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An Assessment of Pb and Cu in Waters, Sediments, and Mud Crabs (*Scylla serrata*) from Mangrove Ecosystem Near Tanjung Api-Api Port Area, South Sumatra, Indonesia

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Abstract
Heavy metal pollution from anthropogenic activities can harm aquatic ecosystems. This study aims to determine the concentration of heavy metals (Pb and Cu) in waters, sediments, and mud crabs (*Scylla serrata*), and to analyze the relationship between environmental parameters and *S. serrata* which is consumed by humans. Samples were taken in the mangrove ecosystem around the Tanjung Api-Api port area in South Sumatra, Indonesia. Pb and Cu analysis used the Atomic Absorption Spectrophotometer (AAS). Pb and Cu linkages in waters, sediments, and *S. serrata* analyzed by SigmaPlot V12.5 and Principal Component Analysis (PCA) analyzed by XLSTAT 2022. The limit consumption of *S. serrata* was calculated using MWI (Maximum Weekly Intake) and MIT (Maximum Intake Tolerance). Based on the results, the heavy metal Pb in water was 0.1055 – 0.1322 mg.L^{-1}, and Cu was not detected. Furthermore, Pb in sediments ranged from 7.0104 - 11.8186 mg.kg^{-1}, Cu 3.7127 - 4.5347 mg.kg^{-1}, and Pb in *S. serrata* ranged from 0.0001 - 0.0021 mg.kg^{-1}, and Cu ranged from 0.03 – 0.0791 mg.kg^{-1}. The concentration of heavy metals in water, sediment, and *S. serrata* had not exceeded the specified quality standard, except for Pb in water. The principal component analysis obtained F1 (44.35%), F2 (27.53%) and F3 (17.83%) groups. Based on MWI and MIT values that *S. serrata* was still safe for human consumption.

Keywords
Anthropogenic Activities, Heavy Metals, Mud Crab, Sediment

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1. INTRODUCTION

The rapid economic development in coastal areas, such as industrial activities, household waste, agriculture, and port activities, produces substantial quantities of pollutants discharged into coastal waters (Apri et al., 2021; Rizk et al., 2022). The waste generated from these activities can cause a decrease in water quality, impacting aquatic ecosystems (Rozirwan et al., 2022). One of the causes of the decline in water quality is heavy metal pollution because it has toxic, persistent, and bioaccumulate characteristics in nature, which can have detrimental effects on global ecosystems and human health (Briffa et al., 2020; Rizk et al., 2022). Heavy metals belong to the group of pollutants because they are difficult to decompose (non-degradable) and are easy to accumulate with a weight of 5 g.cm^{-3} (Shrestha et al., 2021).

In general, heavy metals for the growth and development of organisms are divided into two categories: essential and non-essential heavy metals. Many essential heavy metals such as Cu, Fe, Mn, Co, Zn, and Ni are essential for maintaining the human body metabolism as long as they are not used excessively. Non-essential heavy metals such as Cd, Pb, Hg, Cu, and Al are not even needed in small amounts for every metabolic process and can cause poisoning (toxicity) (Bharti and Sharma, 2022). These metals pollute the waters and accumulate in sediments and organisms (Rizk et al., 2022). The high level of heavy metals in the waters negatively influences the biochemical and morphological traits of microbes, organisms, and the human body, causing many serious diseases such as cancer, paralysis, and carcinogens. Human well-being can be threatened due to heavy metals, which are considered the main components of pollutants in environmental waters (Briffa et al., 2020).

Organisms from the crustacean class can be used as bioindicators of heavy metal contamination in waters and sediments because of their ability to accumulate heavy metals. *S. serrata* lives in muddy substrates, so it has the potential as a bioindicator of heavy metal pollution (Soegianto et al., 2022). *S. serrata* is one of the highest export commodities in Indonesia and is among the most prominent fishery products in Banyuasin

Regency, South Sumatra. Monitoring heavy metals in water, sediment, and *S. serrata* is important to determine the potential for bioaccumulation and for environmental management. The interaction between biotic and abiotic in the waters creates an interconnected atmosphere (Maxwell et al., 2017). All anthropogenic that occurs in the environment seems to be a marker to know the status of the biotic group (Huggett, 2018; Upadhyay, 2020). Waters have a very dynamic and actual character so regular monitoring is needed to determine the latest environmental quality (Whitehead et al., 2019; Ustaoğlu et al., 2020).

Several researchers have studied heavy metal content, including Cu, Zn, Mg, Cd, and Cr, in crabs from mangrove ecosystems in Qi'ao, China (Zhang et al., 2019). The accumulation of heavy metal Cd in *S. serrata* in estuarine (Zhang et al., 2022b), and heavy metal health risk assessment in *S. serrata*, East Java Indonesia (Soegianto et al., 2022). Tanjung Api-Api mangrove areas have an essential role for the people of South Sumatra, such as shipping routes leading to the port and fishery activities. The difference in this study is not only analyzing *S. serrata* but also the relationship between heavy metals in the water and sediments where *S. serrata* is captured. This study aimed to analyze the heavy metal content of Pb and Cu in water, sediment, and *S. serrata* with water parameters and the maximum limit of *S. serrata* consumption.

2. EXPERIMENTAL SECTION

2.1 Study Area and Sampling Location

This research was carried out in the mangrove ecosystem near the Tanjung Api-Api port area in South Sumatra, Indonesia, at five observation stations with extensive mangrove vegetation (Figure 1). This location received seawater from the Bangka strait and freshwater from the Banyuasin river (Saputra et al., 2021; Almaniar and Rozirwan, 2021; Nugroho et al., 2022). Anthropogenic activities such as port, agriculture, industry, fisheries, and households could impact on these quality waters. Apri et al. (2021) stated that anthropogenic sources affect water environmental quality. Samples were taken during low tide conditions. The water conditions at the time were ideal for various crustaceans and gastropods, which dug and moved to terrestrial substrates in mangroves for protection (Rozirwan et al., 2022).

Water samples were taken on the surface of the water using a 500 mL polyethylene bottle and then preserved using HNO_3 until the pH reached ≤ 2 to prevent changes in organic matter by bacterial activity and transferred in an ice box (Rizk et al., 2022). Sediment samples were taken using sediment core, then put in plastic bags and chilled in an ice box (Apri et al., 2021). Crab samples were taken using traps carried out at low tide. All samples obtained were taken to the laboratory for further analysis.

2.2 Environmental Parameters

Water quality measurements were carried out in situ with three repetitions consisting of salinity using a refractometer, water temperature using thermometer, dissolved oxygen (DO) using DO meter (Hanna HI 98193), and pH using pH meter (Hanna HI 9811–5) (Apri et al., 2021).

Figure 1. Map of Sampling Location in Mangrove Areas Near the Tanjung Api-Api Port

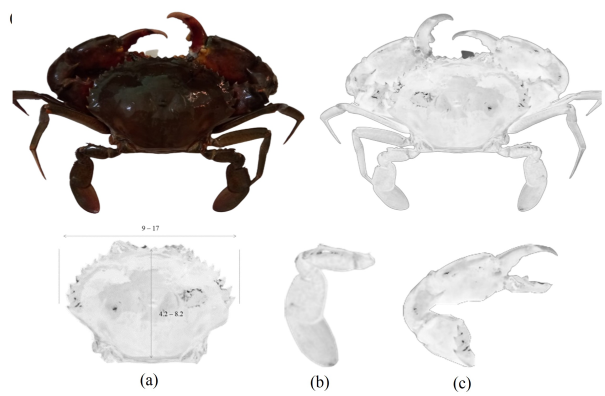

Figure 2. Details of *Scylla serrata* Morphological Characteristic; (a) Carapace, (b) Leg, (c) Cheliped

2.3 Sediment Grain Size Measurement

Sediment grain size analysis was carried out using wet sieving. Substrate type of sediment (gravel, sand, mud, and clay) analyzed using shepard triangle diagram with Microsoft Excel 2019. The type of sediment fraction was determined based on the most dominant values of the composition (Almaniar and Rozirwan, 2021).

2.4 Sample Preparation and Destruction

Water samples was filtered with 0.45 μm whatman filter paper, for sediment samples cleaned of foreign objects such as plastic pieces, and organic materials, to be further dried in an electric oven UF 55 Memmert at 60°C for 30 min and mashed into a powder with a mortar and pestle until fine particles and stored in polyethylene bottles (Yan et al., 2021). *S. serrata* was cleaned and mashed using a blender.

Destruction process were performed on heavy metals Pb and Cu for water, sediment, and *S. serrata* refers to (Rizk et al., 2022). Fifty milliliters of water sample was put into erlenmeyer and added 5 mL of HNO_3, heated with hotplate stirrer C-MAG HS 7 until the water sample reaches 15-20 mL. Furthermore, the sediment was acidly destroyed by putting ± 3 g of the sample in Erlenmeyer and adding 25 mL of distilled water to be heated on a hotplate with a temperature of 105°C-120°C. Mix HNO_3 as much as 5 mL and waited until the volume becomes 10 mL. After removal and cooling, added 5 mL of concentrated HNO_3 and 1 mL - 3 mL of $HClO_4$. The sediment sample was reheated with dampness until white smoke appeared, and the sample became clear, followed by heating for 30 min. After cooling, the sediment sample was filtered using quantitative filter paper.

Destruction of *S. serrata* samples was done using wet digestion to determined metal elements with low concentrations. The weighed sample was put into an Erlenmeyer, and HNO_3 (5–10 mL) and H_2O_2 (2 mL) were added. Digestion was carried out by setting up a microwave program. The result of the digestion was transferred into a 50 mL vial with ultra-distilled water and stored in polyethylene containers at room temperature until further measurements.

2.5 Atomic Absorption Spectroscopic Measurement

Measurement of heavy metal concentrations of Pb and Cu using an Atomic Absorption Spectrophotometer (Shimadzu AA-7000) with a wavelength of 283.3 nm for Pb and 324.7 nm for Cu.

2.6 Data Analysis

2.6.1 Bioconcentration Factor (BCF) Index

Bioconcentration factor (BCF) index were used to determine the pollutants bioaccumulation level in *S. serrata* mud crabs. The BCF calculated using the BCF formula.

$$\text{BCF index} = \frac{\text{Heavy metals concentration in biota}}{\text{Heavy metals concentration in water/sediment}} \quad (1)$$

2.6.2 Distribution Levels of Heavy Metals

The distribution level of heavy metals Pb and Cu in water, sediment, and *S. serrata* was analyzed using SigmaPlot V12.5.

2.6.3 Principal Component Analysis (PCA)

Principal component analysis determined the relationship between water parameters (DO, temperature, pH, and salinity) and the concentration of heavy metals in water, sediment, and *S. serrata*. This analysis was processed using XLSTAT 2022 (Apri et al., 2021).

2.6.4 Maximum Limit of Heavy Metals Consumption

Provisional Tolerable Weekly Intake was weekly intake accepted (without health effects) of trace and toxic metals through marine biota samples. The determination of the maximum limit of heavy metal consumption contained in *S. serrata* could be calculated using the following formula.

$$\text{Maximum Weekly Intake} = \text{Weight} \times \text{Provosional Tolerable Weekly Intake} \quad (2)$$

$$\text{Maximum Tolerable Intake} = \frac{\text{Maximum Weekly Intake}}{\text{Heavy metals concentration in biota}} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Environmental Parameters

The environmental parameters were measured in situ in the sampling station (Table 1). The ecological parameters measured at five stations were pH, dissolved oxygen, temperature, and salinity.

Based on the results of measurements, the pH values at all stations tended to close fresh water in the range of 6.09 to 7.02. The highest value was station 2, and the lowest was station 5. DO had varying values ranging from 4.7 to 7.18 $mg.L^{-1}$. The highest value was station 2, and the lowest was station one. Temperature and salinity at all stations were not much different, the temperature ranging from 23.57 to 25.54°C and salinity from 11 to 12 ‰.

The Tanjung Api-Api has an extensive mangrove area, which is suitable for biota as a place to feed ground and a habitat for their life cycle. The high anthropogenic activity in this location cause changes in environmental water quality. According to Almaniar and Rozirwan (2021), water quality parameters around Tanjung Api-Api waters were classified as moderate to heavily polluted. Water quality parameter changes can be caused by mixing water masses. Based on the results of environmental parameters, good conditions for the growth of *S. serrata* were found in all station based on dissolved oxygen, temperature, pH, and salinity. Mud crabs have good adaptation in different salinity conditions ranging from 10 ‰ to 34 ‰, pH 8.0 to 8.5, temperature 23°C to 30°C, and dissolved oxygen more than 3 $mg.^{-1}$ (Pedapoli and Ramudu, 2014). A significant increase in temperature will cause higher evaporation and impact the drying of the sludge substrate. This situation makes it difficult for mud crabs develop biologically such as mating and molting (Leoville et al., 2021). Moreover, very alkaline or acidic pH conditions will be dangerous because they can cause metabolic and respiratory disorders (Pedapoli and Ramudu, 2014; Paran et al., 2022). Salinity is an essential factor for the spread of organisms in the sea, and oxygen is a limiting factor in determining the presence of organisms in the water (Nugroho et al., 2023). The variety of dissolved oxygen can be affected by waste materials or pollutants in the water. Environmental factors can affect heavy metals variations in chemical and physical parameters tend to affect the presence, displacement, and toxicity (Soegianto et al., 2022).

Table 1. The Measurement of Environmental Parameters in the Sampling Station

Stations	pH	DO ($mg.L^{-1}$)	Temperature (°C)	Salinity (‰)
1	6.76 ± 0.03	4.70 ± 0.17	25.29 ± 0.33	12 ± 0.00
2	7.02 ± 0.05	7.18 ± 0.07	23.57 ± 0.49	11 ± 0.00
3	6.45 ± 0.02	5.91 ± 0.12	24.33 ± 0.03	12 ± 0.00
4	6.47 ± 0.03	6.25 ± 0.22	24.33 ± 0.08	11 ± 0.00
5	6.09 ± 0.05	5.48 ± 0.03	25.54 ± 0.08	11 ± 0.00

Data are shown mean ± SD with 95% confidence level

3.2 Description of *Scylla serrata*

There were two crabs collected in each station. The crab had size at 66.91 – 404.91 g in weight, carapace width ranging from 9 cm to 17 cm, and carapace length ranging from 4.2 cm to 8.2 cm (Figure 2). Morphologically, *S. serrata* had a green carapace with nine spines on the right and left, six spines between the eyes, a red pincer tip larger on the right than the left, and three pairs of walking legs and a pair of swimming legs.

Many people eat mud crabs for seafood consumption. The selection of mud crabs as a measure of feasibility for consumption is also based on measuring the width of the carapace, divided into three phases. The juvenile phase has a carapace width of < 7 cm, the early stage has a carapace width of 7–12 cm, and the adult phase has a carapace width of >12 cm (Paran et al., 2022). Mud crabs have entered the adult phase, which is ready for consumption and has matured the gonads for reproduction. Mud crabs prepared to mate will enter mangrove forests. The environment of mangrove forests indicates a natural resource suitable for mud crabs. Nugroho et al. (2022) stated that the substrate on which mangrove vegetation develops is soft muddy, not hard soil.

3.3 Sediment Grain Size

The substrate type at the study site resulted from the Shephard Triangle Method (Figure 3). The determination of sedimentary substrates around the waters of Tanjung Api-Api mangrove areas were divided into four types (gravel, sand, mud, and clay). The results showed that the substrate type at all stations was clay. The sedimentary substrate around the Tanjung Api-Api mangrove areas was dominated by clay. The percentage of clay from all stations ranged from 83.04 to 91.79% (Table 2). The highest rate of clay was at station three, and the lowest was at station five. In other composition, sand percentage was from 3.04 to 8.37% and silt percentage was from 4.03 to 8.59%.

The sediment is the main accumulation point for metals in the aquatic environment. Heavy metal distribution in sediments is influenced by chemical sediment composition and grain size (Fitrah et al., 2020). *S. serrata* live in the area with clay substrate (Soegianto et al., 2022). Rozirwan et al. (2022) stated that mud crabs are often found in muddy substrates because suitable for their growth, provides a lot of food source and place to make holes to avoid predatory risk. Moreover, clay

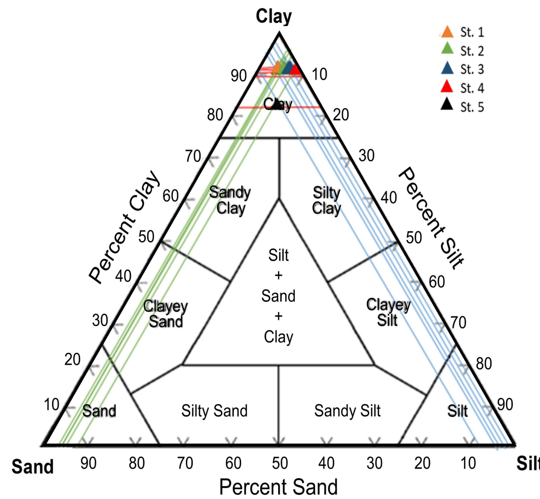

Figure 3. Classifications of Sediment Type with Shepard Triangle Method

Table 2. Sediment Grain Size in Each Station

Station	Sediment fraction (%)				Grain size
	Gravel	Sand	Mud	Clay	
1	0.00	6.74	4.89	88.36	Clay
2	0.00	5.56	4.03	90.41	Clay
3	0.00	3.04	5.17	91.79	Clay
4	0.00	4.30	4.31	91.39	Clay
5	0.00	8.37	8.59	83.04	Clay

substrate is easy to precipitate and accumulate because these particles have a high content of organic matter and high surface area for heavy metal absorption (Yan et al., 2021).

3.4 Heavy Metals Concentration

The results of heavy metal concentrations in water, sediments, and *S. serrata* were showed in (Table 3). Heavy metals in the water at all stations for Pb ranged from 0.1055 to 0.1334 $mg.L^{-1}$, and Cu was not detected (nd). Heavy metals in sediments for Pb ranged from 7.0104 to 11.8186 $mg.kg^{-1}$, and Cu ranged from 3.7127 to 4.5954 $mg.kg^{-1}$. Accumulation Pb in *S. serrata* ranged from nd at station 3 to 0.0021 $mg.kg^{-1}$ at station 4 and

Cu ranged from 0.0300 to 0.0791 mg.kg^{-1}. The accumulation of heavy metal Pb in water had exceeded the quality standard value of 0.0044 mg.L^{-1} at all stations. Accumulation of Pb and Cu in sediments and *S. serrata* had not exceeded the quality standards. Based on the results of One-Way Anova analysis using a confidence level of 95% (α < 0.05) showed significant difference in Pb concentration in sediment.

Aquatic ecosystems become ecosystems that are easily polluted by heavy metals because of mobility. Anthropogenic activities are one of the causes of water pollution (Zhang et al., 2022a). Heavy metal concentrations that have exceeded the quality standard allow for a decrease in water quality, sediments, and biota (Bharti and Sharma, 2022). Based on the analysis results, the concentration of Pb in the waters at each station has exceeded the threshold, and Cu was not detected. Avvari et al. (2022) stated that heavy metals in the water could disperse rapidly from their source because seawater is temporary and is affected by currents, tides, and other physical movements. Sampling in this study was carried out during low tide conditions. According to the conditions, the concentration of heavy metals tends to be higher because of the waters will experience a dilution process that will wash away the pollutants and affect their distribution (Rizk et al., 2022). Another activity factor that was estimated to have the potential to produce waste containing Pb was transportation and ports waste. Pb concentrations in waters are thought to have been influenced by ship maintenance activities and fuel oil spills from transportation activities (Briffa et al., 2020; Fitria et al., 2023).

3.5 Bioconcentration Factor (BCF) Indexes

Bioconcentration factors index (BCF) were used to determine the accumulation proportion of heavy metals Pb and Cu in *S. serrata* against heavy metals in sediment (Figure 4). Based on the results, the BCF value of heavy metals in *S. serrata* against in sediments ranged from 0 to 0.00024 (Pb) and 0.00690 to 0.01721 (Cu). The results showed that bioconcentration of Cu was higher than Pb in *S. serrata*. It could be concluded that the accumulation of Cu is higher than Pb in *S. serrata*.

The value of the BCF describes the ability of biota to accumulate heavy metals in the water and sediment in the environment (Bharti and Sharma, 2022; Rizk et al., 2022). The BCF of Cu is more incredible than Pb due to an essential metal organisms need in small amounts for metabolic processes. Still, if it exceeds the quality standards for heavy metals, it becomes toxic and harmful. High values of BCF indicate high levels of accumulated heavy metals and can have health implications that cannot be ignored for humans. According to Orabi and Khalifa (2020), a high BCF value in an organism indicates that the organism is capable of accumulating heavy metals. Bioaccumulation of heavy metals in organisms depends upon the concentration level in sediments, physiological factors, physicochemical properties, and biological activities in the ecosystem (Leoville et al., 2021; Bharti and Sharma, 2022).

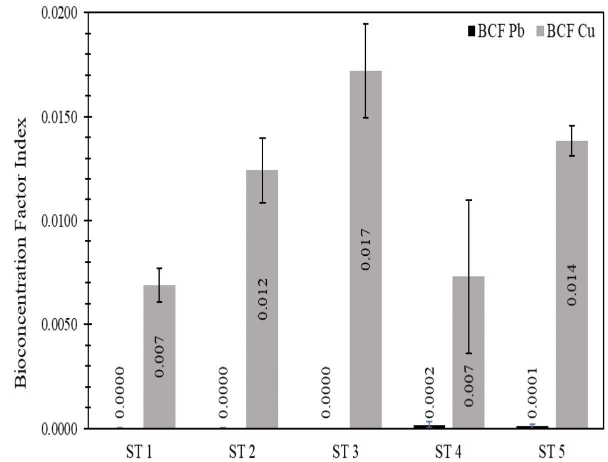

Figure 4. Bioconcentration factor (BCF) index of Pb and Cu in *S. serrata*

3.6 Distribution of Heavy Metals in Water, Sediment, and *Scylla serrata*

The distribution of Pb in waters, sediments, and *S. serrata* showed a parabolic line. In other media, Pb concentration showed fluctuation line in sediments and *S. serrata*. There was no distribution of Cu in the water because it was not detected at the time of measurement, whereas in sediment and *S. serrata* it formed a parabolic line distribution (Figure 5).

The distribution of Pb at the station 1 varied, sediment showed a high value, while water and *S. serrata* showed a low value compared to other stations. The heavy metal Pb at stations 2 to station 3 showed increasing pattern in sediments and waters, while decreasing in *S. serrata*. Furthermore, the distribution of Pb in water and sediment at station 4 had decreasing pattern, while at *S. serrata* it had an increasing pattern. At station 5, all accumulation media of Pb showed decreasing pattern. The distribution of Cu in sediments and *S. serrata* at station 1 showed a different pattern. Sediments showed the highest concentration compared to other stations, while *S. serrata* showed a low pattern. At station 2, the concentration of Cu in the sediment decreased, while at *S. serrata* it had an increasing pattern. The patterns between sediment and *S. serrata* was the same at stations 3, 4, and 5.

The concentrations of Pb and Cu in the sediments at all stations were still below the established quality standards, so it is still suitable for the habitat of *S. serrata*. Heavy metal concentrations in sediments are generally higher than in water (Bharti and Sharma, 2022). Heavy metals are also found to bind organic matter, settle to the bottom of the waters and blend with sediments (Algül and Beyhan, 2020; Rizk et al., 2022). Another factor, the research site is located in an estuary which forbidden place for waste containing heavy metals from anthropogenic activities (Niu et al., 2021; Zhang et al., 2022a). Moreover, the sedimentary substrate type influences the weight

Table 3. Pb and Cu Heavy Metals Accumulation in Water, Sediments, and *S. Serrata*

Sample	Heavy Metals	Quality Standard	Station				
			1	2	3	4	5
Water (mg.L^{-1})	Pb	0.0044	0.1055	0.1322	0.1334	0.1309	0.1192
	Cu	0.0013	nd	nd	nd	nd	nd
Sediment (mg.kg^{-1})	Pb	50	11.5922a	8.2391b	11.8186a	8.6954ab	7.0104c
	Cu	65	4.5347	4.2017	4.5954	3.7127	4.0055
S. serrata (mg.kg^{-1})	Pb	1.5	0.0002	0.0001	nd	0.0021	0.0008
	Cu	10	0.0313	0.0550	0.0791	0.0300	0.0624

Note: nd: not detected

of accumulated metals (Yan et al., 2021). The finer substrate has a high surface area and a stable ionic density to bind heavy metal particles. According to the grain size of the sediment, the smaller one has higher potential heavy metals concentration.

Several studies of heavy metal accumulation in *S. serrata* and other commercial crab species have been reported in *S. serrata* species recovered from the waters off Threspuram, Southeast Coast of India, showed Pb concentrations of 0.72 mg.kg^{-1} and Cu of 10.6 mg.kg^{-1} in gills (Yogeshwaran et al., 2020). From the coast of East Java, Indonesia, several locations have been reported to have *S. serrata* with Pb and Cu accumulation including from Solo River with Pb of 0.395 mg.kg^{-1} and Cu of 6.045 mg.kg^{-1}, Brantas River with Pb of 0.270 mg.kg^{-1} and Cu of 5.627 mg.kg^{-1}, and Banyuwangi Coastal with Pb of 0.260 mg.kg^{-1} and Cu of 5.142 mg.kg^{-1} (Soegianto et al., 2022). Commercial crab species *Portunus trituberculatus* from the coastal waters of Zhejiang Province showed the accumulation of Pb of 0.077 mg.kg^{-1} and Cu of 35.09 mg.kg^{-1} (Liu et al., 2020). In northern Bay of Bengal, *Portunus pelagicus* species contained Pb of 1.67 mg.kg^{-1} and Cu of 21.06 mg.kg^{-1} (Karar et al., 2019).

The presence of heavy metals in the study site will also affect heavy metal accumulation in biota ecosystems. The concentrations of Pb and Cu in *S. serrata* meat were below the quality standard. Although the heavy metal contents were much more significant in the sediment, this value does not mean that the *S. serrata* value was safe. Another factor that causes heavy metal accumulation in *S. serrata* was a detritivor (Pedapoli and Ramudu, 2014; Paran et al., 2022). Crustaceans eat Polychaeta and zooplankton in the sediment, which means they absorb a lot of heavy metals (Fitrah et al., 2020). The higher concentration of Cu compared to Pb is because the body of the organism contains the heavy metal Cu, which functions in metabolic processes and the formation of hemoglobin, and because of its physiology when added to the body of an organism (Harlyan et al., 2015; Rizk et al., 2022). Cu derived from water can increase its concentration.*S. serrata* can regulate the levels of essential heavy metals in their bodies but cannot limit non-essential heavy metals (Leoville et al., 2021; Soegianto et al., 2022).

3.7 Principal Component Analysis (PCA)

The principal component analysis showed three groups of analysis (Figure 6). The cumulative percentage of F1, F2 and F3 were 44.35%, 27.53%, and 17.83%. The biplot of PCA was presented in 6. Based on the biplot, F1 observation was station 1, 2, and 4 while the variable was dissolved oxygen, Pb in waters, Cu and Pb in sediment, salinity, and temperature. F2 observation was station 3 while the variable was Cu and Pb in *S. serrata*. F3 observation was station 5 while the variable was pH.

The variations in Pb and Cu distribution patterns in waters, sediments, and *S. serrata* in this study could be caused by environmental conditions. According to Avvari et al. (2022) and Rizk et al. (2022), distribution of heavy metals can be affected by temperature, dissolved oxygen, pH, brightness, and salinity. Oceanographic factors can also cause differences in heavy metal levels caused by current velocities. Warmer water temperatures provide a higher potential for heavy metal solubility than normal temperature conditions (Selvi et al., 2019; Algül and Beyhan, 2020). The results also showed that the high Pb in the waters was inversely proportional to the low Cu in the sediments. Due to the characteristics of heavy metals, which are generally higher in sediments, it is possible that Pb will be higher in sediments (Bharti and Sharma, 2022; Rizk et al., 2022).

3.8 Maximum Consumption of *Scylla serrata*

The consumption limit of *S. serrata* could be calculated using the MWI (maximum weekly intake) and MTI (maximum tolerable intake) (Table 4). The maximum consumption limit of *S. serrata* (MTI) from the analysis was 2.343 kg per week (Pb) and 4.072 kg per week (Cu).

The limit of consumption of *S. serrata* allowed per week is very high because the concentration of Pb and Cu in *S. serrata* is lower than quality standard. Therefore, *S. serrata* is still very safe for consumption. However, this does not rule out the possibility that the path of heavy metal pollution can disrupt aquatic ecosystems and harm humans if not addressed immediately (Soegianto et al., 2022; Zhang et al., 2022b). Therefore, efforts are needed by the government and society to reduce heavy metal pollution so that aquatic ecosystems can be

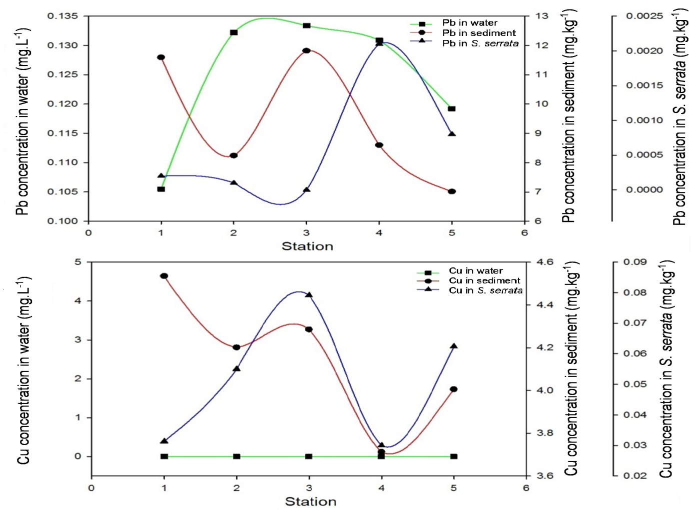

Figure 5. Distribution of Pb and Cu Heavy Metals in Each Station

Table 4. Maximum Consumption Limit of *S. serrata*

Heavy Metals	Average Concentration of Heavy Metals ($mg.kg^{-1}$)	PTWI ($mg.kg^{-1}$ per week)	Weight (kg)	MWI (mg per week)	MTI (kg per week)	Quality Standard (WHO, 1989) PTWI ($\mu g.kg^{-1}$ per week)	Quality Standard (WHO, 1989) PTWI ($mg.kg^{-1}$ per week)
Pb	0.00064	0.025	60	1.500	2.343	25	0.025
Cu	0.05156	3.500	60	210	4.072	3500	3.5

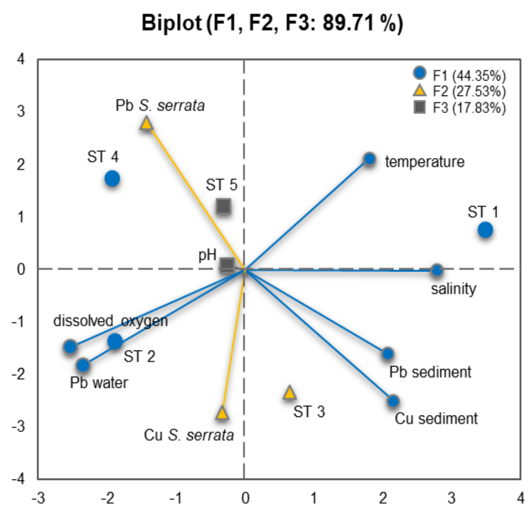

Figure 6. Principal Component Analysis of Environmental Parameters and Heavy Metals

sustainable (Briffa et al., 2020). Monitoring waste disposal into the waters regularly and inspecting ships to reduce oil spills into the seas are two forms of effort to control metal pollution. Outreach to the public about the survival of mud crabs and their relation to heavy metal waste in the waters is necessary to be safe for consumption.

4. CONCLUSION

The concentration of the heavy metal Pb in water has exceeded the quality standard while Pb and Cu concentrations in sediments and *S. serrata* has exceeded the quality standard. Based on the maximum limit value of meat consumption per week, *S. serrata* in Tanjung Api-Api is still safe for consumer. Future research should focus on analyzing heavy metals in another commercial marine biota.

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