²/day)	Total (g/m²/day)
1	1	0.52	0.07	0.21	0.81
	2	3.43	0.64	0.29	4.36
	3	1.66	0.39	0.78	2.83
Average		1.87	0.37	0.43	2.67
	1	0.44	0.14	0.14	0.73
2	2	3.21	0.57	0.36	4.14
	3	1.44	0.31	0.44	2.19
Average		1.70	0.34	0.31	2.36
	1	0.52	0.07	0.21	0.81
3	2	3.43	0.64	0.29	4.36
	3	1.66	0.39	0.78	2.83
Average		1.87	0.37	0.43	2.67

Compared to *Rhizophora apiculata*, the total litterfall production of *S. alba* tends to be lower. *R. apiculata* exhibited a litterfall production range of 1.98 to 2.75 g/m²/day, whereas *S. alba* produced between 2.36 and 2.67 g/m²/day. This difference may be attributed to the morphological and physiological differences between the two species. *R. apiculata* typically grows more densely and has a faster leaf production cycle than *S. alba*, which is predominantly found in the seaward mangrove zone, where it is frequently exposed to tidal fluctuations and wave action **(Duke *et al*., 1998)**. These environmental factors can influence litterfall release rates and decomposition processes in each zone **(Bouillon *et al*., 2008)**.

The composition of litterfall fractions also differed between the two species. In *S. alba*, the flower and fruit fraction contributed an average of 0.34 to 0.37 g/m²/day, whereas in *R. apiculata*, it ranged from 0.23 to 0.64 g/m²/day. This suggests that *S. alba* exhibits a more consistent reproductive pattern compared to *R. apiculata*, which may experience greater variability in reproduction depending on seasonal factors and environmental conditions **(Rahman *et al*., 2020a)**. Additionally, the twig fraction in *S. alba* (0.31–0.43 g/m²/day) was lower than in *R. apiculata* (0.36–0.89 g/m²/day), indicating that *R. apiculata* sheds small branches more frequently as part of its adaptive mechanism to the environment **(Twilley *et al*., 1992)**.

Overall, these findings indicate that *S. alba* and *R. apiculata* exhibit distinct litterfall production patterns, reflecting differences in their ecological roles and adaptive strategies. Further studies are needed to evaluate the environmental factors influencing litterfall production and their implications for the carbon cycle and mangrove ecosystem productivity in Ambon Bay. With increasing anthropogenic pressures in coastal areas, understanding litterfall dynamics can contribute to more effective mangrove conservation and rehabilitation effort **(Rahman *et al*., 2020b)**.

2. Nitrate and phosphate concentrations in mangrove leaves

Litterfall in mangrove ecosystems plays a crucial role in the nutrient cycle, particularly in the cycling of nitrogen and phosphorus, which support coastal ecosystem productivity **(Alongi, 2018)**. The study results indicate that nitrate and phosphate concentrations in the litter of *Rhizophora apiculata* and *Sonneratia alba* in the mangrove ecosystem of Negeri Passo vary across sampling periods and locations. These differences may be influenced by environmental factors such as salinity, tidal fluctuations, and microbial activity, which affect litter decomposition **(Kristensen *et al*., 2008)**.

The nitrate content in *R. apiculata* litter ranged from 0.2159 to 0.5367mg/ L, whereas in *S. alba*, it ranged from 0.2207 to 0.6468mg/ L (Table 4). Overall, the average nitrate concentration was higher in *S. alba* than in *R. apiculata* across most stations. This difference may be attributed to variations in decomposition rates and the initial nitrogen content in leaf tissues of each species **(Kamruzzaman *et al*., 2018)**. *Sonneratia alba* is known to decompose more rapidly than *Rhizophora*, potentially leading to earlier nitrogen release into the environment **(Twilley *et al*., 1992)**.

Phosphate concentrations in the litter followed a similar pattern to nitrate, with consistent values across measurement periods. Phosphate levels in *R. apiculata* litter ranged from 0.2159 to 0.5367mg/ L, while in *S. alba*, they ranged from 0.2207 to 0.6468mg/ L (Table 4). These differences suggest that the phosphate release from the litter is influenced by mineralization processes and microbial activity within the mangrove ecosystem **(Hossain & Bhuiyan, 2016)**.

Table 4. The nitrate and phosphate content (mg/L) in the litter of *Rhizophora apiculata* and *Sonneratia alba*

Nutrient Type	Periods	Station 1		Station 2		Station 3	
		R. apiculata	*S. alba*	*R. apiculata*	*S. alba*	*R. apiculata*	*S. alba*
Nitrate	1	0.5143	0.5136	0.5355	0.4690	0.5308	0.4601
	2	0.5367	0.6468	0.5333	0.6522	0.5311	0.6373
	3	0.2159	0.2207	0.2213	0.2129	0.1986	0.1978
	Average	0.4223	0.4604	0.4300	0.4447	0.4202	0.4317
Phosphate	1	0.5143	0.5136	0.5355	0.4690	0.5308	0.4601
	2	0.5367	0.6468	0.5333	0.6522	0.5311	0.6373
	3	0.2159	0.2207	0.2213	0.2129	0.1986	0.1978
	Average	0.4223	0.4604	0.4300	0.4447	0.4202	0.4317

During the first and second periods, nitrate and phosphate concentrations in the litter were higher than in the third period across all stations. This decline is likely due to increased decomposition activity, leading to faster nutrient release into the environment over time **(Bouillon *et al*., 2008)**. Additionally, environmental factors such as tidal fluctuations and interactions with soil biota may also influence nutrient release from the litter **(Li *et al*., 2025)**.

Differences in nitrate and phosphate concentrations between stations may be associated with substrate characteristics and tidal dynamics in each location. Stations with higher water flow rates tend to experience greater nutrient leaching, reducing nitrate and phosphate accumulation in the litter **(Adame & Lovelock, 2011)**. Furthermore, the activity of organisms such as crabs and microorganisms, which affect decomposition rates, may also contribute to variations in nutrient content among locations **(Lee, 1998; Gao *et al*., 2024)**.

The release of nitrate and phosphate from litter plays a crucial role in supporting primary productivity in mangrove ecosystems and surrounding waters. The released nutrients can be utilized by phytoplankton, macroalgae, and bacterial communities, which contribute to the estuarine food web **(Dittmar & Lara, 2001)**. Therefore, nitrate and phosphate concentrations in litter have significant ecological implications for the overall function of the mangrove ecosystem.

From an ecosystem management perspective, understanding the nutrient release dynamics from mangrove litter can aid in conservation and habitat restoration planning. Ecosystem-based management that considers the role of litter in nutrient cycling can support climate change mitigation efforts and improve coastal environmental quality **(Lovelock *et al*., 2011)**. Further studies are needed to explore additional factors influencing nutrient release from litter, including microbial interactions and hydrological dynamics in mangrove ecosystems.

3. Potential nutrient content in litter

Mangroves play a crucial role in the biogeochemical cycle of coastal waters, particularly in the production and release of nutrients such as nitrate (NO_3) and phosphate (PO_4). The nutrient production by *Rhizophora apiculata* and *Sonneratia alba* shows variation across stations. In general, *Sonneratia alba* produces higher concentrations of NO_3 compared to *Rhizophora apiculata* at all stations, with average production rates of 3.28 g/m²/day and 1.92 g/m²/day, respectively (Table 5). This suggests that *Sonneratia alba* plays a more significant role in providing inorganic nitrogen in the mangrove ecosystem.

Table 5. Nutrient production (g/m^2/day) by mangrove species at each station

Station	***R. apiculate***		***S. alba***	
	NO_3	PO_4	NO_3	PO_4
1	1.40	0.16	2.97	0.18
2	2.05	0.83	2.79	0.45
3	2.32	0.90	4.08	0.51
Average	1.92	0.63	3.28	0.38

The differences in the production of NO_3 and PO_4 between the two-mangrove species can be attributed to variations in their physiological characteristics and nutrient absorption mechanisms. *Sonneratia alba* is more commonly found in areas with lower salinity and tends to have a more complex root system, which supports the release of nitrogen into the environment **(Alongi, 2014)**. In contrast, *Rhizophora apiculata* is more dominant in mud substrates with high organic matter content, which may limit the release of inorganic nitrogen due to the dominance of denitrification processes in the sediment **(Kristensen *et al*., 2008)**.

Moreover, phosphate (PO_4) production from both species shows different patterns. The average PO_4 production by *Rhizophora apiculata* is 0.63 g/m²/day, higher than that of *Sonneratia alba*, which is only 0.38 g/m²/day. Phosphate in mangrove ecosystems generally originates from the decomposition of leaf litter and release processes from sediments **(Hossain & Nuruddin, 2016)**. This difference suggests that *Rhizophora apiculata* may be more efficient in supporting phosphate release, likely due to higher rates of litter decomposition compared to *Sonneratia alba*.

Spatial variation in nutrient production between stations 1, 2, and 3 is also noteworthy. Station 3 has the highest NO_3 production, both for *Rhizophora apiculata* (2.32 g/m²/day) and *Sonneratia alba* (4.08 g/m²/day), which may be due to environmental conditions that better support nitrogen mineralization processes. Factors such as tidal levels, organic matter content, and microbial activity in sediments can influence nutrient release from mangrove root systems **(Li *et al*., 2025)**.

The implications of these differences in nutrient production are highly relevant for supporting primary productivity in coastal waters. An increase in the availability of NO_3 and PO_4 around mangrove ecosystems can enhance the growth of phytoplankton and macroalgae, which serve as a food source for various aquatic organisms **(Dittmar *et al*., 2006)**. However, if nutrient production is excessive, eutrophication may occur, potentially disrupting the balance of coastal ecosystems **(Schourup-Kristensen *et al*., 2023)**. Therefore, monitoring nutrient dynamics in mangrove ecosystems is essential for maintaining ecological balance.

CONCLUSION

This study reveals that mangrove litter from *Rhizophora apiculata* and *Sonneratia alba* plays a significant role in the nutrient cycle of the mangrove ecosystem in Passo Village, Ambon Bay. Litter production shows variation across stations, with *R. apiculata* having higher litter production values compared to *S. alba*. This difference can be attributed to the physiological and ecological characteristics of each species, including canopy density and interactions with environmental factors such as tidal fluctuations and water hydrodynamics.

Nitrate and phosphate contents in the litter also show significant differences between the two species. *S. alba* tends to have higher nitrate content compared to *R. apiculata*, while phosphate content is higher in *R. apiculata*. This suggests that the decomposition processes and nutrient release are influenced by leaf tissue structure as well as the environmental conditions in which each species grows.

Ecologically, nutrient release from mangrove litter contributes to the primary productivity of coastal ecosystems by supporting the growth of phytoplankton and macroalgae. However, if nutrient concentrations increase excessively, eutrophication may occur, potentially disrupting the ecosystem balance. Therefore, monitoring nutrient dynamics in mangrove ecosystems is crucial for conservation efforts and sustainable environmental management.

This research provides valuable insights into the role of mangrove litter in the coastal biogeochemical cycle and can serve as a basis for mangrove ecosystem management policies in Indonesia. Further understanding of the factors affecting nutrient release from mangrove (microbial activity, environmental factors such as temperature, humidity, salinity, leaf litter quality e.g. tannins concentration, soil and water chemistry) are important to present and correlate these data with your findings litter is necessary to support conservation strategies and mitigate environmental impacts from climate change and anthropogenic activities.

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