BIODIVERSITAS
Volume 24, Number 5, May 2023
Pages: 2927-2937

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240548

Adaptive pattern of mangrove species and the mangrove landscaping in the heavy metal polluted area of Eastern Segara Anakan Lagoon, Indonesia

ENDANG HILMI[1,♥], NORMAN ARIE PRAYOGO[1], TEUKU JUNAIDI[2], ARIF MAHDIANA[2], NABELA FIKRIYYA[2]

[1]Program Study of Aquatic Resources Management and Magister SDA Program, Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Banyumas 53122, Central Java, Indonesia. Tel.: +62-281-6596700, ♥email: dr.endanghilmi@gmail.com

[2]Aquatic Resources Management Program, Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Banyumas 53122, Central Java, Indonesia

Manuscript received: 25 March 2023. Revision accepted: 26 May 2023.

Abstract. *Hilmi E, Prayogo NA, Junaidi T, Mahdiana A, Fikriyya N. 2023. Adaptive pattern of mangrove species and the mangrove landscaping in the heavy metal polluted area of Eastern Segara Anakan Lagoon, Indonesia. Biodiversitas 24: 2927-2937.* The mangrove species have specific adaptations to exclude, accumulate, translocate, and exert heavy metal contaminants. Mangrove species' adaptation to Cadmium (Cd) and Zinc (Zn) pollution are shown by their ability to reduce the negative impact of Cd and Zn pollution. This research aimed to analyze the adaptive pattern and mangrove landscaping in Cd and Zn contaminant areas of Eastern Segara Anakan (E-SAL), Indonesia. Cd and Zn content in different tissues (stem, leaves, and root) of 15 mangrove species were analyzed using Atomic Absorption Spectrometric method. Adaptive pattern and mangrove landscaping were assessed using bioaccumulation factor (BAF) and translocation factor (TF). The results showed that the Cd accumulation varied between 0.0610-0.2300 ppm in the stem, 0.0140-0.0480 ppm in leaves, 0.1501-0.3100 ppm in roots, whereas Zn accumulation varied between 5.7781-37.3409 ppm in the stem, 2.3973-32.2859 ppm in leaves, 10.8380-35.842 ppm in roots. Relatively Cd and Zn accumulation was highest in root than other parts. BAF scores of Cd and Zn varied between 0.0111-0.1760 and 0.1936-0.9017, respectively. TF score of Cd and Zn varied between 0.0642-0.9414 and 0.3419-1.3057, respectively. Based on the adaptation pattern, the mangrove landscape showed that *Avicennia marina* (Forssk.) Vierh., *Rhizophora mucronata* Lam., and *Rhizophora apiculata* Blume were the best accumulator of Cd contaminants. At the same time, *A. marina, R. apiculata,* and *X. granatum* were the best accumulator of Zn contaminant. The conclusion explains that mangrove species significantly adapt to life and grow in Zn and Cd-polluted areas. Therefore, mangrove landscaping can be developed to reduce the impact of Zn and Cd pollution.

Keywords: Bioaccumulation, cadmium, and zinc, mangrove landscape, species adaptation, translocation factor

Abbreviations: SAL: Segara Anakan Lagoon, BAF: Bioacculation factor, TF: Translocation Factor, Cd: Cadmium, Zn: Zinc, Ac: *Aegiceras corniculatum,* Af: *Aegiceras floridum,* Am: *Avicennia marina,* Bg: *Bruguiera gymnoriza, Bs*: *Bruguiera sexanggula,* Ct: *Ceriops tagal,* Ea: *Excoecaria agallocha,* Ht: *Hibistus tiliaceus,* Ml: *Melaleuca leucadendra,* Nf: *Nypa fruticans,* Ra: *Rhizophora apiculata,* Rm: *Rhizoph ora mucronata,* Rs: *Rhizophora stylosa,* Rs: *Rhizophora stylosa, Sa*: *Sonneratia alba, Xg*: *Xylocarpus granatum*

INTRODUCTION

Mangrove plants are specific plant because it has specific habitat (Rindyastuti and Sancayaningsih 2018; Hilmi et al. 2022b; Sugiatmo et al. 2023), specific roots, leaves, and stem (de Almeida Duarte et al. 2017; Hilmi et al. 2021a, 2022b; Zhang et al. 2021b), specific metabolism (Leopold et al. 2013; Hilmi et al. 2017b, 2018; Jiang et al. 2017) and specific environment (Xiong et al. 2018; Khadim et al. 2019; Hilmi et al. 2021c, 2022b). These characteristics make mangroves adaptive to heavy metals polluted environments (Syakti et al. 2013; Kibria et al. 2016; Hilmi et al. 2017c; Analuddin et al. 2017; Zhang et al. 2019; Costa-Böddeker et al. 2020; Shi et al. 2020).

Heavy metals become a severe pollutant in various ecosystems, including mangrove ecosystems (Kibria et al. 2016; Costa-Böddeker et al. 2020). Cadmium (Cd) and Zinc (Zn) are among the heavy metal pollutants found in mangrove ecosystems (Analuddin et al. 2017; Liu et al. 2020b). Cd is produced by the coal loading and cement industry (Kibria et al. 2016; El-Amier et al. 2017; Ortega et al. 2017; Analuddin et al. 2017; Zhang et al. 2019; Costa-Böddeker et al. 2020). Cd, especially cadmium oxide, has soft, silver, and shiny white characteristics, is easy to react with, melting at 321°C and boiling points (67°C), and is insoluble. In contrast, Zinc (Zn) is an essential heavy metal used to support organisms developing, growing, and living. Zn also supports hemocyanin production in enzymatic and blood systems (Zhang et al. 2019; Mapenzi et al. 2020).

Heavy metal pollution, including Cd and Zn, give a high threat to an organism to life and growth (Robson et al. 2014; Berg et al. 2015; de Almeida Duarte et al. 2017; Lei et al. 2019; Marambio et al. 2020; Shi et al. 2020). For example, the negative impact of Zn and Cd pollution on mangrove plants are firstly leaves and litterfall, yellowing leaves, stunted growth, roots rot, and mangrove death (Robson et al. 2014; Kibria et al. 2016; Hilmi et al. 2017c;

de Almeida Duarte et al. 2017; Alzahrani et al. 2018; Shi et al. 2020; Yang et al. 2020).

Mangrove vegetation is predicted to have an adaptation pattern to minimize the impact of heavy metal pollution (Yunus et al. 2011), including Zn and Cd pollution. Previous studies reported that mangrove species have a specific pattern to adapt to Cd and Zn-polluted habitats through bioaccumulation and translocation activities (Hilmi et al. 2017c; Nadgórska-Socha et al. 2017; Shi et al. 2020; Jeong et al. 2021). The bioaccumulation index can estimate the adaptation capability of mangrove species to reduce negative impact. The index indicates the absorption, accumulation, and utilization of Cd and Zn from the environment (Xiao et al. 2015; Nour et al. 2019; Ma et al. 2019; Shi et al. 2020; Zhang et al. 2019). The negative impact of Cd and Zn is also reduced through dilution and translocation activities to dead organs. This ability makes mangroves live and grow in area heavily polluted by heavy metals pollution (Alzahrani et al. 2018; Li et al. 2020).

The adaptive species accumulated are essential to reduce Cd and Zn contaminant areas in a particular lagoon, including Segara Anakan Lagoon. The mangroves' capability to reduce the negative impact of Cd and Zn pollution can be used for clustering and landscaping the mangrove ecosystem. The clustering of mangrove species adaptive to heavy metal accumulation is constructed by the dissimilarity method of Cd and zinc accumulation using the hierarchal system with Euclidian distance (Hilmi et al. 2021b, 2021c, 2022c). Whereas the adaptive species to live, grow and reduce the impact of heavy metal contaminants, coastal disasters, and environmental services can be used for mangrove landscaping and zonation (Kibria et al. 2016; Hilmi 2018, 2021a; Cao et al. 2020; Zhang et al. 2021a). However, currently, there is no data on mangrove species that can adapt to various concentrations of Cd and Zn pollution in Segara Anakan Lagoon. The data are essential for mangrove landscaping in the Segara Anakan.

MATERIALS AND METHODS

Research site

This study was conducted in Eastern Segara Anakan (E-SAL), Cilacap District, Central Java, Indonesia where Cd and Zn containments exist (Hilmi et al. 2021d) in June - July 2021 and January-March 2022. The research activities area is illustrated in Figure 1 and Table 1. The mangrove ecosystem is essential in Segara Anakan Lagoon, dominated by *Rhizophora* spp., *Bruguiera* spp., *Sonneratia* spp., *Ceriops* spp., *Aegiceras* spp., *Nypa fruticans* Wurmb, *Avicennia* spp. (Hilmi et al. 2021a, 2022b).

Table 1. Research area and stations in Eastern Segara Anakan (E-SAL), Cilacap District, Central Java, Indonesia

Research stations	The coordinates	
	Latitude (South)	Longitude(East)
Kalipanas River	07°42'36,60"	108°59'43,91"
The Sleko Port	07°43'17,11"	108°59'31,00"
Pertamina Area	07°41'48,64"	108°59'34,98"
Cement Plant	07°40'59,81"	109°00'40,35"
East Pelawangan	07°43'40.87"	108°59'03.31"

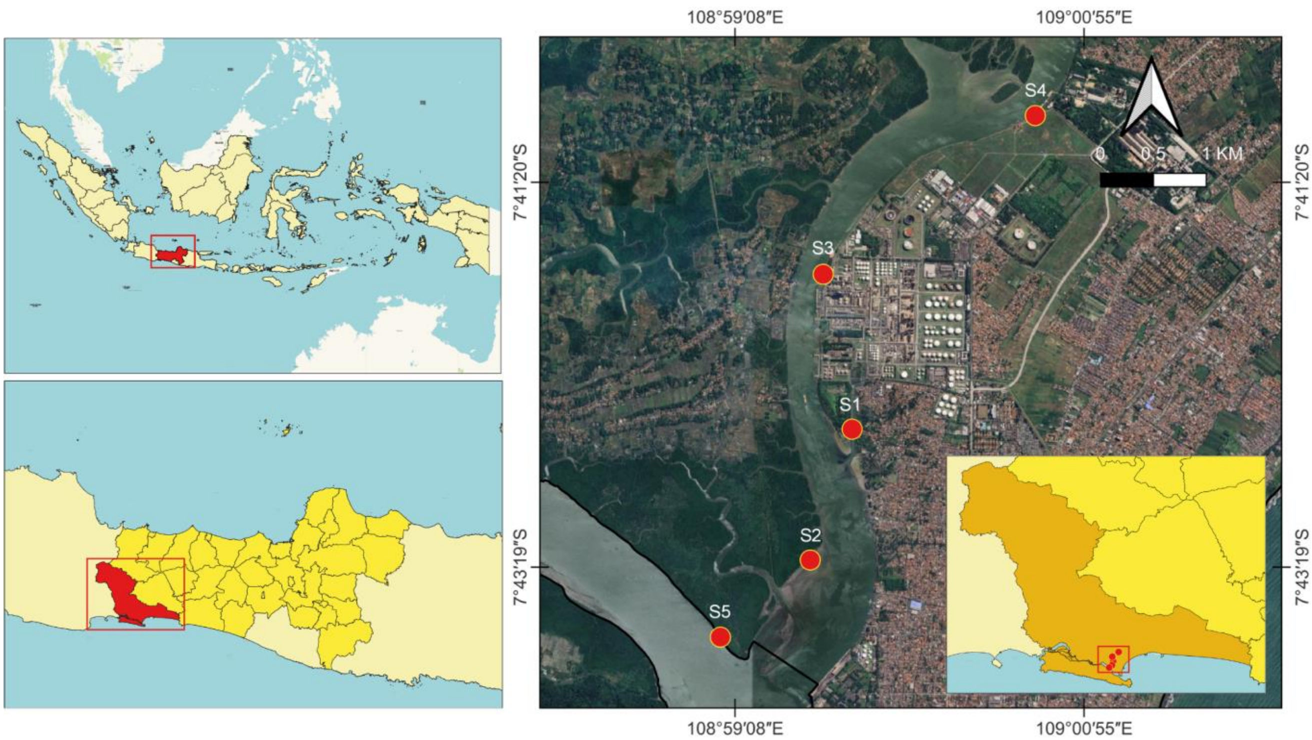

Figure 1. Map showing the study stations in Eastern Segara Anakan (E-SAL), Cilacap District, Central Java, Indonesia

The sampling site to analyze mangrove species' adaptation to reduce the impact of Cd and Zn contaminant was conducted in five stations (Station 1-Kalipanas River, Station 2-the Sleko Port, Station 3-Pertamina Area, Station 4-the Cement Plant, and Station 5-East Pelawangan). The adaptation of mangrove species to live and grow using the activity of Cd and Zn reduction had sampling plots in sediment, and water bodies (15 sampling plots were divided into 5 stations) and sampling plots in vegetations (mangrove roots, mangrove barks, mangrove stems, and mangrove leaves) had 225 vegetation samples from 15 mangrove species following the standard sampling collection system (Monteiro et al. 2014; Xiong et al. 2018)

Research procedure

Research variables

The research variables to analyze mangrove species adaption to reduce the impact of cadmium and zinc pollutions were: (i) cadmium and zinc accumulation for each mangrove species both in mangrove stem, leaves, and roots, (ii) Bioaccumulation and translocation factors of cadmium and zinc contaminant, (iii) mangrove clustering based on the ability of mangrove species to live and grow in Cd and Zn contaminants, (iv) the species mangrove landscape to live and grow in cadmium and zinc contaminant area.

Cd estimation

The analysis of cadmium accumulation in mangrove vegetation, both in leaves, stem-bark, and roots used the Flame of Atomic Absorption Spectrometric method with a precision level was 2×10^{-4} ppm. The filtrate extracted from cadmium will be sucked in using a 20 ml respirator tube, then put into a nebulizer, followed by fogging and evaporation activities. The steam formed from the filtration analysis will be burned with an open flame and the atomization process, then irradiated with cathode rays with a wavelength of about 228.8 nm and 10 mA. The result is the detector will capture the absorption of light. Then the absorbance value of the sample is analyzed, and the standard solution used will appear on the AAS screen through line equation analysis (SNI 2009)

Zn estimation

The analysis of zinc accumulation was carried out using the Spectrophotometric method (Shimatsu brand with an accuracy of 2x10-4 ppm). The study of zinc accumulation began with the extraction of the filtrate from samples of leaves, stem-bark, and roots of mangroves that had been reduced beforehand by mixing 10 mL H2SO4, 2 mL 2% $KMnO_4$, 1 mL $K2S_2O_8$ with 1 mL stannous chloride ($SnCl_2$) 10%. After mixing, extraction activities will be carried out using tetra dithizone liquid. This activity aimed to convert: $Zn^{2+} + SnCl_2 \rightarrow ZnO$ into cold steam using a Zn detector analyzer (SNI 2009)

Data analysis

Bioaccumulation and translocation factors

The analysis of bioaccumulating activity and translocation of cadmium and zinc was determined using the standard deviation and mean values of the bioaccumulation factor (BAF) and translocation factor (TF). BAF and TF scores of cadmium and zinc were analyzed by Equation (Syakti et al. 2013; Hilmi et al. 2017c; Lin et al. 2021).

$$\text{BAF} = \frac{\text{Zinc and cadmium accumulation by mangrove organs } (\text{mg } kg^{-1})}{\text{Zinc and cadmium accumulation by mangrove soil } (\text{mg } kg^{-1})}$$

$$\text{TF} = \frac{\text{Zinc and cadmium accumulation by mangrove organs } (\text{mg } kg^{-1})}{\text{zinc and cadmium accumulation by mangrove roots } (\text{mg } kg^{-1})}$$

Bioaccumulation Factor (BAF) categories refer to (Hilmi et al. 2017c; Marambio et al. 2020): (i) BAF≤1 refers to vegetation less or unable to accumulate Cd and Zn pollution, (ii) BAF>1 refers to vegetation able to accumulate Cd and Zn pollution.

Translocation *Factor* (TF) categories also refer to (Hilmi et al. 2017c; Analuddin et al. 2017; Chai et al. 2020; Marambio et al. 2020): (i) TF≤1 represents vegetation less or unable to translocate Cd and Zn pollution in other organs, (ii) TF>1 refers to vegetation that can translocate Cd and Zn pollution in other organs.

Clustering system

The cluster analysis of cadmium and zinc accumulation used the Euclidian distance analysis following mangrove species' dissimilarity and similarity pattern to accumulate zinc and cadmium (Hilmi et al. 2021b; 2021c).

Stage 1.

$$ED_{jk} = \sqrt{\sum_{i=1}^{s}(xij - xik)^2}$$

Stage 2.

$$D\,(j,k)h = \alpha_1\, D(j,h) + \alpha_2\, D(k,h) + \beta\, D(j,k)$$

Where:

Ed*jk* : Euclidean Distance of cadmium and zinc accumulation

i : mangrove species

X*ij* : potential accumulation in the station- *j*

X*ik* : potential accumulation in the station- *k*

D : Distance

α1 : 0,625

α2 : 0,625

β : - 0, 25

Mangrove landscaping

A mangrove landscape and zonation were developed by the Cd and Zn accumulation ability of mangrove species of mangrove barks, mangrove stems, mangrove roots, and mangrove leaves. This potential accumulation also refers to the potential of BAF, TF Cd, and Zn contaminants in the mangrove ecosystem.

RESULTS AND DISCUSSION

The adaptive mangrove species using the ability of Cd and Zn accumulation

The adaptive mangrove species to live and grow in a polluted area was determined using the Cd and Zn accumulation indicator, as shown in Table 2**.** The data showed the potential for cadmium accumulation in mangrove vegetation. The accumulation values in the stem were between 0.0610-0.2650 ppm, mangrove leaves between 0.0140-0.0480 ppm, and mangrove roots between 0.1501-0.3100 ppm. Furthermore, the potential of zinc accumulation in mangrove vegetation, including mangrove stem, was between 5.77 and 37.34 ppm, mangrove leaves between 5.78-26.20 ppm, and mangrove roots between 10.84-35.88 ppm. The best mangrove species to accumulate Cd are *A. marina, Melaleuca leucadendra* (L.) L. and *N. fruticans* (mangrove stem), *Excoecaria agallocha* L., *Sonneratia alba* Sm., *Xylocarpus granatum* J.Koenig (mangrove leaves) and *Avicennia alba* Blume and *S. alb*a (mangrove roots); whereas the best mangrove species to accumulate Zn were *Avicennia alba* and *M. leucadendra* (mangrove stem), *A. alba* and *M. leucadendra* (mangrove leaves), and *A. alba, S. alba* and *N. fruticans* (mangrove roots).

The ability of mangrove species to accumulate Cd and Zn is influenced by the potential of the accumulation gland, secretion gland, and excretion gland following the activity of nutrient and water uptake (Kumbier et al. 2021; Lin et al. 2021; Hilmi et al. 2022b). Analuddin et al. 2017 have reported the role of mangrove species as a biofilter of heavy metals, including Cd and Zn; which includes *R. apiculata, C. tagal, B. gymnorrhiza, L. racemosa, X. granatum, S. alba,* and *B. parviflora* have the accumulation activity of Cd (10.81 μg g^{-1}) and Zn (70.41 μg g^{-1}). The accumulation ability is influenced by the different partitioning and uptake capabilities of Cd and Zn in the tissues of mangrove species.

Therefore, based on the potential of Cd and Zn in the coastal area was similar to a previous study by (Nour et al. 2019); that revealed the accumulated concentrations of heavy metal were Fe > Sr > Mn > Zn > Ni > Pb > Cu > Co > Cd in sediments that are highly enriched and contaminated with Sr, Cd, Pb, and Zn. Therefore, the potential sources in sediment and water influence the potential of cadmium and zinc accumulation in mangrove species (Kibria et al. 2016; Choi et al. 2020; Mapenzi et al. 2020).

Table 2. The adaptation of mangrove species using the ability to accumulate zinc and cadmium contaminant

Mangrove species	Tree parts			Total	
	Stem	Leaves	Root	Max	Min
Accumulation of Cd contaminant (ppm)					
Aegiceras corniculatum	0.0920-0.1070	0.0180-0.0210	0.2001-0.2005	0.09882	0.10850
Aegiceras floridum	0.0610-0.0670	0.0170-0.0180	0.1501-0.2005	0.07002	0.08390
Avicennia marina	0.1360-0.1800	0.0140-0.0330	0.1670-0.2270	0.11780	0.16000
Bruguiera gymnorrhiza	0.0810-0.0890	0.0200-0.0330	0.1700-0.2024	0.08660	0.10048
Bruguiera sexangula	0.0810-0.0860	0.0170-0.0190	0.1710-0.2024	0.08620	0.09588
Ceriops tagal	0.0710-0.0790	0.0220-0.0230	0.1670-0.2008	0.08040	0.09216
Excoecaria agallocha	0.1030-0.1040	0.0440-0.0480	0.1700-0.2039	0.10460	0.11278
Hibistus tiliaceus	0.0810-0.0880	0.0110-0.0130	0.1705-0.2040	0.08490	0.09620
Melaluca leucadendron	0.1350-0.1450	0.0200-0.0300	0.1710-0.2040	0.11920	0.13380
Nypa fruticans	0.1350-0.1440	0.0210-0.0300	0.1707-0.2080	0.11934	0.13400
Rhizophora apiculata	01270-0.2650	0.0180-0.0330	0.1560-0.3100	0.11100	0.22760
Rhizophora mucronata	0.0930-0.2300	0.0170-0.0410	0.1660-0.1870	0.09240	0.18360
Rhizophora stylosa	0.0930-0.0940	0.0200-0.0210	0.1900-0.2024	0.09780	0.10108
Sonneratia alba	0.1200-0.1300	0.0220-0.0320	0.2010-0.2080	0.11660	0.12600
Xylocarpus granatum	0.1250-0.1270	0.0230-0.0250	0.1850-0.1950	0.11660	0.12020
Accumulation of Zn contaminant (ppm)					
Aegiceras corniculatum	12.3523-25.0397	7.2533-19.9407	16.3238-29.0111	12.1268	24.8142
Aegiceras floridum	11.9205-23.7295	7.3155-19.1245	16.3255-28.1345	11.8805	23.6895
Avicennia marina	22.0834-28.9876	13.7604-20.6646	28.9767-35.8808	21.7975	28.7016
Bruguiera gymnorrhiza	12.0446-21.0554	5.7296-14.7404	17.5288-26.5396	11.8784	20.8892
Bruguiera sexangul.	13.0366-25.5234	7.7766-20.2634	15.7908-28.2776	12.5354	25.0222
Ceriops tagal	18.7616-24.0984	11.6566-16.9934	17.5926-22.9294	17.1068	22.4436
Excoecaria agallocha	8.7827-24.0213	2.8357-18.0743	15.5149-30.7535	8.9397	24.1783
Hibistus tiliaceus	17.5303-25.1497	7.0803-14.6997	18.2245-25.8439	15.5791	23.1985
Melaluca leucadendron	24.4074-29.9706	20.6334-26.1966	19.2526-24.8158	22.6216	28.1848
Nypa fruticans	5.7781-14.8719	2.5731-11.6669	25.6514-34.7452	9.1118	18.2056
Rhizophora apiculata	7.6815-32.6860	2.3973-27.4017	10.8380-35.8425	7.2560	32.2604
Rhizophora mucronata	14.3621-22.5059	9.2331-17.3769	17.9731-26.1169	14.0585	22.2023
Rhizophora stylosa	17.7381-26.5219	12.8731-21.6569	17.6423-26.4261	16.7459	25.5297
Sonneratia alba	13.0337-21.5633	8.2402-16.7698	25.9335-34.4632	14.6550	23.1846
Xylocarpus granatum	19.0391-37.3409	13.9841-32.2859	12.4390-30.7409	16.7081	35.0099

The data also showed the distribution of adaptive mangroves to accumulate cadmium and zinc (Figure 2). Figure 2 showed that the average cadmium accumulation was between 0.095-0.138 ppm and the standard deviation between 0.079-0.101 ppm. On the other hand, the average zinc accumulation in the mangrove ecosystem is between 15.88-25.06 ppm, more than the standard deviation between 2.78-12.05 ppm.

The distribution of mangrove species to live and grow in heavy metal pollution are influenced by species' ability and relationship (Jiang et al. 2017; Kumbier et al. 2021), the ability to absorb nutrient and water (Karl and Church 2017; Alzahrani et al. 2018), ability to reduce, accumulate, exclude and secrete heavy metal (Dai et al. 2017; Zhang et al. 2019; Costa-Böddeker et al. 2020). The distribution of mangrove ability in Figure 2 showed that *R. mucronata, S. alba, H. tiliaceus, E.agallocha* had good stability and adaptive to live in the cadmium-polluted area, and *A. marina, C. tagal, E. agallocha, and S. alba* had good stability and adaptive to live in zinc polluted-area.

The estimation of adaptive mangrove species using the BAF and TF indicators of Cd and Zn accumulation

The adaptive mangrove species was estimated using the BAF and TF indicators of Cd and Zn accumulation, showing the ability of mangrove species to accumulate, absorb and translocate cadmium and zinc contaminants in mangrove stem-bark, leaves and roots. The BAF will be calculated using the value of Cd and Zn in soil. The value of Cd and Zn in the water and soil ecosystem is shown in Table 3. The potential for Cd and Znpollution shows that the Peramina area (petroleum industry) is the highest source of cadmium pollution, while the cement industry is the highest source of zinc pollution.

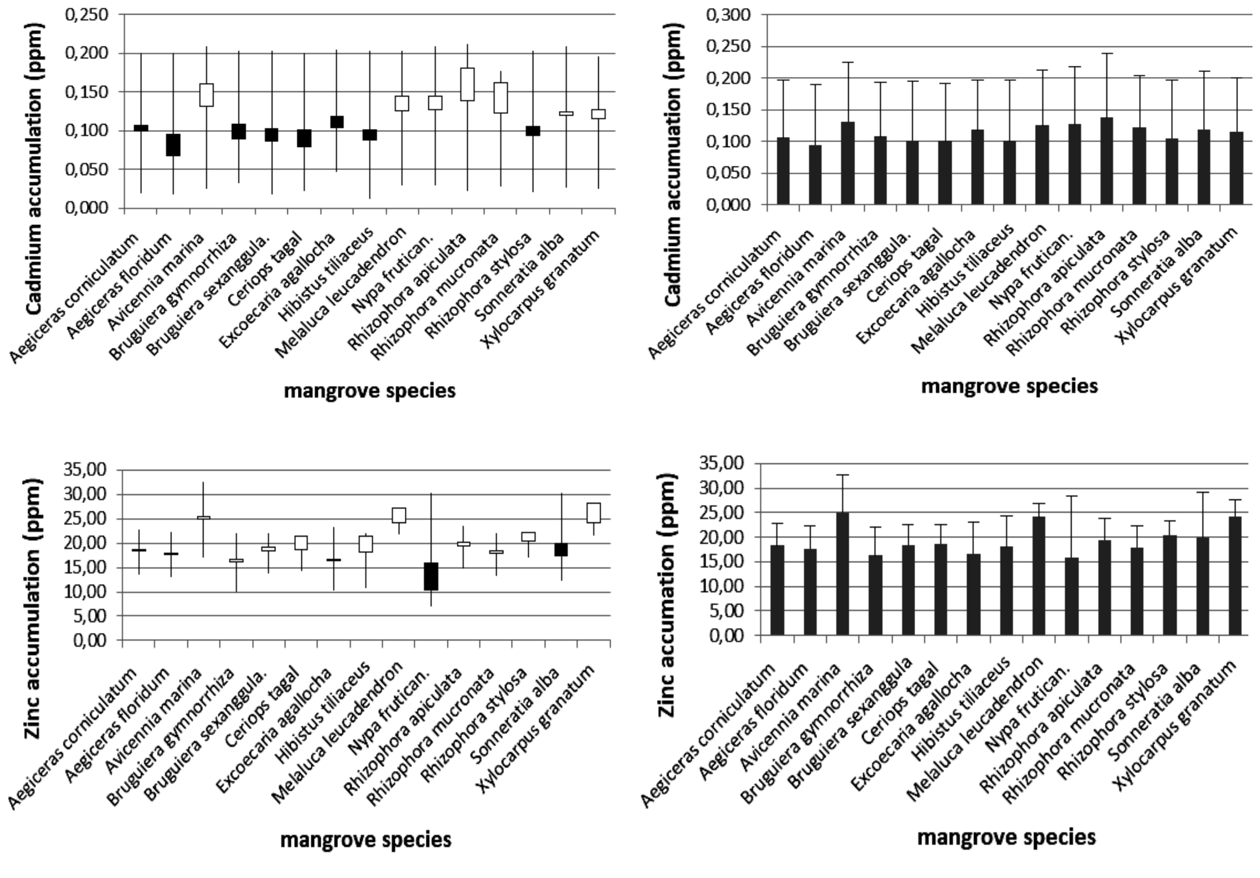

Figure 2. The data distribution of adaptive mangroves accumulate zinc and cadmium contaminant

Table 3. The value of Cd and Zn in water and soil ecosystem (ppm)

Research stations	Cd				Zn			
	Sediment		Water		Sediment		Water	
	Average	Stdev	Average	Stdev	Average	Stdev	Average	Stdev
Kalipanas River	1.37	0.0208	0.035	0.00100	36.21	0.5205	0.059	0.00843
The Sleko Port	1.62	0.0031	0.029	0.00121	31.59	0.3647	0.067	0.00957
Pertamina area	**2.01**	0.0061	0.022	0.00100	35.81	0.7106	0.041	0.00586
Cement plant	1.87	0.0208	0.031	0.00125	**43.48**	0.2081	0.053	0.00757
East Pelawangan	1.13	0.0101	0.019	0.00098	28.36	0.1992	0.039	0.00557

The score of BAF and TF as an indicator of Cd and Zn accumulation are shown in Table 4 and Table 5. The BAF Score of Cadmium contaminant in mangrove vegetation had potency between 0.0412-0.1138 (mangrove stem), 0.0101-0.0356 (mangrove leaves), and 0.1071-0.1743 (mangrove roots). The BAF score of Zinc contaminant in mangrove vegetation was between 0.2807-0.7392 (mangrove stem), 0.1936-0.6366 (mangrove leaves), and 0.5075-0.9017 (mangrove roots). The TF Score of the Cadmium contaminant was between 0.3342-0.9414 (mangrove stem) and 0.0642-0.2354 (mangrove leaves). The TF score of zinc contaminant was between 0.3419-1.3057 (mangrove stem) and 0.2358-1.0716 (mangrove leaves). The data shows that mangrove species have BAF <1 (relatively lower BAF values), which indicates that accumulation in mangroves is less than accumulation in their habitat. This is one of the adaptation techniques of mangrove species to live and grow in areas polluted with Cd and Zn. On the other hand, the translocation factor shows that the translocation activity from root to stem is greater than the translocation activity from root to leaf. However, the range of translocation showed typical translocation activity between tissues. The translocation mobility of Cd and Zn elements in stems was higher than that in leaves, indicating the high activity of stem tissues.

However, regarding pollution risk reduction, mangrove ecosystems play important role in absorbing, accumulating, and neutralizing pollutants, including heavy metals Cd and Zn. Mangrove ecosystems have a variety of species that have different abilities to reduce pollution. Although the BAF value is <1, within the ecosystem, mangroves still play an important role in reducing the risk of Cd and Zn heavy metal pollution.

Based on the distribution of mangrove species showed that the best mangrove species using the BAF score of cadmium contaminant in mangrove stem were *R. mucronata* and *R. apiculata*, in mangrove leaves, were *E. agallocha* and *B. gymnorrhiza,* in mangrove roots, were *C. tagal* and *H. tiliaceus*. The BAF score of zinc contaminant in mangrove stem was dominated by *X. granatum* and *C. tagal*. In mangrove leaves were *R. stylosa* and *X. granatum,* and in mangrove roots were *A. marina* and *S. alba*. Whereas the TF score of cadmium contaminant in mangrove stem was dominant by *R. mucronata* and *R. apiculata*, and in mangrove leaves were *R. mucronata* and *B. gymnorrhiza*. And the TF score of Zinc contaminant in mangrove stem was dominated by *X. granatum* and *M. leucadendra*, and in mangrove leaves were *X. granatum* and *M. leucadendra.*

Another study showed that the Cd bioaccumulation factor in mangrove leaves (0.39) was greater than that in mangrove roots (0.23) (Analuddin et al. 2017; Alzahrani et al. 2018) with different average BAFs in mangrove leaves and roots. Other data also show that mangroves have different TF capabilities. For example, some data showed that TF Cd (2.72) > Cu (1.74) > Ni (1.42) > Pb (1.29) > Cr (0.90) (Analuddin et al. 2017; Alzahrani et al. 2018). A TF value greater than 1 means a high ability to translocate cadmium and zinc pollution in other organs (Analuddin et al. 2017; Alzahrani et al. 2018). The TF and BAF of heavy metals in mangrove species have a variety of trends, which indicate the different partitioning and heavy metal uptake in the tissues of various mangrove species (Analuddin et al. 2017; Alzahrani et al. 2018). The bioaccumulation and translocation of heavy metals are influenced by the water quality, physicochemical properties, organic matter, consumes oxygen, the activity of decomposition, accumulation, absorption, and secretion activity in the gland of mangrove (Kibria et al. 2016; Analuddin et al. 2017; Yang et al. 2020).

Table 4. The BAF Cd and Zn contaminants in mangrove species

Mangrove species	BAF											
	Cd						Zn					
	Stem	Stdev	Leaves	Stdev	Root	Stdev	Stem	Stdev	Leaves	Stdev	Root	Stdev
A. corniculatum	0.0566	0.0001	0.0111	0.0001	0.1147	0.0122	0.5297	0.2531	0.3892	0.2184	0.6240	0.1434
A. floridum	0.0412	0.0109	0.0111	0.0001	0.1234	0.0122	0.5699	0.1550	0.4226	0.1329	0.7254	0.1434
A. marina	0.0959	0.0204	0.0150	0.0033	0.1216	0.0063	0.7114	0.2362	0.4908	0.2733	**0.9017**	0.2492
B. gymnoriza	0.0659	0.0144	**0.0244**	0.0102	**0.1499**	0.0303	0.4500	0.0041	0.2783	0.0316	0.5991	0.0647
B. sexangula	0.0455	0.0056	0.0101	0.0098	0.1071	0.0103	0.4441	0.0159	0.3229	0.0116	0.5075	0.0447
C. tagal	0.0687	0.0164	0.0200	0.0070	**0.1743**	0.0475	**0.7319**	0.2035	0.4892	0.1176	0.7749	0.1891
E. agallocha	0.0770	0.0059	**0.0356**	0.0110	0.1510	0.0165	0.4459	0.2022	0.2843	0.1449	0.6290	0.1032
H. tiliaceus	0.0765	0.0004	0.0113	0.0171	0.1760	0.0177	0.7288	0.2000	0.3719	0.0620	0.7525	0.0874
M. leucadendron	**0.1074**	0.0218	**0.0222**	0.0077	0.1499	0.0184	**0.7392**	0.0074	**0.6366**	0.1872	0.5991	0.1085
N. fruticans	**0.1067**	0.0005	0.0222	0.0000	0.1541	0.0029	0.2807	0.3242	0.1936	0.3133	**0.8211**	0.1570
R. apiculata	0.1059	0.0209	0.0133	0.0029	0.1235	0.0221	0.5370	0.1016	0.3940	0.0832	0.7132	0.1750
R. mucronata	**0.1138**	0.0800	0.0204	0.0141	0.1190	0.0056	0.5546	0.2261	0.4028	0.2071	0.6646	0.2935
R. stylosa	0.0578	0.0004	0.0129	0.0017	0.1246	0.0067	0.7075	0.0050	**0.5520**	0.0019	0.7044	0.1186
S. alba	0.0851	0.0159	0.0180	0.0024	0.1410	0.0184	0.5141	0.1014	0.3703	0.0492	**0.8932**	0.1021
X. granatum	0.0941	0.0143	0.0185	0.0008	**0.1448**	0.0119	**0.7664**	0.1277	**0.6290**	0.1584	0.5870	0.2676

Table 5. The TF of Cd and Zn contaminants in mangrove species

Mangrove species	TF							
	Cd				Zn			
	Stem	**Stdev**	**Leaves**	**Stdev**	**Stem**	**Stdev**	**Leaves**	**Stdev**
Aegiceras corniculatum	0.4963	0.0529	0.0973	0.0106	0.8240	0.2163	0.5993	0.2124
Aegiceras floridum	0.3342	0.1411	0.0898	0.0106	0.7856	0.0810	0.5826	0.0944
Avicennia marina	**0.7842**	0.1341	0.1235	0.0269	0.7804	0.0496	0.5211	0.1378
Bruguiera gymnoriza	0.4397	0.0105	**0.1630**	0.0489	0.7511	0.0876	0.4645	0.1215
Bruguiera sexangula	0.4249	0.0085	0.0939	0.0469	0.8750	0.0856	0.6363	0.1195
Ceriops tagal	0.3941	0.0218	0.1147	0.0147	0.9445	0.0491	0.6313	0.0035
Excoecaria agallocha	0.5101	0.0820	**0.2354**	0.0853	0.7090	0.1665	0.4519	0.1269
Hibistus tiliaceus	0.4348	0.0532	0.0642	0.1210	0.9685	0.1835	0.4942	0.0299
Melaluca leucadendron	0.7164	0.1991	0.1482	0.0594	**1.2339**	0.1877	**1.0627**	0.4019
Nypa fruticans	0.6923	0.0170	0.1442	0.0028	0.3419	0.6308	0.2358	0.5847
Rhizophora apiculata	**0.8577**	0.0818	0.1128	0.0372	0.7525	0.3165	0.5520	0.2514
Rhizophora mucronata	**0.9414**	0.6281	**0.1689**	0.1104	0.8415	0.0314	0.5954	0.0486
Rhizophora stylosa	0.4644	0.0233	0.1038	0.0091	**1.0043**	0.1309	0.7836	0.1087
Sonneratia alba	0.6010	0.0340	0.1298	0.0340	0.5728	0.0481	0.4141	0.0077
Xylocarpus granatum	0.6497	0.0515	0.1279	0.0184	**1.3057**	0.4942	**1.0716**	0.4610

The clustering of adaptive mangroves to accumulate Cd and Zn contaminant

The clustering of adaptive mangroves to accumulate Cd and Zn contaminants is illustrated in Figure 3. The data in Figure 3 showed that *B. sexangula, C. tagal, A. corniculatum, A. floridum, S. alba*, and *R. mucronata* have similar abilities to reduce Cd and Zn contaminant, *A. marina, M. leucadendra,* and *X. granatum* as one cluster, *B. gymnorrhiza,* and *E. agallocha* in one cluster. *C. tagal, H. tiliaceus, R. apiculata,* and *R. stylosa* dominated in one cluster, and *N. fruticans* as Solitary species to live and grow in Cd and Zn contaminant area.

The clustering of mangrove species to reduce Cd and Zn contaminants showed the ability of mangrove species to accumulate Cd and Zn (Kibria et al. 2016; Analuddin et al. 2017; Costa-Böddeker et al. 2020; Liu et al. 2020b), to exclude and reduce the impact of Zn and Cd (Zhang et al. 2019, 2021b), transport and translocate Cd and Zn to death organ (Xiao et al. 2015; Hilmi et al. 2017c). The clustering also showed similar characteristics of mangrove ecosystems adapting in cadmium and zinc pollution areas.

Mangrove landscaping and zonation as the pattern of adaptive mangrove to reduce the negative impact of cd and zn contaminant

The data in Figure 4 showed that the mangrove had a landscape pattern to live, grow and reduce the impact of cadmium and zinc contaminants. The mangrove landscaping and zonation refer to the adaptive ability of mangroves to reduce the adverse effects of Cd and Zn contaminants, as shown in Figure 4. The mangrove landscape to accumulate, lived, and grew in the cadmium contaminant area was *A. marina, R. mucronata and R. apiculata* as zone 1, *S. alba, X. granatum, N. fruticans* and *M. leucadendra* as mangrove zone 2, *B. sexangula, H. tilliaceus, A. corniculatum* and *E. agallocha* dominated mangrove zone 3, and *A. floridum* and *C. tagal* in mangrove zone 4. Whereas the mangrove landscape in the Zinc contaminant area, zone 1 was dominated by *A. marina, R. apiculata,* and *X. granatum.* Zone 2 was dominated by *A. corniculatum, B. sexangula, M. leucadendra, C. tagal* and *R. stylosa*. Zone 3 was dominated by *B. gymnorrhiza, S. alba, A. floridum,* and *Rhizophora mucronata*, and *N. fruticans* and *E. agallocha* dominated the last zone.

The mangrove landscape shows the relationship between environmental factors with mangrove species distribution (Datta and Deb 2017; Hilmi 2018; Hilmi et al. 2019, 2021d; Kumbier et al. 2021). There are many factors affecting mangrove landscaping, such as water salinity (Henmi et al. 2017; Yin et al. 2018; Hilmi et al. 2022b), organic matter, nitrate, phosphate, pH, pyrite and soil texture (Nusantara et al. 2015; Shiau et al. 2017; Taillardat et al. 2018; Zhang et al. 2021b).

Mangrove landscapes and zones also would be developed to support many functions, for example, to reduce coastal disasters (Hilmi 2018; Pham et al. 2019), tidal flooding (Ysebaert et al. 2016; Truong et al. 2017; Hilmi et al. 2022b; Hilmi et al. 2022a), reduce the impact of seawater intrusion (Hilmi et al. 2017a; Obolewski and Glińska-Lewczuk 2020), support ecosystem services (Anneboina and Kavi Kumar 2017; Win et al. 2019; Njana 2020; Hilmi et al. 2021e), carbon conservation (Hilmi et al. 2017b; Bolivar et al. 2018; Njana 2020), reduce the impact of sedimentation (Bomer et al. 2020; Hilmi et al. 2021d; Truong et al. 2017), support economic, social and ecological factors (Abdullah et al. 2014; Dijk et al. 2016; Soares et al. 2018) and organism habitat (Prastyo et al. 2017; Hilmi et al. 2022c; Tebiary et al. 2022).

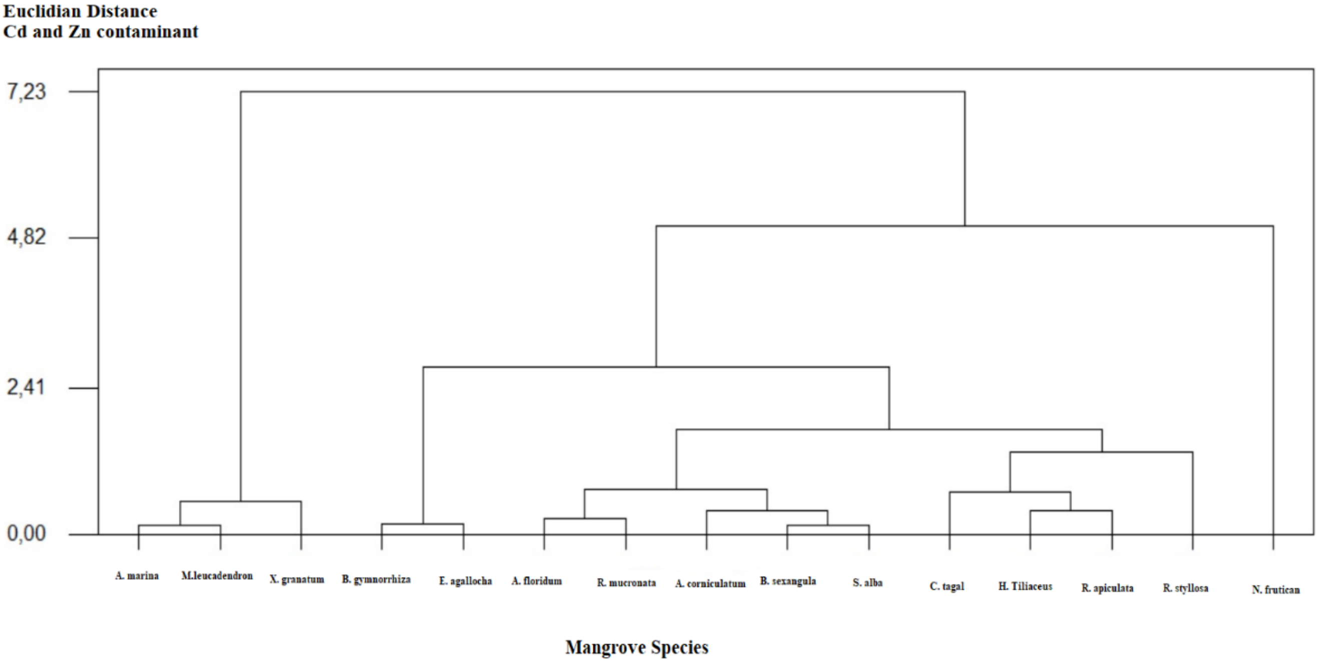

Figure 3. The clustering of mangrove species to live and grow in Cd and Zn Contaminant area

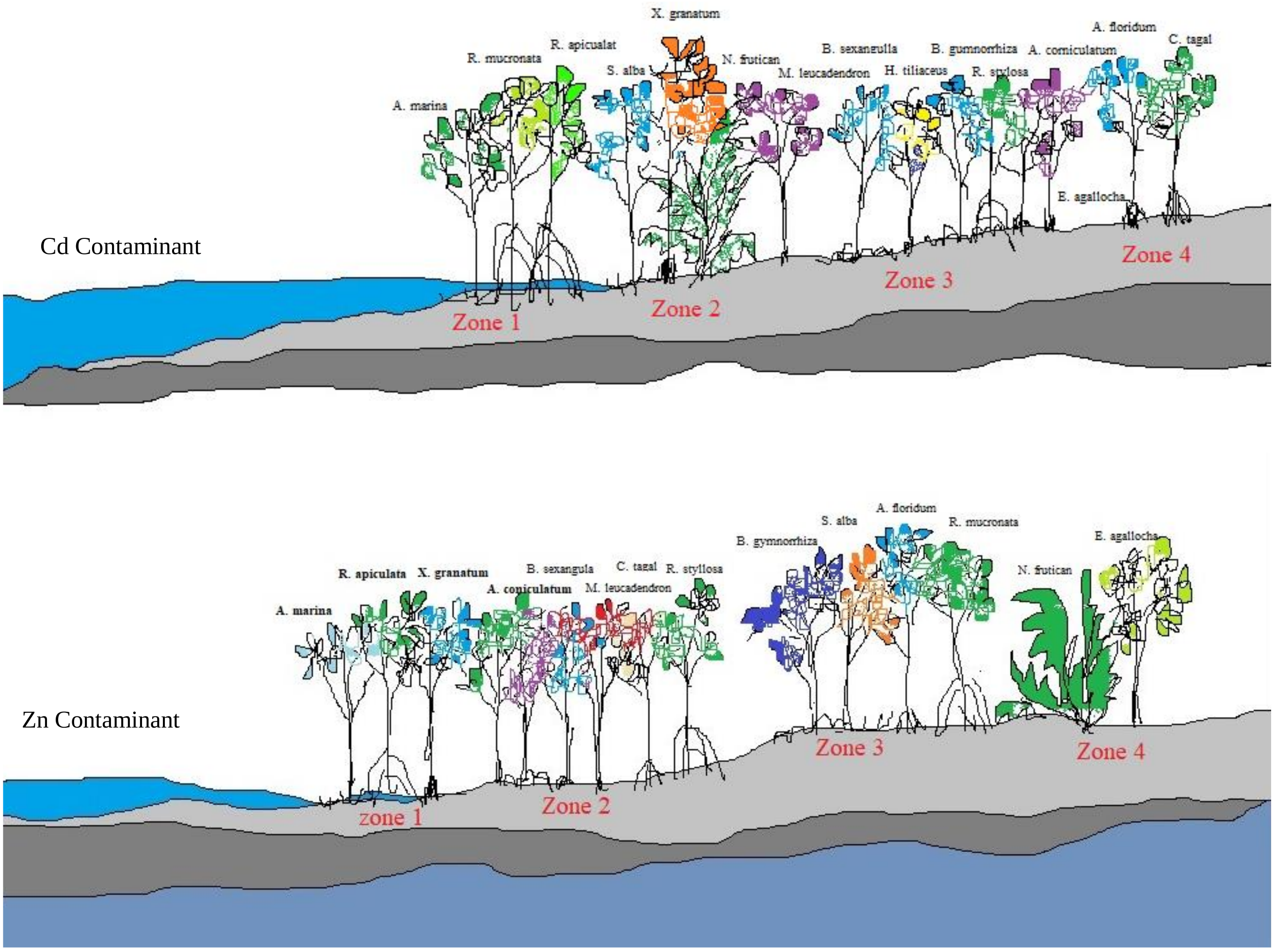

Figure 4. The mangrove landscaping in Cd and Zn contaminant area

The landscape of the mangrove ecosystem in this research showed the ability of mangrove species to live, grow and reduce the impact of Cd and Zn contaminants. *A. marina, R. mucronata,* and *R.apiculata* as the best mangrove to live and grow in the Cd pollution area, whereas *A. marina, R. apiculata,* and *X. granatum* also as the best mangrove to live and grow in the Zn polluted area. The best mangrove in Cd and Zn contaminant indicates the high adaptation of these species to live and grow. Analuddin et al. (2017) and Alzahrani et al. (2018) note that the potential Cd (10.81 $\mu g\ g^{-1}$) and Zn (70.41 $\mu g\ g^{-1}$) have a high impact on aquatic organism. The maximum concentration of cadmium and zinc provides a threshold for the organism's ability to reduce toxic effects and increased risks to aquatic and terrestrial biota. Based metallo-phytoremediation shows that Avicennia marina has a biological concentration factor of >1 and gives an indication that *A. marina* has an excellent ability to accumulate heavy metals (Analuddin et al. 2017; Alzahrani et al. 2018)

The mangrove landscaping in Cd and Zn pollution also requires supporting organic matter, oxygen demand and desorption, dissolution, substitution, hydrolysis of mangrove activity and microbial activity (Marambio et al. 2020; Yang et al. 2020; Dencer-Brown et al. 2020). The mangrove landscaping in the heavy metal pollution (both of Cd and Zn) also is influenced by the an-aerobic condition, salinity factor, and pH to support the ability of mangrove species to absorb the nutrient and water (El-Amier et al. 2017; Hilmi et al. 2017c; Liu et al. 2020a).

In conclusion, the mangrove landscaping to accumulate, reduce, and exclude Cd and Zn contaminants show that *A. marina, R. mucronata, and R. apiculata* grow and live in zone 1, *S. alba, X. granatum, N. fruticans* and *M. leucadendra* as mangrove species live and grow in zone 2, *B. sexangula, H. tiliaceus, A. corniculatum,* and *E. agallocha* dominated area in zone 3, and *A. floridum* and *C. tagal* in mangrove zone 4. Therefore, the activity of mangroves to reduce Cd and Zn contaminants was proven by their ability to accumulate Cd and Zn. The potential of cadmium accumulation in mangrove stems is between 0.0610-0.2650 ppm, mangrove leaves between 0.0140-0.0480 ppm, and mangrove roots between 0.1501-0.3100 ppm. At the same time, the potential of zinc accumulation in mangrove stems is between 5.77-37.34 ppm, in mangrove leaves between 5.7781-26.1966 ppm, and in mangrove roots between 10.84-35.88 ppm.

ACKNOWLEDGEMENTS

The author's praise and respect goes to the Chair of LPPM Unsoed supports Terapan Grand LPPM Unsoed 2022 and 2023 (SK Rektor Unsoed no 1135/UN23/PT.01.02/2022 and SK Rektor Unsoed no 1120/UN23/PT.01.02/2023 the Dean of the Faculty of Fisheries and Marine Sciences Unsoed, and thanks also to the research institute team, all reviews, journal editors for their cooperation in supporting the publication of this journal.

REFERENCES

Abdullah K, Said AM, Omar D. 2014. Community-based conservation in managing mangrove rehabilitation in Perak and Selangor. Procedia Soc Behav Sci 153: 121-131. DOI: 10.1016/j.sbspro.2014.10.047.

Alzahrani DA, Selim E-MM, El-Sherbiny MM. 2018. Ecological assessment of heavy metals in the grey mangrove (*Avicennia marina*) and associated sediments along the Red Sea coast of Saudi Arabia. Oceanologia 60: 513-526. DOI: 10.1016/J.OCEANO.2018.04.002.

Analuddin K, Sharma S, Jamili, Septiana A, Sahidin I, Rianse U, Nadaoka K. 2017. Heavy metal bioaccumulation in mangrove ecosystem at the coral triangle ecoregion, Southeast Sulawesi, Indonesia. Mar Pollut Bull 125: 472-480. DOI: 10.1016/J.MARPOLBUL.2017.07.065.

Anneboina LR, Kavi Kumar KS. 2017. Economic analysis of mangrove and marine fishery linkages in India. Ecosyst Serv 24: 114-123. DOI: 10.1016/j.ecoser.2017.02.004.

Berg T, Fürhaupter K, Teixeira H, Uusitalo L, Zampoukas N. 2015. The marine strategy framework directive and the ecosystem-based approach - pitfalls and solutions. Mar Pollut Bull 96: 18-28. DOI: 10.1016/j.marpolbul.2015.04.050.

Bolivar JM, Gutierrez-Velez VH, Sierra CA. 2018. Carbon stocks in aboveground biomass for Colombian mangroves with associated uncertainties. Reg Stud Mar Sci 18: 145-155. DOI: 10.1016/j.rsma.2017.12.011.

Bomer EJ, Wilson CA, Hale RP, Hossain ANM, Rahman FMA 2020. Surface elevation and sedimentation dynamics in the Ganges-Brahmaputra tidal delta plain, Bangladesh: Evidence for mangrove adaptation to human-induced tidal amplification. Catena 187: 104312. DOI: 10.1016/j.catena.2019.104312.

Cao Z, Wang L, Yang L, Yu J, Lv J, Meng M, Li G. 2020. Heavy metal pollution and the risk from tidal flat reclamation in coastal areas of Jiangsu, China. Mar Pollut Bull 158: 111427. DOI: 10.1016/j.marpolbul.2020.111427.

Chai M, Li R, Qiu Z, Zhiyuan N, Xiaoxue S. 2020. Mercury distribution and transfer in sediment-mangrove system in urban mangroves of fast-developing coastal region, Southern China. Estuar Coast Shelf Sci 240: 106770. DOI: 10.1016/j.ecss.2020.106770.

Choi JY, Jeong H, Choi KY, Hong GH, Yang DB, Kim K, Ra K. 2020. Source identification and implications of heavy metals in urban roads for the coastal pollution in a beach town, Busan, Korea. Mar Pollut Bull 161: 111724. DOI: 10.1016/j.marpolbul.2020.111724.

Costa-Böddeker S, Thuyên LX, Hoelzmann P, de Stigter HC, van Gaever P, Huy HĐ, Smol JP, Schwalb A. 2020. Heavy metal pollution in a reforested mangrove ecosystem (Can Gio Biosphere Reserve, Southern Vietnam): Effects of natural and anthropogenic stressors over a thirty-year history. Sci Total Environ 716: 137035. DOI: 10.1016/j.scitotenv.2020.137035.

Dai M, Lu H, Liu W, Jia H, Hong H, Liu J, Yan C. 2017. Phosphorus mediation of cadmium stress in two mangrove seedlings *Avicennia marina* and *Kandelia obovata* differing in cadmium accumulation. Ecotoxicol Environ Saf 139: 272-279. DOI: 10.1016/J.ECOENV.2017.01.017.

Datta D, Deb S. 2017. Forest structure and soil properties of mangrove ecosystems under different management scenarios: Experiences from the intensely humanized landscape of Indian Sunderbans. Ocean Coast Manag 140: 22-33. DOI: 10.1016/j.ocecoaman.2017.02.022.

de Almeida Duarte LF, de Souza CA, Pereira CDS, Pinheiro MAA. 2017. Metal toxicity assessment by sentinel species of mangroves: In situ case study integrating chemical and biomarkers analyses. Ecotoxicol Environ Saf 145: 367-376. DOI: 10.1016/J.ECOENV.2017.07.051.

Dencer-Brown AM, Alfaro AC, Bourgeois C, Sharma S, Milne S. 2020. The secret lives of mangroves: Exploring New Zealand's urban mangroves with integrated biodiversity assessments. Ocean Coast Manag 191: 105185. DOI: 10.1016/J.OCECOAMAN.2020.105185

Dijk J van, Broersma L, Mehnen N. 2016. Options for socioeconomic developments in ICZM for the tri-national Wadden area. Ocean Coast Manag 119: 76-92. DOI: 10.1016/j.ocecoaman.2015.10.004.

El-Amier YA, Elnaggar AA, El-Alfy MA. 2017. Evaluation and mapping spatial distribution of bottom sediment heavy metal contamination in Burullus Lake, Egypt. Egypt J Basic Appl Sci 4: 55-66. DOI: 10.1016/j.ejbas.2016.09.005.

Henmi Y, Fuchimoto D, Kasahara Y, Shimanaga M. 2017. Community structures of halophytic plants, gastropods and brachyurans in salt marshes in Ariake and Yatsushiro seas of Japan. Plankt Benthos Res 12: 224-237. DOI: 10.3800/pbr.12.224.

Hilmi E, Kusmana C, Suhendang E, Iskandar I. 2017a. Correlation analysis between seawater intrusion and mangrove greenbelt. Indon J For Res 4: 151-168. DOI: 10.20886/ijfr.2017.4.2.151-168.
Hilmi E, Pareng R, Vikaliana R, Kusmana C, Iskandar I, Sari LK, Setijanto. 2017b. The carbon conservation of mangrove ecosystem applied REDD program. Reg Stud Mar Sci 16: 152-161. DOI: 10.1016/j.rsma.2017.08.005.
Hilmi E, Siregar AS, Syakti AD. 2017c. Lead (Pb) Distribution on soil, water and mangrove vegetation matrices in eastern part of Segara Anakan Lagoon, Cilacap. Omni-Akuatika 13: 25-38. DOI: 10.20884/1.oa.2017.13.2.83.
Hilmi E. 2018. Mangrove landscaping using the modulus of elasticity and rupture properties to reduce coastal disaster risk. Ocean Coast Manag 165: 71-79. DOI: 10.1016/j.ocecoaman.2018.08.002.
Hilmi E, Sari LK, Setijanto. 2019. The mangrove landscaping based on water quality: (case study in Segara Anakan Lagoon and Meranti Island). IOP Conf Ser Earth Environ Sci 255: 012028. DOI: 10.1088/1755-1315/255/1/012028.
Hilmi E, Amron A, Sari LK, Cahyo TN, Siregar AS. 2021a. The mangrove landscape and zonation following soil properties and water inundation distribution in Segara Anakan Cilacap. Jurnal Manajemen Hutan Tropika 27: 152-164. DOI: 10.72226/jtfm.27.3.152.
Hilmi E, Sari LK, Amron A, Cahyo TN, Siregar AS. 2021b. Mangrove cluster as adaptation pattern of mangrove ecosystem in Segara Anakan Lagoon. IOP Conf Ser Earth Environ Sci 746 (1): 012022. DOI: 10.1088/1755-1315/746/1/012022.
Hilmi E, Sari LK, Cahyo TN, Mahdiana A, Samudra SR. 2021c The affinity of mangrove species using association and cluster index in North Coast of Jakarta and Segara Anakan of Cilacap, Indonesia. Biodiversitas 22: 2907-2918. DOI: 10.13057/biodiv/d220743.
Hilmi E, Sari LK, Cahyo TN, Amron A, Siregar AS. 2021d. The sedimentation impact for the lagoon and mangrove stabilization. E3S Web Conf 324: 02001. DOI: 10.1051/e3sconf/202132402001.
Hilmi E, Sari LK, Siregar AS, Sulistyo I, Mahdiana A, Junaidi T, Muslih M, Pertiwi RPC, Samudra SR, Prayogo NA. 2021e. Tannins in mangrove plants in Segara Anakan Lagoon, Central Java, Indonesia. Biodiversitas 22: 3508-3516. DOI: 10.13057/biodiv/d220850.
Hilmi E, Amron A, Christianto D. 2022a. The potential of high tidal flooding disaster in North Jakarta using mapping and mangrove relationship approach. IOP Conf Ser Earth Environ Sci 989 (1): 012001. DOI: 10.1088/1755-1315/989/1/012001.
Hilmi E, Sari LK, Cahyo TN, Mahdiana A, Soedibya PHT, Sudiana E. 2022b. Survival and growth rates of mangroves planted in vertical and horizontal aquaponic systems in North Jakarta, Indonesia. Biodiversitas 23: 686-693. DOI: 10.13057/biodiv/d230213.
Hilmi E, Sari LK, Cahyo TN, Dewi R, Winanto T. 2022c. The structure communities of gastropods in the permanently inundated mangrove forest on the north coast of Jakarta, Indonesia. Biodiversitas 23: 2699-2710. DOI: 10.13057/biodiv/d230554.
Jeong H, Choi JY, Choi DH, Noh JH, Ra K 2021. Heavy metal pollution assessment in coastal sediments and bioaccumulation on seagrass (*Enhalus acoroides*) of Palau. Mar Pollut Bull 163: 111912. DOI: 10.1016/j.marpolbul.2020.111912.
Jiang S, Weng B, Liu T, Su Y, Liu J, Lu H, Yan C. 2017. Response of phenolic metabolism to cadmium and phenanthrene and its influence on pollutant translocations in the mangrove plant *Aegiceras corniculatum* (L.) Blanco (Ac). Ecotoxicol Environ Saf 141: 290-297. DOI: 10.1016/J.ECOENV.2017.03.041.
Karl DM, Church MJ. 2017. Ecosystem structure and dynamics in the north pacific subtropical gyre: new views of an old ocean. Ecosystems 20: 433-457. DOI: 10.1007/s10021-017-0117-0.
Khadim FK, Su H, Xu L, Tian J. 2019. Soil salinity mapping in everglades national park using remote sensing techniques and vegetation salt tolerance. Phys Chem Earth 110: 31-50. DOI: 10.1016/j.pce.2019.01.004.
Kibria G, Hossain MM, Mallick D, Lau TC, Wu R. 2016. Trace/heavy metal pollution monitoring in estuary and coastal area of Bay of Bengal, Bangladesh and implicated impacts. Mar Pollut Bull 105: 393-402. DOI: 10.1016/j.marpolbul.2016.02.021.
Kumbier K, Hughes MG, Rogers K, Woodroffe CD. 2021. Inundation characteristics of mangrove and saltmarsh in micro-tidal estuaries. Estuar Coast Shelf Sci 261: 107553. DOI: 10.1016/j.ecss.2021.107553.
Lei P, Zhong H, Duan D, Pan K. 2019. A review on mercury biogeochemistry in mangrove sediments: Hotspots of methylmercury production? Sci Total Environ 680: 140-150. DOI: 10.1016/J.SCITOTENV.2019.04.451.
Leopold A, Marchand C, Deborde J, Chaduteau C, Allenbach M. 2013. Influence of mangrove zonation on CO_2 fluxes at the sediment-air interface (New Caledonia). Geoderma 202-203: 62-70. DOI: 10.1016/j.geoderma.2013.03.008.
Li R, Wu S, Chai M, Xie S. 2020. Denitrifier communities differ in mangrove wetlands across China. Mar Pollut Bull 155: 111160. DOI: 10.1016/j.marpolbul.2020.111160.
Lin Y, Lu J, Wu J. 2021. Heavy metals pollution and health risk assessment in farmed scallops: Low level of Cd in coastal water could lead to high risk of seafood. Ecotoxicol Environ Saf 208: 111768. DOI: 10.1016/j.ecoenv.2020.111768.
Liu L, Wang H jun, Yue Q. 2020a China's coastal wetlands: Ecological challenges, restoration, and management suggestions. Reg Stud Mar Sci 37: 101337. DOI: 10.1016/j.rsma.2020.101337.
Liu S, Liu Y, Yang D, Li C, Zhao Y, Ma H, Luo X, Lu S. 2020b. Trace elements in shellfish from Shenzhen, China: Implication of coastal water pollution and human exposure. Environ Pollut 263: 114582. DOI: 10.1016/j.envpol.2020.114582.
Ma W, Li X, Wang Q, Ren Z, Crabbe MJC, Wang L. 2019. Tandem oligomeric expression of metallothionein enhance heavy metal tolerance and bioaccumulation in *Escherichia coli*. Ecotoxicol Environ Saf 181: 301-307. DOI: 10.1016/j.ecoenv.2019.06.022.
Mapenzi LL, Shimba MJ, Moto EA, Maghembe RS, Mmochi AJ 2020. Heavy metals bio-accumulation in tilapia and catfish species in Lake Rukwa ecosystem Tanzania. J Geochemical Explor 208: 106413. DOI: 10.1016/j.gexplo.2019.106413.
Marambio AY, Saavedra JV, Enciso LÑ, Marras AL, Serrano AE, Peláez RM, Bruna AC, Ávalos GÁ, Maldonado MV. 2020. Data on metal accumulation in the tails of the lizard Microlophus atacamensis in a coastal zone of the Atacama Desert, northern Chile: A non-destructive biomonitoring tool for heavy metal pollution. Data in Brief 32: 106032. DOI: 10.1016/j.dib.2020.106032.
Monteiro JM, de Souza JSN, Lins Neto EMF, Scopel K, Trindade EF. 2014. Does total tannin content explain the use value of spontaneous medicinal plants from the Brazilian semi-arid region? Brazilian J Pharmacogn 24: 116-123. DOI: 10.1016/j.bjp.2014.02.001.
Nadgórska-Socha A, Kandziora-Ciupa M, Trzęsicki M, Barczyk G. 2017. Air pollution tolerance index and heavy metal bioaccumulation in selected plant species from urban biotopes. Chemosphere 183: 471-482. DOI: 10.1016/j.chemosphere.2017.05.128.
Njana MA. 2020. Structure, growth, and sustainability of mangrove forests of mainland Tanzania. Glob Ecol Conserv 24: e01394. DOI: 10.1016/j.gecco.2020.e01394.
Nour HE, El-Sorogy AS, Abd El-Wahab M, Nouh ES, Mohamaden M, Al-Kahtany K. 2019. Contamination and ecological risk assessment of heavy metals pollution from the Shalateen coastal sediments, Red Sea, Egypt. Mar Pollut Bull 144: 167-172. DOI: 10.1016/j.marpolbul.2019.04.056.
Nusantara MA, Hutomo M, Purnama H. 2015. Evaluation and planning of mangrove restoration programs in Sedari Village of Kerawang District, West Java: Contribution of PHE-ONWJ Coastal Development Programs. Procedia Environ Sci 23: 207-214. DOI: 10.1016/j.proenv.2015.01.032.
Obolewski K, Glińska-Lewczuk K. 2020. Connectivity and complexity of coastal lakes as determinants for their restoration - A case study of the southern Baltic Sea. Ecol Eng 155: 105948. DOI: 10.1016/j.ecoleng.2020.105948.
Ortega P, Custódio MR, Zanotto FP. 2017. Characterization of cadmium transport in hepatopancreatic cells of a mangrove crab *Ucides cordatus*: The role of calcium. Aquat Toxicol 188: 92-99. DOI: 10.1016/J.AQUATOX.2017.04.012.
Pham LTH, Vo TQ, Dang TD, Nguyen UTN. 2019. Monitoring mangrove association changes in the Can Gio biosphere reserve and implications for management. Remote Sens Appl Soc Environ 13: 298-305. DOI: 10.1016/j.rsase.2018.11.009.
Prastyo Y, Batu DT. L, Sulistiono S. 2017. Heavy metal contain Cu and Cd on the mullet in the estuary of Donan River, Cilacap, Central Java. Jurnal Pengolahan Hasil Perikanan Indonesia 20: 18-27. DOI: 10.17844/jphpi.v20i1.16393.
Rindyastuti R, Sancayaningsih RP. 2018. The growth strategies analysis of ten woody plant species for effective revegetation. Biotropia (Bogor) 25: 43-55. DOI: 10.11598/btb.2018.25.1.705.
Robson TC, Braungardt CB, Rieuwerts J, Worsfold P. 2014. Cadmium contamination of agricultural soils and crops resulting from sphalerite weathering. Environ Pollut 184: 283-289. DOI: 10.1016/j.envpol.2013.09.001.

Shi C, Yu L, Chai M, Niu Z, Li R. 2020. The distribution and risk of mercury in Shenzhen mangroves, representative urban mangroves affected by human activities in China. Mar Pollut Bull 151: 110866. DOI: 10.1016/j.marpolbul.2019.110866.

Shiau YJ, Lee SC, Chen TH, Tian G, Chiu CY. 2017. Water salinity effects on growth and nitrogen assimilation rate of mangrove (*Kandelia candel*) seedlings. Aquat Bot 137: 50-55. DOI: 10.1016/j.aquabot.2016.11.008.

SNI [Standar Nasional Indonesia]. 2009. SNI 6989.7. Air dan Air Limbah - Bagian 7: Cara Uji Seng (Zn) secara Spektrofotometri Serapan Atom (SSA) - Nyala. Badan Standarisasi Nasional, Jakarta. [Indonesian]

Soares RHR de M, Assunção CA de, Fernandes F de O, Marinho-Soriano E. 2018. Identification and analysis of ecosystem services associated with biodiversity of saltworks. Ocean Coast Manag 163: 278-284. DOI: 10.1016/j.ocecoaman.2018.07.007.

Sugiatmo, Poedjirahajoe E, Pudyatmoko S, Purwanto RH. 2023. Carbon stock at several types of mangrove ecosystems in Bregasmalang, Central Java, Indonesia. Biodiversitas 24: 182-191. DOI: 10.13057/biodiv/d240122.

Syakti AD, Ahmed MM, Hidayati NV, Hilmi E, Sulystyo I, Piram A, Doumenq P. 2013. Screening of emerging pollutants in the mangrove of Segara Anakan nature reserve, Indonesia. IERI Procedia 5: 216-222. DOI: 10.1016/j.ieri.2013.11.095.

Taillardat P, Ziegler AD, Friess DA, Widory D, Truong Van V, David F, Thành-Nho N, Marchand C. 2018. Carbon dynamics and inconstant porewater input in a mangrove tidal creek over contrasting seasons and tidal amplitudes. Geochim Cosmochim Acta 237: 32-48. DOI: 10.1016/j.gca.2018.06.012.

Tebiary LA, Leiwakabessy F, Rumahlatu D. 2022. Species density and morphometric variation of species belonging to *Conus* (Gastropoda: Conidae) genera in the coastal waters of Ambon Island, Indonesia. Biodiversitas 23: 1664-1676. DOI: 10.13057/biodiv/d230358.

Truong SH, Ye Q, Stive MJF. 2017. Estuarine mangrove squeeze in the Mekong Delta, Vietnam. J Coast Res 33: 747-763. DOI: 10.2112/jcoastres-d-16-00087.1.

Win S, Towprayoon S, Chidthaisong A. 2019. Adaptation of mangrove trees to different salinity areas in the Ayeyarwaddy Delta Coastal Zone, Myanmar. Estuar Coast Shelf Sci 228: 106389. DOI: 10.1016/j.ecss.2019.106389.

Xiao R, Bai J, Lu Q, Zhao Q, Gao Z, Wen X, Liu X. 2015. Fractionation, transfer, and ecological risks of heavy metals in riparian and ditch wetlands across a 100-year chronosequence of reclamation in an estuary of China. Sci Total Environ 517: 66-75. DOI: 10.1016/J.SCITOTENV.2015.02.052.

Xiong Y, Liao B, Proffitt E, Guan W, Sun Y, Wang F, Liu X. 2018. Soil carbon storage in mangroves is primarily controlled by soil properties: A study at Dongzhai Bay, China. Sci Total Environ 619-620: 1226-1235. DOI: 10.1016/j.scitotenv.2017.11.187.

Yang HJ, Jeong HJ, Bong KM, Jin DR, Kang TW, Ryu HS, Han JH, Yang WJ, Jung H, Hwang SH, Na EH. 2020. Organic matter and heavy metal in river sediments of southwestern coastal Korea: Spatial distributions, pollution, and ecological risk assessment. Mar Pollut Bull 159: 111466. DOI: 10.1016/j.marpolbul.2020.111466.

Yin P, Yin M, Cai Z, Wu G, Lin G, Zhou J. 2018. Structural inflexibility of the rhizosphere microbiome in mangrove plant *Kandelia obovata* under elevated CO_2. Mar Environ Res 140: 422-432. DOI: 10.1016/j.marenvres.2018.07.013.

Ysebaert T, van der Hoek DJ, Wortelboer R, Wijsman JWM, Tangelder M, Nolte A. 2016. Management options for restoring estuarine dynamics and implications for ecosystems: A quantitative approach for the Southwest Delta in the Netherlands. Ocean Coast Manag 121: 33-48. DOI: 10.1016/j.ocecoaman.2015.11.005.

Yunus K, Mohd Yusuf N, Mohd Shazili NA, Chuan OM, Saad S, Chowdhury AJK, Bidai J. 2011. Heavy metal concentration in the surface sediment of Tanjung Lumpur mangrove forest, Kuantan, Malaysia. Sains Malaysiana 40: 89-92.

Zhang Z, Fang Z, Li J, Sui T, Lin L, Xu X. 2019. Copper, zinc, manganese, cadmium and chromium in crabs from the mangrove wetlands in Qi'ao Island, South China: Levels, bioaccumulation and dietary exposure. Watershed Ecol Environ 1: 26-32. DOI: 10.1016/j.wsee.2019.09.001.

Zhang X, Yu J, Huang Z, Li H, Liu X, Huang J, Zhuo R, Wu Z, Qin X, Gao Y, Wang M, Zhu Y. 2021a. Enhanced Cd phytostabilization and rhizosphere bacterial diversity of *Robinia pseudoacacia* L. by endophyte *Enterobacter* sp. YG-14 combined with sludge biochar. Sci Total Environ 787: 147660. DOI: 10.1016/j.scitotenv.2021.147660.

Zhang Y, Xiao L, Guan D, Chen Y, Motelica-Heino M, Peng Y, Lee SY. 2021b. The role of mangrove fine root production and decomposition on soil organic carbon component ratios. Ecol Indic 125: 107525. DOI: 10.1016/j.ecolind.2021.107525.