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Menggali Potensi Mangrove Untuk Fitoremediasi Logam Berat di Kawasan Pantai: Kajian Cagar Alam Pulau Sempu

Exploring Mangrove Potential for Heavy Metal Phytoremediation Along Coastal Zones: A Study of Sempu Island Nature Reserve

Alfin Fatwa M Afifudin*[1], Rony Irawanto[2], and Hari Purnomo[3]

[1*]Biology, Faculty of Science and Technology, Universitas Airlangga, Indonesia.
[2]Research Center of Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Cibinong, Indonesia.
[3]Center for Natural Resources Conservation (BBKSDA) East Java, Surabaya, Indonesia

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Koresponding:
Alfin Fatwa M Afifudin, Biology, Faculty of Science and Technology, Universitas Airlangga, Indonesia

E-mail:
alfinfatwa@gmail.com

Abstrak

Cagar Alam Pulau Sempu (CASP) di Jawa Timur merupakan salah satu taman wisata alam di Indonesia. Di pulau ini, terdapat berbagai jenis vegetasi asli Indonesia, termasuk hutan bakau. Salah satu fungsi biologis tanaman bakau adalah sebagai tempat berlindung bagi spesies laut, pemecah gelombang, dan sebagai fitoremediasi untuk mencegah polusi air. Penelitian ini merupakan studi eksplorasi yang bertujuan untuk menemukan keanekaragaman jenis mangrove di Pulau Sempu dan mengevaluasi potensinya sebagai fitoremediasi logam berat menggunakan metode tinjauan pustaka. Eksplorasi dilakukan pada bulan Juli 2022 di tiga lokasi berbeda di Pulau Sempu, yaitu Teluk Semut, Teluk Ra'as, dan daerah Air Tawar. Hasil dari penelitian ini menunjukkan delapan spesies telah diidentifikasi sebagai jenis mangrove sejati, diantaranya meliputi: *Aegiceras corniculatum, Ceriops decandra, Exoecaria agallocha, Heritiera littoralis, Rhizophora apiculata, Rhizophora mucronata, Rhizophora stylosa,* dan *Xylocarpus granatum*. Mangrove tersebut berasal dari lima famili dan enam genus. Lebih lanjut, mangrove jenis *Ceriops decandra* memiliki status konservasi "Hampir Terancam". Penelitian ini juga mengungkapkan bahwa hutan bakau di Teluk Semut memiliki zonasi yang lebih baik dibandingkan dengan Teluk Ra'as dan daerah Air Tawar. Selain itu, hasil telaah pustaka menunjukkan bahwa semua jenis mangrove yang ditemukan memiliki potensi untuk meremediasi air yang tercemar logam berat, termasuk Cu, Zn, Pb, Hg, Cd, Mn, Fe, dan Cr..

Kata kunci: Cagar Alam Pulau Sempu, fitoremidiasi, logam berat, mangrove

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Abstract

Sempu Island Nature Reserve (CAPS) in East Java is one of the nature reserves in Indonesia. On this island, there are various native Indonesian vegetation, including mangroves. One of the biological functions of mangrove plants is as a shelter for marine species, wave breaker, and as a phytoremediator to prevent water pollution. This research is an exploratory study that aims to discover the diversity of mangrove species on Sempu Island and evaluate their potential as heavy metal phytoremediator using the literature review method. The exploration was conducted in July 2022 on three different locations on Sempu Island, which are Semut Bay, Ra'as Bay, and Freshwater area. In conclusion, eight species have been identified as true mangrove species in Sempu Island Nature Reserve, East Java. Such as *Aegiceras corniculatum, Ceriops decandra, Exoecaria agallocha, Heritiera littoralis, Rhizophora apiculate, Rhizophora mucronata, Rhizophora stylosa*, and *Xylocarpus granatum*, which originate from five families and six genera. Furthermore, *Ceriops decandra* has a conservation status of "Near Threatened." The study also revealed that the mangrove forest in Semut Bay offers better zonation compared to Ra'as Bay and Freshwater. Importantly, after conducting literature review, it shows that all mangrove species discovered have the potential to remediate waters polluted by heavy metals including Cu, Zn, Pb, Hg, Cd, Mn, Fe, and Cr.

Keywords: heavy metals, mangroves, phytoremediation, Sempu Island Nature Reserve

1. Introduction

Indonesia is one of the world's largest archipelagic countries. Indonesian Central Bureau of Statistics (*Badan Pusat Statistik/BPS*) revealed that Indonesia has 16,766 islands and 54,716 – kilometer coatline from Sabang to Merauke (BPS, 2021; Karimah, 2017). Furthermore, data from BPS shows that East Java Province has approximately 403 islands, making East Java as one of Indonesia's provinces that has the most islands. One of the islands in East Java is Sempu Island, located in Malang Regency. Currently, the status of Sempu Island is one of Nature Resource in Indonesia. Furthermore, Sempu Island has been declared as Nature Resource since Indonesia was colonized by the Dutch the Noter letter number 46 Stbld No. 69 that was issued on March 15, 1928. (Andriyono *et al*., 2016). The colonial government declared Sempu Island as a Nature Reserve because its rich and unique natural resources and biodiversity, which were scientifically has a high value. For instance, the mangrove forest ecosystem remains intact on this island, which is inhabited by various species of unique flora and fauna. The mangrove forest ecosystem on Sempu island is an important part of 4.2 million hectares that consists of 75 species in Indonesia (Rindyastuti *et al*., 2018; Widiawati *et al*., 2021), Therefore, it is essential to preserve mangrove forest ecosystem on the island.

Currently, the mangrove ecosystem on Sempu Island is undergoing deforestation and degradation. Ironically, the environmental degradation of coastal areas is a problem that is frequently confronted in Indonesia, as evidenced by the declining mangrove forest cover and the destruction of coral reef ecosystems (Sumanto, 2020). Whereas, mangrove forests ecologically have many functions including as protecting coastal from abrasion, wave barrier, and mitigator of seawater intrusion into the mainland (Irawanto, 2020). Mangrove forests also serve a habitat for several marine organisms, migratory habitat for several species of birds, and filter water pollution. Rindyastuti *et al*. (2018) revealed that mangrove plants are physiologically able to keep large volumes of water and are able to control, accumulate, and release salt effectively.

Several studies have revealed the potential of mangroves plant in remediating polluted waters, including total petroleum hydrocarbons (TPHs) (Moreira *et al*., 2011), polycyclic aromatic hydrocarbons (PAHs) (Verâne *et al*., 2020), and also heavy metals including Zn, Fe, Mn, Cu and Sr (Hilmi *et al*., 2022; Hossain *et al*., 2021). Heavy metals are released into estuaries and wetland waters as a result of the industry's rapid growth, thereby disrupting ecosystems (Ahmed *et al*., 2019; Liu and Su, 2015). Copper (Cu),

lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) are the types of heavy metal pollution that are currently prevalent in water (Afifudin and Irawanto, 2021). Due to the high level of heavy metal pollution in waters, especially estuaries, the ability of mangrove plants to overcome this problem is important. Thus, this study aims to analyze the diversity, conservation status, and the distribution zone of mangrove plants species on Sempu Island, and also analyzing their potential as heavy metal phytoremediators.

2. Materials and Methods

Study Area

This study is exploratory research conducted in the Sempu Island Nature Reserve, East Java. Data collection was conducted using line method, by recording all of species of mangrove plants found along the observation lines. In this study, the assessment of mangrove diversity was primarily based on the number of different mangrove species identified in the study area. For species identification purpose, each mangrove species found was photographed. The process of identifying mangrove species involved the guidance of field experts who provided their expertise and knowledge in the field. Additionally, plant identification and morphology books were utilized as references to further characterize and identify the specific mangrove species encountered during the study. (Harris and Harris, 2001; Tjitrosoepomo, 2020). Furthermore, the study was conducted on three different mangrove forest locations: Semut Bay (8º26'21.915"S – 112º40'57.972"E), Freshwater Area (8º26'4.833"S – 112º41'26.8728"E), and Ra'as Bay (8º26'0.3768"S – 112º41'27.5352"E) as show as Figure 1. The selection of the location is because in the previous research by Rindyastuti *et al*. (2018) stated that on Sempu Island there are only three areas that have mangroves forest, namely Semut bay, Ra'as Bay, and Freshwater area.

Furthermore, to define the zonation in this study was defined through a field survey approach, followed by the creation of maps or diagrams illustrating the different zones based on mangrove species distribution. The defined zones were further validated through additional field surveys, comparing the findings with the initial survey results. The criteria for considering an area as a zone of a specific mangrove type involved evaluating the dominance and relative abundance of the respective mangrove species within each zone.

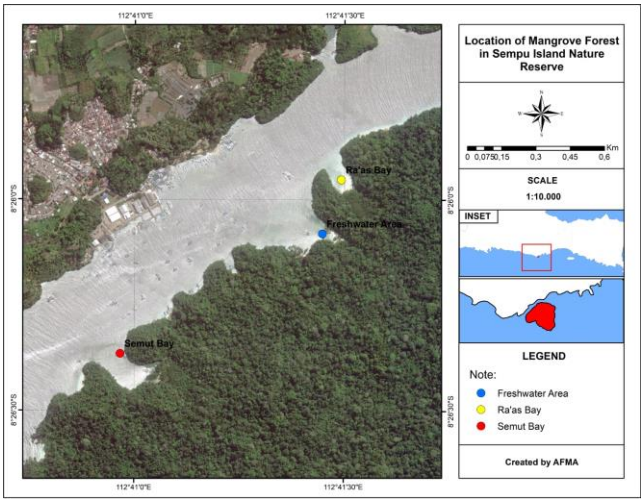

Figure 1. Mangroves forest in Sempu Island Nature Reserve

Analysis

Initially, the identification of mangrove plants was based on the reference book "The Botany of Mangroves." (Tomlison, 1986), then the identification results - the scientific names - were validated with an online database from the Plant of the World Online (POWO) website. Furthermore, the

conservation status of each mangrove species was established by referring to the International Union for Conservation of Nature (IUCN) website. Furthermore, the potential of mangroves as heavy metal remediation was investigated through a literature search conducted on various scientific platforms over the last ten years, including Google Scholar, ScienceDirect, and ResearchGate. Based on the articles found, the analysis of metal compounds in mangrove plants can be conducted using an Atomic Absorption Spectroscopy (AAS) instrument. The collected information was then compared and presented in the subsequent figures and tables. Descriptive analysis was performed to examine the data and derive insights into the diversity of mangroves and their effectiveness as heavy metal remediators.

3. Results and Discussion

Mangrove Diversity in Sempu Island

Based on their habitat, physiology, and ecology, mangrove could be classificated as true mangrove and associated mangrove. True mangroves are plants that only grow in the intertidal zone of the mangrove environment, while mangrove associates can grow in other habitats as well, such as littoral or terrestrial areas (Vijaya Kumar and Kumara, 2014). After conducting an exploration in the Sempu Island Nature Reserve, it was discovered that a total of eight “true” mangrove species are present in three observation areas (Table 1). Rhizophoraceae family found to has the highest number of mangrove species. Other families, such as Primulaceae, Euphorbiaceae, Malvaceae, and Meliaceae, are also present in small populations in Sempu Island Nature Reserve.

Table 1. List of Mangrove Plants in Sempu Island and Their Conservation Status

No	Species of Mangroves	Location	Local Name	Family	IUCN Status
1	*Aegiceras corniculatum*	Freshwater area	gedangan	Primulaceae	Least Concern
2	*Ceriops decandra*	Semut Bay & Freshwater are	tenggar	Rhizophoraceae	Near Threatened
3	*Excoecaria agallocha*	Ra’as Bay	kayu buta, buta-buta	Euphorbiaceae	Least Concern
4	*Heritiera littoralis*	Ra’as Bay	dungun laut	Malvaceae	Least Concern
5	*Rhizophora apiculata*	Semut Bay, Ra’as Bay, Freshwater area	bakau	Rhizophoraceae	Least Concern
6	*Rhizophora mucronata*	Semut Bay & Freshwater area	bakau hitam	Rhizophoraceae	Least Concern
7	*Rhizophora stylosa*	Freshwater area	bakau	Rhizophoraceae	Least Concern
8	*Xylocarpus granatum*	Semut Bay	nyirih, jombok gading	Meliaceae	Least Concern

Source: IUCN Red List of Threatened Species, (2023)

The mangrove forests area in Sempu Island Nature Reserve is relatively small than other low land forest in Sempu Island, it just only covering a total of 5000 m^2 or 0.5 hectares, and it is distributed across three locations: Semut Bay, Ra'as Bay, and the Freshwater area. Among these locations, Semut Bay has the largest mangrove forest area, spanning 1900 m^2, while Ra'as Bay and the Freshwater area cover 1500 m^2 and 1600 m^2, respectively. Semut Bay has a short coastline with

sloping central part that trigger brackish water to enter the area quickly. Rindyastuti *et al*. (2018) stated that Semut Bay belongs to the depositional coastal sub-aerial type. According to Marfai *et al*. (2013) this coastal type was formed by direct accumulation of river sedimentary materials, glacial, wind, or landslides towards the sea. Furthermore, the mangrove area in Semut Bay is located along the coastline and encompasses a moderately shallow section.

Based on Table 1 above, the types of mangroves found in Semut Bay are *Rhizophora apiculata, Rhizophora mucronata, Ceriops decandra,* and *Xylocarpus granatum*. In Ra'as Bay, the types of mangroves found are *Rhizophora apiculata, Exoecaria agallocha,* and *Heritiera littoralis*, belonging to Rhizophoraceae, Euphorbiaceae, and Malvaceae respectively. The freshwater area is dominated by the Rhizophoraceae family, with species like *Rhizophora apiculata, Rhizophora mucronata, Rhizophora stylosa*, and *Ceriops decandra*. Additionally, *Aegiceras corniculatum* was also found in this freshwater area. Based on the data, it shows that Ra'as Bay exhibits the highest diversity, with three different families of mangroves found in this location. Meanwhile, Semut Bay and the Freshwater area only contain mangroves from two families. As seen in Figure 1, Raas Bay has a curvilinear coastal morphology. This allows mangrove habitats in this area to be safer from erosion, making them more diverse than areas directly exposed to the sea (Rindyastuti *et al*., 2018).

The Table 1 also showed that eight mangroves on Sempu Island are listed in the IUCN red list. *Ceriops decandra* is listed as Near Threatened category. The species classified as Near Threatened when a taxon is assessed against certain criteria and doesn't meet the requirements for being Critically Endangered, Endangered, or Vulnerable currently, but is on the verge of meeting those requirements or is expected to meet them soon (*IUCN Red List of Threatened Species*, 2023). However, although the conservation status is categorized as Least Concern, the conservation of mangroves on Sempu Island is still important to avoid its extinction.

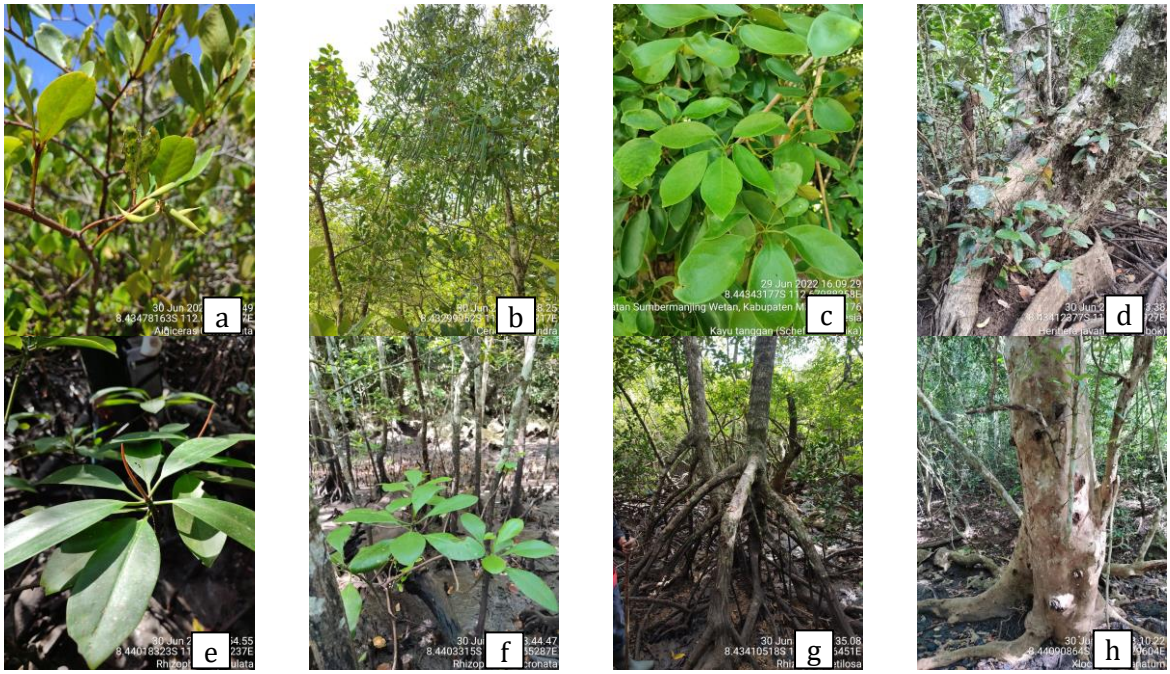

Figure 2. The types of mangroves plant in Sempu Island Nature Reserve. *Aegiceras corniculatum* (a), *Ceriops decandra* (b), *Exoecaria agallocha* (c), *Heritiera littoralis* (d), *Rhizophora apiculata* (e), *Rhizophora mucronata* (f), *Rhizophora stylosa* (g), *Xylocarpus granatum* (h).

Mangrove Zonation in Sempu Island Nature Reserve

Mangrove forests are typically classified into several zones: the fringing zone, intermediate zone, and landward zone. This classification is based on the dominant mangrove species present in each area. The fringing zone is the closest to the open sea, followed by the intermediate zone behind it, and the landward zone, which directly borders the mainland. After conducting an exploration of the mangrove forest on Sempu Island, it showed that in general, the fringing zone is occupied by Rhizophora species, while the intermediate zone is occupied by *Aegiceras corniculatum* and *Ceriops decandra,* and then followed by *Xylocarpus granatum, Excoecaria agallocha*, and *Heritiera littoralis* in the landward zone (Figure 3). This result was match with previus study by Sreelekshmi *et al*. (2018) that stated the foremost part of the mangrove ecosystem bordering the sea waters is usually dominated by *Sonneratia* sp., *Avicenna* sp., and *Rhizophora* sp.

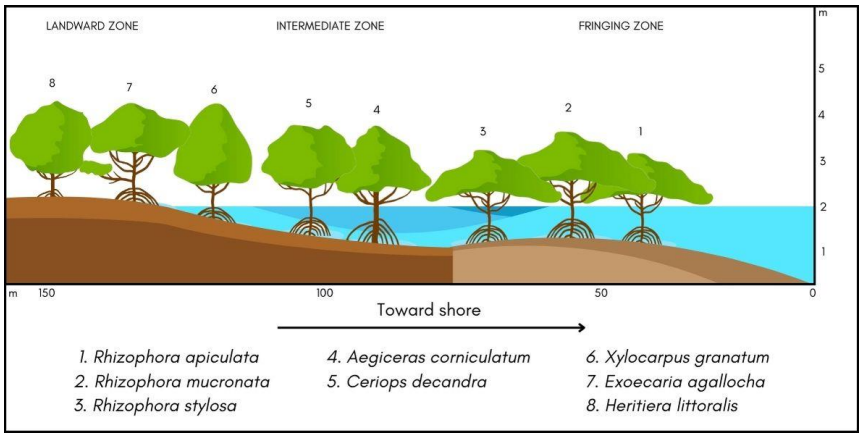

Figure 3. Mangrove zonation in Sempu Island

The composition and zonation of mangrove forests are generally determined by soil geography and the influence of rivers that transport sediment (Rindyastuti *et al*., 2018). Due to the absence of a river delta, the mangrove forest area on Sempu Island is relatively narrow and has not experienced expansion. According to Kartawinata (2013) in (Rindyastuti *et al*., 2018), the number of mangrove plants in Indonesia is 60 species, consisting of true mangroves and associated mangroves. Some mangrove forests in Indonesia that are classified as having high diversity are on Bawean Island, which has 12 types of true mangroves (Fikroh *et al*., 2021), Sampang Regency, Madura with 11 types (Rosadi *et al*., 2018), Maya Island District with ten types (Khairunnisa *et al*., 2020). Meanwhile, in Muara Gembong District, Bekasi is recorded to have seven types (Rahmasari *et al*., 2019). Mangunharjo Village, Tugu District, Semarang City, has six types of mangroves (Tefarani and Nana, 2019). Compared to several mangrove forests mentioned above, the mangrove diversity on Sempu Island is currently classified as moderate with eight types of mangroves. Based on this result, it suggests that Sempu Island has a moderate level of mangrove diversity in relation to other locations in Indonesia. Geographically, Sempu Island is located along the southern coast of Java, facing the Indian Ocean, where it experiences significant wave action that can disturb the structure and growth pattern of mangrove forests. (Jati and Pribadi, 2017).

Potential of Sempu Island Mangroves for Heavy Metals Phytoremediation

Mangroves are known for their exceptional ability in the removal of pollutants, including heavy metals. This is attributed to their prevalence in highly vulnerable areas, such as estuaries, which are susceptible to contamination (Afifudin *et al*., 2022). Consequently, mangrove plants present a viable and sustainable option for addressing water pollution. Their

efficacy in efficiently removing and accumulating heavy metals, combined with their diverse ecological functions, makes them valuable candidates for combating water pollution.

Table 2. Potential of Sempu Island Mangroves for Heavy Metals Phytoremediation

No	Types of Mangroves	Ability (mg/L)	Author/References
1	*Aegiceras corniculatum*	Cr: 113.66±13.42; Cd: 0.28±0.13; Cu: 34.95±9.90 Pb: 108.69±35.75; Zn: 37.90±6.00 and Fe: 13.51 to 15.44	(Huang *et al*., 2020; Sarker *et al*., 2015)
2	*Ceriops decandra*	Cu: 0.081±0.002; Zn: 0.130±0.0023; Hg: 0.0026±0.0001; Pb: 0.0011± 0.001; Cd: 0.006±0.0002	(Analuddin *et al*., 2017)
3	*Exoecaria agallocha*	Zn; 299.47 to 540.2; Cu: 98.59 to 159.8; Pb: 15.75 to 42.04 Mn: 0.57 to 1.49; Fe: 0.55 to 0.94	(Chakraborty *et al*., 2014; Chakrobarti *et al*., 2016)
4	*Heritiera littoralis*	Cu: 0.02-0.07; Mn: 0.23-3.16; Zn: 0.03-0.15; Fe: 0.53-1.37	(Chakrobarti *et al*., 2016)
5	*Rhizophora apiculata*	Cu: 0.07±0.002; Zn: 0.133±0.001; Hg: 0.0026±0.0001; Pb: 0.001±0.001 Cd:0.007±0.0001	(Analuddin *et al*., 2017)
6	*Rhizophora mucronata*	Cu: 18.02 to 19.96; Pb: 4.43 to 5.13; Cd: 0.07 to 0.85; Zn: 7.80 to 38.37	(Ganeshkumar *et al*., 2019; Yunasfi and Singh, 2019)
7	*Rhizophora stylosa*	Cu: 29.31 to 31.76; Pb: 5,17 to 5,43	(Yunasfi *et al*., 2021)
8	*Xylocarpus granatum*	Cu: 8.667±0.333; Zn: 0.223±0.002; Hg: 0.257±0.002; Pb: 8.330±0.019; Cd: 0.0125±0.001	(Analuddin *et al*., 2017)

According to various studies (Ouyang and Guo, 2016; Sodré *et al*., 2013; Tansel *et al*., 2013), mangroves have been widely recognized for their potential as a natural wastewater treatment system through a process called phytoremediation. The issue of pollution in mangrove estuaries, especially heavy metal contamination, has garnered significant global attention due to its detrimental impacts on ecosystems and human health. Several research has been conducted in recent years to investigate the concentration, distribution, sources, and fate of heavy metals in estuarine environment to minimize and remediate pollutants (Nguyen *et al*., 2020). Mangrove plants have the ability to accumulate metals in their tissues, as they uptake and store contaminants from the sediment, thereby providing a mechanism for immobilizing and removing pollutants. This characteristic has been extensively studied and proven to be an effective and practical approach for pollutant management (Pahalawattaarachchi *et al*., 2009).

Ganeshkumar *et al*., (2019) was revealed that *Rhizophora mucronata* is able to accumulate several heavy metals, namely 0.10-0.62 (Cd), 0.76-4.35 (Cu), 6.20-26.57 (Pb) and 1.75-61.67 (Zn) mg/kg. In addition, Chakrobarti *et al*. (2016) also reported that several mangrove species, included *Excoecaria agallocha, Avicennia officinalis, Sonneratia apetala* are able to accumulate heavy metals Fe (737) > Mn (151) > Sr (20.98) > Cu (16.12) > Zn (11.3) mg/kg in the roots. While Fe (598) > Mn (297) >Sr (21) > Cu (14.2) > Zn (12.6) mg/kg in the leaves. This study also stated that all the examined plants could be used as phytoextractors as

they have bioconcentration factors <1 and translocation factors >1. When the translocation factor (TF) score is greater than 1, it means that more heavy metal is distributed to the shoots than to the roots, but when the TF value is less than 1, it means that more heavy metal is distributed to the roots (Anisa, 2020). The translocation factor also determines plant defense mechanisms that restrict inorganic pollutants from roots to prevent trace element translocation to essential plant organs, particularly seeds. As it is typically the case with hyperaccumulators, TF>1 suggests that plants not only tolerate pollutants but also employ them in some way. In this study, *Rhizophora mucronata, Rhizophora apiculata, Rhizophora stylosa*, and *Xylocarpus granatum* exhibited translocation factors greater than 1 in the remediation of heavy metals, including Cd, Cu, Ni, Pb, and Zn. Consequently, TF >1 is a criterion for classifying species of suitable plants for phytoremediation (Afifudin and Irawanto, 2022; Antoniadis *et al*., 2017).

Overall, the implications of this research contribute to the understanding of the ecological significance of mangroves in Sempu Island Nature Reserve and their potential role in addressing water pollution challenges. The findings can guide conservation efforts, inform environmental management strategies, and advocate for the protection and restoration of mangrove habitats in the region.

4. Conclusion

Sempu Island Nature Reserve, East Java is habitat for eight true mangrove species. These are *Aegiceras corniculatum, Ceriops decandra, Exoecaria agallocha, Heritiera littoralis, Rhizophora apiculate, Rhizophora mucronata, Rhizophora stylosa*, and *Xylocarpus granatum*, which originate from five families and six genera. Of these, *Ceriops decandra* has a conservation status of "Near Threatened." The study also revealed that the mangrove forest in Ra'as Bay exhibits the highest diversity than other areas. Furthermore, the diversity of mangrove in Sempu Island could be classified as "moderate" based on a comparison with other mangrove forests in Indonesia. Importantly, all mangrove species discovered have the potential to remediate waters polluted by heavy metals including Cu, Zn, Pb, Hg, Cd, Mn, Fe, and Cr.

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Conflict of interest

Author declares no financial or commercial conflict of interest.

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