BIODIVERSITAS
Volume 23, Number 5, May 2022
Pages: 2482-2492

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230528

Spatio-temporal of heavy metal Pb (Lead) in seawater, sediment, and different organs of *Cymodocea rotundata* in Doreri Gulf, Manokwari, West Papua, Indonesia

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Manuscript received: 25 March 2022. Revision accepted: 23 April 2022.

Abstract. *Sembel L, Setijawati D, Yona D, Risjani Y. 2022. Spatio-temporal of heavy metal Pb (Lead) in seawater, sediment, and different organs of Cymodocea rotundata in Doreri Gulf, Manokwari, West Papua, Indonesia. Biodiversitas 23: 2482-2492.* The Doreri Gulf is a high-activity area that serves as a collection point for pollutants from the mainland, which are conveyed directly or indirectly through five rivers in a semi-enclosed area. *Cymodocea rotundata* in Doreri Gulf is classified as a pioneer seagrass with high density in areas close to pollution sources. Therefore, analysis of Pb concentrations in aquatic and sedimentary environments as well as the reaction of *C. rotundata* to Pb in the Doreri Gulf is required considering its relevance in seagrass ecosystems. This research, then, aims to analyze the spatial and temporal distribution of Pb in waters and sediments, as well as determine the bioaccumulation in the organs of *C. rotundata,* such as roots, rhizomes, and leaves. Besides, an analysis was also carried out on the potential for bioconcentration and translocation of Pb in Doreri Gulf, Manokwari District, West Papua Province, from February to April and August to October 2020. The locations were divided into Yankarwar coastal, Nusmapi Islands, and Tanjung Manggewa. Parameter measurement refers to the Standard Methods for examining Water and Wastewater (APHA 2017). The heavy metal analysis was conducted using the SNI 6989.8:2009 procedure, and the temporal distribution showed that concentrations of Pb in water, sediment, and seagrass organs were high and low in the rainy and dry season. The spatial distribution of Pb in sediments between the Coastal Yankarwar and Nusmapi Islands, as well as between the Coastal Yankarwar locations and Tanjung Manggewa, were very different. However, there were no differences between the Nusmapi Islands and Tanjung Manggewa. Each location showed BCF bioconcentration <1, indicating the lack of ability to mobilize Pb from sediment to roots. Translocation factors for each location showed TF values < 1, showing the lack of ability of *C. rotundata* to transfer Pb to organ tissues. Additionally, translocation of elements from sediment to roots and within plant tissues was related to many factors, including pH, potency reduction, temperature, salinity, and organic matter content. Other factors such as seasonal variations and heavy metal concentrations contribute to bioaccumulation and internal translocation capacity.

Keywords: Doreri Gulf, heavy metal Pb, seagrass *Cymodocea rotundata,* spatio-temporal

INTRODUCTION

Manokwari is the capital city of West Papua Province near the waters of the Doreri Gulf, an area prone to pollution from the mainland. One of the pollutants is heavy metal Pb (lead) from domestic waste, diesel power plants (PLTD), repair of Navy ships (Fasarkhan), ship painting, ship waste disposal, ship loading and unloading, hotels, residential areas, and various industrial waste. It can also come from fuels with the potential for oil spills or scattered into the aquatic environment through large ships, Pelni ships, fishing, and small vessels used as transportation facilities (Sembel and Manan 2018). This situation makes the waters very vulnerable to various ecological stresses and endangers the lives of the surrounding community (Sembel et al. 2021). The sources of pollutant materials have produced high concentrations of nitrate, phosphate, and heavy metals, which have passed the Ministry of Environment Quality Standard No. 51 of 2004 (Sembel et al. 2019).

Heavy metals are chemical elements with an atomic mass of 5 g/cm^3 are commonly found in soil (Hidayaturrahmah et al. 2019; Méndez et al. 2021), also included in the group with the same criteria. The difference between heavy metals and other metals lies in the level of toxins produced. These heavy metals are able to form complex bonds when they enter the bodies of organisms (Palar 1994). These metals have become a global issue due to the increasing human population potentially harmful to aquatic ecosystems and human and animal life (Risjani et al. 2020). There are detrimental impacts on species and the ecosystem when exposed to high concentrations. Over time, this condition has been ongoing, causing water quality degradation and ecological changes. Pb (lead) is more widespread than most other toxic metals and is naturally found in rocks and layers of the earth's crust (Zhou et al. 2021).

Seagrass is an essential ecosystem in environmental balance in coastal. This ecosystem provides food, acts as primary productivity in the waters, dampens the arrival of waves, a place for growth and development of biota, and trapping sediments (Lefaan 2012). Besides, it functions as a trap for contaminants by accumulating heavy metals (Nontji 2005; Lefaan 2012; Sugiyanto et al. 2016; Tupan and Azrianingsih 2016; Bidayani et al.2017; Potouroglou et al. 2017; Sembel et al. 2021). *Cymodocea rotundata* in Doreri Gulf is classified as a pioneer seagrass with the ability to adapt to disturbed conditions. It has a high density in areas close to pollutant sources with a significant value index (Lefaan et al. 2013). The heavy metal accumulation was primarily found in roots and rhizomes (Sembel et al. 2021). It determines the spatial and temporal distribution of heavy metal Pb in water, sediment, roots, rhizomes, and leaves, as well as analyzes the potential for bioconcentration and translocation of Pb. However, information on the ability to absorb and accumulate Pb in *C. rotundata* is still limited; hence, in-depth research is needed. Based on these findings, it is necessary to conduct a spatial and temporal analysis of heavy metal Pb in waters and sediments, as well as determine the bioaccumulation in roots, rhizomes, and leaves of *C. rotundata*.

MATERIALS AND METHODS

Research area

The research was conducted in Doreri Gulf, Manokwari District, West Papua Province, Indonesia from February to April (rainy season) and August to October (dry season) in 2020 (Figure 1). According to the BMKG/Meteorology Climatology and Geophysics Agency (2020), high and low rainfall occurred from February to April and August to October.

Water sampling, sediment, and seagrass organs were carried out at low tide in three locations. Each location consists of 3 transect lines determined by 2 points toward the sea and the land. Sampling was carried out every month during the rainy and dry seasons to obtain a total of 108. The research location was determined based on activities, environmental conditions, and the presence of seagrass *C. rotundata* in the Doreri Gulf (Table 1).

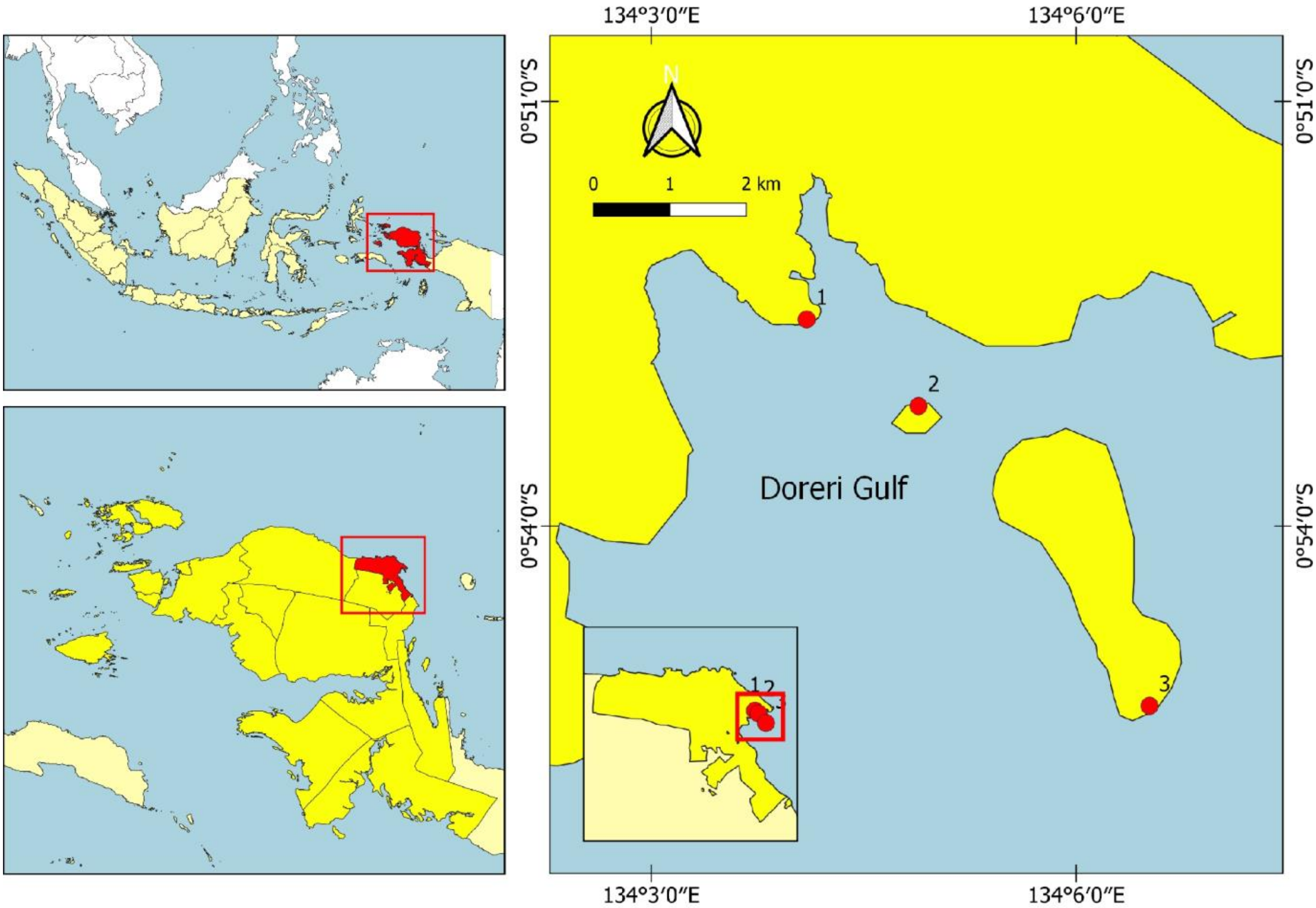

Figure 1. Location of Doreri Gulf, Manokwari District, West Papua Province, Indonesia, sampling of seagrass *Cymodocea rotundata* (1. Yankarwar Coastal; 2. Nusmapi Island; 3. Tanjung Manggewa)

Table 1. Sampling location

Location	Coordinate	Description
Yankarwar Coastal	134.068282 E; -0.875679 S	Dense settlements, the presence of the wirsi, wosi and konto rivers, the activities of the Fasarkhan workshop, loading and unloading of ships, diesel power plants, near the pelni port
Nusmapi Islands	134.081441 E; -0.885875 S	There are few settlements, fishing boat lanes, Pelni, tankers, fishing catch areas, inter-regional ports
Tanjung Manggewa	134.108629 E; -0.921174 S	Mangrove forests, fishing boat lanes, Pelni, tankers, catchment areas

Material and sampling approach

A sampling of surface sediment used a core with a depth of ± 10 cm as much as ± 250 gr from each point. The sample was put into a polyethylene jar and brought to the laboratory to be dried in an oven at 105-110°C for 5 hours. Furthermore, the dry sediment was cooled in a desiccator, crushed using a mortar, and sieved with a size of 0.5 mm to remove large particles. Then, about 1 g was weighed and put into a beaker with 5 mL of HNO_3 and heated until the volume was reduced to 1 mL. A solution was made by adding 10 mL of HNO_3 and 10 mL of $HClO_4$ and was heated until the volume was reduced to 5 mL. It was cooled and filtered with 0.45 μm Whatman filter paper then rinsed with distilled water to 100 mL. The solution was put into a bottle and injected using an atomic absorption spectrophotometer (Aacle Pin Model 900 H) with a wavelength of 228.8 nm (SNI 2354.5: 2011).

Seawater samples were taken using a Van Dorn Water Sampler with a volume of 250 mL made of Poly Vinyl Chloride (PVC). It was then put into a polyethylene bottle and stored in a cool box at 4 ± 1 °C. First, filtration was carried out using 0.45 μm Whatman filter paper, then concentrated nitric acid (HNO_3) was added in a ratio of 1:10 mL. The extraction was performed with 5 mL APDC and 25 mL MIBK to form the organic phase. Finally, the solution was redissolved by adding 2 mL of concentrated nitric acid (HNO_3) to form soluble metal ions in the water phase. The analysis method referred to the Standard Methods for the Examination of Water and Wastewater (APHA 2017). The value of heavy metals was measured using an atomic absorption spectrophotometer (Model Pin Aacle 900 H) with a wavelength of 228.8 nm.

Cymodocea rotundata formed a mix-specific stand densely packed with seagrass area from the coastline at low tide. The seagrasses were extensive with a size of ± 15-20 cm (English, Wilkinson, and Baker 1997) and tightly closed in sterile plastic bags. Seagrass samples in the laboratory were washed with running water to remove large particles and adhering parasites. It was then rinsed with distilled water to remove any remaining fine material. The organs of roots, rhizomes, and leaves were dissected using stainless steel shears, and the sample was dried using an oven at 105°C for 4 hours. It was ground with a mortar, and 1 g was weighed and put into Erlenmeyer before adding 25 mL of distilled water and stirred with a rod. Subsequently, about 5-10 mL of concentrated HNO3 were added, stirred until well mixed, and covered with a watch glass before heating to 105°C-120°C.

The solution was heated until the volume remaining was 10 mL, cooled, and 5 mL of concentrated HNO_3 was slowly added. Then it was reheated using a Waterbaht until white smoke appeared and the sample solution became clear. Then the solution was cooled and filtered using Whatman filter paper of 0.45 μm size. The filtrate was put into a 100 mL volumetric flask, and distilled water was added until the mark was correct. The next step was to analyze the data with an atomic absorption spectrophotometer (Model Pin Aacle 900 H) with a wavelength of 228.8 nm. Finally, the Pb SNI 6989.8:2009 technique analyzed heavy metal content.

Data analysis

Calculation of Bioconcentration Factor (BCF)

Bioconcentration factor (BCF) was used to determine the Pb concentration absorbed by *C. rotundata*. In addition, this value was used to measure the ability of plants to accumulate Pb particles from the sediment. The higher the BCF value, the more suitable the plant as a phytoremediation agent (Arnot and Gobas 2006; Bonanno et al. 2017; Nguyen et al. 2017; Bonanno and Borg 2018; Hu et al. 2021). The value of the bioconcentration factor obtained was based on the following items:

$$\text{Bioconcentration Factor (BCF)} = C_{root}/C_{sediment}$$

Where:

C_{root} = Heavy metal concentration in roots (mg.kg^{-1}DW)

$C_{sediment}$ = Heavy metal concentration in sediments (mg.kg^{-1}DW)

Calculation of Translocation Factor (TF)

The translocation factor (TF) was calculated to evaluate the potential of *C. rotundata* as a phytoremediation agent. TF analysis showed the translocation ability to transfer heavy metals from roots to rhizomes and leaves (Tupan and Azrianingsih 2016; Bonanno et al. 2017; Bonanno and Raccuia 2018a). TF calculation is:

$TF = C_{rhizome}/ C_{root}$

$C_{leaf}/ C_{rhizome}$

C_{leaf} / C_{root}

Higher TF value results in greater translocation capability (Deng et al. 2004).

Where:

C_{root} = Heavy metal concentration in roots (mg.kg^{-1}DW)

$C_{rhizome}$ = Heavy metal concentration in rhizome (mg.kg^{-1}DW)

C_{leaf} = Heavy metal concentration in leaves (mg.kg^{-1}DW)

Metals are accumulated by plants and are primarily stored in the roots. The TF value indicates this when TF < 1, resulting in a smaller translocation ability to transfer heavy metals. Meanwhile, TF > 1 resulted in greater translocation ability to transfer heavy metals from roots to stems and leaves.

Statistical test

Data were analyzed descriptively using standard deviation and correlation between parameters. The relationship between metal concentrations in seagrass and the environment was conducted using Pearson correlation. One-way ANOVA examined significant differences in Pb concentrations between sediment and water at different locations, seagrass organs, and seasons. Tukey post hoc test was used to detect significant differences between organs, seasons, and locations, with F values having a significant difference when P<0.05. Statistical analysis was performed using IBM SPSS Version 25.

RESULTS AND DISCUSSION

In sediments, the Pb temporal distribution showed a high and low concentration in February-April and August-October 2020 with an average of 54.777±7.567 mg/kg and 46.338 ±7.619 mg/kg (Figure 2). This situation illustrates the influence of rainfall on waste, and high Pb indicated a buildup in Doreri Gulf. Heavy metals in sediments are influenced by those from suspended particles, which causes a lack of movement for deposition to occur (Roem et al. 2021b). Furthermore, the type and size of the sediment will affect the mobility of metals (Risjani et al. 2020). The statistical results of ANOVA (P <0.05) showed a very significant difference in the Pb concentration between the dry and rainy seasons.

The Pb temporal distribution in waters shows a tendency for dissolved heavy metal concentrations to be high and low with an average of 0.008±0.001mg/L and 0.007±0.001 mg/L. The increase in Pb was caused by people taking advantage of the rainy season to dispose of waste in heavy metals, causing the concentration to rise. According to Leung et al. (2020), people often use high rainfall conditions to pour waste containing B3 into the waters, influenced by rainfall intensity (Figure 3). The statistical results of ANOVA (P <0.05) showed a very significant difference in Pb concentration between the dry and rainy seasons.

Pb concentration in the waters of the Doreri Gulf ranged from 0.007-0.008 mg/L. The quality standard issued by the Ministry of Environment No. 51 of 2004 for marine biota is 0.008 mg/L since Pb in the Doreri Gulf is at the highest limit. The concentration in the sediment ranged from 46.337-54.777 mg/kg. According to the Canadian Council of Ministers of the Environment (CCME 2001), the Interim Sediment Quality Guidelines (ISQG) average value is 30.2 mg/kg. The Swedish assessment criteria are 47 mg/kg, while the Italian legal limit is 30. Additionally, the Norwegian assessment criteria are 120 mg/kg, hence this condition is a safe level.

Based on these parameters, it is vital to control the condition of Pb in water and sediments due to ecological pressures in the aquatic environment, which will have an impact on aquatic biota through the food chain. Heavy metal is a hazardous contaminant that causes lethal and non-lethal effects in aquatic creatures, such as decreased growth, behavior, and morphological traits (Usero et al. 2005). It can enter and accumulate in the body of aquatic organisms through the gills, body surface, digestive tract, muscles, and liver (Juniardi et al. 2022).

Comparison with several research shows that the average Pb concentration in sediment is higher than in water (Table 2). According to Werorilangi et al. (2016), Pb is insoluble and settles in the sediment; therefore, the concentration is higher. Leung et al. (2020) stated that heavy metals have properties that easily bind organic matter and settle at the bottom of the waters. The difference in Pb concentration is the result of many factors, such as the source of input to the environment and the characteristics of environmental factors (Yona et al. 2020).

The temporal distribution of Pb in *C. rotundata* demonstrates the influence of rainfall. High rainfall indicates that Pb is higher in each seagrass organ with an average of 1.360±0.567 mg/kg in leaves, 2.961±1.103 mg/kg in the rhizome, and 5.142±1.014 mg/kg in roots. In contrast, low rainfall causes lower Pb with an average of 1.007±0.264 mg/kg, 1.909±0.621 mg/kg, and 3.915±0.756 mg/kg in leaves, rhizomes, and roots (Figure 4).

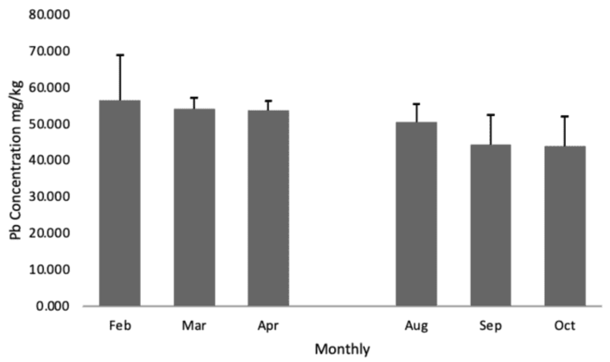

Figure 2. Temporal distribution of Heavy metal Pb in Sediment (mean ± SD)

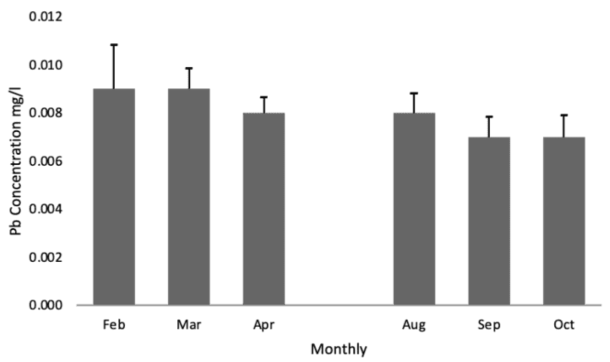

Figure 3. Temporal distribution of Heavy metal Pb in waters (mean ± SD)

Table 2. Comparison of Pb concentration in waters and sediments

Location	Method	Pb concentration		References
		Seawater	Sediments	
Doreri Gulf, Papua (Indonesia)	Aomic Absorption Spectrophotometer AAS (Model Pin Aacle 900 H) with a wavelength of 228.8 nm	0.007-0.008 mg/L	46.338-54.777 mg/kg	*This study*
Doreri Gulf, Papua (Indonesia)	Aomic Absorption Spectrophotometer AAS	0.006-0.008 mg/L		(Sembel et al. 2019)
Prigi Harbor, Trenggalek (Indonesia)	Atomic Absorbtion Spectrophotometry (AAS).	0.22-0.60 mg/L	0.17-0.57 mg/kg	(Yona et al. 2020)
Perairan Segara Anakan, Cilacap (Indonesia)	Atomic Absorbtion Spectrophotometry (AAS).	0.12-0.24 mg/L	3.96-21.99 mg.kg	(Yona et al. 2016)
Ambon Islands (Indonesia)	Atomic Absorbtion Spectrophotometry (AAS).	0.013-0.084 mg/L	0.084-2.096 mg/kg	(Tupan and Uneputty 2017)
Pamujaan Besar Teluk Banten (Indonesia)	Atomic Absorbtion Spectrophotometry (AAS).	0.006-0.027 mg/L	0.222-18.447 mg/kg	(Juniardi et al. 2022)
Perairan Bangka Selatan (Indonesia)	Atomic Absorbtion Spectrophotometry (AAS).	0.18-0.26 ppm	4.74-19.58 mg/kg	(Bidayani et al. 2017)
Northern Liadong Bay (China)	Inductively coupled plasma-mass spectrometry (ICP-MS)	3.98 µg/L	18.77 mg/kg	(Zhang et al. 2017)
Sicily Coastal (Italy)	AA Spectroscopy, ICP-OES, ICP-MS (Inductively coupled plasma-mass spectrometry)	0.64-0.80 µg/L	4.66-7.89 mg/kg	(Bonanno and Di Martino 2016)
Xincuan Bay, Hainan Island (China)	Inductively coupled plasma-mass spectrometry (ICP-MS)	1.47-8.04 µg/L	4.13-13.71 mg/kg	(Li and Huang 2012)
Thracian Coastal, Greece	Inductively coupled plasma-mass spectrometry (ICP-MS)	0.504-10.39 µg/L	24.55-47.67 mg/kg	(Malea et al. 2019)

This condition illustrates the correlation between *C. rotundata* and the surrounding environment. The ANOVA statistics ($P < 0.05$) showed a significant difference between the Pb concentration. Based on the results obtained, the response in water and sediment is strongly influenced by rainfall. According to Bonanno and Borg (2018), the difference in concentration indicates an interspecific relationship that seagrass accumulates metals from water and sediment. Its availability influences differences in seagrass tissue by absorbing heavy metals in the water column and sediment (Werorilangi et al. 2016)

Seagrasses accumulate heavy metals directly from the water through their body surface in the leaves and stems. In contrast, the leaves of aquatic plants can absorb water and dissolved substances, including heavy metals, through the stomata and cuticle (Bonanno and Di Martino 2016; Risjani et al. 2020; Hu et al. 2021). Risjani et al. (2021) stated that metals in water could be absorbed and accumulated in leaf tissue through a passive absorption process. Furthermore, metal translocation occurs through active transport and accumulates in the upper body of the leaves. Seagrass has ligands and can translocate Pb metals with other elements through the transport network (xylem) (Lee et al. 2019).

The largest concentration was observed in the roots, followed of the rhizome, and the leaves, based on the average of the three seagrass organs. This is consistent with Sembel et al. (2021), where heavy metals in the Doreri Gulf accumulate more in roots and rhizomes than in leaves caused by the high concentration of Pb in the sediment. Roots are morphological parts of plants that have the primary purpose of sustaining plant establishment above ground and absorbing water and minerals from the substrate (Birch et al. 2018a). This situation causes the concentration of Pb in the roots to be reasonably high.

In roots, heavy metal Pb accumulates mainly in the endodermal and exodermal tissues (Rosalina et al. 2019). According to Tupan and Azrianingsih (2016), these tissues are essential in protecting plants from stress due to heavy metals. With the strategy of accumulating heavy metals, plants can reduce the translocation to the rhizome and leaves. As a result, thickening of the tissue and premature aging of cells occurs after the accumulation process.

Llagostera et al. (2011) showed that seagrass *C. rotundata* responds to the entry of Pb like other vascular plants.

The heavy metal distribution in water was relatively the same (ANOVA P > 0.05) with an average value for Coastal Yankarwar, Nusmapi Islands, and Tanjung Manggewa as 0.007±0.001 mg/L, 0.007±0.002 mg/L, and 0.007±0.001mg/L. This does not differ at all locations due to an even distribution by the current pattern, which is the exact (Figure 5). Doreri Gulf is a semi-enclosed body of water; therefore, tidal current is the dominant current pattern. The tidal type of the water area is a transition between single and double types.

The spatial distribution of heavy metal Pb in sediments in Doreri Gulf shows that the Coastal Yankarwar location is relatively higher with an average value of 54.335±6.486 mg/kg compared to the locations of Nusmapi Islands 48.366±7.216 mg/kg and Tanjung Manggewa 48.588±6.989 mg/kg (Figure 5). This existence is strongly influenced by Coastal Yankarwar, which is close to settlements, ship repair shops, and diesel power companies. The results of the ANOVA statistic (P < 0.05) showed a significant difference between the Coastal Yankarwari location with the Nusmapi Islands and Tanjung Manggewa. Furthermore, the concentration of heavy metal Pb in the sediment did not differ between the Nusmapi Islands and Tanjung Manggewa (ANOVA P > 0.05). The sediment type strongly influences the concentration of heavy metals in sediments. The form of sediment at the Yankarwar Coastal location is terrigenous and has sedimentary rocks with grain sizes in the silt range, more refined than sand and coarser than claystone. The materials of terrigenous sediment are obtained from the terrestrial environment (Kanhaiya et al. 2017).

Fine sediments have a higher percentage of organic matter than coarse types. This is related to oceanographic conditions and calm waters, allowing the deposition of mud sediments followed by the accumulation of organic matter and heavy metals to the bottom of the waters (Roem et al. 2021a). In addition, the surface of fine or small particles has a maximum surface area since the durability and storage against nutrients heavy metals are higher (Sembel et al. 2021).

Heavy metal Pb in sediments at the Nusmapi Islands and Tanjung Manggewa locations had similar concentration values. This is because both locations are slightly far from the high activity of the city of Manokwari with carbonate. Additionally, it is coarser than silt and contains more than 50% carbonate material; hence, sediments' adsorption of heavy metals is lower (Anggraini et al. 2020).

Seagrass beds also affect the ability of incoming waves and currents to transport particles. These conditions modify the oceanographic environment by (i) attenuating currents and wave energy losses, (ii) changing the velocity profile near the bottom to prevent affecting the thicker boundary layer, and (iii) increasing or decreasing turbulence and promoting material transport (Potouroglou et al. 2017; Lanuru et al. 2018; Anggraini, Yanuhar and Risjani 2020). Additionally, the ability to inhibit sediment movement has been reported (Roem et al. 2021a). Lefaan et al. (2013) have shown that the species in the Doreri Gulf can reduce turbulence, intensity, and shear velocity by proportionally varying amounts based on canopy height, leaf blade density, and morphometry.

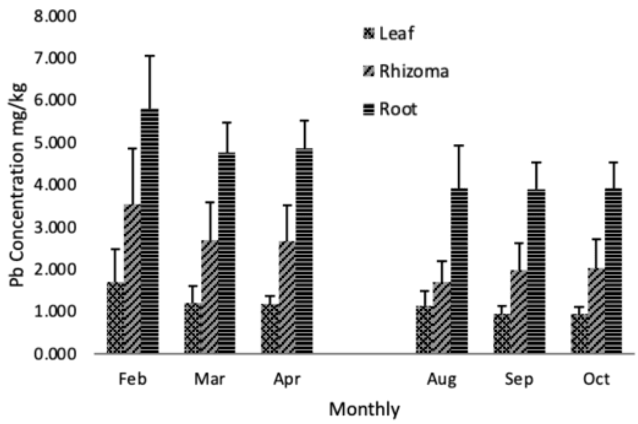

Figure 4. Temporal distribution of Heavy metal Pb in Seagrass *Cymodocea rotundata* (mean ± SD)

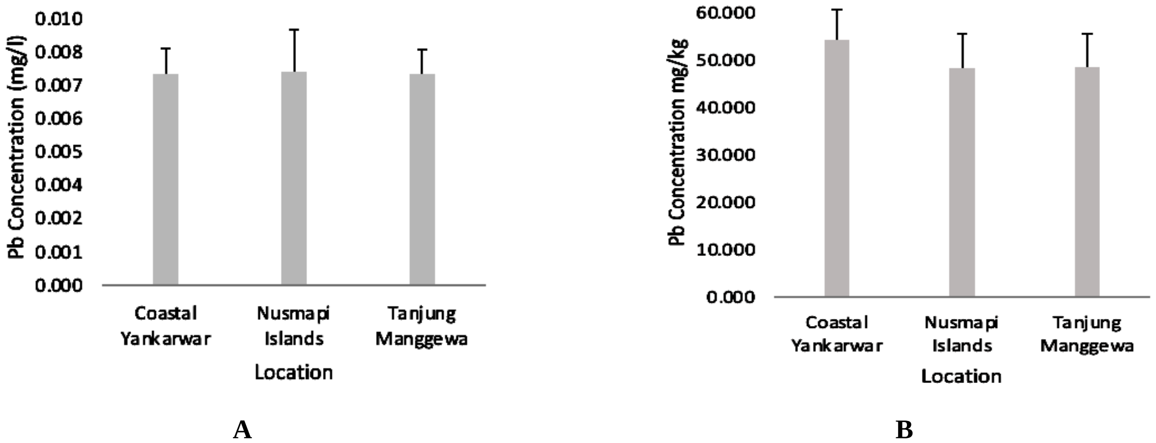

Figure 5. Spatial distribution of Heavy metal Pb in waters (A) and Sediment (B) (mean ± SD)

Tidal currents in the Doreri Gulf are alternated in almost opposite directions (Figure 6). Minimal current velocity occurs when the flow reverses direction, this condition is called slack water. The speed of tidal currents in conditions toward high and low tides varies from zero to maximum speed (Alianto et al. 2016). This illustrates the concentration of heavy metal Pb in the gulf's waters following the tidal current pattern, therefore, the distribution is relatively even.

The spatial distribution of bioaccumulation of heavy metal Pb in seagrass *C. rotundata* at each location shows that the entire organ trend to be the same as the average leaf in Coastal Yankarwar 1.082±0.240 mg/kg, Nusmapi Islands 1.088±0.342 mg/kg and Tanjung Manggewa 1.245±0.460 mg/kg. Furthermore, the rhizome is the average of 2.372±1.005 mg/kg in Coastal Yankarwar, 2.461±0.854 mg/kg in the Nusmapi Islands, and 2.313±0.842 mg/kg in Tanjung Manggewa. The average root in Coastal Yankarwar, Nusmapi Islands and Tanjung Manggewa was 4.262±0.913 mg/kg, 4.552±1.219 mg/kg and 4.734±0.907 mg/kg (Figure 7). The results of the ANOVA statistic ($P > 0.05$) showed that there was no difference between the locations of each organ. This equation is influenced by the pattern of tidal currents that spread evenly and are responded to by the seagrass. The presence of heavy metal Pb is obtained directly through absorption by roots from sediments and leaves (Bidayani et al. 2017). Therefore, each location has about the same level of heavy metal Pb in the water and sediment.

The mechanism for the entry of heavy metal Pb coincides with the entry of nutrients into the roots, and the process occurs in leaves through photosynthesis (Tupan and Azrianingsih 2016). The type and size of seagrass significantly affect the amount of heavy metal absorption (Werorilangi et al. 2016). Additionally, environmental factors such as water conditions, substrate type and size, pH, temperature, salinity, current, turbidity, nutrient content, and rainfall significantly affect the response of seagrass to heavy metals (Buwono et al. 2021).

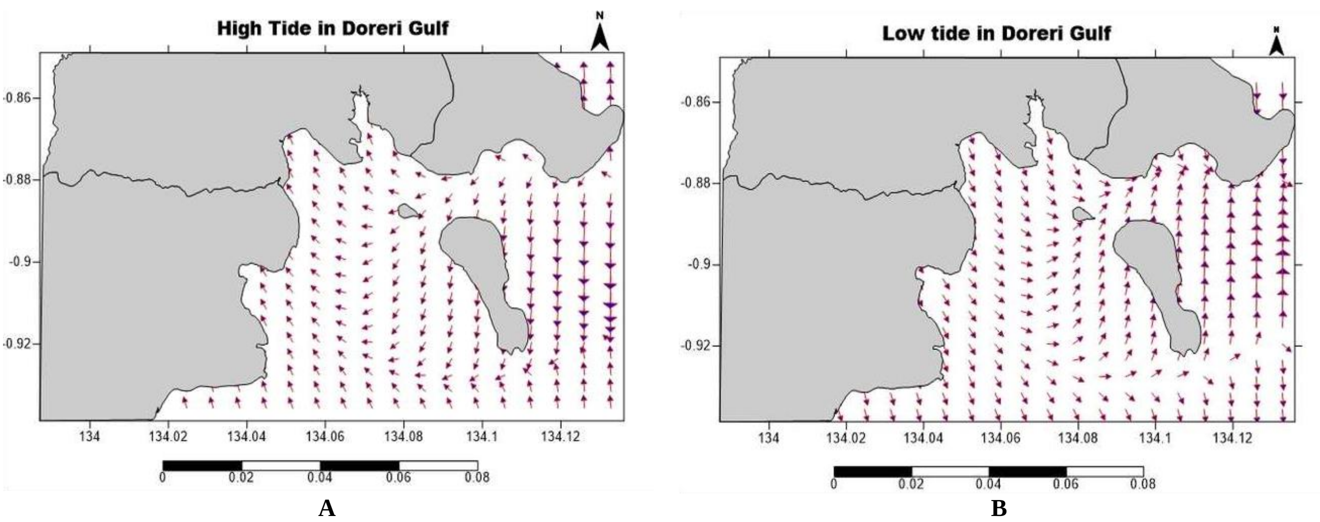

Figure 6. Tidal currents research results in Doreri Gulf: (A) High tide and (B) Low tide

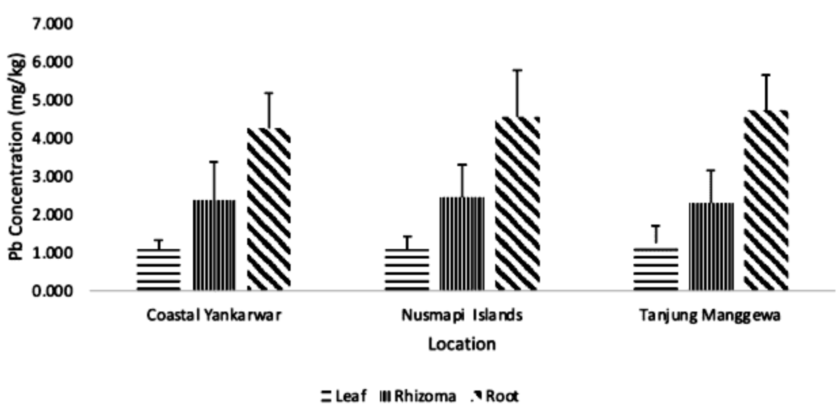

Figure 7. Spatial distribution of heavy metal Pb in seagrass *Cymodocea rotundata* (mean ± SD)

The comparison of several studies showed that the accumulation of heavy metal Pb was different for each type and organ of seagrass. For example, *Cymodocea rotundata* and *Halophila stipulacea* showed the same accumulation level: root> rhizome > leaf. On the other hand, the species *Cymodocea cerulata*, *Cymodocea nodosa*, *Posidonia oceanica*, and *Thalassia hemprichii* had the same sequence of accumulation, namely roots > leaf > rhizomes (Table 3). These results illustrate the more prominent role of rhizomes in *C. rotundata* and *H. stipulacea* as bioaccumulator structures than *C. serulata*, *C. nodosa*, *P. oceanica*, and *T. hemprichii*. The rhizomes generally show the lowest levels of heavy metal Pb concentration. The Pb accumulates in the roots and leaves; hence, this presence can be used as a bioindicator in an aquatic environment.

This seagrass has the potential to have two pathways to absorb elements through its leaves and roots from the water column and sediment (Bonanno and Borg 2018). According to Ambo-Rappe (2014), most of the heavy metals in aquatic ecosystems are concentrated in sediments and act as absorbers of several pollutants, resulting in the risk of pollution. Therefore, roots and leaves are the structures that best reflect the amount of heavy metal Pb in seagrass. Organ selection should be considered an essential criterion during biomonitoring campaigns because roots are more effective for long-term campaigns, while leaves are more suitable for monthly biomonitoring (Risjani et al. 2020).

Table 3. Comparison of Pb concentration in seagrass

Location	Sample	Pb concentration	Seagrass	Method	References
Dorery Gulf, Indonesia	Root Rhizome Leaf	4.529 ± 1.083mg/kg 2.436 ±1.036 mg/kg 1.183 ± 0.474 mg/kg	*Cymodocea rotundata*	Aomic Absorption Spectrophotometer AAS (Model Pin Aacle 900 H) with a wavelength of 228.8 nm	*This study*
Hincun Bay, China	Leaf	10-15.5 µg/g	*Cymodocea rotundata*	AA 220 graphite furnace atomic absorption equipped with background correction	(Li and Huang 2012)
South Bangka, Indonesia	Root Rhizome Leaf	0.34 ± 0.08-3.04 ± 0.11 mg/kg 0.11 ± 0.00-3.01 ± 0.08 mg/kg 0.26 ± 0.03-0.94 ± 0.07 mg/kg	*Cymodocea serulata*	Test flame with AAS	(Bidayani et al. 2017)
Sicily Italy	Root Rhizome Leaf Root Rhizome Leaf	3.85-6.99 mg/kg 0.21-1.87 mg/kg 1.42-3.85 mg/kg 1.67-2.64 mg/kg 0.95-1.10 mg/kg 1.46-1.55 mg/kg	*Cymodocea nodosa*	AA Spectroscopy, ICP-OES, ICP-MS (Inductively coupled plasma-mass spectrometry)	(Bonanno et al. 2017; Bonanno and Di Martino 2016) (Bonanno and Raccuia 2018b)
	Root Rhizome Leaf	1.25-1.57 mg/kg 0.93-1.04 mg/kg 0.18-0.21 mg/kg	*Halophila stipulacea*	AA Spectroscopy, ICP-OES, ICP-MS (Inductively coupled plasma-mass spectrometry)	(Bonanno and Raccuia 2018a)
	Root Rhizome Leaf	2.78-3.28 mg/kg 0.75-0.86 mg/kg 0.13-1.53 mg/kg	*Posidonia oceanica*	AA Spectroscopy, ICP-OES, ICP-MS (Inductively coupled plasma-mass spectrometry)	(Bonanno and Raccuia 2018a)
Gulf of Gabes (SE,Tunisia)	Root Rhizome Leaf	1.27 ± 0.20 0.23 ± 0.05 2,50 ± 0.16	*Posidonia oceanica*	Inductively coupled plasma optical emission spectrometry (ICP-OES) method (ULTIMA Expert Horiba Scientific, GET)	(El Zrelli et al. 2017)
Paciran Coastal, Lamongan	Root	0.0567-0.0794 ppm	*Enhalus acoroides*	Atomic Absorbtion Spectrophotometry (AAS)	(Sugiyanto et al. 2016)
Indonesia	Rhizome	0.1-0.3 µg/g		Inductively coupled plasma-mass spectrometry (ICP-MS)	(Sidi et al. 2018)
	Leaf	0.05-0.0684 ppm		Atomic Absorbtion Spectrophotometry (AAS)	(Sugiyanto et al. 2016)
Ambon Island, Indonesia	Root Rhizome Leaf	0.18-0.59 ppm 0.15-0.18 ppm 0.16-0.46 ppm	*Thalassia hemprichii*	Atomic Absorbtion Spectrophotometry (AAS)	(Tupan and Uneputty 2017)

All seagrass morphological tissues or parts can be used as bio accumulators and bioindicators of heavy metal pollution from waters and sediments (Hu et al. 2021). However, the concentration in each morphological section differs depending on environmental conditions and seagrass physiology. This determines the ability of a part to store or accumulate heavy metals to permit active or passive transport. Furthermore, this allows the seagrass to absorb and accumulate heavy metals simultaneously because the whole body is submerged in water. The metal concentration in each seagrass morphological organ is different (Llagostera et al. 2011).

The distribution of heavy metal concentrations of Pb can be found in the water, sediment, and seagrass organs of *C. rotundata* (Table 4). BCF describes the efficiency of picking up heavy metals from sediments and accumulating them in the network. The results showed that the seagrass species *C. rotundata* had average bioconcentration of Pb <1 per location and season. This illustrates the lack of ability to mobilize Pb from sediment to roots (Bonanno and Di Martino 2016; Bonanno et al. 2017; Bonanno and Borg 2018). However, seagrass *C. rotundata* has the potential to reduce contamination by absorbing these heavy metals and storing them in the body. In general, the translocation from sediments to above-soil organs is through deep plant tissues (Werorilangi et al. 2016; Bonanno et al. 2017; Risjani et al. 2021). Therefore, the morpho-anatomical and physiological differences between seagrass species will affect the translocation of Pb, then the number of environmental factors that influence and interact, such as organic matter content, reduction potential, pH, temperature, salinity, plant phenology, and metal speciation (Bonanno and Raccuia 2018a). Subsequently, BCF >1 and BCF<1 were strongly influenced by the concentration of heavy metals in the waters and sediments (Ambo-Rappe 2014).

Contamination of sediment and seagrass is one of the most dangerous forms of pollution. It causes severe problems for environmental sustainability and the health of plants, animals, and humans. Therefore, information on the content of Pb was carried out to determine the pollution conditions in Doreri Gulf. Bioaccumulation is the act of progressively increasing the concentration of a type of compound in an organism caused by the rate of uptake is more significant than its release (Gopi et al. 2020). According to Bonanno and Di Martino (2016), bioindicators for heavy metal pollution-induced water quality degradation benefit from an organism's high accumulation capacity.

Translocation Factor (TF) shows the distribution pattern of heavy metals. It is influenced by metal properties, environment, and plant physiology. Llagostera et al. (2011) stated that the accumulation in seagrass body parts is influenced by metal uptake, the availability of metals in the environment, and seagrass physiology. Translocation results showed the highest and lowest leaf-rhizome average in Tanjung Manggewa and Nusmapi Island, the highest and lowest root-rhizome in Nusmapi Island and Tanjung Manggewa, as well as the highest and lowest leaf-root in Yankarwar Coastal and Nusmapi Island. Seasonally, the leaf-rhizome and leaf-root organs were the most abundant, while the rhizome-root organ was the least abundant. On the other hand, the leaf-rhizome and leaf-root organs had the lowest levels during the rainy season, while the rhizome-root organ had the highest. Yankarwar Coastal showed a decreasing order of Pb concentration from root>rhizome>leaf. This is the same as the seagrass species *H. stipulacea* (Bonanno, Borg, and Di Martino 2017; Bonanno and Borg 2018; Bonanno and Raccuia 2018b). Meanwhile, in Tanjung Manggewa, the order of decreasing Pb concentration was root > leaf > rhizome. This is the same as the species *Cymodocea nodosa* and *Posidonia oceanica* (Paz-Alberto et al. 2015; Werorilangi et al. 2016; Bonanno and Raccuia 2018b). The results showed the different roles of rhizomes in *C. rotundata* as bioaccumulator structures.

Table 5 shows the value of TF < 1, indicating the lack of translocation ability to transfer Pb to the organ tissues. This is in line with the research of Sembel et al. (2021), where the TF value of heavy metals Pb, Cd, Cu, and Cr^{6+} shows an average TF value of <1 for each location. Based on the range of each location from the season, leaf-rhizome in Yankarwar Coastal and dry season show TF value close to one. This illustrates the potential ability of *C. rotundata* to translocate heavy metals to the deep organ tissues. According to Deng et al. (2004), the TF value is directly proportional to the ability to translocate heavy metals to various organ tissues. The translocation from sediments to roots and within plant tissues is related to pH, reduction potential, temperature, salinity, organic matter content, and other elements present. Similarly, other factors such as seasonal variations in physiology can also contribute to bioaccumulation and internal translocation capacity (Lanuru et al. 2018).

The condition of heavy metal Pb in the Doreri Gulf showed that the temporal distribution in water, sediment, roots, rhizomes, and leaves tend to be high and low in the rainy and dry seasons. In contrast, the spatial distribution shows Pb in water, roots, rhizomes, and leaves at each location are relatively similar. The spatial distribution of Pb in the sediments between the Coastal Yankarwar and Nusmapi Islands, as well as the Coastal Yankarwar and Tanjung Manggewa were very different. However, there was no difference between the Nusmapi Islands and Tanjung Manggewa. Each location showed bioconcentration of BCF <1, indicating the lack of ability to mobilize Pb from the sediment to the roots. The translocation factors showed a TF value < 1, implying the inability to transfer Pb to the organ tissues in the seagrass. This study shows the different roles of each organ in seagrass *C. rotundata* as a bioaccumulator structure. Roots and leaves are the structures that best reflect the concentration of heavy metal Pb in seagrass, so organ selection should be considered an important criterion during biomonitoring. Roots are more effective for long-term biomonitoring while leaves are more suitable for short-term.

Table 4. Bioconcentratin factor in seagrass *C.rotundata* ($C_{root}/C_{sediment}$) (mean ± SD)

	Location			Season	
	Yankarwar coast	**Nusmapi Island**	**Tanjung Manggewa**	**Rainy**	**Dry_Season**
BCF	0.080 (0.054-0.167)	0.094 (0.042-0.142)	0.098 (0.068-0.142)	0.094 (0.058-0.142	0.086 (0.042-0.133)

Table 5. Translocation factors in seagrass *C. rotundata* (mean ± SD)

Sample type	Location			Season	
	Yankarwar coast	**Nusmapi Island**	**Tanjung Manggewa**	**Rainy**	**Dry_Season**
C_{leaf}/C_{root}	0.268 (0.170-0.390)	0.248 (0.104-0.443)	0.260 (0.131-0.428)	0.250 (0.104-0.443)	0.259 (0.131-0.428)
C_{rhzome}/C_{root}	0.538 (0.263-0.836)	0.548 (0.285-0.897)	0.483 (0.212-0.746)	0.551 (0.212-0.836)	0.494 (0.247-0.897
$C_{lea}f/C_{rhizome}$	0.529 (0.242-0.980)	0.475 (0.151-0.788)	0.567 (0.258-0.837)	0.477 (0.151-0.852)	0.571 (0.266-0.980)

Seagrass *C. rotundata* can be used as a promising bioindicator of heavy metal Pb in sediments. High concentrations in roots and leaves, can contribute to and be an important element for the survival of *C. rotundata* in highly contaminated environments. Further research on how important *C. rotundata* is in accumulating heavy metal Pb. This study also showed that *C. rotundata* did not significantly reflect the heavy metal content of Pb in the water. Seagrass communities have proven useful not only as bioindicators of heavy metal Pb but also as early detectors in contamination across trophic levels that can lead to warning concentrations for human consumption. Lack of biomonitoring of heavy metal Pb, seagrass *C. rotundata* can provide an important model for decision making. Effective management of environmental resources in coastal marine ecosystems.

ACKNOWLEDGEMENTS

The authors are grateful to the coastal and marine pollution team of the Faculty of Fisheries and Marine Science, Universitas Papua (FPIK UNIPA), Manokwari, Indonesia, for assisting in data collection and collection in the field, as well as to the Laboratory of Aquatic Resources, FPIK UNIPA, and the Laboratory of Productivity and Aquatic Environment of IPB University, Bogor, Indonesia for facilitating and analyzing the samples.

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