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Potential of *Rhizophora apiculata* Blume. in Phytoremediation of Heavy Metals Pb and Cu in the Mangrove Forest Nature Reserve East Coast, Alang-Alang Village, Tanjung Jabung Timur, Jambi

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Abstract. The Mangrove Forest Nature Reserve East Coast (CAHBPT) in Jambi Province has functions, one of which is to improve water quality by absorbing dangerous heavy metals such as Pb and Cu which come from various human activities around the waters. This absorption can be done by using hyperaccumulator plants such as *Rhizophora apiculata* Blume. This study aims to determine the potential and mechanism of *R. apiculata* in the phytoremediation of heavy metals Pb and Cu in the CAHBPT area, Alang-Alang Village, Tanjung Jabung Timur Regency, Jambi Province. Sampling was carried out using the purposive sampling method at three stations. The calculation of the Bioconcentration Factor (BCF) aims to determine the potential of *R. apiculata* in phytoremediation Pb and Cu metals, as well as the calculation of the Translocation Factor (TF) to determine the phytoremediation mechanism of *R. apiculata*. The results of this research found that the accumulation of Pb and Cu metals in sediments ranged from 11.04-12.36 mg/kg and 7.93-9.08 mg/kg. The accumulation of Pb and Cu metals in the roots of *R. apiculata* ranges from 2.34-2.65 mg/kg and 1.56-2.93 mg/kg. The accumulation of Pb and Cu metals in the shoots of *R. apiculata* ranged from 2.77-3.16 mg/kg and 0.61-1.05 mg/kg. The phytoremediation potential of *R. apiculata* at the research site is included in the excluder category or plants still limit the accumulation of heavy metals entering the body (BCF<1). *R. apiculata* at the research site translocated Pb metal using a phytoextraction mechanism (TF>1) and Cu metal using a phytostabilization mechanism (TF<1).

Keyword: Phytoremediation; East Coast Mangrove Forest Reserve area; Heavy Metals; *Rhizophora apiculata* Blume.

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1 Introduction

Alang-alang Village is included in the buffer zone of the East Coast Mangrove Forest Reserve (Kawasan Cagar Alam Hutan Bakau Pantai Timur, CAHBPT), in Muara Sabak Timur District, Tanjung Jabung Timur Regency. This area plays an important role for the life of the surrounding community which is useful as protection from abrasion, erosion and sea waves, as well as a place for the development of aquatic biota which has economic value for fulfilling life's needs [1]. In addition,

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the mangrove forest area surrounding Alang-Alang village is also useful as an absorbent for various pollutants from the land that enter the waters, because mangroves have high adaptability and accumulation so that they can survive in polluted aquatic environmental conditions [2]. Water pollution is one of the most common environmental problems nowadays. Human activities on land are the cause of water pollution which creates various wastes, which can provide opportunities for heavy metals to enter the waters [3].

Rhizophora apiculata Blume. or known as Tall-stilt mangroves or bakau Minyak is a type of mangrove that grows in the mangrove ecosystem of Alang-Alang Village. This type of mangrove has tolerance for extreme environmental conditions. Research concluded, that overall the range of water quality parameters is still within tolerance limits for the life of *R. apiculata* mangroves, where this mangrove species has a strong correlation with redox potential, pH, temperature, and DO parameters [4]. In addition research, stated that *R. apiculata* was able to tolerate and grow well at a low salinity level of 0.5 percent. These various environmental parameters also affect the problem of environmental pollution [5].

The ability of mangroves to accumulate heavy metals is different for each species, and the concentration of heavy metals between plant organs is also different for each species. According to stating that the ability to absorb heavy metals in mangroves of the species *R. apiculata* on the east coast of Asahan, North Sumatra, found that the highest accumulation of heavy metal Pb was in the roots, while the absorption capacity of heavy metal Pb in bark, leaves and fruit was low [6].

The East Coast Mangrove Forest Nature Reserve (CAHBPT area) has a function, one of which is to improve water quality so that it is not polluted, by absorbing all dangerous heavy metals such as Pb and Cu which originate from community activities around the waters. Overcoming this can utilize *R.apiculata* as a phytoremediator. This study aims to determine the potential and mechanism of *R. apiculata* in the phytoremediation of heavy metals Pb and Cu in the East Coast Mangrove Forest Nature Reserve, Alang-Alang Village, Tanjung Jabung Timur, Jambi.

2. Materials and Methods

- Time and Location

This research was conducted from November 2022 to January 2023. Sampling was carried out at three locations with three repetitions of the sample test in the laboratory. The sampling location is in the CAHBPT Area, Alang-Alang Village, Tanjung Jabung Timur, Jambi (Figure 1). Laboratory analysis was carried out at the Environmental Laboratory, South Sumatra Province Environment and Land Agency.

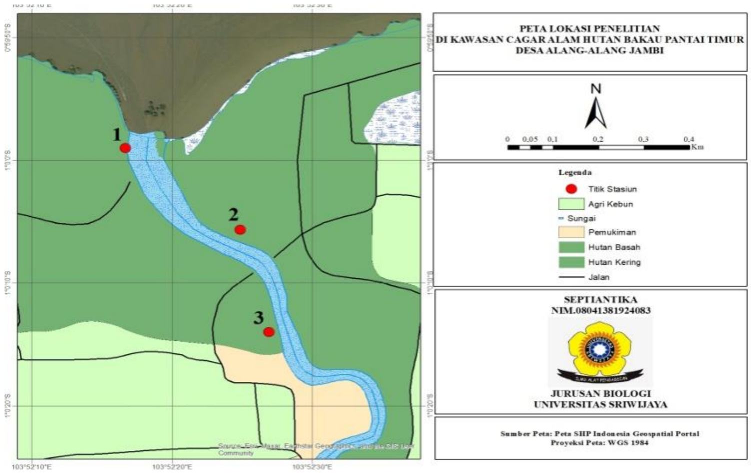

Figure 1. Map of research locations at points sampling 1, 2 and 3 in the East Coast Mangrove Forest Reserve Area (CAHBPT), Alang-Alang Village, Tanjung Jabung Timur, Jambi

- Measurement of Environmental Parameters

Environmental factors measured by *in situ*, were temperature, pH and salinity

- Sampling and Sample Preparation

Sediment samples were taken at a depth of ± 30 cm as much as 500 gs per station. *R. apiculata* root samples were taken a root length of 10-15 cm as much as 50 gs per repetition and *R. apiculata* leaf samples were taken by picking dark green leaves, located at the bottom of the tree stand, with a total of 30 leaves per sample in each repetition of each station. Sample preparation was carried out according to SNI no. 06-6992.3-2004 for the determination of Pb levels and SNI no. 06-6992.3-2004 for Cu levels by acid destruction to a sample solution that is ready to be measured with an Atomic Absorption Spectrophotometer (AAS). Furthermore, the results of the measurements are recalculated using the formula to determine the levels of heavy metals Pb and Cu

$$Metal\ Concentration\ of\ Pb\ or\ Cu = (C.V.Fp)/B$$

Information:

Metal concentration : Metal content in the sample (µg/g)
C : Pb or Cu levels obtained from the calibration curve (µg/ml)
V : Final volume (ml)
Fp : Dilution factor if no dilution is done, then Fp=1
B : Sample weight (gs)

- Bioconcentration Factor (BCF)

The BCF calculation aims to determine the occurrence of metal accumulation in mangroves which is done by calculating the metal content in the roots and leaves as a potential phytoremediation with the formula:

$$BCF\ of\ root = \frac{Concentration\ of\ heavy\ metal\ in\ roots}{Concentration\ of\ heavy\ metals\ in\ sediments}$$

$$BCF\ of\ leaf = \frac{Concentration\ of\ heavy\ metal\ in\ leaves}{Concentration\ of\ heavy\ metals\ in\ sediments}$$

- Translocation Factor (TF)

Calculation of TF aims to determine the transfer of heavy metal accumulation from roots to leaves as a phytoremediation mechanism with the formula:

$$TF = \frac{Concentration\ of\ heavy\ metal\ in\ leaves}{Concentration\ of\ heavy\ metals\ in\ roots}$$

- Data Analysis

Data obtained from BCF (Bioconcentration Factor) and TF (Translocation Factor) calculations are presented in the form of diagrams and tables. Quantitative data in the form of measurements temperature, pH, and salinity of water as an environmental factor will be analyzed using average and standard deviation.

3. Results and Discussion

Concentration of Heavy Metals Pb and Cu in Sediments

Accumulation of heavy metals Pb and Cu in sediments at station 1, station 2 and station 3, is presented in Figure 2.

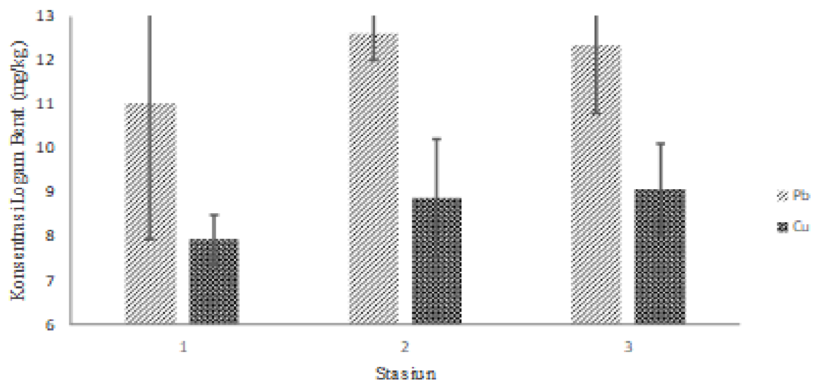

Figure 2. Concentration of heavy metals Pb and Cu in sediment from several stations at CAHBPT, Alang-alang Village, Tanjung Jabung Timur, Jambi.

Based on Figure 2. it can be seen that the average accumulation of heavy metal Pb in sediments at station 1, station 2, and station 3 respectively is 11.04 ± 3.09 mg/kg, 12.60 ± 0.61 mg/ kg, and 12.36 ± 1.57 mg/kg. The accumulation of heavy metal Pb in sediments was more abundant at station 2 and less at station 1. This is presumably because the location of station 1 is at the mouth of the river in Alang-alang village which refers to the sea while the locations of stations 2 and 3 point to to residential areas that are suspected of being heavy metal suppliers due to nearby human activities. This causes the concentration of the heavy metal Pb at station 1 to be less due to the slow flow of heavy metals from upstream (station 3) to the estuary (station 1) due to the influence of river water currents. According to, the entry of heavy metals into the estuary can occur due to flow from upstream areas due to erosion caused by the movement of river water currents. Besides that, tidal currents greatly affect the accumulation of Pb metal which at station 1 is in a high tide while stations 2 and 3 are still calm or receding [7]. This is in accordance with the research, explained that tidal currents that occur due to pressure from river waters cause the metals in the waters to be more likely to be carried away by the currents than to the bottom of the waters so that the metals in the sediment are less [8].

Accumulation of heavy metal Cu in sediments at station 1, station 2, and station 3 respectively 7.92 ± 0.57 mg/kg, 8.87 ± 1.36 mg/kg, and 9.07 ± 1.05 mg/kg. The metal accumulation at the station is suspected to be influenced by the river currents which carry Cu metal from station 3 to station 1 and the concentration of Cu metal at station 3 is also suspected due to its location close to residential areas so that Cu metal enters the waters as a result of community activities. Which uses materials containing Cu metal and is discharged into the waters, while the location of station 1 is far from residential areas so that the accumulation of metals is much less than stations 2 and station 3. This is in accordance with the opinion, that the increase in the heavy metal Cu was due to the area being close to residential areas so that it was affected by household waste [9]. Furthermore, explained that the further away from the pollutant source, the waste carried by the river flow partially settles on its way to the estuary [10].

Based on the accumulation of heavy metals Pb and Cu, it shows that the concentration of accumulated Pb in sediments at each station is higher than that of Cu (Figure 2). The different accumulation of Pb and Cu metals is thought to be due to higher Pb heavy metal contamination than Cu heavy metal, in which the study sites at stations 1, 2 and 3 are fishing boat transportation routes so that fuel oil from boats is a source of heavy metal Pb and there is also household domestic waste containing Pb. According, that anthropogenic activities that contribute to lead (Pb) contaminants are transportation that uses fuel containing lead [11]. The difference in the accumulation of Pb and Cu metals is in accordance with the research, showed that the content of the heavy metal Pb in the sediment where *R. apiculata* grew was higher than the heavy metal Cu [12].

The accumulation of heavy metals Pb and Cu at several different stations can also be influenced by environmental factors such as pH, temperature and salinity. The average value of environmental parameters can be seen in Table 1.

Table 1. Environmental factors pH, temperature and salinity at several stations at CAHBPT, Alang-alang Village, Tanjung Jabung Timur, Jambi.

Station	**Environmental Parameters**		
	pH	**Temperature (°C)**	**Salinity (ppt)**
1	8,03±0,68	27,33±0,58	13,67±2,08
2	7,00±0,20	28,33±0,58	10,67±0,58

3	4,80±0,44	28,67±0,58	10,33±0,58

Based on Table 1, it can be seen that the pH at station 1 (8.03), station 2 (7.00), and station 3 (4.80). Low pH at station 3 was followed by low metal concentrations in the sediment. This is presumably because at low pH the solubility of metals in water is high so that the metals that will precipitate in sediments will also be high. According to, if the pH in the waters is high, the solubility level of heavy metals in the waters will decrease, and vice versa if the pH is low, the solubility of metals in the waters will be higher [13]. Then added, that changes in stable solubility levels usually occur in the form of shifting compounds, generally at higher pH the stability will change from carbonate to hydroxide which easily forms surface bonds with particles in the waters [14].

Other environmental factors that also affect the accumulation of heavy metals are temperature and salinity. In Table 1 it can be seen that the average temperature from station 1 to station 3 is around 27-28°C. The temperature at station 3 is higher than the other stations and is followed by more accumulation of heavy metals at station 3. This is because the high water temperature will make it easier for metals to dissolve in the waters so that a lot of metals precipitate in the sediments. This is supported by stated that high water temperatures will increase the solubility of heavy metals in waters [15]. While the measured salinity (Table 1), shows that the high salinity at station 1 has an effect on the accumulation of heavy metals which is less compared to stations 2 and station 3 which have low salinity values. These results are in accordance with research, showed that decreasing salinity has an effect on increasing heavy metal accumulation [13].

Based on the environmental factor data obtained from pH, temperature, and salinity (Table 1), it is known that under conditions of low pH, high temperature, and low salinity, the accumulation of metals in sediments is greater. This is presumably because in these conditions the river water is experiencing a low tide so that more metal will be deposited into the sediments rather than being carried away by the flow of river water. In accordance with stated that conditions of low pH, low salinity, and high temperatures occur when the river water recedes [16].

The results of measuring the accumulation of heavy metals Pb and Cu can be used to determine the environmental status of CAHBPT, Alang-alang Jambi village by comparing the values obtained with the quality standard values. Referring to the Environmental Protection Authority (EPA) (2017), the quality standard for sediments of heavy metal Pb is 50 mg/kg and metal Cu is 65 mg/kg. When compared between the concentrations of the heavy metals Pb and Cu measured at the study site, namely 11-12 mg/kg and 7-9 mg/kg, it has not exceeded the threshold of the predetermined quality standard, so that the aquatic environment in CAHBPT, Alang- Jambi reeds are still in good condition and in the category of not disturbing the life of aquatic biota.

- Heavy Metal Concentrations of Pb and Cu in the Roots of *Rhizophora apiculata*

Accumulation of heavy metals Pb and Cu in the roots of *R. apiculata* at station 1, station 2 and station 3 is presented in Figure 3.

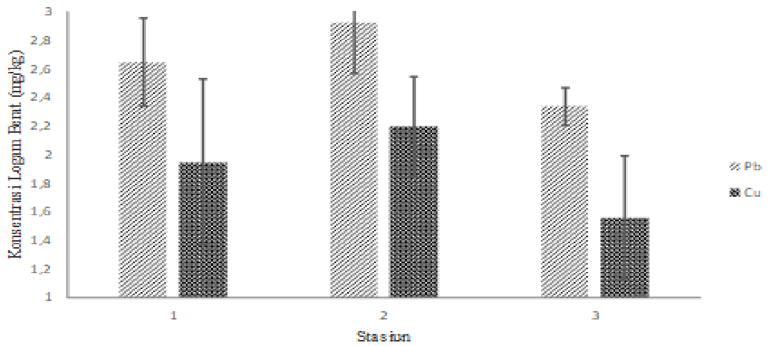

Figure 3. Concentration of heavy metals Pb and Cu in the roots of *Rhizophora apiculata* from several stations at CAHBPT, Alang-alang Village, Tanjung Jabung Timur, Jambi.

Pb accumulation in the roots of *R. apiculata* at station 1 (2.65 ± 0.31 mg/kg), station 2 (2.93 ± 0.36 mg/kg), and station 3 (2.34 ± 0.13 mg/kg). Based on this accumulation, it is known that the accumulation of Pb metal is more abundant at station 2, presumably because there is also more metal in the sediment at station 2. This is related to the interaction between roots and sediment. According that the concentration of heavy metals in the roots occurs because the roots interact directly with water and sediments that have been contaminated with heavy metals [17]. Furthermore added, the metals in the environment around the roots come into direct contact with the root surface through 3 stages, namely by diffusion into the soil solution, transported passively by underground water flow, and when the roots grow to the position of the metal in the soil matrix [18].

The concentration of Cu metal in the roots of *R. apiculata* at station 1, station 2, and station 3 were 1.95 ± 0.58 mg/kg, 2.2 ± 0.35 mg/kg, and 1.56 ± 0.43 mg/kg (Figure 3). The accumulation shows that the pattern of distribution of Cu metal in roots and sediments is different, where Cu metal is more abundant in station 3 while in roots it is more abundant in station 2. However, the concentration of metal in sediments is higher than in roots. This is presumably because the roots have the ability to reduce the uptake of heavy metals from the environment into the root cells with the help of phytosiderophores as metal binders. According, the roots are able to release substances including root exudates to bind heavy metals thereby reducing the absorption and toxicity of metals into root cells [19]. Then explained that phytosiderophores are chelating substances produced by plant roots to bind metals in the rhizosphere and then limit metals from being absorbed into the root cells [20].

Based on Figure 3, it is known that the accumulation of Pb metal in the roots of *R. apiculata* is more than Cu metal. This is presumably because the accumulation of Pb metal in sediments is more than Cu metal, so that accumulation in roots is also the case. These results are in accordance with research, that the heavy metal Pb is absorbed in the roots of *Rhizophora* compared to other parts [21]. Then, explained that the correlation between heavy metal accumulation between sediments and roots is directly proportional, that is, the higher the concentration of heavy metals in the sediment, the better the accumulation by mangrove roots [6].

The accumulation of Pb and Cu metals in the roots of *R. apiculata* can occur through two pathways, namely the symplast and apoplast pathways. Symplast is the transport of solutes through the cytoplasm while apoplast is the system of transporting solutes through the spaces between cells. This is in accordance with the opinion, stated that metals can be absorbed into plants either through the intercellular space called the apoplast pathway or by crossing the plasma membrane which is called the symplast pathway [22]. Furthermore explained, that the metal transport and uptake system in root cells that occurs through the plasma membrane is carried out in 3 stages, namely the containment of heavy metals in the root cells, sympatic transport to the stele, and release into the xylem assisted by organic compounds [23].

Plants that are tolerant of excessive metal concentrations have the ability to transport and release metals with the help of organic compounds, namely phytochelatin and metallothionein. According to phytochelatins are a group of proteins with the amino acids cysteine, glycine, and glutamic acid which can induce plants when they experience heavy metal stress [24]. Furthermore explained that metallothionein is a polypeptide that functions as a storage space for excess metal ions and then detoxifies the excess metal through the thiol group [25]. Then, explained that there are 2 functions of metallothionein namely, metallothionein provides ion storage for excess chelating free heavy metal ions until used by plants when needed and the second function, metallothionein as a transport protein which is responsible for eliminating heavy metal toxicity excess from where it accumulates to plants where the metal is needed in plants [26].

Heavy Metal Concentrations of Pb and Cu in Leaves *Rhizophora apiculata*.

Pb and Cu metals accumulated in the leaves of *R. apiculata* at station 1, station 2 and station 3, are presented in Figure 3.

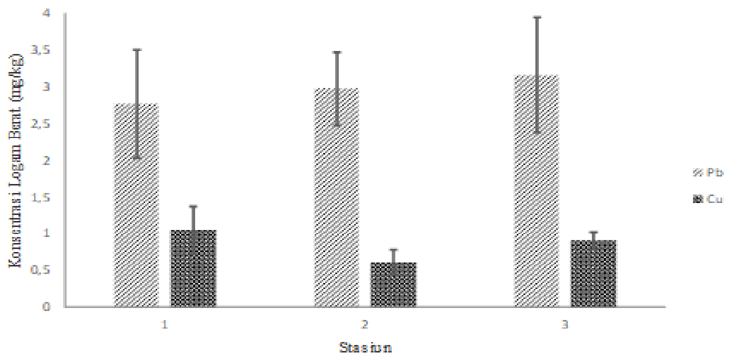

Figure 4. Concentration of heavy metals Pb and Cu in *Rhizophora apiculata* leaves from several stations at CAHBPT, Alang-alang Village, Tanjung Jabung Timur, Jambi.

Concentrations of heavy metal accumulation of Pb in leaves of *R. apiculata* at stations 1, 2, and 3 respectively were 2.77 ± 0.74 mg/kg, 2.98 ± 0.50 mg/kg, and 3.16 ± 0.78 mg/kg (Figure 4). Based on this accumulation, it is known that the accumulation of heavy metal Pb in leaves is higher than the accumulation of heavy metal Pb in roots of *R. apiculta* (Figure 3). This is presumably due to the non-essential or toxic Pb metal so that the mobility of the metal from roots to leaves is high with the aim that this toxic Pb metal is immediately released into the environment by means of leaf abortion (abscission). This is in accordance with research, that the mobility of non-essential metals (Pb) from roots to leaves is very high [27]. Then added, that the high accumulation of metals in the leaves is not only due to the high level of mobility of heavy metals, but also because of the leaf tissue as a localization site for metals before being released into the environment [17]. Furthermore added, that in the leaves, metals will be stored in old leaves which will experience abscission thereby reducing the concentration of metals in plants [18].

Heavy metal Cu accumulated in the leaves at station 1 (1.05 ± 0.32 mg/kg), station 2 (0.62 ± 0.17 mg/kg), and station 3 (0.91 ± 0.12 mg/kg) (Figure 4). Based on this accumulation, it can be seen that the heavy metal Cu in the leaves is less than the accumulation of heavy metal Cu in the roots of *R. apiculata* (Figure 3). This is presumably because Cu Metal is essential so that when it is absorbed by the roots, some of the absorbed Cu metal will be used for plant metabolism, as a result less Cu metal is translocated to leaves. According to stated that copper (Cu) is included in an essential metal which when in low concentrations can stimulate the growth of an organism and when in high concentrations it can inhibit growth, but plants that are tolerant to Cu metal will not be disturbed [27]. Furthermore, explained that Cu is involved in many physiological and biochemical processes in plants such as, Cu is needed in chloroplast and mitochondrial reactions, cell wall lignification, enzyme systems related to photosynthesis, electron transport, protein synthesis, and carbohydrate metabolism [28].

The accumulation of Pb and Cu metals in leaves occurs due to metal translocation from roots to leaves and then localized in the vacuole. According to research, states that the accumulation of metals in the leaves is a form of adaptation of mangrove plants to heavy metals by localizing them to one part of the plant. Furthermore, added that localization is a working process of plants to collect metals in one organ [19]. According to the mechanism for translocation of heavy metals to the leaves is initiated by the metal being absorbed by the roots and then transported through the symplast pathway by xylem and then distributed to the top of the plant until it is finally stored in the vacuoles contained in the leaf cells. Metal storage in the vacuole is intended so that the metal does not interfere with plant metabolic processes [30]. This is in accordance, which states that the final step of metal accumulation is the transport of metals into the vacuole to separate metals from cellular processes that may occur and be stored in the long term [31].

- **Bioconcentration Factor (BCF) and Translocation Factor (TF) of Pb and Cu Heavy Metals in *Rhizophora apiculata***

Table 2. Average BCF and TF values on *Rhizophora apiculata* at CAHBPT, Alang-alang Village, Tanjung Jabung Timur, Jambi.

Heavy Metals	BCF		TF
	Leaf	Root	
Pb	0.22	0.25	1.14
Cu	0.22	0.07	0.49

Based on Table 2, it can be seen that the BCF Pb and Cu values in the roots are the same, namely 0.22, while the BCF Pb values in the leaves are 0.25 and Cu 0.07. These results indicate that the BCF value for both roots and leaves is <1, which means that *R. apiculata* found in CAHBPT, Alang-alang Village, Tanjung Jabung Timur Jambi, belongs to the category of plants that exclude heavy metals Pb and Cu, which still limit absorption. metal to enter the plant. According to, the nature of plants in accumulating heavy metals is categorized into three, namely Accumulators if the BCF value is > 1, Excluders if the BCF value is <1, and Indicators if the BCF value is close to 1 [32]. Further explained, that the excluder is the nature of plants which limits the accumulation of heavy metals that enter the plant through the roots, but when it enters the plant roots it will be translocated to other parts [33].

The BCF values for Pb and Cu in the roots and leaves of *R. apiculata* were less than 1, presumably due to the accumulation of heavy metals, both Pb and Cu, in the sediments more than in the roots and leaves of *R. apiculata*. This was also confirmed, BCF values in leaves and roots <1 indicates that the heavy metal content is higher in the substrate tissue (sediment) compared to the heavy metals present in leaves and roots [21].

Based on Table 2. it can also be seen that the average TF value of heavy metals Pb 1.14 and Cu 0.46 in *R. apiculata*. These values indicate that the TF of Pb > 1 while the TF of Cu < 1 which is thought to be the result of the non-essential nature of Pb metal so that the mobility from roots to leaves is high while Cu is essential so that the mobility from roots to leaves is low due to it being needed for plant metabolism. This is in accordance with the statement, that in general the translocation of essential metals such as Cu from roots to leaves is lower than that of non-essential metals such as Pb because essential metals are used by mangroves for metabolism and growth before being translocated while Pb metals move from roots to leaves quickly because these metals not used in metabolic processes, so the aim is to place heavy metals in certain parts so that these heavy metals can be decomposed or diluted [34].

The BCF and TF values for Pb and Cu metals (Table 2) can be used as indicators to determine the heavy metal accumulation mechanism carried out by *R. apiculata*, where Pb metal was accumulated by a phytoextraction mechanism while Cu metal was by a phytostabilization mechanism. These results are in accordance with research, explained that the BCF <1 and TF> 1 values for Pb metal, the mechanism used is phytoextraction, while the BCF <1 and TF <1 values, the mechanism is phytostabilization. Phytoextraction is a phytoremediation mechanism in accumulating heavy metals by roots which are translocated to other plant parts such as stems and leaves, while phytostabilization is accumulation of heavy metals in roots which are not translocated to other parts [35]. According to that phytoextraction is a situation where roots absorb pollutants which are then transferred to other organs to be reprocessed or disposed of [33]. Meanwhile, explained that phytostabilization is a plant mechanism that uses roots to limit the movement of metals absorbed and accumulated from the environment to other plant organs [36].

4. Conclusion

Based on the results of research that has been done regarding the potency of *Rhizophora apiculata* Blume. in the phytoremediation of heavy metals Pb and Cu in the East Coast Mangrove Forest Nature Reserve (CAHBPT), Alang-alang Village, Jambi, it was concluded that the accumulation of Pb and Cu metals in sediments ranged from 11.04-12.36 mg/kg and 7, 93-9.08 mg/kg., accumulation of Pb and Cu metals in the roots of *R. apiculata* ranged between 2.34-2.65 mg/kg and 1.56-2.93 mg/kg. Cu in *R. apiculata* leaves ranged from 2.77-3.16 mg/kg and 0.61-1.05 mg/kg. Phytoremediation of heavy metals Pb and Cu by *R. apiculata* has a BCF value <1 in roots and leaves so that the potential of *R. apiculata* in overcoming Pb and Cu metal pollution at the study site is still in the excluder category or plants still limit the accumulation of heavy metals to enter the top plant. *R. apiculata* at the research site translocated Pb metal using a phytoextraction mechanism (TF>1) and Cu metal using a phytostabilization mechanism (TF<1).

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