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Nutrients in Mangrove Sediment as a Growth Factor in Coastal Rehabilitation Areas in East Halmahera, North Maluku, Indonesia

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ABSTRACT

The implementation of coastal ecosystem rehabilitation through mangrove replanting has been carried out in East Halmahera, North Maluku, Indonesia. Based on evaluation and monitoring conducted every six months after replanting, mangrove growth has been relatively slow, with an average monthly stem growth of 0.99cm and a leaf growth rate of only 1–2 leaves per month. Thus, this study aimed to analyze sediment nutrient content as a determining factor for mangrove growth in rehabilitation areas of East Halmahera. Field data collection was conducted in June 2024 at the mangrove rehabilitation site in Buli, followed by laboratory analysis of sediment nutrient content. Results from phosphate and nitrate measurements in mangrove vegetation on the Moronopo side indicated that phosphate content was the highest in research area B (0.39 mg/100 g), compared to area A (0.0441mg/ 100g). The highest nitrate content was recorded at location B2 (0.37%), followed by B3 (0.31%), while the lowest nitrate concentration was observed at location B4 (0.10%). Overall, the analysis shows that nitrate levels at the study site are relatively low. Both phosphate and nitrate concentrations in the sediment were low, which is likely due to limited organic matter inputs in the rehabilitation area. This condition is exacerbated by the high sludge content of the site, which may further constrain nutrient availability and hinder mangrove growth.

INTRODUCTION

Mangrove ecosystems are unique coastal ecosystems found in tidal zones, beaches, and small islands, and represent highly valuable natural resources **(Priatna *et al.*, 2021)**.

As one of the most important coastal ecosystems, mangroves play ecological, economic, and social roles, including supporting climate change mitigation and adaptation. Physically, mangroves help control coastal abrasion and seawater intrusion, while their root systems effectively trap terrestrial waste and sediments.

Given these wide-ranging benefits, mangrove restoration is essential in degraded areas. Successful restoration improves coastal protection, fisheries, aquaculture, carbon sequestration, and even aesthetic values **(Priatna *et al.*, 2021)**. One such effort has been the rehabilitation of mangrove ecosystems at the Moronopo site, implemented by PT Antam Tbk Buli. The replanting program aimed to protect coastal ecosystems and marine resources, particularly seagrass beds and coral reefs, from sedimentation associated with mining activities during the rainy season.

Mangrove replanting at Moronopo has been ongoing for approximately 15 years. However, monitoring results show that growth remains very slow and dwarfed. Evaluations conducted every six months indicate an average monthly height increase of only 0.99cm, with a leaf growth rate of just 1–2 leaves per month. Despite various efforts by PT Antam to accelerate mangrove growth at the site, results have been unsuccessful. Therefore, this study seeked to identify the factors inhibiting mangrove growth at the Moronopo rehabilitation site, focusing specifically on analyzing sediment nutrient content and other determinants of mangrove growth in rehabilitation areas.

MATERIALS AND METHODS

1. Place and time of research

This research was carried out at the rehabilitation area in June 2024 followed by laboratory analysis at the Environmental Water Laboratory Nusantara (WLN) laboratory of Manado, North Sulawesi.

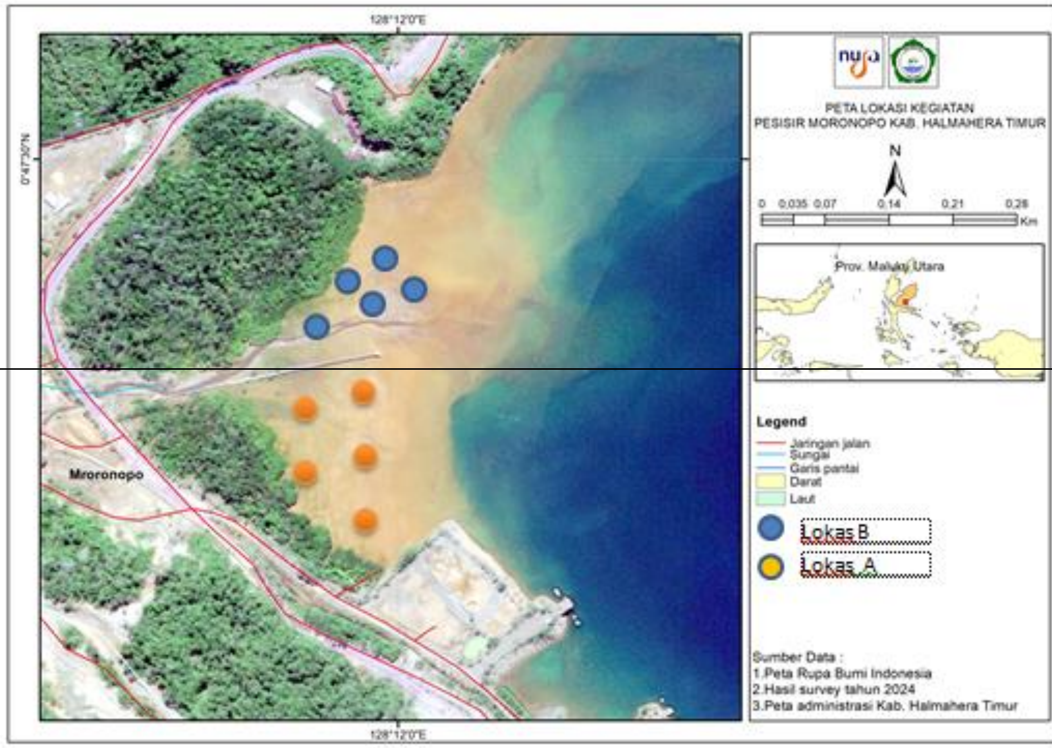

Fig. 1. Research location

2. Sediment measurement

Sediment texture was measured using the method of **Buchanan (1971)**. Sediment samples were collected using a core sampler made from a 30 cm-long paralon pipe inserted into the substrate to the desired depth. Samples were transferred into labeled ziplock plastic bags, stored in a cool box to prevent damage or contamination, and subsequently transported to the laboratory for analysis.

Phosphate measurement

Phosphate analysis was conducted using 100g of sediment samples, which were diluted prior to measurement. Test preparations included preparing a 500mg/ L phosphate stock solution, a 10mg/ L standard solution, working solutions, and a calibration curve. For sample measurement, 50mL aliquots were pipetted in duplicate into Erlenmeyer flasks. One drop of phenolphthalein indicator was added; if a pink color appeared, drops of 5 N H_2SO_4 were added until the color disappeared. Then, 8mL of reagent was added, the mixture was homogenized, and transferred into a cuvette. Absorbance was measured using a spectrophotometer at a wavelength of 880nm, recorded within 10–30 minutes.

Nitrate measurement

Nitrate analysis was performed using 100g of diluted sediment samples. Prior to measurement, samples suspected to contain chlorine were filtered through 0.45µm

Millipore filter paper and treated with one drop of sodium arsenite solution to neutralize residual chlorine. For analysis, 50mL aliquots were pipetted, filtered if necessary, and treated with 1mL of 1 N HCl before homogenization.

Measurement of physical and chemical parameters

At each research location, *in situ* measurements of water quality parameters were carried out. These included temperature (thermometer), salinity (refractometer), and pH (soil pH meter).

RESULTS

1. Sediment type

The substrate plays a crucial role in the development of mangrove habitats, as sediment grain size and type can directly or indirectly influence hydrology and soil fertility. At the study site, sediment texture was generally dominated by sandy clay. The composition of sand ranged from 62.28 to 77.90%, silt from 0.30 to 0.36%, and clay from 29.65 to 36.55%. The complete results are presented in Table (1).

Table 1. Results of sediment type analysis at the research site

Location	**Sediment Granule Percentage (%)**			**Sediment Faction**
	Sand	**Silt**	**Clay**	
A(Nort)				
1	67.6	0.36	30.04	Sandy clay clay
2	69.96	0.13	30.91	Sandy clay clay
3	66.3	0.35	31.35	Sandy clay clay
4	63.2	0.25	36.55	Sandy clay
5	61.28	0.4	32.32	Sandy clay clay
B (south)				
1	70.1	0.25	29.65	Sandy clay clay
2	68.92	0.32	30.76	Sandy clay clay

Location	Sediment Granule Percentage (%)			Sediment Faction
3	69.32	0.28	30.4	Sandy clay clay
4	63.3	0.3	36.4	Sandy clay
5	77.9	0.31	31.79	Sandy clay clay

2. Phosphate

The content of phosphate and nitrate in mangrove forests originates both from within the ecosystem and from surrounding environmental inputs. Nutrient availability is influenced by land-based contributions carried by rivers, as well as by the decomposition of mangrove leaf litter, in which bacterial activity converts organic matter into phosphate and nitrate.

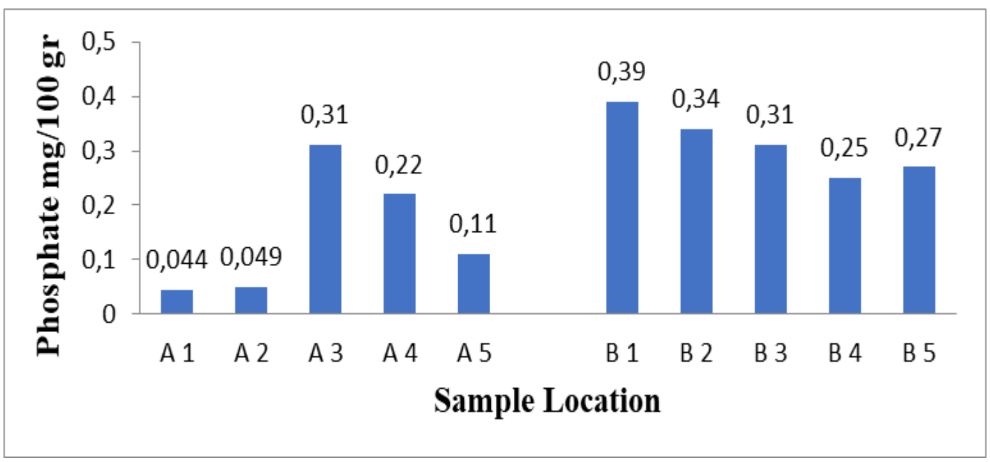

Fig. 2. Phosphate content at the research site

3. Nitrate

The results of the nitrate content analysis are presented in Fig. (2).

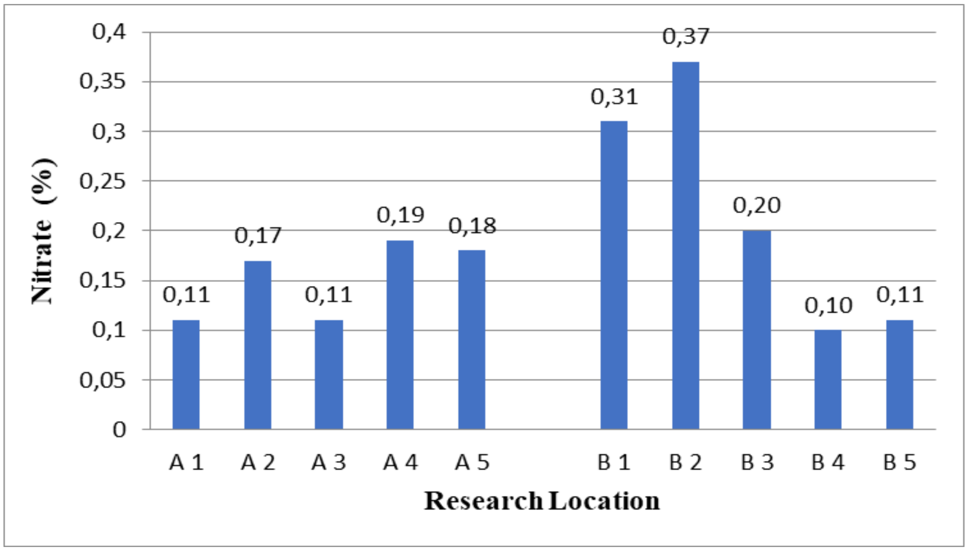

Fig. 3. Nitrate content at the research sites

Fig. (3) shows the distribution of nitrate content in mangrove forest sediments on the Moronopo side, which varied considerably across sampling points. The highest nitrate concentration was recorded in location B2 (south) with a value of 0.37%, followed by 0.31% in location B3 (south). The lowest concentration was observed in location B4, with a value of 0.10%. Overall, the analysis indicates that nitrate content at the study site is relatively low.

4. Environmental parameters

In addition to soil organic matter content, mangrove growth rates are also influenced by various environmental factors. Field observations in this study identified key physical parameters affecting mangrove development, namely salinity, pH, and temperature. Measurements of these environmental quality parameters were conducted to characterize site conditions, and the results are presented in Table (2).

Table 2. Other environmental parameters

Number	**Location**	**Environmental Parameters**		
		Soil pH	**Salinity (‰)**	**Temperature (°C)**
Noth				
1	A 1	7,7	26,8	27
2	A 2	7,6	27,9	25
3	A 3	7,3	29,9	26
4	A 4	6,2	28,7	27

5	A 5	7,9	28,9	26
South				
6	B 1	7,1	24,9	25
7	B 2	7,2	27,1	27
8	B 3	6,9	2,73	27
9	B 4	7,1	28,2	26
10	B 5	6,7	27,9	26

DISCUSSION

The high dominance of sandy clay sediments at the study site is likely related to its proximity to nickel mining activities, which increase sediment supply during the rainy season. In addition, the site is located within a narrow bay, where weak current circulation reduces sediment transport and enhances deposition. **Rachman *et al.* (2016)** noted that coastal waters in bays undergo dynamic changes driven by physical oceanographic processes, which in turn influence sedimentation. Sediments may be eroded, resuspended, and redeposited depending on current velocity, leading to diverse patterns of sediment grain distribution both spatially and within individual sediment populations.

Phosphate content

Sediment analysis revealed that phosphate concentrations were the highest in research area B (south) at 0.39mg/ 100g, while the lowest value (0.0441mg/ 100g) was recorded in area A (north). Overall, phosphate levels at both sites were relatively low. According to **Supriyantini *et al.* (2020)**, phosphate concentrations of 0.00– 0.20mg/ 100g indicate low fertility, 0.21– 0.50mg/ 100g stand for medium fertility, 0.51– 1.00mg/ 100g for good fertility, and >1mg/ 100g for high fertility. The low phosphate availability at the study sites is likely due to limited organic matter inputs, such as mangrove litter or easily decomposed waste. **Yahra *et al.* (2020)** emphasized that higher mangrove density increases litter production and thus enhances sediment phosphate levels. Furthermore, **Lalik *et al.* (2020)** reported that phosphate content also varies by species: *Avicennia marina* sediments contain higher phosphate than those associated with *Rhizophora mucronata*, which produces higher tannin levels. This aligns with the study site, where *Rhizophora mucronata* and *Rhizophora apiculata* were the dominant species.

Nitrate content

Nitrate is an essential nutrient for plant growth, particularly in the development of roots, stems, and leaves **(Wiyantoko *et al.*, 2017)**. Nitrate in sediments is derived from the biodegradation of organic matter into ammonia, which is subsequently oxidized **(Seitzinger, 1988)**. **Mustafa *et al.* (1982)** classified sediment nitrate levels as very high

(>0.75%), high (0.50–0.70%), moderate (0.20–0.50%), low (0.10–0.20%), and very low (<0.10%). At the study site, nitrate concentrations were generally low, consistent with limited organic matter supply. This condition is compounded by high sludge input from nickel ore processing. During heavy rainfall, large volumes of mud are deposited at the rehabilitation site, reducing nutrient availability. **Santoso *et al.* (2016)** emphasized that mangroves require substantial nutrient inputs, particularly organic matter, which is normally supplied through bacterial decomposition into nitrogen and phosphate.

Salinity

Salinity measurements across both study sites ranged from 24–29‰. The relatively low salinity values may be attributed to the prolonged rainy season. Nonetheless, this range still supports mangrove growth. **Saibi and Tolangara (2017)** highlighted that salinity plays an important role in adaptation processes and influences the abundance of microorganisms. Higher salinity reduces microbial diversity, as many species cannot tolerate extreme conditions.

pH

Soil pH measurements indicated neutral conditions (around pH 7) at both sites. This falls within the range of productive waters (6.2–7.9) **(Kaswadji, 1971** as cited in **Kusmana, 2002)** and suggests fertile conditions. **Sembel and Manan (2018)** noted that pH values may be lower at low tide due to increased organic matter and freshwater input from land runoff.

Temperature

Water temperature at the study sites ranged between 25 & 27°C, which is favorable for mangrove growth and supports metabolic processes of associated organisms. According to **Aksornkoae (1993)**, mangroves grow best in tropical climates where temperatures exceed 20°C. Temperature is a critical factor for metabolism, and sudden or extreme fluctuations can disrupt physiological processes or lead to mortality.

CONCLUSION

The nutrient content of phosphorus and nitrate at the research site was relatively low, which is likely a contributing factor to the slow growth of mangrove seedlings. Low nutrient availability may also limit the biodegradation of organic matter, further constraining seedling development. Nevertheless, other environmental parameters remain within ranges that can support mangrove growth. Rehabilitation efforts, despite these challenges, have enriched and maintained mangrove cover along the coastline, representing a tangible contribution to environmental sustainability. Continued maintenance is essential to preserve the flora and fauna within the rehabilitation area, particularly along the eastern coast of Halmahera.

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