Mangrove Root Diversity and Structure (cone, pencil, prop) Effectiveness in Accumulating Cu and Zn in Sediments and Water in River Blanakan

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Abstract. The effectiveness of metal accumulation in mangrove species is related to the root structure and diversity. This study aims to investigate the type of roots belong to *Avicennia marina*, *Rhizophora mucronata*, and *Sonneratia caseolaris* in accumulating Cu and Zn from sediment and water. The samples consist of roots, water and sediment collected from 9 stations in River Blanakan. The heavy metals in samples were analyzed by using AAS. The Zn in *A. marina*, *R. mucronata* and *S. caseolaris* roots were 18.08-54.64 mg/kg, 9.75-54.75 mg/kg, and 19.58-33.33 mg/kg. While, the Cu in *A. marina*, *R. mucronata* and *S. caseolaris* roots were 0.33-0.89 mg/kg, 0.2-54.75 mg/kg and 0.4-0.99 mg/kg. The effectiveness of mangrove roots in accumulating metals is measured by Transfer Factor (TF). The results of this study showed that *R. mucronata* has the highest TF. The TF of sediment-to-root for Zn in mangrove species is *R. mucronata>**S. caseolaris>**A. marina*. While, the TF of sediment-to-root for Cu is *R. mucronata>**S. caseolaris>*A. marina*. The TF ranges of *R. mucronata* for Zn are 0.30-0.38 and for Cu is 0.36-0.46. Hence, the *R. mucronata* with its unique prop root has significant potential in accumulating metals Cu and Zn from sediment.

1. Introduction
Mangrove is a unique vegetation assemblage ever found in the unique environment, including the submerged ecosystem in the river banks and beaches. This ecosystem receives constant environmental pressure, which is extreme water inundation along with the high salinity. This condition causes mangrove to be unique by developing an organ that is able to take air above the water level. As a result, mangrove can be distinguished by its root diversity and structure. It is different from the common terrestrial vegetation, mangrove species has a high diversity of roots. The diversity ranges from spreading root (*Ceriops* sp.), buttress root (*Heritiera*), cone root (*Sonneratia*), pencil root (*Avicennia*), knee root (*Bruguiera*) and stilt/prop root (*Rhizophora*).

The diversity of roots has influenced the content of heavy metals that can be accumulated from the environment. In peninsular Malaysia, the contents of Cd, Cr, Cu, Pb, and Zn in roots of *Sonneratia caseolaris* were 0.6, 20.4, 31.2, 92.9, and 10.0 mg/kg respectively [1]. In Muara Angke, the *S. caseolaris* has Zn equal to 83.05 mg/kg. [2].

Other dominant mangrove species also has the capability to absorb mangrove through its roots. In Muara Angke, the Cu, Pb, and Zn in *Rhizophora mucronata* were 12.17, 53.89, and 55.38 mg/kg. While the Cu, Pb, and Zn in *Avicennia marina* were 13.88, 57.52, and 66.18 mg/kg [2]. *A. marina* is known to
accumulate Cu and Pb in root tissue to levels higher than surrounding sediment levels. Furthermore, this species is considered as a biological indicator of environmental exposure of Cu and Pb [3].

Blanakan river in West Java is having a high diversity of aquatic vegetation along its river banks. The aquatic vegetation consists of mangrove and mangrove related species. The common mangroves found in river banks of Blanakan including Avicennia sp., Rhizophora sp., and Sonneratia sp. [3]. The mangrove related species include Colocasia esculenta and plants from family Asteraceae. However, River Blanakan is also experiencing anthropogenic influences and waste disposal. The settlements near Blanakan can contribute pollutants to the river, such as heavy metals. Recently, the data regarding the potential of mangroves, especially their root structures in accumulating the metals from water and sediments, are still limited. Most literature is discussing the mangrove and heavy metals by neglecting the root structure aspects. This study aimed to investigate the diversity of root structure related to the accumulation of heavy metals.

2. Methods

2.1. Study site
This study was conducted along River Blanakan in Subang regency, West Java province. The station geo-coordinates were from upstream at lat: 6°16'38", long: 107°39'35" (station 1) to downstream (river mouth) lat: 6°14"24", long: 107°40'2" (station 9) (Figure 1). The width of River Blanakan is varied from 60 m near the river mouth to 11 m in the upstream. In upstream, station 1-3 were surrounded by settlements and paddy field, station 4-6 were transition area for paddy field to the fish pond, and station 7-9 were dominated by the fish pond and revegetated by mangrove.

![Figure 1](image-url). The locations of 9 stations across River Blanakan

2.2. Heavy metals sampling analysis for mangrove, water and sediment
Sampling was done twice in April and June 2019 in river Blanakan based on purposive sampling. In the river, the water was sampled by using a polyethylene bottle and kept in a cooler box to be transported to the laboratory. In the laboratory, the water sample was analyzed by using Shimadzu AAS 6300 atomic absorption spectrophotometer (AAS) to obtain the Cu and Zn values [4].
The river sediment at the surface layer (5 cm) was collected by using Ekman grab sampler. The collected sediments were kept in the plastic bag and kept in a cooler box to be transported to the laboratory. In the laboratory, the sediment sample was analyzed by using AAS to obtain the Cu and Zn values [4].

The mangroves of *Avicennia marina*, *Rhizophora mucronata*, and *Sonneratia caseolaris* were collected from station 4 to 9 since those mangroves grow only in those areas. The mangrove root samples were cleaned and cut into small pieces. The mangrove roots were dried in the oven at 80 °C. Then, 0.5 g of dry roots were digested by the aqua regia method (HCL:HNO₃ = 3:1) and heated until achieving a volume of 1 ml. The distilled water was then added to each root sample, and samples were filtered until obtaining a volume of 25 ml. The resulting filtrate was submitted to Zn analysis using AAS.

2.3. Water-sediment-to-root transfer assessment

Water-sediment-to-root tissue metal transfer was computed as Transfer Factor (TF), which is defined by the equation, where Cr is the concentration of heavy metals in mangrove roots and Cw/s is the concentration of heavy metals in water or sediment [4].

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TF = \frac{Cr}{Cw/s}
\]

2.4. Two way anova analysis and Tukey test

Two Way Factor ANOVA analysis were used to analyze the effects of mangrove species (Avi: *Avicennia*, Rhi: *Rhizophora*, Son: *Sonneratia*) and months (Apr: April, Jun: June) on Cu and Zn contents. The 2 Way ANOVA then presented in boxplot and 95% wise confidence level Tukey Test.

3. Result and Discussion

In this study, three species of mangrove consisting of *Avicennia marina*, *Rhizophora*, and *Sonneratia caseolaris* have been observed. Those species have different root structures (Figure 2). Figure 3A describes the comparison of Zn accumulation in sediments, roots of *A. marina* (pencil root), *R. mucronata* (prop root), *S. caseolaris* (cone root), and water in April and June. In April, the order of Zn was sediment > *R. mucronata* > *S. caseolaris* > *A. marina* > water. While the order of Zn was sediment > *A. marina* > *R. mucronata* > *S. caseolaris* > water in June. For Cu in April (Figure 3B), the order was sediment > *R. mucronata* > *A. marina* > *S. caseolaris* > water. In June, the Cu order was sediment > *S. caseolaris* > *R. mucronata* > *A. marina* > water.

![Figure 2](image.png)

Figure 2. The root diversity and structure of *Avicennia marina* (pencil root), *Rhizophora mucronate* (prop root) and *Sonneratia caseolaris* (cone root) [5].
Figure 3. The content of A) zinc – Zn and B) copper – Cu in sediments, roots of Avicennia marina (pencil root), Rhizophora mucronata (prop root), Sonneratia caseolaris (cone root) and water in April and June (mg/kg for roots, sediment; and mg/l for water).

Sediment was consistently higher for Zn and Cu in both months. Zn in sediments was ranging for 91.99-108.95 mg/kg in April and reduced to 85.44-96.18 mg/kg in June. While the ranges of Zn in water were 0.44-1.53 mg/l in April and 0.08-0.42 mg/l in June, the Zn in sediment and water ranges was still below in comparison to Zn in other locations (Table 1). The range of Cu in sediments of Blanakan was 1.85-2.48 mg/kg in April and 2.08-2.37 mg/kg in June. Furthermore, the Cu range in water was 0.03-0.05 mg/l in April and 0.02 mg/l in June. The Cu in sediment and water ranges were comparable to Cu in other locations (Table 1).

The fluctuations of Zn and Cu in sediments and water were related with the environment factors. In April, metal tends to be higher due to rainfall. In April (Figure 6), rainfall in Blanakan is higher than in June. The high rainfall brought more dissolved materials to the river, including heavy metals. Those materials will then be settled in the sediment. This condition will cause the high metal in sediment and increase the metal in mangroves.
Table 1. Comparison of Zn minimum and maximum values detected in roots, sediment and water from other locations (mg/kg for leaves, sediment, and mg/l for water).

| Samples | Time         | Zn Content | Cu content | Location                                      |
|---------|--------------|------------|------------|-----------------------------------------------|
| A. marina | June         | 66.18-99.88 | 13.88-37.68 | Muara Sungai Angke [2]                        |
| A. marina | June         | n/a        | 0.0035     | Tanjung Api api [8]                           |
| A. marina | March-April  | n/a        | 7.17       | Lamong river [9]                              |
| A. marina | January      | n/a        | 0.04-0.149 | Probolinggo river mouth [10]                  |
| A. marina | April        | 29.77      | 0.6        | Blanakan (this study)                         |
| A. marina | June         | 18.08-54.64| 0.33-0.89  | Blanakan (this study)                         |
| R. mucronate | June     | 55.38      | 12.17      | Muara Sungai Angke [2]                        |
| R. mucronate | June     | n/a        | 0.0028     | Tanjung Api api [8]                           |
| R. mucronate | July      | 12.50-30.74| n/a        | Sungai Tallo [6]                             |
| R. mucronate | October  | 11.50-16.74| n/a        | Probolinggo river mouth [10]                  |
| R. mucronate | January   | n/a        | 0.083-0.185| Blanakan (this study)                         |
| R. mucronate | April     | 29.75-52.22| 0.98-1.28  | Blanakan (this study)                         |
| R. mucronate | June       | 9.75-54.75 | 0.2-1.38   | Blanakan (this study)                         |
| S. caseolaris | June      | 83.05      | 15.36      | Muara Sungai Angke [2]                        |
| S. caseolaris | November | 5.88-24.40 | n/a        | Songkla river [12]                           |
| S. caseolaris | April     | 33.33      | 0.4        | Blanakan (this study)                         |
| S. caseolaris | June       | 19.58-23.51| 0.59-0.99  | Blanakan (this study)                         |
| Sediment  | June         | 56.58-69.3 | n/a        | Muara Sungai Angke [2]                        |
| Sediment  | July         | 201.62-338.07 | n/a    | Sungai Tallo [6]                             |
| Sediment  | October      | 145.06-338.55 | n/a    | Songkla river [12]                           |
| Sediment  | March-April  | 48.6-126.60 | n/a        | Lamong river [9]                             |
| Sediment  | January      | 91.99-108.95 | 1.85-2.48 | Probolinggo river mouth [10]                  |
| Sediment  | June         | 85.44-96.18 | 2.08-2.37  | Blanakan (this study)                         |
| Water     | June         | 0.04-0.06  | n/a        | Muara Sungai Angke [2]                        |
| Water     | n/a          | 0.02-0.11  | n/a        | Sungai Kunden [7]                            |
| Water     | March-April  | n/a        | 0.02       | Lamong river [9]                             |
| Water     | January      | n/a        | 0.08-0.19  | Probolinggo river mouth [10]                  |
| Water     | April        | 0.44-1.53  | 0.03-0.05  | Blanakan (this study)                         |
| Water     | June         | 0.08-0.42  | 0.02       | Blanakan (this study)                         |

The Zn and Cu in sediments were observed ten folds higher than in water (Figure 3, Table 1). Cu is bond easily with organic material and reduced its mobility and settled easily into sediment rather than solved in water [9]. Cu was used as antifouling paint for a boat. The River Blanakan is used frequently for boat traffic and parking. Those activities may contribute to increasing the Cu in water and sediment.

Figures 4A and 4B show the significance of the effect of mangrove root type-species and month to the Zn accumulations. In April, the root of *R. mucronata* was significantly accumulating more Zn in comparison to the *S. caseolaris* and A. marina roots. The range for *R. mucronata* was 29.75-52.22 mg/kg. While, in June, the roots of *A. marina* (18.08-54.64 mg/kg) have accumulated more Zn in comparison to the Sonneratia and *R. mucronata* roots.
Figure 4. The boxplots of ANOVA for A) zinc – Zn and B) copper – Cu in roots related to mangrove species (Avi: *Avicennia*, Rhi: *Rhizophora*, Son: *Sonneratia*) and months factor (Apr: April, Jun: June)

The significance of Cu accumulation in roots was described in Figure 5A and 5B. Statistically in April, the Cu accumulation in *Rhizophora* root (0.98-1.28 mg/kg) was higher than in *S. caseolaris* and *A. marina* roots. In June, *S. caseolaris* was species that accumulate more metal than *R. mucronata* and *A. marina*. The range for *S. caseolaris* was 0.59-0.99 mg/kg.

Figure 5. The 95% family-wise confidence level Tukey Test to test A) zinc –Zn and B) copper – Cu in roots related to mangrove species (Avi: *Avicennia*, Rhi: *Rhizophora*, Son: *Sonneratia*) and months factor (Apr: April, Jun: June)

The different Cu and Zn contents in roots were related to the metabolism and environmental factors, for example, *A. marina* was known as a species that has the lowest Cu in April and June. Low Cu in *A. marina* in comparison to *R. mucronata* and *S. caseolaris* because *A. marina* has the capability to reduce and expel the metals. While *R. mucronata* and *S. caseolaris* cannot expel the metals and tends to accumulate it in the root, furthermore, Cu is an essential element required by the mangrove. Lower Cu in roots is observed because the plants used that Cu rather than accumulate it. Meanwhile, other mangrove species keep retaining and accumulating Cu in roots.
Besides the metabolism factors, the structure of root also influences Zn accumulation in roots. The root type of *R. mucronata*, which is prop root has a more complex structure than cone root or pencil root belong to *A. marina* and *S. caseolaris*. The prop root is connecting each other and forming cage a like structure. Hence, this structure can retain more sediment. More sediment that can be retained will lead to more materials, including metals, than can be trapped and stored in the sediment of *R. mucronata*. As a result, *R. mucronata* roots will receive and absorb more metals. Likewise, *R. mucronata* has root structures with more surface area [13]. This area enlargement will increase the amount of metals that can be absorbed.

The TF order of Zn of sediment-to-root was *Rhizophora* > *Sonneratia* > *Avicennia* in April. The same pattern was also observed in June. All TF in April was higher than in June. While the TF order of Cu of sediment-to-root in April was *Rhizophora* > *Avicennia* > *Sonneratia*. In June, it was slightly changed to *Rhizophora* > *Sonneratia* > *Avicennia*. The TF order of Zn of water-to-root in April and June was *Rhizophora* = *Sonneratia* > *Avicennia*. While the TF order of Cu of water-to-root in April was *Rhizophora* > *Avicennia* > *Sonneratia*. In June, it was slightly changed to *Sonneratia* > *Rhizophora* > *Avicennia*. 

**Table 2.** The comparison of TF of Zn and Cu of sediment-to-root in nearby Blanakan fish pond and other locations

| Samples         | Time   | Zn          | Cu          | Location                        |
|-----------------|--------|-------------|-------------|---------------------------------|
| *Avicennia* sp. | August | 0.23-0.29   | 0.1-1.29    | Blanakan fish pond [4]          |
| *A. marina*     | April  | 0.28        | 0.32        | Blanakan (this study)           |
|                 | June   | 0.21        | 0.15        |                                  |
| *Rhizophora* sp.| August | 0.34-1.95   | 0.38-0.64   | Blanakan fish pond [4]          |
| *R. mucronate*  | April  | 0.38        | 0.46        | Blanakan (this study)           |
|                 | June   | 0.30        | 0.36        |                                  |
| *S. caseolaris* | November | 0.12-0.19 | n/a         | Songkla river [12]             |
| *S. caseolaris* | April  | 0.36        | 0.20        | Blanakan (this study)           |
|                 | June   | 0.25        | 0.36        |                                  |

The TF order of sediment-to-root values was all below zero. For accumulating Zn from sediment, *R. mucronata* and *S. caseolaris* are considered as potential species since the TF was always high. In this study, the TF of Zn of sediment-to-root in *S. caseolaris* ranging from 0.25 to 0.36 was higher than values obtained from Songkla river (Table 2). The TF of Zn of sediment-to-root in *R. mucronata* and *A. marina*
was comparable with the values obtained from nearby mangrove growth in nearby ponds. In this study, the TF of Zn in *R. mucronata* was higher than *A. marina*. The TF value was 0.30-0.38 for *R. mucronata* and 0.21-0.28 for *A. marina*. The similar trends were also observed in the TF of *R. mucronata* and *A. marina* from nearby fish ponds, which is TF of Zn of sediment-to-root of *R. mucronata* always higher (Table 2). For accumulating Cu from the sediment, the *R. mucronata* was also had higher TF in comparison to other species (Table 2). The *R. mucronata* in fish ponds has also shown similar trends.

4. Conclusion

The most effective roots in accumulating Zn from sediment based on the TF values are *R. mucronata* followed by *S. caseolaris* and *A. marina*. While the most effective roots for accumulating Cu from the sediment are *R. mucronata* followed by *S. caseolaris* = *A. marina*. In general, *R. mucronata* has the potential root structure in absorbing metals from sediment.

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