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Bioconcentration of Heavy Metals in Milkfish Reared in Stick-Net Pens System: Implications for Open Water Environmental Contamination and Food Safety

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Abstract. The coast of Tanjung Mas, Semarang City, is an industrial area used by the community to cultivate milkfish using stick-net pens. Furthermore, heavy metal contamination such as Cr, Cd, Cu, and Pb potentially disrupts milkfish meat's growth, quality, and safety. This study aims to determine heavy metals concentration in the waters and milkfish meat in stick-net pens cultivation in Tanjung Mas, Semarang City. The study was conducted using exploration, with five observation sites representing household waste disposal flow, industrial discharge, open sea, and intermediate areas. The observation sites were selected based on the milkfish cultivation activity. The sample and data, including water, milkfish, and environmental factors (temperature, pH, salinity, water current, and dissolved oxygen), were collected three times every two weeks. The heavy metals were detected using *Atomic Absorption Spectrometry* (AAS). The highest heavy metal concentration is Cr, which ranges from 1.70 ± 0.32 ppm to 2.36 ± 0.63 ppm in milkfish and 2.77 ± 0.65 ppm to 3.05 ± 0.58 ppm in the environment. The heavy metals contamination in Semarang City's water areas is still relatively low and has no impact on milkfish growth. Industrial waste, mainly heavy metals, potentially threatens the stick-net pens cultivation model developed by the community in Semarang City. This study can be used as an input for mitigation and adaptive action in anticipating future environmental changes and maintaining their business sustainability.

Keywords: Cd; Cr; Cu; heavy metal; Pb; stick-net pens; Tanjung Mas

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INTRODUCTION

Semarang City is one of the largest milkfish producers in coastal areas in Central Java, Indonesia. Milkfish is the primary commodity for 510 households from 1168 home fish entrepreneurs in Semarang coastal areas, reaching 1,526 ha or 42.05% of the total coastal areas for cultivation. The leuronect model for milkfish cultivation in Semarang City is carried out using a stick-net pens model, and it is a cultivation system using double-layer nets and bamboo sticks that are embedded 50 cm into the seabed in shallow water to make 20 x 20 m^2 of the square plot (Rumondor et al., 2019). The cultivation model has increased in popularity because it provides advantages in providing natural nutrients for milkfish growth and reduces production costs. However, the model cannot control the contamination and distribution of hazardous materials into stick-net pens that may affect milkfish's growth and meat quality (Martuti et al., 2021). The presence of heavy metals potentially decreases milkfish production and poses serious health problems for consumers

(Adimalla et al., 2020; Cai et al., 2019; Keshavarzi et al., 2018).

The potential for heavy metal contamination comes from various industries that occupy more than 493.49 ha or around 13.54% of the total coastal areas of Semarang City. Several studies have also shown that Semarang City water areas have been contaminated with various industrial wastes, including textiles, plastics, workshops, metals, coal reservoirs, and papers (Kariada et al., 2016; Khoironi et al., 2020; Martuti et al., 2020; Tjahjono et al., 2018). Previous research also showed that the cultivated milkfish in the West Semarang coastal area is contaminated by copper (Cu) metals and found in the leaves and fruits of *Avicennia* mangroves that grow in the same habitat (Martuti et al., 2016). On the other hand, textile industrial waste contains higher chromium (Cr) metal than other metal ions (Ahsan et al., 2019) because it is used as a dye-binding mineral in fabrics (Panhwar et al., 2022). In addition, the process of decomposition of waste landfills in the upstream area also releases heavy metals such as lead (Pb) and cadmium (Cd), which are carried by rainwater to the coastal areas (Wahyoto et al., 2019).

Heavy metal contamination will potentially accumulate in milkfish cultured in stick-net cages, which can be measured as bioconcentration. Bioconcentration is essential to determine whether or not the cultivation product is safe to consume (Mwakalapa et al., 2019a). It may reduce milkfish physiology, affect growth, meat nutrition (Rajeshkumar et al., 2014), and fish farmers' productivity and incomes. Identification and analysis of heavy metal contamination levels in Semarang City waters must be done to evaluate milkfish cultivation's safety and quality. Therefore, this study aims to analyze the bioconcentration of heavy metals (Cr, Cd, Cu, and Pb) in the milkfish in the stick-net pens grown by Semarang's fisherman. Semarang City stakeholders can use this study to conduct community-based sustainable milkfish cultivations by developing beneficial multi-stakeholder partnerships with private sectors. Furthermore, this study can be used as a baseline to improve industrial waste management and develop a mitigation plan for metal contamination in coastal areas.

METHODS

This study was an observational exploratory to analyze the heavy metals contamination in the milkfish cultivation center of Tanjung Mas water areas, Semarang City (Figure 1). The sampling process was carried out during the dry season from June to July 2022 to predict the highest potential for metal contamination because high rainfall during the rainy season can reduce heavy metal concentrations in the coastal waters of Semarang City. The sample point was determined based on the following criteria: 1) the location of the stick-net pens plot was in the household waste flow (site 1), industrial discharge (sites 3 and 5), open sea area (site 2), intermediate area (site 4); 2) there were active milkfish cultivation activities in stick-net pens; 3) no external feeding during the study. The sample of water, milkfish, and environmental factors (temperature, pH, salinity, water current, and dissolved oxygen [DO]) was collected at five sites and repeated three times every two weeks to determine fluctuations in the aquatic ecosystems at the observation site. The environmental factors were measured directly in the field using a Digital Water Temperature Thermometer (Applied Membrans Inc: California, USA), Smart Sensor AS218 pH Value Tester, Refractometer for salinity; and Dissolved Oxygen Analyzer (Dongrun; Shandong, China). In each sampling site is a cultivation pond covering an area of ± 20 x 20 m^2; samples were taken using the composite technique. The samples were taken from the four spots in the pond, including one from the middle, and then mixed and homogenized.

Measurement of heavy metal content

A total of 500 mL of water samples were put into a dark bottle, placed in a dark room with a temperature of 26 – 28 °C, and continued with metal measurements without acidification. Furthermore, as many as ten milkfish per observation site were taken, and length measurements from the head to the tail, width from dorsal to ventral fin, and body weight were taken as growth parameters. The milkfish meat was collected from the end of the operculum to the tail, then ground and mixed until homogeneous. Then, 1 g of fresh meat (wet weight) per milkfish was put into a beaker glass of 100 mL and added with 3 mL NHO_3 for acid destruction. The acid destruction process was run out using a hotplate stirrer set at 60 °C for 30 minutes. The remaining solution was then cooled at room temperature and applied deionization water up to 20 mL. Measurements of heavy metal content including Cr, Cd, Cu, and Pb were carried out at the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Semarang State University using the flame Atomic Absorption Spectrophotometer (AAS) Aanalyst™ 400 with WinLab32™ (PalkinAlmer: Massachusetts, USA) software according to the manufacturer's procedure.

The blank solution was made from deionization water, and then standard solutions were made separately for Cr, Cd, Cu, and Pd, with concentrations of 0, 2, 3, and 5 ppm. The standard solution for each metal was then analyzed for its absorbance using flame AAS to generate a graphed line in Ms. Excel where the concentration is on the y-axis and the absorbance value on the x-axis. The linear equation of a graphed line was generated in y-intercept ($y = mx + b$) form. The equation determined the metals' concentration by replacing the absorbance value with the x value.

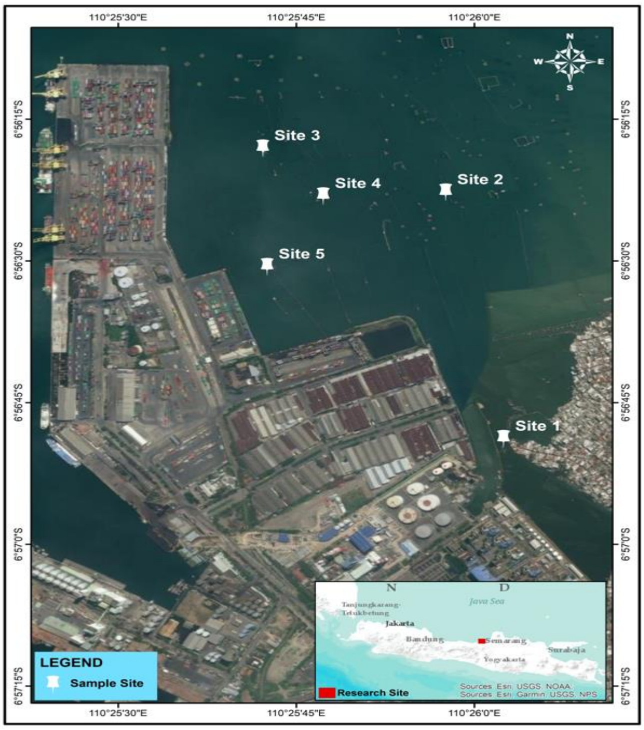

Figure 1. Sampling site

Bioconcentration measurement

Bioconcentration factor (BCF) indicates the number of heavy metals directly absorbed from habitats to aquatic organisms. This study observed BCF from the water (habitat) to the milkfish's meat. BCF measurements were carried out using the Rosioru et al. (2016) method (Rosioru et al., 2016), where the concentration of heavy metals in milkfish (C_B) (mass of heavy metals per kg of organism/dry weight) and the concentration of dissolved heavy metals in waters (C_W) as performed in Eq. 1:

$$BCF = \frac{C_B}{C_W} \qquad \text{Eq. 1}$$

Analysis Data

The data that have been obtained include the length, width, and weight of milkfish, and the content of heavy metals (Cr, Cd, Cu, Pb) in water (ecosystem) and fish meat were then analyzed using one-way ANOVA with a confidence level of 95% and level significance p-value < 0.05. The relationship between heavy metal content in habitat and meat and milkfish growth was determined using Pearson's Bivariate Correlation test with a confidence level of 95% and level significance p-value < 0.05. All statistical analysis is performed using the SPSS v22.0 package.

RESULTS AND DISCUSSION

Based on the environmental characterization, the water conditions in the stick-net pens area, Tanjung Mas, Semarang City, are suitable for milkfish cultivation (Table 1). Furthermore, there were no significant differences in environmental conditions in each sampling period in the sampling areas. It indicates that the Semarang City water areas have low fluctuated material change.

Table 1. Environmental parameters in Tanjung Mas cultivation area, Semarang City.

Parameters	Days Observation				Thresholds*
	I	II	III	Average	
Temperature (°C)	31.80± 0.45	31.20 ± 0.45	32.40 ± 1.82	31.80 ± 0.60	23.00 – 32.00
pH	7.98 ± 0.22	7.56 ± 0.09	7.96 ± 0.05	7.83 ± 0.24	7.00 – 8.50
Salinity (ppt)	30.40 ± 0.89	32.00 ± 0.00	33.60 ± 0.89	32.00 ± 1.60	5.00 – 35.00
Water current ($m\ s^{-1}$)	0.053 ± 0.02	0.081 ± 0.06	0.043 ± 0.01	0.059 ± 0.02	-
DO ($mg\ L^{-1}$)	5.44 ± 0.29	5.81 ± 0.08	5.57 ± 0.20	5.61 ± 0.19	≥ 3.00

Note: *) Based on the Indonesian National Standard (SNI) number 6148.3: 2013.

Furthermore, the pH value ranges between neutrals tending to alkaline, potentially reducing heavy metals' toxicity in the water area. Alkaline inhibits metal ionization, making it bound as complex compounds with other metals or organic molecules in the waters and deposited at the seabed (Pradhan et al., 2023). In contrast, a low pH or acid condition triggers the metals ionization process, making it more soluble and reactive and increasing toxicity in the water (Vardhan et al., 2019)

Water salinity at the sampling site reaches 31.00 – 32.00 ppt, required for milkfish cultivation based on SNI 6148.3: 2013, around 5 – 35 ppt. On the other hand, low salinity levels may increase the reactivity of several free heavy metal cation ions because of low levels of salt minerals. Furthermore, the Tanjung Mas water area is also supported by the high quality of oxygen level that makes it suitable for cultivation. The study's dissolved oxygen (DO) ranged from 5.08 – 5.93 $mg\ L^{-1}$. These results follow the criteria of SNI 6148.3: 2013, which is at least 3 $mg\ L^{-1}$. According to (Masriadi, 2019), the higher level of dissolved oxygen in the waters indicates that they are rich in oxygen content, so they are suitable for aquatic life.

In addition, the DO concentration exceeds a threshold level, showing that the water areas have sufficient O_2 levels to support milkfish growth. Then, the low DO concentrations also indicate high organic pollution in the water (Rusydi, 2018). The oxygen levels were observed to fluctuate daily and seasonally and may be affected by water mixing and turbulence events, photosynthetic activity, respiration, and waste entering water bodies. In this research, we found that environmental factors may also have an effect in supporting the growth of milkfish. Growth estimation was calculated by measuring the body length from mouth to tail, and body width without calculating the fins length (Figure 2). This is due to the increase in the mass and size of milkfish within one month from the first observation period to the third (Figure 3).

Based on the measurement results, the increase in milkfish growth is characterized by a change in body length that increases to 21.82% during one month of the observation. Then, the difference in the milkfish width also increased to 26.16%, while the body weight increased to 23.04% after one month of observation. It shows that the average growth of milkfish reaches more than 20% per month. However, the factors that may directly contribute to milkfish growth are still undefined because of study limitations in controlling moderation variables. Therefore, further research can be conducted by analyzing various variables involved in milkfish growth, such as plankton abundance and diversity.

Figure 2. Appearance of body length and width measurements of milkfish obtained from Tanjung Mas.

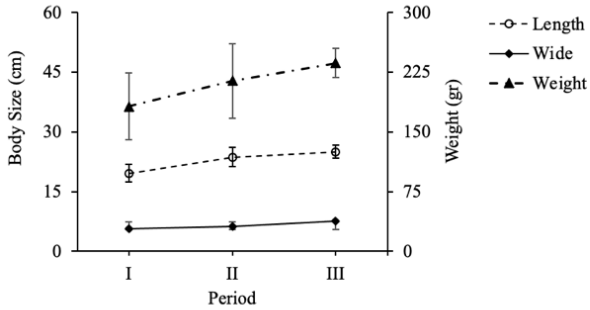

Figure 3. The average growth of milkfish in stick-net pens, Tanjung Mas, Semarang City in each observation period

Recent studies show that milkfish growth is influenced by various environmental conditions, including temperature (Hanke et al., 2019), plankton and nutrition (Hussain et al., 2021; Vasava, 2018), microbiota communities in the environment (Chang et al., 2019), and heavy metals contaminations such as Cr, Cd, Cu, and Pb (Mukherjee et al., 2022; Mwakalapa et al., 2019b). The facts found during field observation show that heavy metal contamination in Tanjung Mas waters is still at the quality standards for aquaculture cultivation according to the Standard Indonesian regulation (*Standard National Indonesia* [SNI]). The concentration of heavy metals in water is also influenced by water quality parameters such as temperature, pH, salinity, and dissolved oxygen (Yeh et al., 2022)

Table 2. Concentration of Cr, Cd, Cu, and Pb on the environment and milkfish meat per observation site in Tanjung Mas Area, Semarang City from June to July 2022.

Observation site	Metal Concentration (ppm)					
	Meat	Environment	Change (%)	Meat	Environment	Change (%)
	Cr			Cd		
Site 1	1.70 ± 0.32	2.77 ± 0,65*	61.50 ± 30.80	0.04 ± 0.02	0.08 ± 0.02*	42.74 ± 10.44
Site 2	1.88 ± 0.54	2.88 ± 0.60*	65.37 ± 9.86	0.03 ± 0.03	0.09 ± 0.03*	33.33 ± 7.75
Site 3	2.29 ± 0,38	2.52 ± 0.84*	90.92 ± 5.48	0.03 ± 0.04	0.09 ± 0.03*	32.48 ± 31.13
Site 4	2.16 ± 0.60	3.29 ± 0.50*	65.48 ± 17.04	0.04 ± 0.02	0.08 ± 0.04*	46.52 ± 20.59
Site 5	2.36 ± 0.63	3.05 ± 0.58*	77.64 ± 5.48	0.02 ± 0.02	0.08 ± 0.03*	25.72 ± 15.93
Average	2.08 ± 0.25	2.90 ± 0.26*	72.18 ± 10.83	0.03 ± 0.01	0.08 ± 0.01*	36.16 ± 7.50
	Cu			Pb		
	Meat	Environment	Change (%)	Meat	Environment	Change (%)
Site 1	0.13 ± 0.02*	0.19 ± 0.02*	69.05 ± 10.44	0.65 ± 0.35*	0.69 ± 0.26*	93.32 ± 51.29
Site 2	0.14 ± 0.03*	0.19 ± 0.03*	72.82 ± 7.75	0.63 ± 0.28*	0.53 ± 0.18*	118.40 ± 23.60
Site 3	0.20 ± 0.04*	0.18 ± 0.03*	107.87 ± 31.13	0.64 ± 0.23*	0.94 ± 0.27*	68.09 ± 20.16
Site 4	0.14 ± 0.02*	0.18 ± 0.04*	79.02 ± 20.59	0.54 ± 0.30*	0.66 ± 0.34*	81.48 ± 73.01
Site 5	0.15 ± 0.02*	0.18 ± 0.03*	83.50 15.93	0.53 ± 0.17*	1.04 ± 0.28*	51.26 ± 5.09
Average	0.15 ± 0.02*	0.19 ± 0.01*	82.45 ± 13.65	0.60 ± 0.05*	0.77 ± 0.19*	82.51 ± 22.76

Note: superscript star mark (*) Indicates the heavy metal content exceeds the safety threshold. The change score (%) shows heavy metal fluctuation levels from the first observation to the third observation (end of observation). The safe limit of heavy metal contamination refers to the SNI quality standard 7387: 2009 concerning the maximum limit of metal contamination in food, including Cr = 2.5 ppm; Cd = 0.1 ppm; Cu = 0.1 ppm; and Pb = 0.3 ppm. Meanwhile, the maximum allowable level of aquaculture waters is regulated in the Government Decree of Indonesian Republic No. 22, Year 2021 about Water Quality Management and Water Pollution Control with the maximum allowable content, namely Cr = 0.05 ppm; Cd = 0.01 ppm; Cu = 0.02 ppm; and, Pb = 0.3 ppm.

The AAS result reveals that the metal concentration in the stick-net pens water in five observatory stations is beyond the national standard threshold for aquaculture. However, the metal concentration in milkfish meat is still categorized as safe. Even though the high accumulation of Cu and Pb in milkfish meat is over the threshold, it is still safe and tolerated. Based on the measurement results, Cr metal was found to have the highest concentration compared to other metals, and it can be concluded that the concentration of Cr > Pb > Cu > Cd both in meat and in water.

The high contamination of Cr, Pb. Cd and Cu were found in three sampling sites, including site-3, site-4, and site-5, located in sewage disposal channels from industrial areas. Meanwhile, site 1 is the estuary, and the river outlet may contain more household waste with a lower concentration of heavy metals. Then, in site 2, the concentration of heavy metals is likely to dissolve higher because it is directly adjacent to the free sea and is affected by ocean currents. Furthermore, the concentration of heavy metals in milkfish meat is lower than in the waters in all observation sites. The dissolved heavy metals in milkfish and water are also observed dynamically in various observation periods (Figure 3).

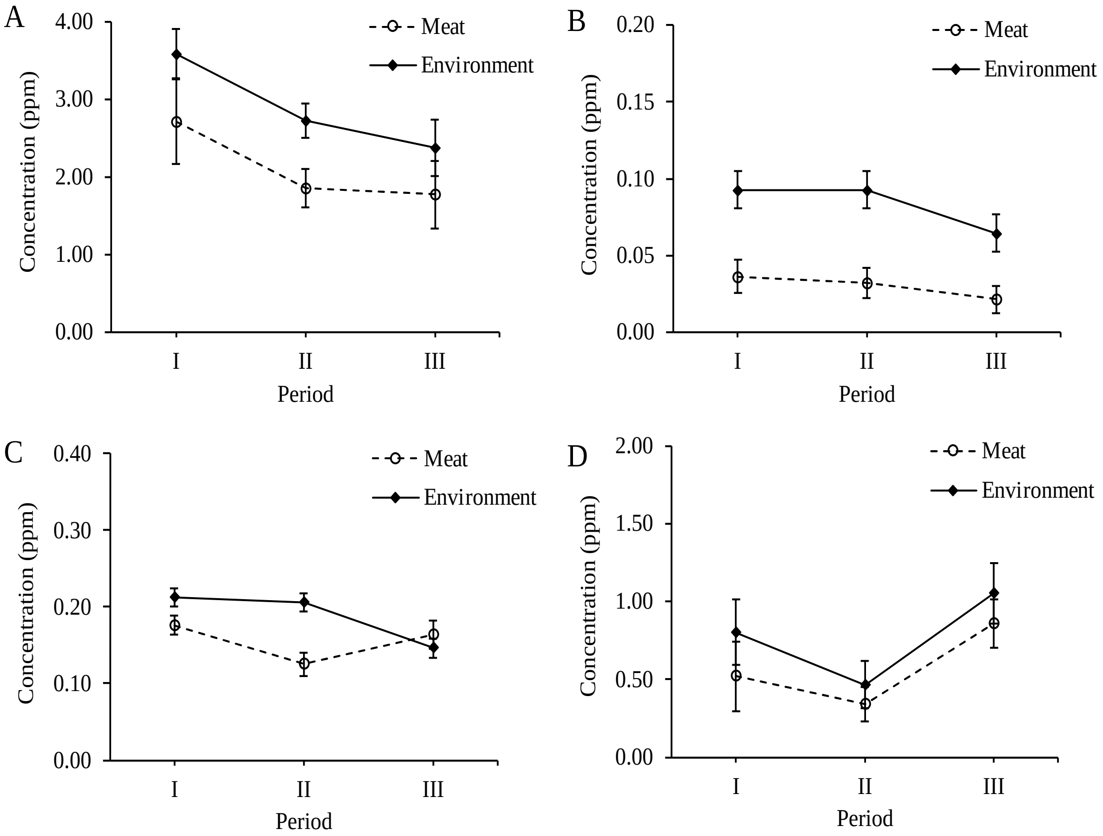

Figure 3. Concentration of the Cr (A), Cd (B), Cu (C), and Pb (D) in milkfish meat and environment per observation period.

The presence of heavy metal contamination in the waters for an extended period is absorbed by the milkfish and accumulated in body tissue. Abundance metals in the waters are potentially absorbed by soil and mud particles and then deposited at the seabed, making heavy metals in the sediment much higher than in the seas (Warni et al., 2017). It is in line with previous studies that showed a higher accumulation of Cu in the pond sediments than in waters; however, the low concentration of Cu does not affect the milkfish growth in fishpond in the Semarang City coastal area (Martuti et al., 2016). In addition, the seabed's moving process (water turbulence) due to ocean currents and weather changes also impacts the increasing heavy metals in the waters. High current stirring the shallow seabed so that the mud containing metal deposits will be lifted, whereas in calm conditions, it tends to have smaller amounts of heavy metals (Zhou et al., 2022). Even though the content of heavy metals in water is relatively low, the bioabsorption and bioaccumulation in the food chain may increase the contamination in the upper aquatic organism. Bioaccumulation is the accumulation of chemical substances such as pesticides, methylmercury, and other organic chemicals (including heavy metals) in the body parts of an organism (Gómez-Regalado et al., 2023)

Sources of metal contamination come from industrial and anthropogenic activities. For example, Cr comes from the garment industry, and the mobilization of fuels is also found in the integrated industrial area on the coast of Semarang City. Then, Pb contamination will likely come from transportation mobility and fossil fuels, which increase yearly in Semarang City. In addition, metal contamination, such as Cd and Pb, is also likely to come from natural processes resulting from the decomposition of waste from landfills in upstream areas carried by river flows to the coast (Wahyoto et al., 2019). Contamination in the aquatic environment then undergoes a process of accumulation in the tissues of marine organisms expressed in the value of bioconcentration factor (BCF) (Luthfi et al., 2019). The analysis showed that the highest BCF values came from Cu and Pb (Figure 4).

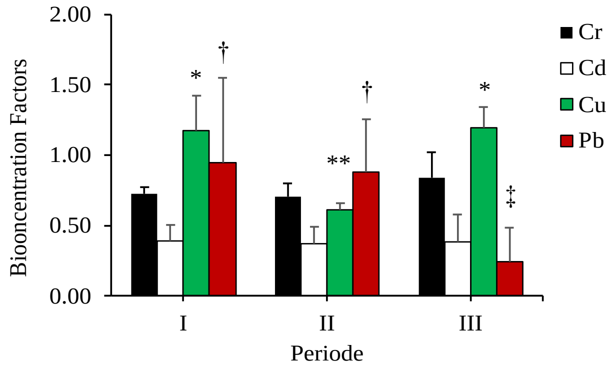

Figure 4. Bioconcentration of heavy metals in each observation period

Heavy metal bioconcentrations during the sampling period in June-July 2022 showed a fluctuating trend (Figure 4). This is likely due to the carrying capacity of coastal waters, which allows the natural reduction of heavy metals. However, during this period, the Tanjung Mas area, Semarang City, experienced a dry season with an average rainfall of ≤ 20 mm/day or relatively low (Meteorology, Climatology and Geophysics Agency [MCGA], 2022). Waste disposal channels from most industries on the coast of Tanjung Mas, Semarang City, lead to water areas that are a source of heavy metal pollution. Apart from that, the mouth of the Dead River (the upstream of the river is in residential areas in the middle of the city) also contributes to pollution in the coastal area. Low rainfall waste discharge from industry and households increases heavy metal concentrations, thereby possibly increasing bioconcentration in milkfish meat compared to the rainy season.

BCF is the ability of organisms to accumulate heavy metals directly from the environment (Oliveira et al., 2018). Based on the BCF value, metals Cr and Cd experienced relatively stable absorption. At the same time, Cu and Pb were volatile and differed significantly for each observation period. According to Burkhard et al. (2021), the BCF is a valuable parameter for evaluating the potential of biota in accumulating metals. The calculation of the BCF value determines the accumulation of heavy metals in fish organs compared to the environmental medium of water. In other words, the higher the metal contamination in the water, the more likely the BCF value indicates the metal content in organisms (Komala et al., 2022). Even though BCF value may depend on the organism species and environmental factors, Krivokapić et al. (2021) state that the BCF value has three categories, namely 1) The BCF value of more than > 1000 scores is included in the category of high accumulative properties, 2) The BCF value of 100-1000 scores is included in the category of medium accumulative properties, 3) The BCF value < 100 scores, falls into the category of low accumulative properties.

The absorption of heavy metals occurs in the form of ions because they are more reactive and are the most common form found in the aquatic environment, both in the form of free ions, pairs of organic ions, complex ions, and other forms of ions. Consequently, the contamination properties of heavy metals are influenced by the electronegativity of the metal ions (Lee et al., 2023). The metal ions that have formed the compound have properties that vary by the degree of their ionicity. Heavy metals dissolved in water at a specific concentration will accumulate in the organism's body tissues and are toxic (Breton et al., 2013; Gómez-Regalado et al., 2023). Heavy metals at the threshold of bioconcentration cause the destruction of proteins up to nucleic acids that trigger cancer and organ malfunctions (Adimalla et al., 2020).

Heavy metals enter the fish muscle simultaneously with mineral-water diffusion in the gills, spreading throughout the body through the blood vessels (Cahyani et al., 2016). It gradually accumulates in its tissues, especially in the liver, where they are biologically transformed and excreted or passed on to the consumer through the food chain (Amini et al., 2013). The heavy metals may enter the body through mouth osmosis or simultaneously when the fish takes food in the intestines, allowing the process of elimination through the process of secretion. The fish can excrete heavy metals along with the excreted feces. Heavy metals' absorption by penetrating the skin into the body (occurs in small quantities) may be possible because heavy metal compounds can dissolve in oils and fats (Zhaoyong et al., 2019).

Table 3. Correlation between heavy metals in milkfish meat and water

Heavy metals	Cr_M	Cr_E	Cd_M	Cd_E	Cu_M	Cu_E	Pb_M	Pb_E
Cr_M		0.209	-0.216	-0.285	-0.540*	0.545*	0.548*	-0.249
Cr_E	0.456		-0.167	0.165	-0.063	0.12	0.109	-0.293
Cd_M	0.439	0.552		0.193	0.334	-0.215	0.105	-0.103
Cd_E	0.304	0.558	0.490		0.876**	0.12	-0.274	0.587*
Cu_M	0.038	0.823	0.224	0.000		-0.046	-0.342	0.573*
Cu_E	0.036	0.670	0.441	0.669	0.870		0.058	0.011
Pb_M	0.034	0.700	0.710	0.323	0.212	0.839		-0.368
Pb_E	0.371	0.289	0.715	0.021	0.026	0.969	0.177	

Note: Subscript letter ($_{M-E}$) representing the sample, M = milkfish meat, and E = environment (water). *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). The top row shows the Pearson correlation value, while the bottom row (grey sheet) shows a significant value at the level ≤ 0.05

The bioconcentration of factors in milkfish is relatively low due to the high concentration of Cr in water compared to the milkfish meat. The high Cr content in water is possibly a very high current, so the metal content in the sediment is dissolved in the water (Al-Asadi et al., 2020). Although it is low accumulative, the presence of heavy metals in milkfish must still be watched out for because accumulative properties are at risk of causing poisoning of a chronic nature in humans (Ali & Khan, 2018; Kim et al., 2019; Mwakalapa et al., 2019b).

Fish meat plays a vital role as a human nutrient, and humans are the last consumers in the food chain system (Elfidasari et al., 2018). When the heavy metals contained in milkfish meat enter the body, the heavy metals can enter the human body if consumed and cause serious health problems (Liu et al., 2020; Okereafor et al., 2020). Foods that contain high levels of heavy metals can cause indigestion, liver and kidney damage (Khan et al., 2020), asthma, and decreased lung function (Sonone et al., 2012).

Table 4. Correlation of heavy metals in meat with milkfish growth

Heavy Metal	Pearson Correlation Score	P-value
Cr_M	0.064	0.822
Cd_M	0.222	0.426
Cu_M	0.180	0.520
Pb_M	0.252	0.365

Note: Subscript letter ($_{M-E}$) representing the sample, M = milkfish meat, and E = Environment (water). *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). Significance at the sig. level ≤ 0.05

Heavy metals enter the cells and are also distributed by the blood to all body tissues so that they accumulate in the body organs, and blood circulation causes heavy metals to accumulate in the walls of blood vessels and connective tissues found around muscles or fish meat (Junianto et al., 2017; Sabdono, 2009). In their natural habitat, milkfish may reduce metal contamination by avoiding pollution sources, but the condition may differ when living in limited habitats such as stick-net pens. Nonetheless, this study indicates that Tanjung Mas, Semarang City's coastal area, still has an excellent environmental carrying capacity for milkfish cultivation. The environmental and geographical factors of the Tanjung Mas coast that may directly relate to the high seas may be able to eliminate and minimize heavy metal contamination.

This research shows the type and condition of water pollution in Tanjung Mas, Semarang City, concerning the sustainability of community milkfish cultivation. This research is essential to inform about the potential threats to the stick-net pens cultivation model developed by the community to maintain their business sustainability in the future. It is important to be investigated as an input for mitigation and adaptive action in anticipating future environmental changes. Apart from that, this study shows that the quality of milkfish in the Semarang City coastal area is still in a safe condition for consumption. However, a comprehensive solution needs to be carried out with a multi-stakeholder partnership between the government, society, and the private sector for the sustainability of community businesses and the protection of the environment at the same time.

CONCLUSION

The bioconcentration of Cr, Cd, Cu, and Pb in milkfish meat is still within the tolerance limits of aquatic commodities and is safe for consumption. Furthermore, the Tanjung Mas, Semarang City's water area is still appropriate for aquaculture even though several heavy metals contaminate it. Heavy metal contamination in the Tanjung Mas water area, Semarang City, exceeded a level above the reasonable threshold; however, it is still at the tolerated level. Cu and Pb are also detected above the threshold for aquaculture products found in milkfish meat but are considered acceptable. The Cr metal was the highest, exceeding the standard quality threshold, likely caused by the overflow of waste from the textile and energy industries near the research site. Further study needs to be carried out on mapping the contamination sources and comprehensively depict heavy metal fluctuation in different seasons and milkfish growth from juvenile to harvesting.

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