JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(2), 169–177
https://doi.org/10.12911/22998993/131032
ISSN 2299-8993, License CC-BY 4.0

Received: 2020.11.16
Accepted: 2020.12.14
Published: 2021.01.01

Performance of *Avicennia alba* and *Rhizophora mucronata* as Lead Bioaccumulator in Bee Jay Bakau Resort, Indonesia

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ABSTRACT

Mangroves are a crucial ecosystem in coastal areas and serve a significant ecological function. However, this ecosystem is under the continuous pressure of anthropogenic activities which create toxic contaminants, such as heavy metals. The presence of marine ports and electric steam power plants next to Bee Jay Bakau Resort (BJBR) Mangrove Forest may worsen the heavy metal pollution, especially in the case of non-essential metals like lead (Pb). The vegetation in mangrove ecosystems can help store and trap this contaminant. Therefore, the objective of this study was to determine the potency of the *Avicennia alba* and *Rhizopora mucronata* mangrove species, which dominate the mangrove vegetation in BJBR Mangrove Forest, as Pb phytoremediation agents. The samples were taken from the sediment, roots, stems, and leaves of the mangrove trees. The results showed that the Pb found in the sediment of these species ranged from 10.323 to 11.071 ppm, while the Pb concentration in the mangrove parts was less than 1 ppm with the order roots > stems > leaves. Furthermore, the statistical analysis indicated that there were no statistically significant differences in the Pb values across sites and species. Moreover, the BCF, BAC, and TF in this study were less than 1, making the observed mangrove species unsuitable for phytoextraction or phytostabilization.

Keywords: *Avicennia alba*; *Rhizopora mucronata*; lead accumulation; toxic metal

INTRODUCTION

Mangrove forests are an undeniably predominant coastal ecosystem located in the intertidal zone of tropical and subtropical coasts [Kathiresan, 2012; Himes-Cornell et al., 2018]. They offer ecological services, such as protecting the coast from the greenhouse effect, floods, rising sea levels, wave action, and erosion and providing nutrients for a large number of organisms [Carugati et al., 2018]. Mangrove ecosystems are considered a foremost ecosystem, as they are important sites for primary production and habitats for many species [Ribeiro et al., 2019], leading them to play a significant role in complex food webs as well as energy transfer [Mendoza-Carranza et al., 2010].

The existence of mangrove ecosystems is continuously under the pressure of numerous anthropogenic activities, including industrial effluent wastewater, port activities, mining, agricultural runoff, and aquaculture waste [Maiti and Chowdhury, 2013; Santos et al., 2014]. Amidst the diverse pollutants produced by these activities, heavy metals such as lead (Pb) are a serious pollutant for mangrove ecosystems [He et al., 2014; Abou Seedo et al., 2017]. Because of its persistence and toxicity, the accumulation of Pb in natural environments may threaten the human health and biodiversity [Ali et al., 2019]. Globally, coastal and marine habitats are polluted by Pb from urban waste and runoff from agricultural and industrial sources [Qian et al., 2015]. Thus, the vegetation in coastal areas serves an important function in storing and trapping these contaminants [Martin et al., 2019].

As a tropical country, Indonesia is an ideal site for mangrove forests [Feller et al., 2017]. It is estimated that this country is home to around 20% of the world's mangrove forests and more than 50% of those in Asia [Choong et al., 1990]. Most are situated on Papua Island and are still in relatively good condition [Sillanpää et al., 2017]. However, the mangroves located in populated areas in Indonesia, such as the island of Java, have been exploited [Hakim et al., 2017; Puryono and Suryanti, 2019]. Specifically, a coastal area in Java situated in Probolinggo Regency called BJBR Mangrove Forest has been heavily used for tourism, port activities, aquaculture, and community settlements and is located near the largest electric steam power plant in southeast Asia [Parmawati and Hardyansah, 2020]. Agricultural runoff, municipal waste, and industrial sewage discharged into the river may contain the Pb pollutants [Iloms et al., 2020]. While many regulations have been developed to handle waste before discharge into a natural ecosystem, it is frequently discharged indiscriminately into nearby bodies of freshwater and eventually ends up in estuaries [Liu et al., 2015]

The presence of marine ports has worsened the heavy metal contamination in aquatic ecosystems due to shipping traffic, repairs, loading, and dredging. In addition, the electric steam power plant uses coal as fuel [Galkus et al., 2012]. The heavy metals from coal may be contained in solid and gaseous materials, collecting in the form of ash from coal [Huang et al., 2017]. Some of this ash is released into the atmosphere through stacks and is transferred into soils and waters via wet or dry deposition [Wuana and Okieimen, 2011].

BJBR Mangrove Forest is dominated by the species *Avicennia alba* and *Rhizopora mucronata* [Fattah et al., 2020]. *A. alba* is able to absorb heavy metals because it has a complex root system [Paz-alberto et al., 2014] and can therefore be used as a phytoremediation agent [Nguyen et al., 2020]. *R. mucronata* can be used as a bio-indicator for monitoring the Pb pollution [Pahalawattaarachchi et al., 2009]. The objective of this study was to determine the Pb phytoremediation by *A. alba* and *R. mucronata* in BJBR Mangrove Forest. Such research is essential for this site, as it has been heavily exploited and is surrounded by many activities that may heighten the Pb contamination in its aquatic environment.

METHOD AND MATERIALS

Sampling Location and Procedure

There were three sampling locations in this study, each 200 m away from the others. The distance of each sampling plot was 20 m. The location was determined using GPS (Figure 1). Sampling was performed on the sediments, roots, stems, and leaves of mangrove trees *A. alba* and *R. mucronata*. The trees used in this research had trunks with a diameter of 10–15 cm. The stem samples were taken by harvesting the stem at chest height, while the root samples were taken from mangrove roots in the soil with a length of 10–20 cm. The leaves taken for this study were old leaves that were dark green in color. The sediment samples were taken under the sampled tree at a depth of 15–30 cm. In order to analyze the Pb content in these samples, HNO_3 was added, and the samples were then heated at 200°C for 2–3 hours. Next, the samples were analyzed using an atomic absorption spectrophotometer at wavelength 235.5 nm.

Bio-Concentration Factor (BCF), Bioaccumulation Coefficient (BAC), and Translocation Factor (TF)

BCF is a coefficient that is used to measure the metal uptake of a plant [Amin et al., 2018]. It denotes the ratio of metal concentration in roots to its concentration in sediment (equation 1).

$$BCF = \frac{MC_{roots}}{MC_{sediment}} \quad (1)$$

where: BCF = Bio-concentration factor
MC_{roots} = Metal concentration in roots (ppm)
$MC_{sediment}$ = Metal concentration in sediment (ppm)

The metal uptake of other plant parts relative to sediment is called the bioaccumulation coefficient, or BAC (equation 2) [Amin et al., 2018].

$$BCF = \frac{MC_{stems/leaves}}{MC_{sediment}} \quad (2)$$

where: BCF = Bio-concentration factor
$MC_{stems/leaves}$ = Metal concentration in stems/leaves (ppm)
$MC_{sediment}$ = Metal concentration in sediment (ppm)

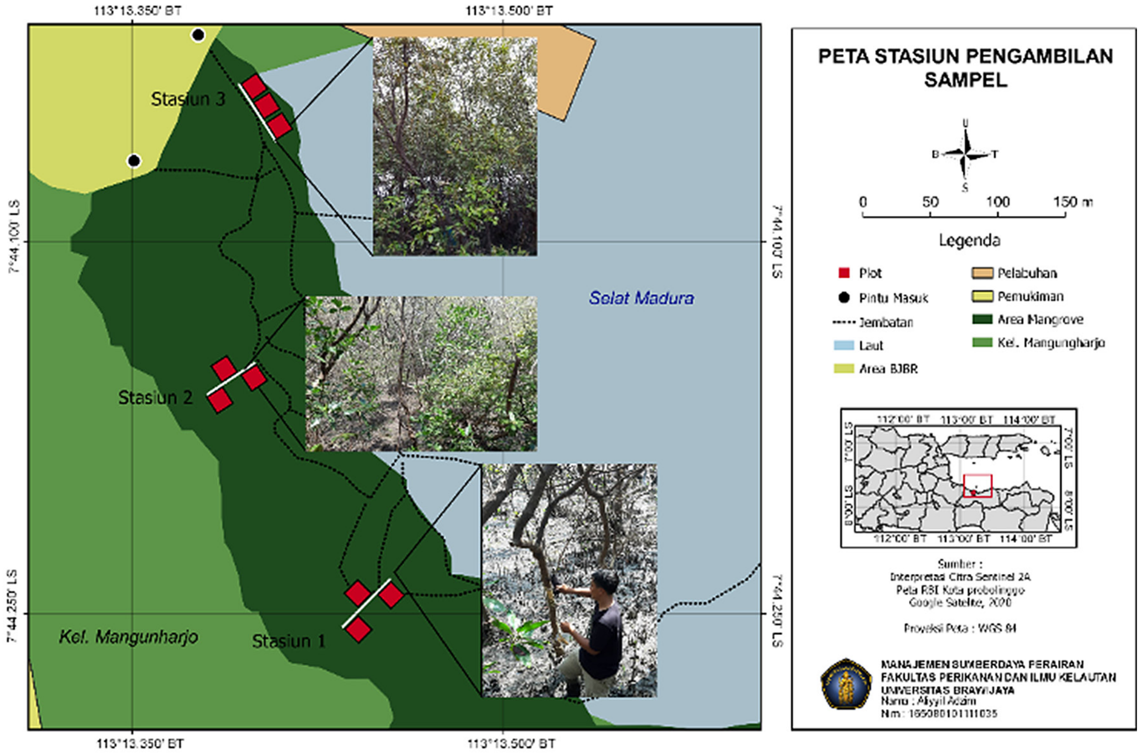

Figure 1. Research location at BJBR mangrove forest, Probolinggo, Indonesia

In addition to BCF, TF is also used to quantify the metal translocation from roots to leaves, which represents the phytoextraction of the plant [Nirola et al., 2015]. The formula for TF is shown in equation 2.

$$TF = \frac{MC_{stems/leaves}}{MC_{roots}} \quad (3)$$

where: TF = Translocation factor
MC_{roots} = Metal concentration in roots (ppm)
$MC_{stems/leaves}$ = Metal concentration in stems or leaves (ppm)

Statistical Analysis

The data obtained from this research were analyzed using two-way analysis of variance (ANOVA) incorporating two factors: site and mangrove species. The purpose of this analysis was to determine the differences in the Pb concentration and BCF, BAC, and TF across sites and mangrove species.

RESULTS AND DISCUSSION

As shown in Figure 2, the Pb concentration in the sediment under *A. alba* was observed to be 10.43 ± 0.14 ppm, while that of *R. mucronata* was 10.76 ± 0.38 ppm. The limit for the Pb concentration in sediment set by CCME is 30.2–112 ppm. Therefore, the Pb content in this study was deemed to be at a safe level. Moreover, the Pb concentration in sediment showed no significant difference across sites or mangrove species ($p > 0.05$). The contamination of heavy metal sediments is an important environmental problem with implications for marine life and human health. Sediments serve as the principal metal layer in the marine world. Their quality may indicate the water pollution status [Zahra et al., 2014]. Sediments act as both sinks and sources of heavy metals and release them into the water column [Fernandes and Nayak, 2012]. Continued deposition of heavy metals into sediments can also result in groundwater pollution from these pollutants [Sanyal et al., 2015].

On the other hand, low concentrations of Pb were found in the roots, stems, and leaves of the mangrove tree (< 1.00 ppm) with order roots > stems > leaves (Figure 3–5). However, the ANOVA results showed that there was no statistically significant difference in the Pb concentration in these mangrove parts, both across sites and between species ($p > 0.05$). Many studies have shown that metal contaminants such as Pb accumulate primarily in the root tissues,

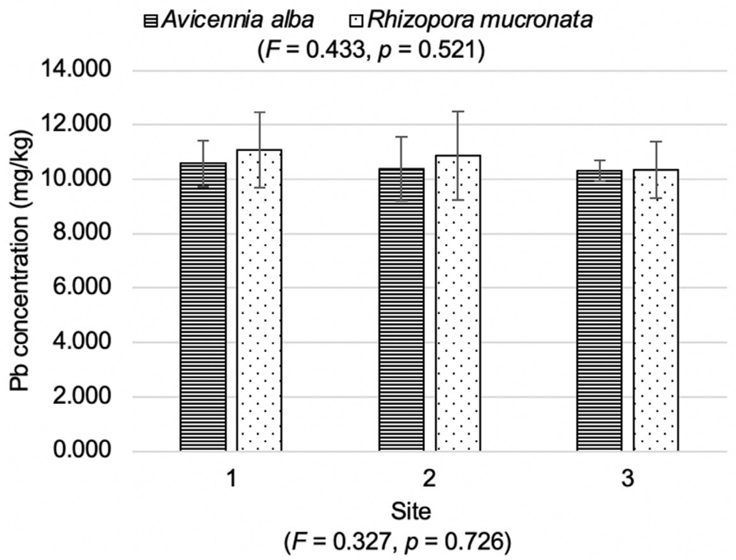

Figure 2. Pb concentration in sediment

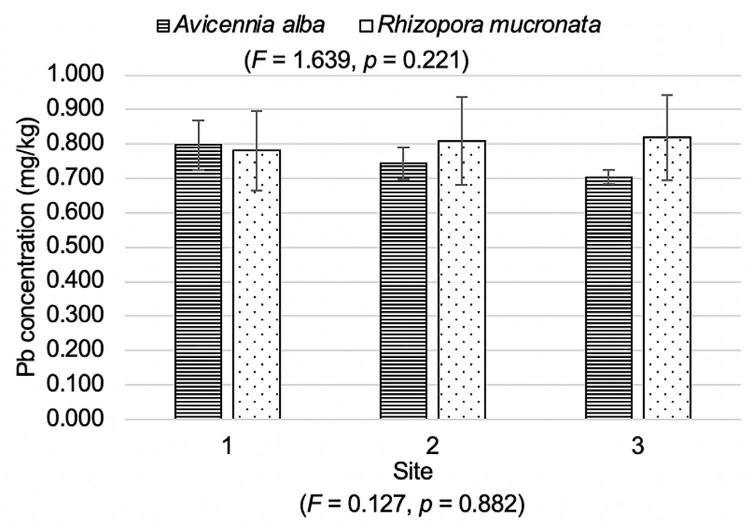

Figure 3. Pb concentration in roots

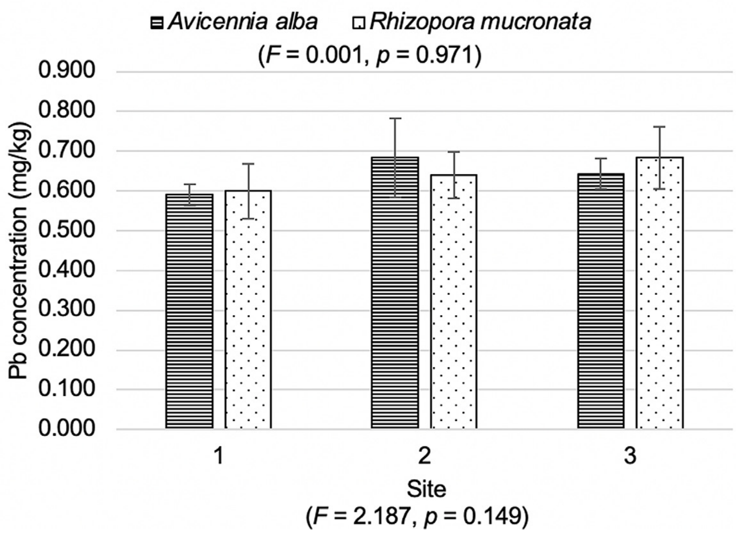

Figure 4. Pb concentration in stems

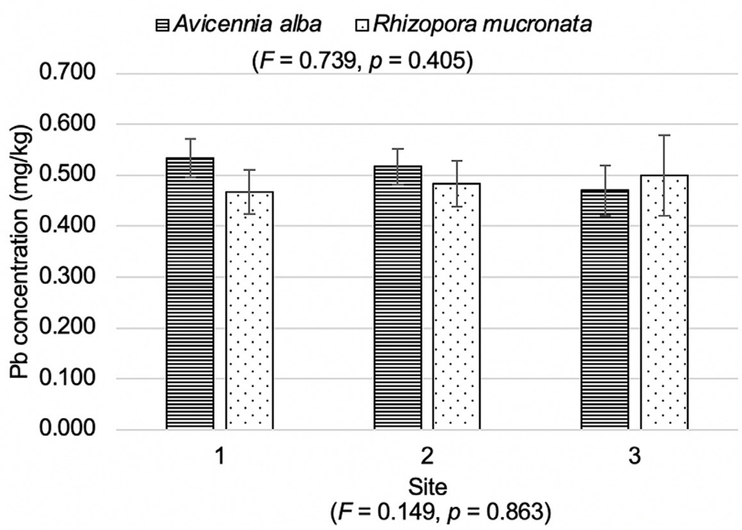

Figure 5. Pb concentration in leaves

relative to those in other mangrove taxa such as *Rhizophora* spp., *Avicennia* spp., and *Kandelia* spp. [Peters et al., 1997; Tam and Wong, 2000; MacFarlane and Burchett, 2002]. Moreover, a higher percentage of heavy metals is present in stems, compared to leaves [Yim and Tam, 1999]. The persistent deposition of heavy metals and the long-term filtration of heavy metals in mangrove plant roots will produce higher concentrations of heavy metals in roots, relative to sediments. More metals are collected in the roots than in the leaves, since the concentration of the leaves decreases with the leaf litter [Abohassan, 2013]. Furthermore, Pb has been reported to be selectively abundant in the bark, wood, and stems of mangroves, while zinc and copper are at their maximum concentrations in young leaves [Saenger and McConchie, 2004].

In the present study, the BCF values of *A. alba* and *R. mucronata* were below 0.1 (Table 1), which indicates that these species are potential low accumulators for Pb. Similarly, the BAC of stems and leaves was also less than 0.1. These mangrove species can thus be classified as excluders. Furthermore, the translocation factor (TF) of *A. alba* and *R. mucronata* ranged from 0.730 to 0.926, both in stems and leaves (Table 2). This finding suggests that *A. alba* and *R. mucronata* are not suitable for either phytoextraction or phytostabilization [Fitz and Wenzel, 2002].

Low BCFs of heavy metals in both roots and leaves are likely due to their low bioavailability in sediments. This may occur as the result of some emerging mechanisms in mangrove plants to prevent the absorption of toxic substances and to limit their transport within plant components

Table 1. BCF and BAC of *Avicennia alba* and *Rhizopora mucronata*

Site	*Avicennia alba*									*Rhizopora mucronata*								
	Roots (BCF)			Stems (BAC)			Leaves (BAC)			Roots (BCF)			Stems (BAC)			Leaves (BAC)		
1	0.076	±	0.013	0.056	±	0.002	0.051	±	0.006	0.071	±	0.01	0.054	±	0.003	0.043	±	0.005
2	0.073	±	0.013	0.066	±	0.003	0.050	±	0.006	0.075	±	0.01	0.059	±	0.007	0.045	±	0.006
3	0.068	±	0.003	0.062	±	0.004	0.046	±	0.004	0.079	±	0.01	0.066	±	0.007	0.049	±	0.008

Table 2. TF of *Avicennia alba* and *Rhizopora mucronata*

Site	*Avicennia alba*						*Rhizopora mucronata*					
	Stems			Leaves			Stems			Leaves		
1	0.746	±	0.095	0.906	±	0.092	0.773	±	0.090	0.783	±	0.058
2	0.926	±	0.181	0.768	±	0.131	0.797	±	0.066	0.756	±	0.015
3	0.914	±	0.028	0.735	±	0.119	0.838	±	0.053	0.730	±	0.045

[Almeida et al., 2006], especially by cell wall immobilization and/or epidermal sequestration layers [MacFarlane et al., 2007]. They therefore accumulate in perennial tissues, particularly roots [Zhou et al., 2011]. In order to reduce the adverse effects of the heavy metal toxicity and retention, plants have typically established biological detoxification processes, including avoidance, excretion, and retention. This makes mangrove plants weak accumulators of trace metals [Sruthi et al., 2017]. The accumulations occur at the root, with limited mobilization to the aerial part of the plant [Silva et al., 1990; Chiu and Chou, 1991; Lu et al., 2014]. The absorption of heavy metals into roots may occur by passive diffusion through the cell membrane, active transport to an opposite concentration, and/or electrochemical potential gradients passed by the carrier. The metal may also be transported within the cell along the concentration gradient across the cation channel of the membrane cell [Prasad et al., 2006].

The TF and BAC of *A. alba* tended to be higher than those of *R. mucronata*, while the opposite was true for BCF. However, the ANOVA results showed that the differences were not statistically significant across sites or species ($p > 0.05$). The previous research conducted in Wonorejo, Surabaya, revealed that *A. alba* was a potential phytoextractor agent of Pb. The metal mobility process for non-essential metals like Pb from roots to leaves is very high, as the metal is not used for metabolism. Thus, an attempt was made to localize heavy metals in certain parts of the plant so that they can be degraded or dissolved [Rachmawati et al., 2018]. On the other hand, as seen in the Kelantan Delta analysis, *R. mucronata* is capable of absorbing heavy metals and is tolerant to relatively high levels of heavy metal in the sediment. This tolerance might be the outcome of primarily unavailable metals in sediments in relation to the phase of exclusion in root tissue [Baruddin et al., 2017].

Pb is an extremely toxic element and a dangerous, non-biodegradable heavy metal that quickly accumulates in the human body [Abbas et al., 2016]. It affects the blood supply through the human body, the central nervous system, the liver, and the kidneys [Kamaruzzaman and Ong, 2009]. The awareness of the Pb accumulation is therefore vitally necessary for the use of fish for human consumption. Although the Pb bioavailability in the marine environment is poor, its constant bioaccumulation by aquatic organisms, especially fish, poses serious threats to the human health if these organisms are consumed [Yunus et al., 2020]. The Pb concentrations in *A. alba* and *R. mucronata* found in this study are lower than some previous related studies. The research on the Pb accumulation in *R. mucronata* parts (roots, stem, and leaves) at Muara Angke (Jakarta) reported the concentrations greater than 5 ppm in the rainy season, while during the dry season, the concentration was less than 3 ppm [Rumanta, 2019]. On the other hand, *A. alba* in Wonorejo, Surabaya, was observed to accumulate Pb at the concentrations of more than 50 ppm in sediment and above 20 ppm in the roots [Titah and Pratikno, 2020].

This result indicates that the Pb pollution in BJBR Mangrove Forest is minor compared to other coastal areas in Indonesia. This might be due to ecotourism management at this site that enables the control of pollution. BJBR Mangrove Forest has recently become a popular ecotourism destination. The main attraction of this site is the mangrove forest itself. Visitors can enjoy the mangrove scenery by walking along a bridge path that is built across the forest so that it does not disturb the mangrove trees. The manager has also initiated mangrove planting as another attraction. Its impact on the mangrove tree maintenance is to minimize direct waste into the mangrove area and improve the mangrove tree density. The high density of trees combined with a large number of pneumatophores has an effect on wave attenuation along the coast of the bay, which in turn alters the sediment movements through the trapping processes that alter the distribution of heavy metals [Abou Seedo et al., 2017].

CONCLUSIONS

The anthropogenic activities around BJBR Mangrove Forest may heighten the pollution from toxic metals such as Pb in this area, which is dominated by the *A. alba* and *R. mucronata* mangrove species. This research showed that the Pb found in the sediment of these species ranged from 10.323 to 11.071 ppm. These values can be classified as safe according to the CCME standard. Meanwhile, the Pb concentration in the mangrove parts was less than 1 ppm, with the order roots > stems > leaves. The statistical analysis indicated that there were no statistically significant differences in the Pb values across sites and species. The BCF, BAC, and TF values also suggested that neither mangrove species was suitable for phytoextraction or phytostabilization. Furthermore, compared to other mangrove areas in Indonesia, the Pb accumulations in this study were minor. This might be due to the ecotourism practices in this area that successfully control pollution levels as well as improve the mangrove tree density.

Acknowledgement

We would like to express our gratitude to Brawijaya University for providing funds for this research through the PNBP-UB fund in 2020 and the ecotourism management of BJBR Mangrove Forest for their help and cooperation during the research sampling.

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