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Nutrient Distribution in Natural and Rehabilitated Mangroves with Various Types of Mangroves, Lampung, Indonesia

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ABSTRACT

Mangroves play a crucial role in coastal ecosystems by providing essential nutrients for both animal and plant life. This study aims to compare the nutrient content in various parts (leaves, fruit, roots, and sediment) of natural and rehabilitated mangroves in Lampung, Indonesia. This research was conducted from November to December 2023 in Pesawaran (5.57185° N), for natural mangrove locations and South Lampung (105.24189° E) for rehabilitated mangrove locations in Lampung Province, Indonesia. Nutrient analyses including nitrogen, phosphorus, magnesium, iron and zinc contents in leaves, fruit, roots, and sediment were also conducted using a spectrophotometer. Statistical analysis using the Principal Component Analysis was carried out to determine the relationship between trace elements with part of mangrove in natural and rehabilitated mangroves. This research revealed that the Phosphorus (natural and rehabilitated mangrove) was found in leaves (0.018 - 0.029 mg kg^{-1}), fruits (0 - 0.034 mg kg^{-1}), roots (0.038 – 0.18 mg kg^{-1}) and sediment (0.008 – 0.063 mg/kg). Natural mangroves had the highest nitrogen (N) content in leaves (*Rhizophora stylosa* > *Rhizophora mucronata* > *Ceriop tagal*). The highest magnesium (Mg) content in sediment was in *Ceriop tagal* in both natural (8.979 mg/kg) and rehabilitated (368.24 mg/kg) mangroves. The highest P content in natural mangroves was found in leaves (*Rhizophora mucronata*= *Rhizophora stylosa* > *Ceriop tagal*), fruits (*Rhizophora stylosa* > *Rhizophora mucronata* > *Ceriop tagal*), roots (*Rhizophora mucronta* > *Rhizophora stylosa* > *Ceriop tagal*), and sediment (*Rhizophora mucronta* > *Rhizophora stylosa* > *Ceriop tagal*). Trace element in leaves, fruits, and roots showed Magnesium > Zinc > Iron > Nitrogen > Phosphorus in natural mangrove and rehabilitated mangrove. Trace element in sediment showed Magnesium > Iron > Zinc > Nitrogen > Phosphorus in natural mangrove while Magnesium > Zinc > Iron > Nitrogen in rehabilitated mangrove. The bioaccumulation factor (BAF) results showed that leaves had a BAF value < 1 in Iron, Zinc, both in natural and rehabilitated mangroves. Natural mangroves contain a wider variety of trace elements than rehabilitated mangroves.

1. INTRODUCTION

The mangrove ecosystem is known as a productive ecosystem in storing and repairing carbon [1, 2]. Mangrove conditions often experience nutrient deficiencies caused by varying tidal cycles in the mangrove ecosystem. Therefore, mangroves have the ability to modify the environment from rising sea levels and changes in salinity. In these changes, mangroves are able to modify water absorption and the interaction between salt excretion and transpiration [3]. Therefore, the mangrove ecosystem is very dynamic in its physicochemical, hydrological, sedimentological, and geomorphological conditions [4]. Mangrove rehabilitation needs to enhance coastal community participation [5] and social capital empowerment [6].

Nutrients are stored in the form of macro (nitrogen, phosphorus, and potassium), meso (magnesium, calcium and sulfur), and micro (iron, manganese, zinc, boron, copper, molybdenum, and silicon) elements, which are found at the top and bottom of the mangrove. The upper part is found in the leaves, stems, and mangrove trees, while the lower part is stored in the roots and sediment. The influence of tidal movements and the amount of freshwater entering the mangrove ecosystem causes the circulation of nutrients, some of which are stored and maintains the stability of the ecosystem and the level of stress that occurs [7]. Prolonged waterlogging causes oxidative stress, stunted growth, and low survival rates [8]. Mangroves also have potential antibacterial [9] and antifungal [10] properties, contain crude protein, carbohydrates, and tannins in the green leaves [11], and amino acids [12], and function in carbon sequestration [13-15].

The mangrove ecosystem continues to experience pressure from destruction and degradation which results in disruption of mangrove health. Several factors that cause this are rising temperature conditions [16], rising sea levels [17], and microplastic pollution [18]. The availability of nutrients in mangrove ecosystems can be beneficial for marine biota as a food source for gastropods [19], support habitats and diversity of marine biota [20, 21], filter pollutants, and promote biogeochemical cycles of nutrients [22, 23]. Previous research also reported that with the presence of different types of mangroves, the survival level was different, for example, *Rhizophora mucronata* by 67% [24]. Sediment with its nutrient contents can function as a supplier of nutrients in sufficient quantities so as to optimize growth conditions and sustainability of mangroves [25]. Furthermore, mangroves experienced an increase in tree trunk height and diameter as well as tree density [26]. The ability of mangroves to grow well and survive is influenced by various factors, one of which is the availability of nutrients in the mangrove ecosystem. This study aims to compare the nutrient content in various parts (leaves, fruit, roots, and sediment) of natural and rehabilitated mangroves in Lampung, Indonesia.

2. METHODOLOGY

2.1 Research area

This research was conducted from November to December 2023 in Pesawaran (5.57185° N), for natural mangrove locations and South Lampung (105.24189° E) for rehabilitated mangrove locations in Lampung Province, Indonesia (Figure 1). This research was divided based on the types of mangroves in the research locations, i.e., the mangrove *Rhizophora mucronata* Lamk (Rm), *Rhizophora stylosa* Griff, *Ceriop tagal* C.B. Rob both in natural and rehabilitated mangrove locations.

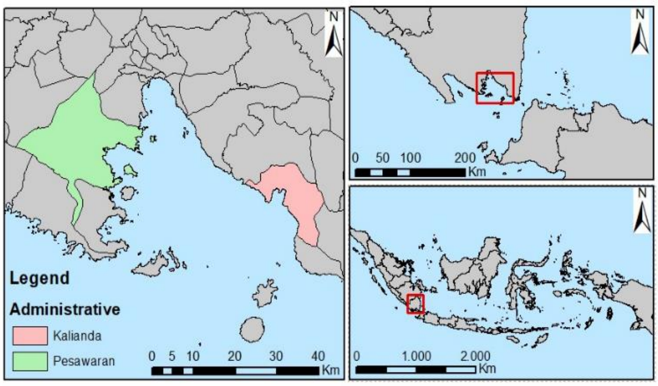

Figure 1. Research locations in Pesawaran and South Lampung, Lampung Province, Indonesia

2.2 Data colletion

Sampling was based on the location of the mangrove type at the top and bottom of the mangrove organ. The upper parts of the mangrove organs were leaves and fruit, while the lower parts were mangrove roots and sediment. Sediment collection was carried out using a PVC pipe measuring 1.5 inches with a depth of 30 cm.

2.3 Data analysis

50 g of mangrove parts were collected in the form of leaves, fruit, and roots for the analyses in the laboratory. Measurements of elements (macro, micro, and meso) of leaf, fruit, and root samples as well as mangrove sediments including nitrogen, phosphorus, magnesium, iron, and zinc were conducted using a Spectrophotometer.

The bioaccumulation factor (BAF) is a measurement of the ratio of elements present in the environment and parts of the mangrove (roots, bark, and leaves) [27]. Meanwhile, translocation is the ability of a plant to uptake and distribute the various elements across the plant body, and it is estimated by calculating the translocation factor (TF). Bioaccumulation factor (BAF) and translocation factor (TF) are useful as indicators of phyto-remediation [28]:

$$\text{BAF} = \text{concentration in tissues / concentration in rhizosphere sediment} \tag{1}$$

$$\text{TF} = \text{concentration in tissue (leaf; fruits) / concentration in root} \tag{2}$$

where, BCF > 1 = Accumulator plant; BCF = 1 = Indicator plant; BCF < 1 = Excluder plant, phytoextraction (TF > 1) and phytostabilization (TF < 1) mechanisms.

2.4 Statistical analysis

The statistical analysis used was R studio 4.3.2 through Principal Component Analysis. It determine the relationship between nutrient in mangrove organs and sediments in natural mangrove and mangrove rehabilitation with consider factor loading value. The relationship between nutrients is also linked to each other so as to find out the strongest relationship between nutrients.

3. RESULTS AND DISCUSSION

3.1 Distribution of nutrient in the mangrove organs

Table 1 shows the nitrogen (N) and phosphorus (P) contents in various types of mangroves in natural and rehabilitated mangroves. Natural mangroves had the highest N content in leaves (*R. stylosa* > *R. mucronata* > *C. tagal*), fruits (*R. stylosa* > *C. tagal* > *R. mucronata*), roots (*R. mucronata* > *R. stylosa* > *C. tagal*), and sediment (*R. stylosa* > *R. mucronta* > *C. tagal*).

Meanwhile, the highest P content in natural mangroves was found in leaves (*R. mucronata* = *R. stylosa* > *C. tagal*), fruits (*R. stylosa* >Rm> *C. tagal*), roots (*R. mucronata* > *R. stylosa* > *C. tagal*), and sediment (*R. mucronata* > *R. stylosa* > *C. tagal*). Rehabilitated mangroves showed the highest N in leaves (*R. stylosa* > *R. mucronata* = *C. tagal*), fruit (the highest was *R. stylosa*, while *R. mucronata* and *C. tagal* were not in the fruiting season), roots (*C. tagal* > *R. mucronata* > *R. stylosa*). The P (natural and rehabilitated mangrove)was found in leaves (0.018 - 0.029 mg kg^{-1}), fruits (0 - 0.034 mg kg^{-1}), roots (0.038 - 0.18 mg kg^{-1}) and sediment (0.008 - 0.063 mg kg^{-1}).

The highest Mg contents were found in the leaves in both natural and rehabilitated mangroves (Table 1). Natural mangroves showed the highest Mg content in leaves (*R. mucronata* > *R. stylosa* > *C. tagal*), fruits (*R. stylosa* > *C. tagal* > *R. mucronata*), roots (*R. stylosa* > *R. mucronata* > *C. tagal*), and sediment (*C. tagal* > *R. stylosa* > *R. mucronata*). Meanwhile, rehabilitated mangroves had the highest Mg content in leaves (*C. tagal* > *R. mucronata* > *R. stylosa*), fruits (the highest was *R. stylosa*), roots (*C. tagal* > *R. stylosa* > *R. mucronata*), and sediment (*C. tagal* > *R. mucronata* > *R. stylosa*).

Comparison of the Mg concentration in both natural and rehabilitated mangroves in the upper and lower parts showed that the leaves were the highest in *R. mucronta* (872.21 mg kg^{-1}) and *C. tagal* (930.51 mg kg^{-1}) in rehabilitated mangroves, the flowers were the highest in Rs in both natural and rehabilitated mangroves. The Mg content in the roots was highest in *R. stylosa* (505.02 mg kg^{-1}) in natural mangroves and in *C. tagal* (277.12 mg kg^{-1}) in rehabilitated mangroves. The highest Mg content in sediment was in *C. tagal* in both natural (897.49 mg kg^{-1}) and rehabilitated (368.24 mg kg^{-1}) mangroves.

Table 1. Nutrient content (N, P and Mg) in various mangrove organs and sediments in various types of mangroves in natural and rehabilitated mangroves

Type	Mangrove	N (mg kg^{-1})	P (mg kg^{-1})	Mg (mg kg^{-1})	
Leaves					
Natural	*R. mucronata*	0.11	0.029	872.21	This study
Natural	*R. stylosa*	0.119	0.029	840.97	This study
Natural	*C. tagal*	0.053	0.018	839.5	This study
Rehabilitated	*R. mucronata*	0.056	0.026	881	This study
Rehabilitated	*R. stylosa*	0.076	0.032	800.79	This study
Rehabilitated	*C. tagal*	0.056	0.031	930.51	This study
India	*A. marina*			3117	[22]
Brazil	*R. mangle*	1.18-1.50	0.09-0.11	0.42-0.62	[29]
Fruits					
Natural	*R. stylosa*	0.037	0.03	251.91	This study
Natural	*R. mucronata*	0.035	0.027	177.18	This study
Natural	*C. tagal*	0.052	0.023	214.54	This study
Rehabilitated	*R. stylosa*	0.046	0.034	308.27	This study
Rehabilitated	*R. mucronata*	0	0	0	This study
Rehabilitated	*C. tagal*	0	0	0	This study
Roots					
Natural	*R. stylosa*	0.022	0.032	505.02	This study
Natural	*R. mucronata*	0.019	0.027	415.04	This study
Natural	*C. tagal*	0.036	0.038	412.5	This study
Rehabilitated	*R. stylosa*	0.033	0.18	190.56	This study
Rehabilitated	*R. mucronata*	0.032	0.02	190.12	This study
Rehabilitated	*C. tagal*	0.02	0.012	613.07	This study
Sediment					
Natural	*R. stylosa*	0.022	0.052	857.11	This study
Natural	*R. mucronata*	0.016	0.063	849.11	This study
Natural	*C. tagal*	0.014	0.045	897.49	This study
Rehabilitated	*R. stylosa*	0.004	0.013	277.12	This study
Rehabilitated	*R. mucronata*	0.006	0.008	365.35	This study
Rehabilitated	*C. tagal*	0.009	0.018	368.24	This study
Indonesia	*R. mucronata*	0.24-1.18			[30]
Indonesia	*R. stylosa*	0.27-1.42			[30]

Table 2. Nutrient content (Fe and Zn) in various mangrove organs and sediments in various types of mangroves in natural and rehabilitated (r) mangroves

Type	Mangrove	Fe (mg kg^{-1})	Zn (mg kg^{-1})	
Leaves				
Natural	*R. mucronata*	0.27	5.85	This study
Natural	*R. stylosa*	0.10	3.54	This study
Natural	*C. tagal*	0.74	3.54	This study
Rehabilitated	*R. mucronata*	0.1	4.54	This study
Rehabilitated	*R. stylosa*	0.73	2.97	This study
Rehabilitated	*C. tagal*	0.27	7.2	This study
Indonesia	*R. mucronata*	16.83±9.65	11.75±7.06	[31]
India	*Avicennia marina*	137	10.50	[22]
Brazil	*Rhizophora mangle*	88		[29]
Malaysia	*R. apiculata*	9.23	1.14±0.34	[32]
Fruits				
Natural	*R. stylosa*	0.10	2.08	This study
Natural	*R. mucronata*	0.10	1.50	This study
Natural	*C. tagal*	0.10	2.8	This study
Rehabilitated	*R. stylosa*	0.74	4.19	This study
Rehabilitated	*R. mucronata*	0	0	This study
Rehabilitated	*C. tagal*	0	0	This study
Indonesia	*Bruguiera gymnorrhiza*	0.34	0.11±0.01	[33]
Indonesia	*Xylocarpus granatum*	0.38	0.52±0.18	[33]

Roots				
Natural	*R. stylosa*	0.10	3.580	This study
Natural	*R. mucronata*	0.10	3.19	This study
Natural	*C. tagal*	0.10	5.78	This study
Rehabilitated	*R. stylosa*	0.10	3.66	This study
Rehabilitated	*R. mucronata*	0.720	5.41	This study
Rehabilitated	*C. tagal*	4.9	4.81	This study
Malaysia	*R. apiculata*	48.48±12.25	3.60±0.97	[32]
Sediment				
Natural	*R. stylosa*	619.88	31.34	This study
Natural	*R. mucronata*	520.52	34.34	This study
Natural	*C. tagal*	38.72	34.35	This study
Rehabilitated	*R. stylosa*	5.84	8.07	This study
Rehabilitated	*R. mucronata*	0.1	10.38	This study
Rehabilitated	*C. tagal*	2.13	20.44	This study
India			23.01-82.21	[34]
Southern Vietnam			25.7-108.1	[35]
China			78.6-220	[36]

The nutrients of Fe and Zn in natural and rehabilitated mangroves (Table 2). The highest Fe content was (*C. tagal* > *R. mucronata* > *R. stylosa*) in natural mangroves and (*R. stylosa* > *C. tagal* > *R. mucronta*) in rehabilitated mangroves in the leaves. The Fe content in natural mangroves was similar of 0.10 mg kg^{-1}, while the Fe content in rehabilitated mangroves was 0.10 mg/kg in *R. stylosa*. The Fe content in roots in natural mangrove was found to be the same at 0.10 mg/kg in the 3 types of mangroves (*R. stylosa*, *R. mucronata*, and *C. tagal*); while in rehabilitated mangroves, it was found to be the highest (*C. tagal* > *R. mucronata* > *R. stylosa*).

The highest Fe content in natural mangroves showed (*R. stylosa* > *R. mucronta* > *C. tagal*); while in rehabilitated mangroves, it showed (*R. stylosa* > *C. tagal* > *R. mucronata*). Trace elements showed Zn > Fe in Leaves fruits, and roots showed in natural mangrove and rehabilitated mangrove. Sediment > leaves > roots > fruits in natural mangrove and rehablitated mangrove.

Table 2 shows in the lower organ including roots and sediment, the highest nutrient content of Fe (0.720 mg kg^{-1}) was found in rehabilitated mangroves, while the highest Zn (5.78 mg/kg) was found in *C. tagal* in natural mangroves. The highest Fe content in sediment was in *R. stylosa* (619.88 mg/kg) in natural mangroves, while the highest Zn was in *C. tagal* (34.35 mg/kg) in natural mangroves. The comparison of roots with fruit and leaves shows that the leaves have a higher trace element content. The others research also showed that iron in leaves [37]. The roots of mangrove type *C.tagal, R. mucronata*, and *R.stylosa* showed the same effect. Sediment of *C.tagal, R. mucronata*, and *R.stylosa* also had the same effect. Sediment showed a negative effect on roots. Fruits had a significant effect on sediment. Litter that falls and experiences decomposition can control nutrients in the mangrove ecosystem [38].

The highest Zn content in the leaves was (*R. mucronata* > *R. stylosa* = *C. tagal*) in natural mangroves and was (*C. tagal* >Rm> *R. stylosa*) in rehabilitated mangroves. The Zn content showed the highest (*C. tagal* > *R. stylosa* > *R. mucronta*) in natural mangroves and Rs in rehabilitated mangroves. In the roots, the highest Zn content was (*C. tagal* > *R. stylosa* >Rm) in natural mangroves and was (*R. mucronata* > *C. tagal* > *R. stylosa*) in rehabilitated mangroves. Meanwhile, the highest Zn content in sediment was (*C. tagal* > *R. mucronata* > *R. stylosa*) in natural mangroves and was (*C. tagal* > *R. mucronata* > *R. stylosa*) in rehabilitated mangroves. The highest nutrient content in the upper organ of leaves of Fe was found in *C. tagal* (0.74 mg kg^{-1}) in natural mangroves, while the highest in fruits was in *R. Stylosa* (0.74 mg kg^{-1}) in rehabilitated mangroves. The highest in roots of Fe was found in *C. tagal* (4.9 mg kg^{-1}) in rehabilitated mangroves.

3.2 BAF and TF in various types of mangroves in natural and rehabilitated mangroves

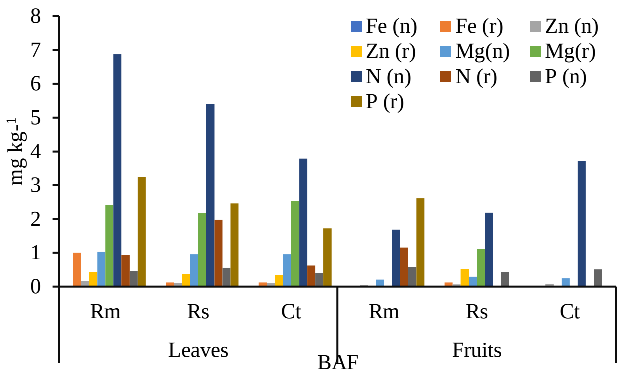

Figure 2. BAF in various types of mangroves in natural and rehabilitated mangroves, Lampung

The differences in BAF and TF values for various types of mangroves in natural and rehabilitated conditions (Figure 2 and Figure 3). BAF showed that leaves had BAF values = 1 (*R. mucronata*) in rehabilitated mangrove. BAF showed that leaves had values >1 in Mg (*R. mucronata*) in natural mangrove) and *R. mucronata*, *R. stylosa* and *C. tagal* in rehabilitated mangrove. BAF showed that leaves had values >1 in N (*R. mucronata*, *R. stylosa* and *C. tagal*) in natural mangrove and *R. stylosa* in rehabilitated mangrove. BAF showed that leaves had values >1 in P (*R. mucronata*, *R. stylosa* and *C. tagal*) in rehabilitated mangrove and value < 1 in natural mangrove.

BAF showed that fruits had values >1 in Mg (*R. stylosa*) in rehabilitated mangrove, N (*R. mucronata, R. stylosa* and *C. tagal*) in natural mangrove and *R. mucronata* in rehablitated mangrove), and P (*R. mucronata*) in rehabilitated mangrove. BAF showed that fruits had values < 1 in Fe, Zn in natural mangrove and rehabilitated mangrove), Mg in natural mangrove and P in natural mangrove (*R. muconata, R. stylosa* and *C. tagal*). The TF value of leaves and fruits > 1 in Fe (*R. mucronata, R. Stylosa* and *C. tagal*) in natural mangrove while rehabilitated mangrove in leaves and fruits (*R. stylosa*). The TF value of leaves > 1 in Zn (*R. mucronata*) in natural mangrove and *C. tagal* in rehabilitated mangrove. The TF value of leaves > 1 in Mg (*R. mucronata, R. Stylosa* and *C. tagal*) in natural mangrove and *R. Stylosa* and *C. tagal* in rehabilitated mangrove. The TF value > 1 presented in N (*R. mucronata, R. Stylosa* and *C. tagal*) in natural mangrove while *R. stylosa* in rehabilitated mangrove in fruits. *R. mucronata* revealed the TF value (>1) in fruits and *R. Stylosa* and *C. tagal* showed TF values < 1 in P (natural mangrove and rehabilitated mangrove).

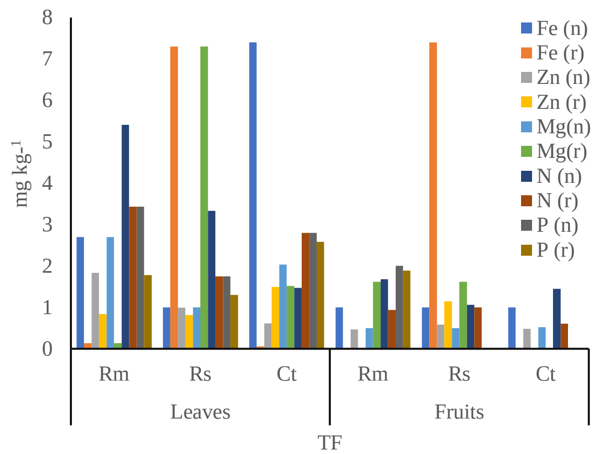

Figure 3. TF in various types of mangroves in natural and rehabilitated mangroves, Lampung

In mangrove *R. stylosa*, the Fe (rehabilitated) had TF>1, while the Fe (natural), Zn (natural) and Zn (rehabilitated) showed TF<1. Mangrove *C. tagal* was found to have TF >1 in Fe (natural) and Zn (rehabilitated). The TF value in fruits with TF > 1 was found in Rs in the Fe (natural). *R.stylosa*, R. *mucronata* and *C. tagal* in the Fe (natural mangrove). BAF and TF had the best function for mangrove ecosystem as phytoremediation. This research found that in natural and rehabilitated mangroves, Zn of 34.34 and 10.38 were higher than Fe 1.75–61.67 mg kg^{-1} in India in the same type of mangrove [39]. A BAF value <1 indicated that mangrove types *R. mucronata, R. stylosa,* and *C. tagal* in natural and rehabilitated mangroves function well in plant metabolism in terms of nutrient requirements for growth and survival. It was also reported that BAF values below BAF (BAF < 1) can be used as an indication that mangroves are quickly utilizing the nutrients [40]. Mangrove *R. mucronata* had BAF and TF <1 for essential and >1 for non-essential elements [41]. BAF and TF can indicate as phytoremediation.

3.3 The principal component analysis to determine trace element in natural and rehabilitated mangrove

The results of processing using the PCA method show the percentage of variance explained in each PCA with PC1 (42%), PC2 (29.2%), PC3 (19%), PC4 (7.1%) and PC5 (2.7%). Cumulatively, PC1 and PC2 contributed 71.1% of the data variability. Next, the nutrients that represent the PC can be seen based on the Loading Factor in the table. Based on the loading factor, it can be seen that PC1 destroys negatives with most nutrients except N, where the nutrient that has the largest correlation is Zn. The opposite is shown by PC2 where most show a positive correlation except Fe and Zn with the largest correlation shown by N.

Figure 4 showed the highest P content in rehabilitated mangroves was found in leaves (*R. stylosa*> *C. tagal* > *R. mucronata*), fruits (the highest was Rs, while Rm and *C. tagal* were not in the fruiting season), roots (*R mucronata* > *R. stylosa* > *C. tagal*), and sediment (*R. mucronata* > *R. stylosa* > *R mucronata*).

Through PCA, the distribution of samples in natural and rehabilitated mangroves can be observed. The graph shows that natural mangroves display a much more random distribution compared to rehabilitated mangroves. This suggests that natural mangroves possess more diverse nutrient values compared to rehabilitated mangroves.

The relationship trace element in natural mangrove and rehablitated mangrove in Figure 5. A quite significant relationship was shown by Zn and Fe and the lowest was shown by Mg and P. Correlation results for other nutrients showed a correlation of 0.5. In general, most nutrients are positively correlated except N with Fe and Zn.

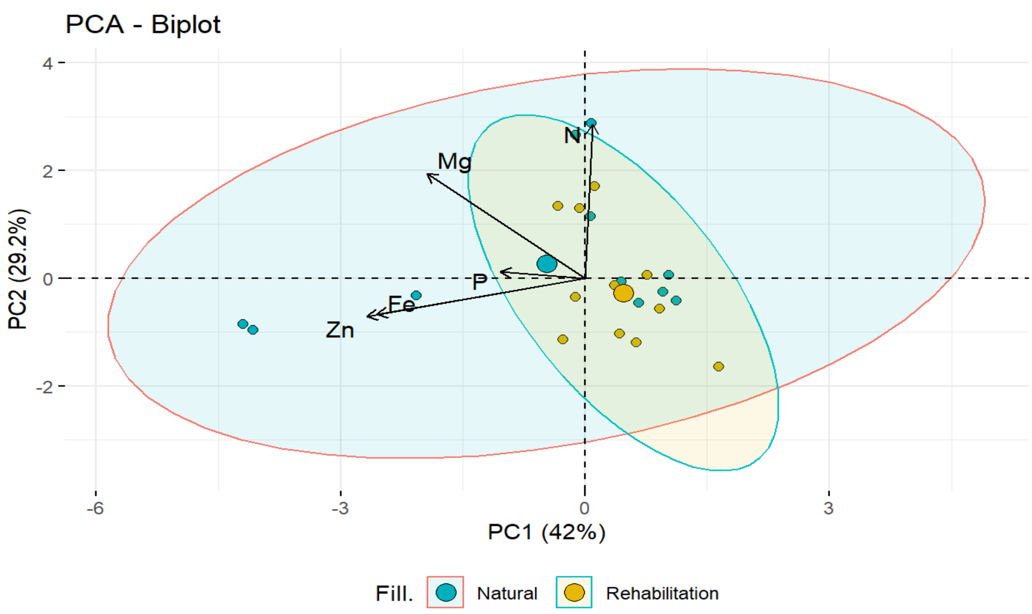

Figure 4. Relationship the trace element in natural and rehabilitated mangrove with PCA

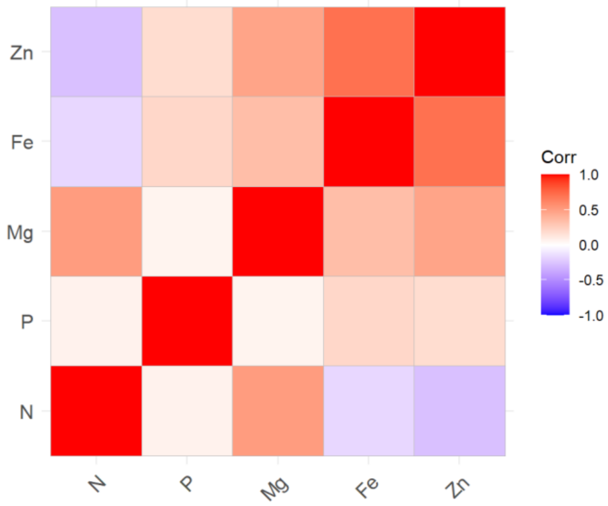

Figure 5. Headmap of the trace element in natural and rehabilitated mangrove

This research revealed that the N content was higher in the leaves, fruit, roots, and sediment (Figure 5). This is in agreement with N that the highest content was in the leaves [22]. Overall, green leaves showed a higher content of microelements than yellow leaves [31]. The presence of nitrogen has an important role in enriching sediment [42] and is influenced by various factors including tides, vegetation and season [43].

Figure 5 shows the relationship between leaves, fruit, roots, and sediment in rehabilitated mangroves. The roots of mangrove type *C. tagal*, *R. mucronata* and > *R. stylosa* showed the same effect. Sediment of *C. tagal*, *R mucronata*, and > *R. stylosa* also had the same effect. This had no significant effect, and the effect was very weak. Rooting was more influenced by leaves. Fruit had a significant effect on sediment, while leaves had a negative effect on sediment.

Nutrients that can be used for healthy mangrove growth and development are N and P [44]. Other research reported that P, Mg, Fe, and Zn can function as elements required for growth and survival. The roots have a function of accumulating and excreting metals [45]. The process of leaf aging is an important nutrient mechanism for N and P [46]. High levels of nutrients (P, Mg) in sediments have an important role in supporting the above ground biomass [47]. Fe and N cycle can modulate nitrification rates [48], denitrification activity is closely linked to the total ambient Fe concentrations in mangrove sediments [49], and Nitrogen loss through anaerobic ammonium oxidation with iron [50].

4. CONCLUSIONS

The highest Zn content in the leaves was (*R. mucronata* > *R. stylosa* = *C. tagal*) in natural mangroves and was (*C. tagal* >Rm> *R. stylosa*) in rehabilitated mangroves. The Zn content showed the highest (*C. tagal* > *R. stylosa* >Rm) in natural mangroves and Rs in rehabilitated mangroves. Indirectly, natural mangroves show more diverse nutrient values compared to rehabilitated mangroves. Trace element in leaves, fruits, and roots showed Magnesium > Zinc > Iron > Nitrogen > Phosphorus in natural mangrove and rehabilitated mangrove. Trace element in sediment showed Magnesium > Iron > Zinc > Nitrogen > Phosphorus in natural mangrove while Magnesium > Zinc > Iron > Nitrogen in rehabilitated mangrove. In this study, a BAF value of <1 indicated that mangrove type *R. mucronata, R. stylosa*, and *C. tagal* in natural and rehabilitated mangroves function well in plant metabolism in terms of nutrient requirements for growth and survival. BAF showed that fruits had values >1 in Mg (*R. stylosa*) in rehabilitated mangrove, N (*R. mucronata, R. stylosa* and *C. tagal*) in natural mangrove and *R. mucronata* in rehablitated mangrove), and P (*R. mucronata*) in rehabilitated mangrove. BAF showed that fruits had values < 1 in Fe, Zn in natural mangrove and rehabilitated mangrove), Mg in natural mangrove and P in natural mangrove (*R. muconata, R. stylosa* and *C. tagal*).

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REFERENCES

[1] Malik, A., Rahim, A., Rasyid, A., Fathurachman, M., Setiawan, D., Rizal, M., Husain, J., William, D., Jihad, N. (2023). Mangrove blue carbon stocks estimation in South Sulawesi Indonesia. Continental Shelf Research, 269: 105139. https://doi.org/10.1016/j.csr.2023.105139

[2] Lin, W.J., Lin, C.W., Wu, H.H., Kao, Y.C., Lin, H.J. (2023). Mangrove carbon budgets suggest the estimation of net production and carbon burial by quantifying litterfall. Catena, 232: 107421. https://doi.org/10.1016/j.catena.2023.107421

[3] Lovelock, C.E., Feller, I.C. (2003). Photosynthetic performance and resource utilization of two mangrove species coexisting in a hypersaline scrub forest. Oecologia, 134(4): 455-462. https://doi.org/10.1007/s00442-002-1118-y

[4] Feller, I.C., Lovelock, C.E., Berger, U., McKee, K.L., Joye, S.B., Ball, M.C. (2010). Biocomplexity in mangrove ecosystems. Annual Review of Marine Science, 2(1): 395-417. https://doi.org/10.1146/annurev.marine.010908.163809

[5] Listiana, I., Ariyanto, D. (2024). Enhancing coastal community participation in mangrove rehabilitation through structural equation modeling. Global Journal of Environmental Science and Management, 10(2): 873-890. https://doi.org/10.22035/gjesm.2024.02.28

[6] Listiana, I., Ariyanto, D. (2024). Structural equation modeling for social capital empowerment in supporting mangrove rehabilitation. Global Journal of Environmental Science and Management, 10(4): 2031-2044. https://doi.org/10.22034/gjesm.2024.04

[7] Wimmler, M.C., Bathmann, J., Peters, R., Jiang, J., Walther, M., Lovelock, C.E., Berger, U. (2021). Plant-soil feedbacks in mangrove ecosystems: Establishing links between empirical and modelling studies. Trees - Structure and Function, 35(5): 1423-1438. https://doi.org/10.1007/s00468-021-02182-z

[8] Barnuevo, A., Asaeda, T. (2018). Integrating the

ecophysiology and biochemical stress indicators into the paradigm of mangrove ecology and a rehabilitation blueprint. PLoS ONE, 13(8): 1-17. https://doi.org/10.1371/journal.pone.0202227

[9] Pringgenies, D., Setyati, W.A., Djunaedi, A., Pramesti, R., Rudiyanti, S., Ariyanto, D. (2021). Exploration of antimicrobial potency of mangrove symbiont against multi-drug resistant bacteria. Jurnal Ilmiah Perikanan dan Kelautan, 13(2): 102-112. https://doi.org/10.20473/jipk.v13i2.26199

[10] Pringgenies, D., Wilis, A.S., Feliatra, F., Ariyanto, D. (2023). The antibacterial and antifungal potential of marine natural ingredients from the symbiont bacteria of mangrove. Global Journal of Environmental Science and Management, 9(4): 819-832. https://doi.org/10.22035/gjesm.2023.04

[11] Ariyanto, D., Gunawan, H., Puspitasari, D., Ningsih, S.S., Jayanegara, A., Hamim. (2019). Identification of the chemical profile of *Rhizophora mucronata* mangrove green leaves from the eastern coast of Asahan, North Sumatra, Indonesia. Plant Archives, 19(2): 4045-4049.

[12] Ningsih, S.S., Ariyanto, D., Puspitasari, D., Jayanegara, A., Hamim, H., Gunawan, H. (2020). The amino acid contents in mangrove *Rhizophora mucronata* leaves in Asahan, North Sumatra, Indonesia. E3S Web of Conferences, 151(01047): 1-3. https://doi.org/10.1051/e3sconf/202015101047

[13] Wirasatriya, A., Pribadi, R., Iryanthony, S.B., Maslukah, L., Sugianto, D.N., Helmi, M., Ananta, R.R., Adi, N.S., Kepel, T.L., Ati, R.N.A., Kusumaningtyas, M.A., Suwa, R., Ray, R., Nakamura, T., Nadaoka, K. (2022). Mangrove above-ground biomass and carbon stock in the Karimunjawa-Kemujan Islands estimated from Unmanned Aerial Vehicle-Imagery. Sustainability (Switzerland), 14(706): 1-15. https://doi.org/10.3390/su14020706

[14] Hayati, A.N., Afiati, N., Supriharyono, Helmi, M. (2023). Carbon sequestration of above ground biomass approach in the rehabilitated mangrove stand at Jepara Regency, Central Java, Indonesia. Jurnal Ilmiah Perikanan dan Kelautan, 15(1): 224-235. https://doi.org/10.20473/jipk.v15i1.35318

[15] Ariyanto, D., Pringgenies, D. (2024). Carbon sequestration rate in sediment mangroves from natural and rehabilitated mangroves. Global Journal of Environmental Science and Management, 10(4): 1951-1960. https://doi.org/10.22034/gjesm.2024.04

[16] Alongi, D.M. (2022). Impacts of climate change on blue carbon stocks and fluxes in mangrove forests. Forests, 13:149. https://doi.org/10.3390/f13020149

[17] Saintilan, N., Khan, N.S., Ashe, E., Kelleway, J.J., Rogers, K., Woodroffe, C.D., Horton, B.P. (2020). Thresholds of mangrove survival under rapid sea level rise. Science, 368(6495): 1118-1121. https://doi.org/10.1126/science.aba2656

[18] Deng, H., He, J., Feng, D., Zhao, Y., Sun, W., Yu, H., Ge, C. (2021). Microplastics pollution in mangrove ecosystems: A critical review of current knowledge and future directions. Science of the Total Environment, 753: 142041. https://doi.org/10.1016/j.scitotenv.2020.142041

[19] Ariyanto, D. (2019). Food preference on *Telescopium telescopium* (Mollusca: Gastropoda) based on food sources in mangrove. Plant Archives, 19(1): 913-916.

[20] Ariyanto, D., Pringgenies, D. (2024). Natural mangrove associated gastropods at Bengkalis island, Riau Province, Indonesia: Prelimanary survey. IOP Conference Series: Earth and Environmental Science, 1356(1): 012045. https://doi.org/10.1088/1755-1315/1356/1/012045

[21] Ariyanto, D., Bengen, D.G., Prartono, T., Wardiatno, Y. (2020). Distribution and abundance of *Cerithideopsilla djadjariensis* (Martin 1899) (Potamididae) on *Avicennia marina* in Rembang, Central Java, Indonesia. Egyptian Journal of Aquatic Biology and Fisheries, 24(3): 323-332. https://doi.org/10.21608/EJABF.2020.95329

[22] Ray, R., Mandal, S.K., González, A.G., Pokrovsky, O.S., Jana, T.K. (2021). Storage and recycling of major and trace element in mangroves. Science of the Total Environment, 780: 146379. https://doi.org/10.1016/j.scitotenv.2021.146379

[23] Su, J., Friess, D.A., Gasparatos, A. (2021). A meta-analysis of the ecological and economic outcomes of mangrove restoration. Nature Communications, 12: 1-13. https://doi.org/10.1038/s41467-021-253

[24] van Bijsterveldt, C.E.J., Debrot, A.O., Bouma, T.J., Maulana, M.B., Pribadi, R., Schop, J., Tonneijck, F.H., van Wesenbeeck, B.K. (2022). To plant or not to plant: when can planting facilitate mangrove restoration? Frontiers in Environmental Science, 9: 1-18. https://doi.org/10.3389/fenvs.2021.690011

[25] Nurul Mayzaitul Azwa, J., Hanafi, M.M., Hakim, M.A., Idris, A.S., Sahebi, M., Rafii, M.Y. (2022). The relationship between soil characteristics and the nutrient status in roots of mangrove (Rhizophora apiculata) trees. Arabian Journal of Geosciences, 15(12): 1-9. https://doi.org/10.1007/s12517-022-10416-8

[26] Salmo, S.G., Lovelock, C., Duke, N.C. (2013). Vegetation and soil characteristics as indicators of restoration trajectories in restored mangroves. Hydrobiologia, 720(1): 1-18. https://doi.org/10.1007/s10750-013-1617-3

[27] MacKay, D., Fraser, A. (2000). Bioaccumulation of persistent organic chemicals: Mechanisms and models. Environmental Pollution, 110: 375-391. https://doi.org/10.1016/S0269-7491(00)00162-7

[28] Yoon, J., Cao, X., Zhou, Q., Ma, L.Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of the Total Environment, 368(2-3): 456-464. https://doi.org/10.1016/j.scitotenv.2006.01.016

[29] Bernini, E., da Silva, M.A.B., do Carmo, T.M.S., Cuzzuol, G.R.F. (2010). Spatial and temporal variation of the nutrients in the sediment and leaves of two Brazilian mangrove species and their role in the retention of environmental heavy metals. Brazilian Journal of Plant Physiology, 22(3): 177-187. https://doi.org/10.1590/S1677-04202010000300005

[30] Ariyanto, D., Bengen, D.G., Prartono, T., Wardiatno, Y. (2019). The physicochemical factors and litter dynamics (*Rhizophora mucronata* Lam. and *Rhizophora stylosa* Griff) of replanted mangroves, Rembang, Central Java, Indonesia. Environment and Natural Resources Journal, 17(4): 11-19. https://doi.org/10.32526/ennrj.17.4.2019.27

[31] Ariyanto, D., Gunawan, H., Puspitasari, D., Ningsih, S.S., Jayanegara, A., Hamim, H. (2019). The differences of the elements content in *Rhizophora mucronata* leaves from Asahan Regency, North Sumatra, Indonesia. Polish Journal of Natural Sciences, 34(4): 481-491.

[32] Abdullah, F., Shaari, H., Satyanarayana, B., Mohd Khalik, W.M.A., Mohd Jaafar, M.Z. (2018). Macro, micro, and non-essential elements in different parts of *Rhizophora apiculata*. Malaysian Journal of Analytical Sciences, 22(4): 570-578. https://doi.org/10.17576/mjas-2018-2204-01

[33] Analuddin, K., Septiana, A., Nasaruddin, Sabilu, Y., Sharma, S. (2019). Mangrove fruit bioprospecting: Nutritional and antioxidant potential as a food source for coastal communities in the Rawa Aopa Watumohai National Park, Southeast Sulawesi, Indonesia. International Journal of Fruit Science, 19(4): 423-436. https://doi.org/10.1080/15538362.2018.1555507

[34] Manju, M.N., Ratheesh Kumar, C.S., Resmi, P., Gireeshkumar, T.R., Joseph, M.M., Salas, P.M., Chandramohanakumar, N. (2020). Trace metal distribution in the sediment cores of mangrove ecosystems along northern Kerala coast, south-west coast of India. Marine Pollution Bulletin, 153: 110946. https://doi.org/10.1016/j.marpolbul.2020.110946

[35] Constance, A., Oehri, J., Bunbury, N., Wiesenberg, G.L.B., Pennekamp, F., A'Bear, L., Fleischer-Dogley, F., Schaepman-Strub, G. (2022). Soil nutrient content and water level variation drive mangrove forest aboveground biomass in the lagoonal ecosystem of Aldabra Atoll. Ecological Indicators, 143: 109292. https://doi.org/10.1016/j.ecolind.2022.109292

[36] Yang, G., Song, Z., Sun, X., Chen, C., Ke, S., Zhang, J. (2020). Heavy metals of sediment cores in Dachan Bay and their responses to human activities. Marine Pollution Bulletin, 150: 110764. https://doi.org/10.1016/j.marpolbul.2019.110764

[37] Arrivabene, H.P., Campos, C.Q., Souza, I.D.C., Wunderlin, D.A., Milanez, C.R.D., Machado, S.R. (2016). Differential bioaccumulation and translocation patterns in three mangrove plants experimentally exposed to iron. Consequences for environmental sensing. Environmental Pollution, 215: 302-313. https://doi.org/10.1016/j.envpol.2016.05.019

[38] Kamruzzaman, M., Basak, K., Paul, S.K., Ahmed, S., Osawa, A. (2019). Litterfall production, decomposition and nutrient accumulation in Sundarbans mangrove forests, Bangladesh. Forest Science and Technology, 15(1): 24-32. https://doi.org/10.1080/21580103.2018.1557566

[39] Ganeshkumar, A., Arun, G., Vinothkumar, S., Rajaram, R. (2019). Bioaccumulation and translocation efficacy of heavy metals by *Rhizophora mucronata* from tropical mangrove ecosystem, Southeast coast of India. Ecohydrology and Hydrobiology, 19: 66-74. https://doi.org/10.1016/j.ecohyd.2018.10.006

[40] Arumugam, G., Rajendran, R., Ganesan, A., Sethu, R. (2018). Bioaccumulation and translocation of heavy metals in mangrove rhizosphere sediments to tissues of Avicenia marina - A field study from tropical mangrove forest. Environmental Nanotechnology, Monitoring and Management, 10: 272-279. https://doi.org/10.1016/j.enmm.2018.07.005

[41] Pahalawattaarachchi, V., Purushothaman, C.S., Vennila, A. (2009). Metal phytoremediation potential of *Rhizophora mucronata* (Lam.). Indian Journal of Marine Sciences, 38(2): 178-183.

[42] Shifflett, S.D., Schubauer-Berigan, J. (2019). Assessing the risk of utilizing tidal coastal wetlands for wastewater management. Journal of Environmental Management, 236: 269-279. https://doi.org/10.1016/j.jenvman.2018.12.082

[43] Peng, X., Yu, X., Zhai, X., Gao, X., Yu, Z., Yang, J. (2023). Spatiotemporal patterns of different forms of nitrogen in a coastal mangrove wetland invaded by Spartina alterniflora. Estuarine, Coastal and Shelf Science, 280: 108167. https://doi.org/10.1016/j.ecss.2022.108167

[44] Yahaya, S.M., Mahmud, A.A., Abdullahi, M., Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: A review. Pedosphere, 33(3): 385-406. https://doi.org/10.1016/j.pedsph.2022.07.012

[45] MacFarlane, G.R., Koller, C.E., Blomberg, S.P. (2007). Accumulation and partitioning of heavy metals in mangroves: A synthesis of field-based studies. Chemosphere, 69(9): 1454-1464. https://doi.org/10.1016/j.chemosphere.2007.04.059

[46] Wang, W.Q., Wang, M., Lin, P. (2003). Seasonal changes in element contents in mangrove element retranslocation during leaf senescene. Plant and Soil, 252: 187-193. https://doi.org/10.1023/A:1024704204037

[47] Li, X., Cheng, X., Cheng, K., Cai, Z., Feng, S., Zhou, J. (2024). The influence of tide-brought nutrients on microbial carbon metabolic profiles of mangrove sediments. Science of the Total Environment, 906: 167732. https://doi.org/10.1016/j.scitotenv.2023.167732

[48] Krishnan, K.P., Loka Bharathi, P.A. (2009). Organic carbon and iron modulate nitrification rates in mangrove swamps of Goa, south west coast of India. Estuarine, Coastal and Shelf Science, 84(3): 419-426. https://doi.org/10.1016/j.ecss.2009.07.015

[49] Fernandes, S.O., Gonsalves, M.J., Michotey, V.D., Bonin, P.C., LokaBharathi, P.A. (2013). Denitrification activity is closely linked to the total ambient Fe concentration in mangrove sediments of goa, India. Estuarine, Coastal and Shelf Science, 131: 64-74. https://doi.org/10.1016/j.ecss.2013.08.008.

[50] Guan, Q., Li, T., Zhou, Y., Yang, F., Li, Q. (2023). Nitrogen loss through anaerobic ammonium oxidation coupled with ferric iron reduction in the Yellow River Wetland, Sanmenxia, China. Limnologica, 102: 126106. https://doi.org/10.1016/j.limno.2023.126106