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Heavy Metals Bioaccumulation in Different Sizes of the Green Mussel (Perna viridis) from Ujungpangkah Waters, Gresik, Indonesia

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ABSTRACT

Green mussels (*Perna viridis*) are non-selective filter feeders that can be used as aquatic bioindicators. The development of green mussel (*P. viridis*) cultivation is due to the ease of cultivation techniques, including the bamboo pole method, pole raft, floating raft, and long line. One of the potential areas for clam production is the Ujungpangkah waters located in Gresik Regency. However, in addition to potential coastal areas, countless industrial areas may impact surrounding aquaculture activities. This study aimed to determine the concentration of heavy metals in green mussels (*P. viridis*), water, and sediment. This study aimed to assess the differences in heavy metal accumulation levels in green mussels (*Perna viridis*) of varying sizes and to evaluate water quality conditions in the Ujungpangkah coastal waters, Gresik. *Ex-situ* testing of seawater, sediment, and green mussel samples was conducted using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine the concentrations of heavy metals, including lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg). The results showed significant variation in the levels of these heavy metals. Among them, arsenic (As) exhibited the highest average concentration (1.22 mg/kg), while mercury (Hg) was not detected in any of the samples. Based on the calculated water quality index, the Ujungpangkah coastal area is classified as having low pollution. Furthermore, evaluation of the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) values indicated that green mussels across all three size categories remain safe for human consumption and do not pose health risks.

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INTRODUCTION

The fishing industry is a vital economic sector in Indonesia, contributing to food security, coastal community income, employment opportunities, and national economic growth **(Zulkarnain *et al*., 2014)**. The rapid development of the fisheries sector is evident from the increased production value between 1980 and 2012, placing Indonesia as the world's fourth-largest fishery producer—accounting for 4.6% of global output with a total production of 3,067,660 tons. This makes Indonesia a key player in animal protein production from fisheries **(Yusuf and Trondsen, 2013)**.

In Indonesia, particularly in East Java, the availability of animal protein from white meat and fishery products continues to grow. Freshwater fisheries (e.g., catfish and tilapia) are being developed alongside brackish and marine fisheries. Among the top five fishery export commodities—shrimp, tuna, seaweed, crab, and squid—white shrimp (*Litopenaeus vannamei*) provides the highest per-kilogram revenue, generating approximately USD 2,040.2 million, or 39% of the total export value. Tuna and octopus contributed 14% and 10%, respectively, while seaweed and other fishery commodities accounted for 5% and 25% of total Marine and Fishery Management (MFM) output in 2020. However, shrimp production in Southeast Asia, particularly in Indonesia, has declined in recent years due to deteriorating water and environmental quality, leading to increased disease prevalence **(Pauly & Zeller, 2019)**.

Various pollution sources are believed to contribute to the degradation of water quality, adversely affecting shrimp yields. Among these, heavy metal contamination—such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg)—poses a significant threat to aquatic life, including shrimp, and poses serious health risks to humans through bioaccumulation in seafood. These heavy metals are hazardous to human health, and their presence in the environment has been exacerbated by industrialization and anthropogenic activities. Toxic metal pollution in water and air is a global environmental issue that affects hundreds of millions of people, particularly children **(Ahmed *et al*., 2019; Balali-Mood *et al*., 2021)**. Heavy metals are persistent in the environment, difficult to degrade, and tend to bioaccumulate in living organisms, potentially leading to fatal concentrations **(Prasetyo *et al*., 2018; Briffa *et al*., 2020)**. Exposure to toxic metals such as mercury and lead can result in serious health complications including chronic abdominal pain, gastrointestinal bleeding, diarrhea, and kidney failure **(Bernhoft, 2013; Jaishankar *et al*., 2014)**.

Mussels, particularly green mussels, are recognized as bioaccumulators due to their benthic nature. As non-selective filter feeders with low mobility, green mussels (*Perna viridis*) are effective bioindicators of aquatic pollution. Their tissues can reflect the concentration of heavy metals in their habitat. Additionally, green mussel farming is low-cost and environmentally sustainable **(Putranto, 2011)**.

According to data from the Ministry of Maritime Affairs and Fisheries, Indonesia produced 10,509,177 tons of shellfish in 2019, increasing to 11,240,652 tons in 2021 **(Hidayat, 2017)**. One of the most promising areas for shellfish production in East Java is Ujungpangkah, located in Gresik Regency. Ujungpangkah waters serve as important fishing grounds and supply water for aquaculture ponds. The local community relies heavily on the cultivation of green mussels, which are abundant in the area. In 2016, the production and harvest of green mussels in Ujungpangkah reached 3,052.89 tons, slightly declining to 2,923.46 tons in 2017 **(Nurdiani *et al*., 2023)**. However, environmental quality in Ujungpangkah waters has declined, in part due to heavy metal pollution.

Therefore, research is needed to assess the concentrations of lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg), and evaluate the food safety of green mussels, which are a key fishery commodity in the region.

The objectives of this study were to determine the concentrations of heavy metals in green mussels, water, and sediment from the Ujungpangkah Subdistrict, East Java, Indonesia. Additionally, the study aimed to assess differences in heavy metal accumulation across green mussels of different sizes, and evaluate water quality conditions in the area.

The findings of this study are intended to provide essential information on the levels of heavy metal pollution—specifically Pb, As, Cd, and Hg—in green mussels. This can serve as a basis for future research and monitoring related to heavy metal contamination and environmental management in Ujungpangkah waters.

MATERIALS AND METHODS

Sampling collection

Sampling was conducted from September to December 2023 in Ujungpangkah waters, Ujungpangkah District, Gresik Regency, East Java (6°53'10.482"S, 112°30'33.316"E), an area known for green mussel cultivation. Samples of green mussels, water, and sediment were collected during the transition from the dry to rainy season, with the mussels harvested at approximately seven months of age. Approximately 100 grams of green mussels were collected from each site for heavy metal analysis. Mussels were sampled in various sizes, measured from the anterior to posterior ends, and grouped by size as follows: small (<5 cm), medium (5–10 cm), and large (>10 cm), with 10 individuals per size group. All samples were immediately stored in ice-filled cool boxes to prevent decomposition.

Water samples were collected at three depth levels—surface, middle, and bottom—to represent the vertical water column. Sampling was supported by local fishermen, who retrieved the mussel cultivation substrates using bamboo poles. Each water sample (600mL) was collected in sterile bottles and sampled in triplicate by submerging the vials to a depth of one meter.

Sediment samples were collected using a 30 × 30cm Ekman grab sampler. Approximately, 1kg of sediment was gathered and placed in labeled plastic containers. Following collection, all mussel, water, and sediment samples were transported in cool boxes for laboratory analysis.

Heavy metal concentrations (Pb, As, Cd, and Hg) were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at PT Angler BioChemLab, a certified private laboratory located in Surabaya.

Additionally, water quality parameters—including salinity, pH, dissolved oxygen (DO), and chemical indicators such as ammonium, nitrate, nitrite, and phosphate—were analyzed to assess environmental conditions.

Data analysis

This study employed the observation approach. Data were quantitatively examined using multiple indices to represent the level of pollution and safety caused by the accumulation of heavy metals Pb, Cd, As, and Hg in green musscle (*P. viridis*), water, and sediments. The calculation results are presented in a table to help understand the quantitative data gathered during the investigation. The indices are as follows:

***Geo-accumulation index* (I*geo*)**

The geo-accumulation Index (Igeo) measures heavy metal pollution in sediments **(Kabir *et al*., 2011)**. **Muller (1969)** classified pollution levels based on Igeo as unpolluted (Igeo≤0), unpolluted to moderately polluted (0<Igeo≤1), moderately polluted (1<Igeo≤ 2), moderately to heavily polluted (2<Igeo≤3), heavily polluted (3<Igeo≤ 4), heavily polluted to highly polluted (4<Igeo≤5), and highly polluted (Igeo≥5).

$$\mathrm{Igeo} = \mathrm{Log}_2 \left[\frac{\mathrm{Cn}}{1.5\ \mathrm{Bn}} \right]$$

Where:

Cn: Metal concentration of the sample examined

Bn: Standard concentration of heavy metals in nature (As = 1.5 mg/kg **(Taylor & McLennan 1995)**; Pb = 17 mg/kg **(McLennan, 2001)**; Cd = 0.08 mg/kg **(Chen Chiu-Wen *et al*., 2012)**; Hg = 0.03 mg/kg **(Haris & Aris 2013)**.

***Contamination factor* (CF)**

The Contamination Factor (CF) is a measure used to assess heavy metal contamination in sediments **(Hidayati *et al*., 2020)**. The CF value is classified into four levels: CF<1, which indicates little contamination, 1≤CF≤3, which indicates moderate contamination, 3≤CF≤6, which indicates significant contamination, and CF>6, which indicates extremely high contamination **(Satapathy & Panda 2015)**. CF was calculated using the following Hakanson-based formula **(Hakanson, 1980)** as follows:

$$CF = \frac{C_{metal}}{C_{background}}$$

Where:
C_{metal}: Heavy metal concentration in the sediment sample
$C_{background}$: Standard concentrations of heavy metals in nature (As = 1.5 mg/kg **(Taylor & McLennan, 1995)**; Pb= 17 mg/kg **(McLennan, 2001)**; Cd= 0.08 mg/kg **(Chen *et al*., 2012)**; Hg= 0.03 mg/kg **(Haris & Aris, 2012)**.

Bio concentration factor **(BCF)**

The Bio Concentration Factor (BCF) is an index that measures the rate at which aquatic organisms accumulate heavy metals in soil or water **(Bo *et al*., 2015)**. **Baker (1981)** divided BCF into two accumulation levels: low accumulation (BCF < 100) and medium accumulation (BCF 100-1000). Connell and Miller's BCF measurement formula **(Connel & Miller 2006)** was used as follows:

$$BCF = \frac{kb}{cw}$$

Where:
BCF = Bio Concentration Factor/bioconcentration factor
Kb = Heavy metal content in biota
Cw = Heavy metal content in water or sediment

Estimated daily intake **(EDI)**

Estimated daily intake (EDI) is the amount of metals consumed by the human body each day through food **(Purbonegoro, 2020)**. EDI is expressed in milligrams per kilogram of body weight per day. If the EDI value of heavy metals is equal to or less than the RfD (oral reference dose), the danger to health from heavy metals is considered negligible. EDI is deemed low risk if it is greater than 1-5 times the RfD. If the EDI is greater than 5-10 times the RfD, it is regarded moderate risk, while greater than 10 times is deemed high risk **(Javed & Usmani, 2016)**. Hidayati's earlier study **(Hidayati *et al*., 2020)** provides the following formula for calculating EDI:

$$EDI = \frac{EF \times ED \times IR \times C_m}{BAW \times TA}$$

Where:
EF: Frequency of exposure (365 days/year)
ED: Duration of exposure
IR: Consumption rate (41.3 x 10-3 kg/day)
Cm: heavy metal concentration in mussels (mg/kg)

BAW: Body weight (kg)
TA: ED x 365 days

***Target hazard qoutient* (THQ)**

Target hazard qoutient (THQ) is an index that measures the level of risk to human health. A THQ value of <1 shows that daily exposure has no adverse health consequences, whereas a THQ value >1 suggests that daily exposure has long-term negative health impacts on people **(USEPA, 2011)**. THQ can was computed using the formula proposed by **Anandkumar *et al*. (2018**) as follows:

$$THQ = \frac{EDI}{Rfd}$$

Where:
EDI: Estimated daily intake (mg/kg body weight/day)
RfD : Oral reference dose (Pb: 0.0035 mg/kg body weight/day; Cd: 0.001 mg/kg body weight/day **(USEPA, 2011)**; Hg = 0.0001 mg/kg/day **(Alik *et al*., 2022)**; RfD As = (0.0003 mg/kg/day **(Liono *et al*., 2022)**).

***Hazard index* (HI)**

The hazard index (HI) is an index that evaluates the potential human health impacts of all metals. HI values less than one suggest that adverse health concerns are uncommon, however HI values greater than one indicate that it may be harmful to human health **(USEPA, 2011)**. The HI can be estimated using the formula developed by **Yap *et al.* (2016)** as follows:

$$HI = \sum_{i=1}^{n} THQi$$

Where:
THQ_i: health hazard target result of each metal
n: number of heavy metals used (4 types: Pb, Cd, As, and Hg).

RESULTS

Heavy metals in green mussels (*Perna viridis*)

The results of heavy metal testing on green mussels (*Perna viridis*) concentrations of heavy metals lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg) were the highest in large size mussels (>10cm) (Fig. 1).

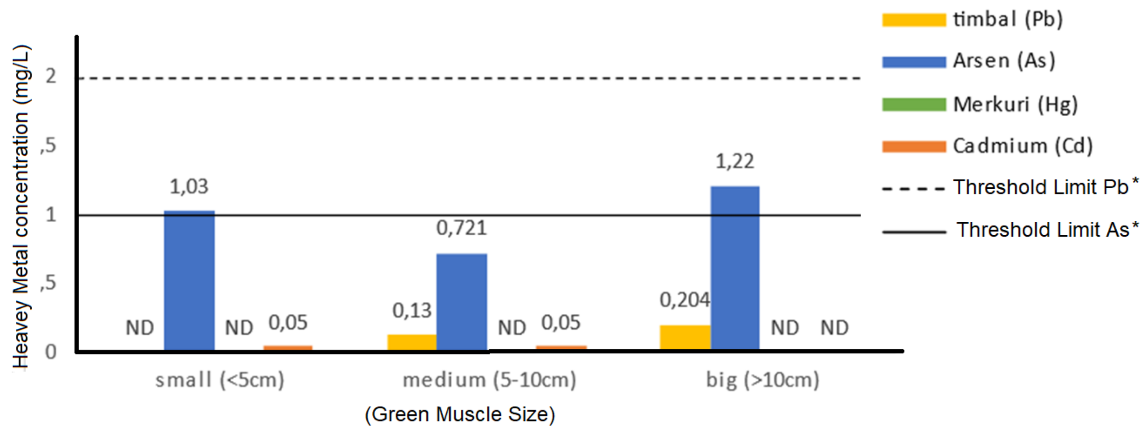

Fig. 1. Measurement results of heavy metal concentrations (Pb, As, Hg, and Cd) in various sizes of green mussels (*) Indonesia of Quality Standard (SNI 7387-2009). ND: (Not detected)

The results of heavy metal testing in green mussels (*Perna viridis*) showed that lead (Pb) concentrations ranged from 0.13 to 0.204mg/ kg, while arsenic (As) concentrations ranged from 0.721 to 1.22mg/ kg. For lead (Pb), green mussels in all size categories—small (< 5cm), medium (5– 10cm), and large (> 10cm)—had concentrations that did not exceed the quality standard based on SNI 7387-2009. However, arsenic (As) concentrations in small (< 5cm) and large (> 10cm) mussels exceeded the quality standard, while medium-sized mussels (5– 10cm) remained within acceptable limits.

Variations in heavy metal concentrations are influenced by several factors, including water quality, seasonal changes, and biological characteristics such as the age and size of the mussels **(Denil *et al.*, 2017)**. Among all tested groups, large mussels (> 10cm) exhibited the highest concentrations of Pb, As, Cd, and Hg (Fig. 1).

Pollution index in green mussels, water, and sediment

Pollution levels were assessed using seven different indices: Concentration Factor (CF), Enrichment Factor (EF), Geoaccumulation Index (Igeo), Bio-Concentration Factor (BCF), Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) (Table 1). Each index reflects the degree of pollution associated with the two primary heavy metals under investigation: Pb and As.

ICP-MS analysis of water samples revealed that lead (Pb) concentrations were below the minimum detection limit (0.005mg/ kg), and thus not detected (ND). However, arsenic (As) concentrations exceeded the quality standard for marine biota, with values reaching 0.027mg/ kg—surpassing the limit set by the Decree of the Minister of Environment No. 51 of 2004, which specifies a maximum allowable concentration of 0.0125 mg/kg for arsenic in seawater.

Mercury (Hg) and cadmium (Cd) were also undetected in the water samples, as their concentrations were below the detection limits of 0.010 mg/kg for Hg and 0.0125 mg/kg for Cd, respectively. All three water sampling points showed ND (Not Detected) results for Pb, Hg, and Cd. These findings indicate that the average concentrations of these metals are still below the seawater quality standards outlined in Ministerial Decree No. 51 of 2004, which sets the maximum allowable limits for Hg and Cd at 0.001mg/ kg.

Conclusion on water suitability

Based on the test results, the Ujungpangkah waters are still classified as suitable for green mussel cultivation. Despite elevated arsenic levels, the overall water quality remains within acceptable environmental thresholds for sustaining marine biota and aquaculture operations.

Table 1. Pollution index in green mussels (*Perna viridis*) and sediment

No	Index	Heavy metal	*Perna viridis* size categories			Pollution level
			S (<5 cm)	L (5-10 cm)	L (>10cm)	
1	BCF (Bio-Concentration Factor	Pb	ND	ND	ND	Low
		As	57,300	40,110	67,87	Low
		Hg	ND	ND	ND	Low
		Cd	0,05	0,05	ND	Low
2	EDI (Estimated Daily Intake)	Pb	ND	$0,42\ x\ 10^{-4}$	$0,66\ x\ 10^{-4}$	Low
		As	$3,5\ x\ 10^{-4}$	$2,3\ x\ 10^{-4}$	$3,9\ x\ 10^{-4}$	Low
		Hg	ND	ND	ND	Low
		Cd	0,0163	0,0163	ND	Low
3	THQ (Target Hazard Quotient)	Pb	ND	$0,1\ x\ 10^{-4}$	$0,2\ x\ 10^{-4}$	Low
		As	$11,2\ x\ 10^{-4}$	$7,8\ x\ 10^{-4}$	$13,2\ x\ 10^{-4}$	Low
		Hg	ND	ND	ND	Low
		Cd	$0,1\ x\ 10^{-4}$	$0,1\ x\ 10^{-4}$	ND	Low
4	HI (Hazard Index)	Pb, As, Cd, Hg	0,00112	0,00079	0,00134	Low
Sediment						
5	CF (Concentration Factor)	Pb	0,294			Low
		As	0,441			Low
		Hg	ND			Low
		Cd	0,391			Low
6	Igeo (Geo Accumulation Index)	Pb	0,059			Low
		As	0,089			Low
		Hg	ND			Low
		Cd	0,391			Low
7	EF (Enrichment Factor)	Pb	0,401			Low
		As	0,826			Low
		Hg	ND			Low
		Cd	2,432			Low

ND: not detected

DISCUSSION

This study successfully examined the heavy metal content in mussels with three size groups and the heavy metal content in the habitat where they live (water and sediment). Heavy metals enter green mussels through two ways, namely the digestive system and the respiration system **(Ali *et al*., 2022)**. In the respiration process, the organ that plays an important role is the gills. The gills are the part that comes in direct contact with water contaminated with heavy metals. Heavy metals that are filtered will be distributed to the digestive system and will accumulate in the shellfish meat and water-soluble heavy metal compounds will enter the blood circulation and be distributed to the kidneys and mantle **(Melinda *et al*., 2021; Rahim & Yaqin 2022)**. Small (< 5cm) and medium (5- 10cm) green mussels are more susceptible to heavy metals due to the high metabolic rate to grow at that size. At adult size (> 10cm) the ability to absorb heavy metals is more efficient because adult green mussels reach the reproductive stage **(Adeyeye & Ayoola 2013; Chen Yueh-Min *et al*., 2014)**.

The accumulation of heavy metals has a direct impact on the life of green mussels due to the tendency to store heavy metals over a long period of time. One of the negative impacts is the malformation of green mussel shells up to 1.5 times thicker than normal, making it relatively difficult to notice when the green mussels are small and the larger the size of the green mussel, the greater the deformation of the shell. Penetration of the shell is due to the exposure of green mussels to heavy metals during the shell formation process **(Nour, 2020)**.

The test results on sediments showed heavy metals such as lead (Pb) of 20.6mg/ kg and arsenic (As) of 6.62mg/ kg, and these values did not exceed the quality standards based on Australian and New Zealand Guidelines for Fresh and Marine Water Quality. This guideline is called the Australian and New Zealand Environment and Conservation Council 2000 **(ANZECC, 2000)**. The average concentration of heavy metals Hg and Cd in sediment samples with heavy metal parameters Hg in three locations is ND (Not Detected), this is because the concentration when testing the sample is below the limit of the tool (0.250mg/ kg for Hg limit and 0.125mg/ kg for Cd limit). While in the heavy metal parameter, Cd levels in three locations are 0.39, 0.286, and 0.29mg/ kg, respectifely. The average concentration of both heavy metals at all sampling site are still below the standard of the ANZECC / Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) quality standard **(Simpson *et al.*, 2013)**, which sets the maximum limit of heavy metal contamination of Hg (0.15mg/ kg) and Cd (1.5mg/ kg). Therefore, the results of sediment testing at the bottom of Ujungpangkah waters are suitable as a medium for cultivating green mussels.

Ujungpangkah waters have experienced heavy metal contamination because polluted water conditions can be detected from the sediment at the bottom of the water. The results of heavy metal testing in sediments obtained values with high concentrations compared to water and green mussels. The concentration of heavy metals in sediment is generally 1000 times more than that of water. Farmers will also be disturbed by the heavy metal sedimentation process that occurs in Ujungpangkah Waters. However, heavy metal concentrations are subject to change because observations are still limited **(Sari *et al.*, 2016; Rayyan *et al.*, 2019)** to monitoring to support the mussels culture in Ujungpangkah waters **(Safitri, 2023)**.

Based on the results of the Contamination Factor (CF) calculation, the highest value is in arsenic (As) with a value of 0.441 while the lowest is in lead (Pb) at 0.294. The results show that it is on the CF<1 scale so that heavy metals in sediments in Ujungpangkah waters indicate low pollution. The results of the calculation of Enrichment Factor (EF) the highest value in cadmium (Cd) was 2.432, while the lowest value in lead (Pb) was 0.401. EF can be used to identify changes in heavy metals in waters caused by humans so that it can inform the impact on humans and the environment and as a basis for decision making for water management **(Yona *et al*., 2018, Yona *et al*., 2021)**. The results show that the EF scale is < 2, indicating low or minimal enrichment. The highest Geo Accumulation Index (Igeo) value for cadmium (Cd) is 0.391 while for lead (Pb) it is 0.59. The Igeo is used to determine the accumulation of heavy metals in rocks or sediments by providing information on the level of heavy metal contamination in the location with the condition of the aquatic environment before human activity **(Hidayati *et al*., 2020)** . The calculation results show that it is on the Igeo scale <1 so that heavy metals in sediments in Ujungpangkah waters indicate low pollution. The highest Bio-Concentration Factor (BCF) calculation results in arsenic (As) ranged from 40.11-67.87. The BCF value of heavy metals will differ depending on each size, habitat depth, and metabolic system of the green mussel body **(Potipat *et al*., 2015; Krismonita *et al*., 2023**). The calculation results are on the BCF <100 scale so that heavy metals in green mussels in Ujungpangkah waters indicate low pollution.

The results of the Estimated Daily Intake (EDI) analysis of heavy metal lead (Pb) in small green mussels cannot be calculated because heavy metals in small green mussels are not detected, in medium-sized green mussels (5- 10cm) at mg/kg/day and large green mussels (>10cm) at mg/kg/day. The Rfd value for heavy metal lead (Pb) was 0.004 mg/kg/day. The EDI analysis of heavy metal arsenic (As) showed the highest value in large green mussels at mg/kg/day and the lowest value in medium green mussels at mg/kg/day. The Rfd value for heavy metal arsenic (As) was 0.0003. This indicates that heavy metals for lead (Pb) and arsenic (As) are low because the EDI value of both heavy metals is less than 10 times the Rfd value **(Javed & Usmani, 2023)**. The Estimated Daily Intake (EDI) value is influenced by the concentration of heavy metals in green mussel meat and the body weight of the consumer **(Saleem *et al*., 2022; Javed & Usmani, 2023**). From the calculation results, heavy metal contamination in green mussels cultivated in Ujungpangkah waters does not exceed 1 times the RfD value so that heavy metals do not adversely affect consumer health, and thus it falls into the low risk category.

The target hazard quotient (THQ) analysis for lead (Pb) in small green mussels could not be calculated, as Pb was not detected in this size group. However, THQ values were determined for medium and large green mussels **(Anandkumar *et al*., 2018)**. For arsenic (As), the THQ ranged from 7.8×10^{-4} to 13.2×10^{-4}. The Hazard Index (HI) values for green mussels ranged from 0.00079 to 0.00134.The results of THQ and HI are on the scale of THQ<1 and HI<1, that indicating food safety due to heavy metal pollution of Pb and As in green mussels in Ujungpangkah waters indicates a low risk level **(USEPA, 2011; Yap *et al*., 2016; Anandkumar *et al*., 2018)** .

Observations of water quality conditions carried out in September-December 2023 in Ujungpangkah were not significantly different. The water quality parameters values and their average gave the brightness of 33cm. The low brightness is due to the location getting suspended solids from organic and inorganic materials **(Boyd & Boyd, 2020)**. The average temperature measurement was recorded at 30.9℃. The high temperature in the waters will accelerate the reaction of ions in the formation of heavy metals **(Wardani *et al*., 2014)**. The normal temperature for green mussels to live is 20-35℃. This shows that the temperature in Ujungpangkah waters is still good for the growth of green mussels. The salinity measurement results obtained were 31ppt; this value can still be tolerated because the growth temperature of green mussels is between 27- 37°C with a salinity of 26- 33ppt **(Erlania & Radiarta, 2011)**. Salinity can affect heavy metals in waters because heavy metals dissolve faster when salinity is low **(Budiastuti *et al*., 2016)**.

Measurement of pH value in Ujung Pangkah waters obtained an average of 8.04 which indicates that the waters are slightly alkaline. The process of heavy metal adsorption in sediments is influenced by pH because the toxicity of heavy metals will increase when there is a decrease in pH **(Yulis, 2018)**. The average result of DO measurements in Ujung Pangkah waters is 6.8mg/ l, which is in accordance with quality standards for marine biota life. High DO will oxidize heavy metals into a form of high oxidation number to change the solubility speed of heavy metals **(Paramita, 2017)**.

The average measurement of nitrite in Ujung Pangkah waters was 0.26mg/ l, nitrate was 3mg/l, and phosphate was 0.26mg/ l. Based on the quality standards of nitrite, nitrate, and phosphate, the current values recorded exceed the limit and are not suitable for the life of marine biota, because nitrite in the blood oxidizes hemoglobin into metahaemoglobin, which is unable to circulate oxygen **(Helms & Kim-Shapiro, 2013)** while phosphate in waters acts as a nutrient, if phosphate levels are high, it will interfere with biota in the waters **(Kirby & Nome, 2015)**. On the other hand, the ammonium value is 0.3mg/l showing that the concentration in the Ujung Pangkah waters does not exceed the limit.

CONCLUSION

Based on the results of this study, the concentration of heavy metals in green mussels (*Perna viridis*) across three size groups indicates that accumulation tends to increase with mussel size. Larger mussels exhibited higher concentrations of lead (Pb), cadmium (Cd), and arsenic (As), suggesting a positive correlation between mussel size and heavy metal bioaccumulation.

The Geoaccumulation Index (Igeo) values for Pb, Cd, and As suggest that sediment in the study area ranges from unpolluted to moderately polluted. Among the contamination indicators, arsenic showed the highest Contamination Factor (CF) value (0.441), while cadmium exhibited the highest Enrichment Factor (EF) value (2.432), indicating mild anthropogenic influence.

Health risk assessments based on Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) confirm that green mussels from Ujungpangkah waters—regardless of size—are still safe for human consumption and do not pose significant health risks.

Nevertheless, it is important to exercise caution and consider alternative seafood sources with lower levels of heavy metal contamination, particularly for communities with high seafood consumption, to minimize long-term exposure and health risks.

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