South Western Journal of
Horticulture, Biology and Environment
P-Issn: 2067- 9874, E-Issn: 2068-7958

Vol.16, No.2, 2025
pp. 93 - 112
Art.no. e25107

DANGERS BEHIND THE LEAD AND COPPER CONTENT OF TRADITIONALLY CULTIVATED BLOOD COCKLES (*Anadara granosa*) IN ROKAN HILIR REGENCY, INDONESIA

Irwan EFFENDI [1, *], Dini ONASIS [2], Arizal NAABAI [3],
Wita Dwika LISTIHANA [3], Fatkhurahman FATKHURAHMAN [3],
Noor Ismawati JAAFAR [4], Mozard MOHTAR [5],
Azni Zarina TAHA [5], and Sefni HENDRIS [1]

1. Department of Marine Sciences, University of Riau, Pekanbaru 28293, Indonesia.
2. Department of Accounting, University of Lancang Kuning, Pekanbaru 28265, Indonesia.
3. Department of Management, University of Lancang Kuning, Pekanbaru 28265, Indonesia.
4. Department of Decision Science, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.
5. Department of Management & Marketing, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.
*Corresponding author: I. Effendi, E-mail: helpingirwan@gmail.com.

Abstract. *Blood cockles (Anadara granosa) have high economic value as a source of protein. As filter-feeding animals, they are also bioaccumulators of heavy metals in their bodies. This research aimed to measure the levels of heavy metals lead (Pb) and copper (Cu) and analyse the food safety aspects of this commodity. The study was conducted from July to December 2024. Samples were collected from the blood cockle cultivation area at the mouth of the Rokan River, Rokan Hilir Regency, Indonesia. Analysis was carried out on blood cockle flesh, seawater, and sediment. Blood cockles with a 2-3 cm diameter were collected, cleaned, opened to remove 5 g of flesh, and stored aseptically. Seawater (10 mL) and sediment (10 g) were collected and stored aseptically in dark-colored bottles. All samples were put into an icebox and taken to the laboratory. This study revealed that Pb concentrations in blood clam flesh, seawater, and sediment ranged between 6.218 and 7.864 mg/kg, 0.022 and 4.286 mg/L, and 3.249 and 7.134 mg/kg, respectively. Pb levels in blood cockle flesh have far exceeded the threshold. However, the Pb content in water and sediment is still below the threshold. The Cu content ranged between 5.031-7.427 mg/kg, 0.024-1.707 mg/L, and 0.434-1.251 mg/kg, in flesh, seawater, and sediment, respectively. Compared to national and international standards, the Cu levels were still below the threshold for all samples. BCF (bioconcentration factor) analysis revealed that Pb and Cu in blood cockle flesh were much higher than in seawater and sediment.*

Keywords: *heavy metal, marine pollution, toxic material, bio-accumulator, food safety.*

INTRODUCTION

In some countries, including Indonesia, blood cockles (*Anadara granosa*) are regarded as a significant marine commodity and one of the clams with the highest economic worth. Given that it contains protein (9–13%), fat (0–2%), glycogen (1–7%), omega-3, vitamin A, vitamin B12, and vitamin C, the animal has the potential to be a highly valuable and nutritious diet (Permata et al. 2023, Rahman et al. 2020). Antioxidant minerals, including Zn, Fe, Se, and Cu, are also found in the biota (Rozirwan et al. 2023, Min et al. 2011). Due to a growing demand, fishermen are actively capturing these invertebrates. (Riza et al. 2021, Mahary et al. 2023). Because they are nonselective filter feeders and can store heavy metals in their bodies if they live in contaminated waters, *A. granosa* can also be utilised as a bioindicator of saltwater pollution (Padmiswari et al. 2021, Srisuksawad & Prasertchiewchan 2007). This organism's life cycle as a filter feeder made it susceptible to the accumulation of metal contaminants from the sediment. Human health hazards could arise from consuming blood cockles tainted with heavy metals (Yona et al. 2020).

The most crucial element of the food industry is food safety. Consumers, employees, the local community, and the environment in which the sector operates must all be safe from the food products and the production process. Certain facets of food safety, including food hygiene or the chemical and microbial components of food, have been well-researched. The FAO and WHO have established international food standards for maximum limits of heavy metals in food to protect public health (Collado-López et al. 2022). The EU and Russian Federation have specific permissible levels for heavy metals in various food products, such as arsenic in rice and mercury in fish (Khamidulina et al. 2021). Coliforms are used as indicators of unsanitary processing conditions, especially in dairy products, where their presence can signal contamination from fecal sources or environmental factors (Martin et al. 2016). Food safety is governed by FAO and WHO regulations. From a chemical standpoint, food safety involves addressing the existence of several harmful substances in the food (Galanakis 2024, Karanth et al. 2023, Verma et al. 2023).

The blood cockle is increasingly recognized for its vulnerability to heavy metal contamination, particularly in coastal environments (Riza et al. 2021). Research indicates that these organisms accumulate harmful metals such as cadmium, lead, and copper, which can adversely affect their physiological functions (Tu et al. 2022, Peng et al. 2015). Al, Hg, Pb, Zn, Cr, Cu, Cd, and Co are among the heavy metals that can cause harm to the human body, such as the development of several deadly illnesses (Teng & Yu 2023, Jomová et al. 2024). These metals are hazardous when they are found in food or water because they can build up in the blood cockles (Bhavani et al. 2024, Panghal et al. 2024). Long-term consumption of these contaminated mollusks may lead to chronic health issues, including neurological and kidney damage (Hossen et al. 2014, Mishra et al. 2024, Machado & Maltez 2021).

Lead (Pb) is a significant environmental contaminant that poses serious health risks through food consumption (Mandal et al. 2023, Patočka & Kuca 2016). Its presence in food can arise from various sources, including contaminated soil and water, and it is particularly harmful to vulnerable populations such as children and pregnant women (Miller et al. 1983, O'Connor et al. 2020, Singh et al. 2023). Lead can enter the food chain through contaminated soil and water, affecting crops and livestock (Sani & Amanabo 2021). Historical industrial practices, such as the using of lead in paints and gasoline, have contributed to increasing environmental lead levels (Alankarage & Juhasz 2023). While lead contamination in food is a pressing concern, some argue that the overall dietary intake of lead is generally below health-based guidance values for the general population (Zhao et al. 2024). However, the risks remain significant for vulnerable groups, necessitating ongoing monitoring and intervention.

Copper (Cu) can pose significant toxicity risks in the food chain, particularly through its accumulation in plants and animals (Wang et al. 2022). Research indicates that elevated Cu levels can adversely affect both plant physiology and animal health, raising concerns about food safety. Increased Cu levels result in reduced growth and elevated enzyme activity related to oxidative stress, indicating physiological damage (Schmitt et al. 2022). Dusky grouper fish showed significant gut Cu accumulation after consuming contaminated food, leading to reduced antioxidant enzyme activity, and suggesting systemic toxicity (Francisco et al. 2020). The cumulative nature of heavy metals, including Cu, poses long-term health risks, as they can reach harmful levels in the food chain due to environmental pollution (Gil & Olmedo 2023, Alkhanjaf et al. 2024). While Cu is essential in trace amounts, its toxicity at higher concentrations necessitates careful monitoring in agricultural practices and food safety regulations to mitigate health risks (Zitoun 2018). This study aimed to analyse the food safety aspects of farmed *A. granosa*, based on heavy metal analysis, namely Pb and Cu, by taking samples at the mouth of the Rokan River, Rokan Hilir Regency, Indonesia.

MATERIALS AND METHODS

Sample collection

This research was conducted from July to December 2024. Samples were collected from *A. granosa* farming in coastal areas at the mouth of the Rokan River, in Bangko District, Rokan Hilir Regency, Indonesia (Figure 1). Water, sediment, and blood cockle flesh samples were collected from three stations in July, September, and November 2024.

Analysis of heavy metal content

Analysis of Pb and Cu was carried out on blood cockle flesh, seawater, and sediment around the cultivation area. The blood cockles, with a diameter of 2-3 cm, were caught and cleaned. Then the blood cockle was opened, and 5 g of the flesh was taken out and stored aseptically in an icebox. Seawater (10 ml) and sediment (10 g) were collected and stored in a dark bottle aseptically and stored in an icebox. These samples were then taken to the Marine Chemistry Laboratory, Riau University, for analysis. Analysis of heavy metal content was carried out using the Atomic Absorption Spectrophotometer method (SNI 06-6992.5-2004, SNI 06-6992.3-2004, Okewale & Grobler 2023, Maurya et al. 2018).

Water quality analysis

The water quality parameters measured included temperature, pH, salinity, dissolved oxygen, and biological oxygen demand, as described in the INS (2008), Rice & Bridgewater (2012), and MER (2014) methods.

Data analysis

The data obtained in this study were tabulated and analysed statistically by calculating the standard deviation, average, maximum, and minimum of the values. The data analysis was also continued with bioconcentration factor (BCF) analysis, following the methods presented in other studies (DeForest et al. 2007). Furthermore, the results of the analysis were interpreted descriptively by comparing them with some previous research results and national and international standards.

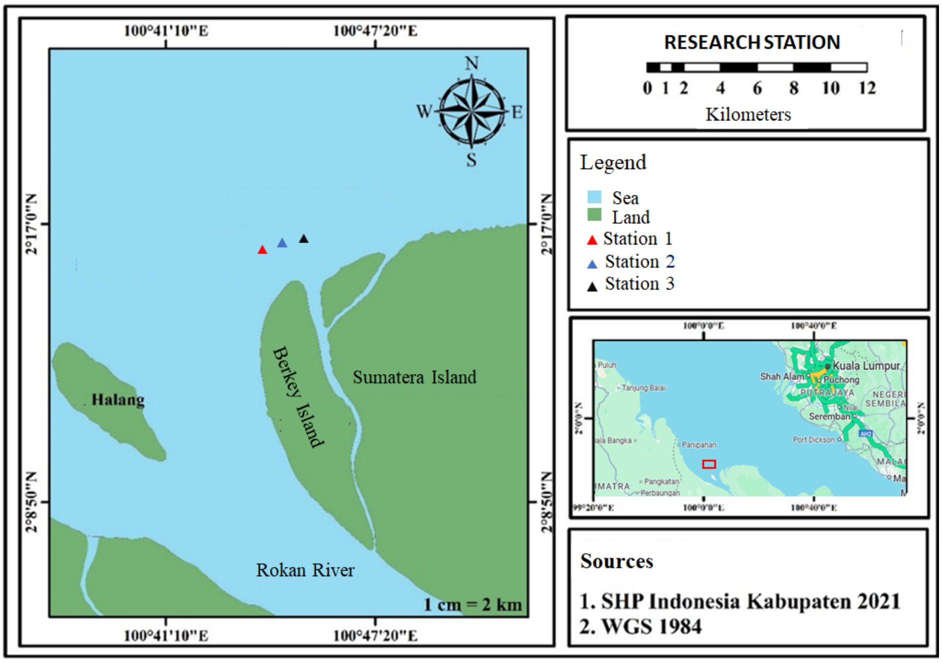

Figure 1. Research stations in Bangko District, Rokan Hilir Regency, Indonesia.

RESULTS

Pb levels

Samples were collected through three periods of sampling, namely in July, September, and November 2024. Of all the research stations, the highest levels of Pb metal in blood cockle flesh were 7,864 mg/kg (station 2), and the lowest were 6,218 mg/kg (station 2). Table 1 presents more details.

In seawater, for all research stations, Pb metal levels ranged between 0.111 mg/L (station 2) and 0.022 mg/L (station 3). Table 2 contains more specific details.

In sediment samples of all stations, the average Pb levels from all research samplings were the highest at 4,286 mg/L (station 1) and the lowest at 3,249 mg/kg (station 2). More details are presented in Table 3.

Cu levels

It was noted that the average Cu content in blood cockle flesh from all stations ranged from 5.031 mg/kg (station 1) to 8,841 mg/kg (station 3). More details are presented in Table 4.

Table 1. Pb levels in farmed blood cockle flesh (mg/kg) in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	6.451	6.441	6.532	
	7.534	7.532	7.546	
	6.956	7.562	7.654	
Average	6.980	7.178	7.244	7.134
Standard Deviation	0.442	0.522	0.505	0.534
Maximum	7.534	7.562	7.654	7.654
Minimum	6.451	6.441	6.532	6.441
Station 2	7.065	7.105	7.142	
	7.786	7.582	7.864	
	6.271	6.364	6.218	
Average	7.041	7.017	7.075	7.044
Standard Deviation	0.619	0.501	0.674	0.639
Maximum	7.786	7.582	7.864	7.864
Minimum	6.271	6.364	6.218	6.218
Station 3	6.884	6.848	6.484	
	6.740	6.704	6.460	
	7.173	7.164	7.373	
Average	6.932	6.905	6.772	6.870
Standard Deviation	0.180	0.192	0.425	0.315
Maximum	7.173	7.164	7.373	7.373
Minimum	6.740	6.704	6.460	6.460

Table 2. Pb levels in seawater (mg/L) around the blood cockle farming in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	0.110	0.109	0.108	
	0.101	0.101	0.101	
	0.097	0.097	0.077	
Average	0.103	0.102	0.095	0.100
Standard Deviation	0.005	0.005	0.013	0.010
Maximum	0.110	0.109	0.108	0.110
Minimum	0.097	0.097	0.077	0.077
Station 2	0.087	0.083	0.028	
	0.098	0.091	0.091	
	0.105	0.102	0.111	
Average	0.097	0.092	0.077	0.088
Standard Deviation	0.007	0.008	0.035	0.024
Maximum	0.105	0.102	0.111	0.111
Minimum	0.087	0.083	0.028	0.028
Station 3	0.093	0.033	0.092	
	0.082	0.022	0.073	
	0.103	0.103	0.103	
Average	0.093	0.053	0.089	0.078
Standard Deviation	0.009	0.036	0.012	0.031
Maximum	0.103	0.103	0.103	0.103
Minimum	0.082	0.022	0.073	0.022

Table 3. Pb levels in sediment (mg/kg) around the blood cockle farming in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	3.781	3.777	3.817	
	4.286	4.276	4.265	
	3.601	3.621	3.621	
Average	3.889	3.891	3.901	3.894
Standard Deviation	0.290	0.279	0.270	0.297
Maximum	4.286	4.276	4.265	4.286
Minimum	3.601	3.621	3.621	3.601
Station 2	3.493	3.393	3.439	
	3.384	3.284	3.354	
	3.709	3.249	3.607	
Average	3.529	3.309	3.467	3.435
Standard Deviation	0.135	0.061	0.105	0.148
Maximum	3.709	3.393	3.607	3.709
Minimum	3.384	3.249	3.354	3.249
Station 3	3.817	3.717	3.817	
	3.926	3.862	3.841	
	3.637	3.633	3.673	
Average	3.793	3.737	3.777	3.769
Standard Deviation	0.119	0.095	0.074	0.107
Maximum	3.926	3.862	3.841	3.926
Minimum	3.637	3.633	3.673	3.633

In seawater samples from all stations, the Cu content ranged from 0.024 mg/L (station 1) to 0.060 mg/L (station 2). More details are presented in Table 5.

In sediment samples, the highest and the lowest Cu content in all stations were 1.712 mg/kg (station 2) and 0.434 mg/kg (station 3), respectively. More details are presented in Table 6.

Bioconcentration factors

Bioconcentration factors (BCF) were calculated by dividing the concentration of the metal in the tissue of the blood cockle by that in the sediment. From BCF analysis, it can be seen that the blood cockle is an actual bioaccumulator animal for Pb, where the Pb levels in its flesh are 59.283-112.458 times higher than in the surrounding seawater. Pb levels in blood cockle flesh were 1.784-2.318 times higher than Pb levels in the surrounding sediment. BCF > 1 indicates that the mussels accumulated more metals in their tissues than in the sediment. On the other hand, BCF < 1 shows more metals in the sediments than in the blood cockle tissues, as it was shown in other studies (DeForest et al. 2007). More details about the BCF analysis results are presented in Table 7.

Table 4. Cu levels in farmed blood cockle flesh (mg/kg) in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	5.031	5. 314	5.321	
	6.878	6.785	6.786	
	7.247	7.427	7.247	
Average	6.385	7.106	6.451	6.648
Standard Deviation	0.969	0.321	0.821	0.907
Maximum	7.247	7.427	7.247	7.427
Minimum	5.031	6.785	5.321	5.031
Station 2	6.098	6.078	6.068	
	5.934	5.394	5.634	
	8.396	8.693	8.369	
Average	6.809	6.722	6.690	6.740
Standard Deviation	1.124	1.422	1.200	1.332
Maximum	8.396	8.693	8.369	8.693
Minimum	5.934	5.394	5.634	5.394
Station 3	5.401	5.141	5.412	
	8.584	8.841	8.684	
	6.262	6.362	6.162	
Average	6.749	6.781	6.753	6.761
Standard Deviation	1.344	1.539	1.400	1.517
Maximum	8.584	8.841	8.684	8.841
Minimum	5.401	5.141	5.412	5.141

Table 5. Cu levels in seawater (mg/L) around the blood cockle farming in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	0.044	0.043	0.042	
	0.047	0.046	0.045	
	0.051	0.056	0.060	
Average	0.047	0.048	0.049	0.048
Standard Deviation	0.003	0.006	0.008	0.006
Maximum	0.051	0.056	0.060	0.060
Minimum	0.044	0.043	0.042	0.042
Station 2	0.034	0.041	0.034	
	0.024	0.033	0.024	
	0.041	0.042	0.041	
Average	0.033	0.039	0.033	0.035
Standard Deviation	0.007	0.004	0.007	0.007
Maximum	0.041	0.042	0.041	0.042
Minimum	0.024	0.033	0.024	0.024
Station 3	0.047	0.046	0.046	
	0.035	0.035	0.034	
	0.039	0.033	0.028	
Average	0.040	0.038	0.036	0.038
Standard Deviation	0.005	0.006	0.007	0.007
Maximum	0.047	0.046	0.046	0.047
Minimum	0.035	0.033	0.028	0.028

Table 6. Cu levels in sediment (mg/kg) around the blood cockle farming in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Sampling 1	Sampling 2	Sampling 3	Sampling 1, 2, 3
Station 1	0.845	0.845	0.845	
	1.092	1.092	1.092	
	1.584	1.458	1.544	
Average	1.174	1.132	1.160	1.155
Standard Deviation	0.307	0.252	0.289	0.302
Maximum	1.584	1.458	1.544	1.584
Minimum	0.845	0.845	0.845	0.845
Station 2	1.707	1.702	1.712	
	0.886	0.876	0.896	
	1.091	1.092	1.090	
Average	1.228	1.223	1.233	1.228
Standard Deviation	0.349	0.350	0.348	0.370
Maximum	1.707	1.702	1.712	1.712
Minimum	0.886	0.876	0.896	0.876
Station 3	0.476	0.466	0.434	
	1.051	1.043	1.043	
	1.215	1.251	1.214	
Average	0.914	0.920	0.897	0.910
Standard Deviation	0.317	0.332	0.335	0.348
Maximum	1.215	1.251	1.214	1.251
Minimum	0.476	0.466	0.434	0.434

Table 7. Bioconcentration factors (BCF) of Lead (Pb) contents of blood cockle flesh, seawater, and sediments in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Flesh (mg/kg)	Seawater (mg/l)	Sediment (mg/kg)	BAF of Seawater	BAF of Sediment
Station 1	6.475	0.109	3.792	59.404	1.708
	7.537	0.101	4.276	74.624	1.763
	7.391	0.090	3.614	82.122	2.045
Station 2	7.104	0.066	3.442	107.636	2.064
	7.744	0.093	3.341	83.269	2.318
	6.284	0.106	3.522	59.283	1.784
Station 3	6.739	0.073	3.784	92.315	1.781
	6.635	0.059	3.876	112.458	1.712
	7.237	0.103	3.648	70.262	1.984

From BCF analysis, it can be seen that the blood cockle is an actual bioaccumulator animal for Cu, where the Cu levels in its flesh are 115.609-248.657 times higher than in the surrounding seawater. Cu levels in blood cockle flesh were 3.562-11.586 times higher than in the surrounding sediment. BCF > 1 indicates the mussels accumulated more metals in their tissues than in the sediment (Table 8). On the other hand, BCF < 1 shows more metals in the sediments than in the blood cockle tissues (DeForest et al. 2007).

Table 8. Bioconcentration factors (BCF) of Copper (Cu) contents of blood cockle flesh, seawater, and sediments in Bangko District, Rokan Hilir Regency, Indonesia.

Research Stations	Flesh (mg/kg)	Seawater (mg/l)	Sediment (mg/kg)	BAF of Seawater	BAF of Sediment
Station 1	5.176	0.043	0.845	120.372	6.125
	6.816	0.046	1.092	148.174	6.242
	7.307	0.056	1.529	130.482	4.779
Station 2	6.081	0.037	1.707	164.351	3.562
	5.654	0.027	0.886	209.407	6.381
	8.486	0.041	1.091	206.976	7.778
Station 3	5.318	0.046	0.459	115.609	11.586
	8.703	0.035	1.046	248.657	8.320
	6.262	0.033	1.227	189.758	5.104

Water Quality Analysis

The average temperature of the seawater during the study was 29.3-29.5 ^{o}C, the degree of acidity ranged from 7.50-7.9, and the salinity was in the range of 20-22 ppt. The two chemical parameters measured, namely dissolved oxygen (DO) and biological oxygen demand (BOD_5), ranged from 5.1-6.1 ppm and 1.5-4.1 ppm, respectively (Table 9).

Table 9. Water quality parameters around the blood cockle cultivation area on the Bangko District, Rokan Hilir Regency, Indonesia.

Station	Water quality parameters				
	Temperature (^{o}C)	pH	Salinity (ppt)	DO (ppm)	BOD_5(ppm)
	29.4	7.79	20	5.5	2.5
I	29.3	7.76	21	5.1	2.8
	29.5	7.74	22	5.4	2.4
	29.5	7.67	20	5.8	1.5
II	29.6	7.69	21	5.3	2.3
	29.4	7.70	22	5.4	2.0
	29.4	7.69	20	6.1	4.1
III	29.5	7.50	21	6	3.3
	29.6	7.67	22	5.8	2.9

DISCUSSION

Pb levels

In blood cockle flesh, the Pb content from all stations and sampling collection ranged from 6,218 -7,864 mg/kg, an indication that this organism has been exposed to significant amounts of lead. The food safety standard reference according to the FAO/WHO Codex Alimentarius sets the safe limit for Pb content in seafood, especially molluscs, at a maximum of 1.5 mg/kg wet weight (FAO 1983, FAO 1989). The average value of 7.016 mg/g has far exceeded this limit, indicating a severe potential health risk. However, the Food and Drug Administration (FDA) allows a maximum Pb limit of 10 ppm (see Riza et al. 2021, Sánchez-Marín et al. 2019, Ulinuha & Perwira 2023). This data is critical to evaluate because blood cockles are a food source that humans often consume, and the accumulation of heavy metals such as Pb can harm human health. The high Pb concentration in blood cockles most likely originates from the aquatic environment in which they live (Hossen et al. 2014, Mohamed et al. 2006).

In seawater, the Pb content from all stations and sampling collection ranged from 0.022 to 0.111 mg/kg. Minister of Environment Decree No. 51 of 2004 (MER 2004) states the maximum limit of Pb content permitted in seawater for various purposes in Indonesia. For example, for marine biota purposes, this figure is a maximum of 0.008 mg/L. For recreational seawater, the limit is 0.05 mg/L, and for protection of marine conservation areas, the limit is stricter, namely around 0.005 mg/L. At all stations, the average Pb metal content in seawater is 0.089 mg/L (DSME 2004). This figure far exceeds the limits set for marine biota and is also higher than the limits for recreational waters. This indicates that the waters are polluted, which can endanger both marine life and human activities in the area (Benítez-Fernández et al. 2023).

In sediment, the Pb content from all stations and sampling collection ranged from 3.249 to 4.286 mg/kg. If we look at the average Pb levels in sediment, it can be said that these waters are still relatively safe. For example, the United States Environmental Protection Agency (USEPA 2004) sets a maximum limit for Pb levels in sediment of 47.82 mg/kg. Another agency, the Swedish Environmental Protection Agency (SEPA 2000), sets a lower limit, namely 25 mg/kg. Sources of lead pollution can include factories that dump industrial waste containing heavy metals into water, which can pollute the environment. Lead pollution in Rayer Bazaar primarily originated from adjacent battery recycling industries and other nearby industrial activities. The study found extremely high lead concentrations in soil (up to 2157.1 mg/kg) and vegetative tissues, indicating severe environmental contamination. Tannery and textile industries, although primarily associated with chromium pollution, also contribute to lead contamination in areas where they operate (Rikta et al. 2016). Mining activities that are not appropriately managed can release heavy metals such as Pb into the water system. Mining and e-waste processing activities released lead into the environment, affecting both local ecosystems and human health (Poudel et al. 2023). Heavy metal release into water from mining activities poses significant environmental and health risks. Various studies highlight the mechanisms and consequences of this pollution, particularly through acid mine drainage (AMD) and direct contamination from mining operations. AMD results from the exposure of sulfide minerals during mining, leading to increased acidity and heavy metal leaching into water bodies (Mukherjee et al. 2024). Direct discharges from mining activities, including runoff from tailings and waste rock, contribute to heavy metal contamination (Hudson et al. 2018). Ship fuel containing lead can also pollute seawater and affect marine biota (Sofiana et al. 2024, Qian et al. 2023), including blood cockle.

Cu levels

In blood cockle flesh, the Cu content from all stations and sampling collection ranged from 5.031-7.427 mg/kg. Based on standards set by various health institutions, such as the FAO/WHO Codex Alimentarius, the Cu content in seafood is generally not regulated as strictly as other heavy metals such as lead (Pb), mercury (Hg), or cadmium (Cd). This is considering that Cu is an essential metal that the human body needs in small amounts. Copper (Cu) is an essential trace element crucial for various physiological functions in the human body. It plays a significant role in enzyme activity, energy production, and the maintenance of connective tissues. The body requires approximately 1.0 to 1.5 mg of copper daily, with most intake derived from dietary sources such as grains (Aggett 2023). Cu is vital for enzymes like cytochrome c oxidase, which is essential for cellular respiration, and superoxide dismutase, which protects against oxidative stress (Hara 2022). The metal is involved in the synthesis of catecholamines through dopamine β-hydroxylase (Aggett 2023). Copper supports the cross-linking of elastin and collagen, crucial for bone strength and tissue integrity (Vetlényi & Rácz 2020). Copper is primarily absorbed in the small intestine, with about 60-70% of dietary copper being utilized. The body also recycles copper through gastrointestinal secretions (Hara 2022). However, Cu levels in seafood still need to be monitored since a high concentration can still be dangerous. The safe limit for Cu in seafood usually ranges from 10 to 30 mg/kg. In this study, data from all stations reveal that Cu metal of 5.141-8.693 mg/kg in blood cockles is far below the safe limit, so it is considered safe for consumption and does not pose a direct health risk to humans (FAO 1989).

In seawater, the Cu content from all stations and sampling collection ranged from 0.024 to 0.060 mg/kg. Of all stations, the highest Cu metal content in seawater was 0.0560 mg/L. Based on the Decree of the State Minister for the Environment No. 51 of 2004 concerning seawater quality standards in Indonesia, the maximum limit for copper (Cu) content in seawater varies according to its use. Class I (for marine biota and conservation areas) is 0.008 mg/L. Class II (for marine recreation activities, aquaculture, and marine tourism) is 0.01 mg/L. Class III (for port and industrial waters) is 0.05 mg/L. Based on this data, the value of 0.0560 mg/L exceeds the safe limit for marine biota and marine recreational activities, which are only 0.008 mg/L and 0.01 mg/L, respectively. This means that seawater at all research stations has much higher levels of Cu to support the survival of marine biota or for recreational and cultivation activities. However, this Cu content is almost equivalent to the maximum limit for industrial and port seawater (0.05 mg/L), indicating that these waters may be located near industrial areas or ports that have copper pollution activities (DSME 2004).

The Cu content in seawater can come from various anthropogenic sources. For example, waste disposal from metal processing, chemical, or manufacturing industries near coastal areas often contains heavy metals, including Cu. Organic wastes are notable sources of Cu contamination in agricultural soils, with Cu(I) and Cu(II) species varying during treatment processes. In Brazil, Cu from organic waste contributes to moderate soil contamination levels, alongside other sources like antifouling paints and mining tailings (Poggere et al. 2023). Electronic waste, particularly from discarded electronics, is a rapidly growing source of Cu. Studies show that printed circuit boards (PCBs) contain high Cu concentrations, with extraction methods yielding up to 82% Cu recovery (Hsu et al. 2021, Olubanjo et al. 2015). Shipping and port activities use Cu in anti-fouling paint on ship hulls to prevent the growth of marine organisms; when this paint dissolves, copper can pollute seawater (Elmas et al. 2021). Agricultural waste, pesticides, and fertilizers containing copper carried by water run-off from agricultural land can pollute seawaters (Comber et al. 2023, Zalewska et al. 2024).

In the surrounding sediment, the Cu content from all stations and sampling collection ranged from 0.434 to 1.712 mg/kg. Cu levels in sediment in this study appear to still be below the standard threshold. The United States Environmental Protection Agency (USEPA 2004) set a Cu sediment level of 49,98 mg/kg. The Swedish Environmental Protection Agency (SEPA 2000) set the Cu sediment maximum level of 15 mg/kg.

Decree of the Minister of Environment of the Republic of Indonesia in Indonesia, standards for Cu content in marine sediments vary depending on the type of water. For public or industrial waters, Cu concentrations below 20-30 mg/kg are considered reasonable and not dangerous. For conservation areas or more sensitive ecosystems, this limit may be lower. The highest Cu content of 6.761 mg/kg in blood cockle flesh is relatively low and is not considered a dangerous level. However, monitoring is still needed to ensure that there is no increase in levels of this metal in the long term (DSME 2004).

The average Cu concentration in sediments is generally below established guidelines, but maximum levels can indicate significant contamination. While the hazard index for Cu exposure is typically below 1, indicating low non-carcinogenic risk, specific locations show elevated risks, particularly for children. Some studies suggested that local point sources contribute to Cu levels, with some sediments exceeding 500 mg/kg, particularly in regions like China (Yap et al. 2022). Cu-based antifouling paints are a primary anthropogenic source of Cu contamination, particularly in marinas, where sediment cores show varying Cu isotope compositions, indicating complex interactions between Cu sources and sediment deposition (Briant et al. 2022, Little et al. 2017).

Bioconcentration factors

The bioconcentration factors (BCFs) of lead (Pb) and copper (Cu) are critical in understanding how these metals accumulate in aquatic organisms and their potential ecological risks. BCFs are used to assess the extent to which organisms can concentrate metals from their environment, providing insights into pollution levels and potential hazards to aquatic life and humans. The blood cockle is an actual bioaccumulator animal for Pb, where the Pb levels in its flesh were 59.283-112.458 and 1.784-2.318 times higher than in the surrounding seawater and sediment, respectively. A similar result was also noted for Cu, where the Cu levels in its flesh are 115.609-248.657 and 3.562-

11.586 times higher than in the surrounding seawater and sediment. BCF > 1 indicates the mussels accumulated more metals in their tissues compared to their surrounding area.

The bioconcentration factors (BCFs) of cockles, particularly the blood cockle (*Anadara granosa*) and common cockle (*Cerastoderma edule*), reveal significant insights into their ability to accumulate heavy metals and other contaminants from their environment. These factors are crucial for understanding the ecological risks associated with heavy metal exposure in coastal ecosystems. *A. granosa* has shown high bioconcentration factors for metals such as cadmium (Cd) and mercury (Hg), with maximum concentration factors (CFM) reaching 166 for Hg (Srisuksawad & Prasertchiewchan 2007). Ecological monitoring of *C. edule* demonstrated bioaccumulation of trace elements like nickel (Ni), copper (Cu), and zinc (Zn), which were used as ecological indices for assessing sediment contamination. The bioaccumulation patterns varied significantly based on sediment quality, highlighting the importance of environmental conditions in determining BCFs (Lobo et al. 2010).

Water Quality Analysis

Based on water quality standards for fish cultivation needs (INS 2008, Rice & Bridgewater 2012, MER 2014), it appears that these waters are quite optimal and can support the normal life of biota around the blood cockle cultivation area.

CONCLUSIONS

Pb levels in blood cockle flesh have far exceeded the threshold. Laboratory analysis revealed that Pb contents in blood cockle flesh, seawater, and sediment ranged between 6.218 -7.864 mg/kg, 0.022-4.286 mg/L, and 3.249-7.134 mg/kg, respectively. However, the Cu content in water and sediment was still below the threshold. The Cu content ranged between 5.031-7.427 mg/kg, 0.024-1.707 mg/L, and 0.434-1.251 mg/kg, respectively. Cu levels were still below the threshold for all samples.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to 1) Lancang Kuning University, Pekanbaru, Indonesia, 2) Universiti Malaya, Kuala Lumpur, Malaysia, and 3) Riau University, Pekanbaru, Indonesia, for funding assistance and active participation until the completion of this research.

REFERENCES

Aggett, P.J. (2023): Copper. pp. 200–208. In: Caballero, B. (ed.), Encyclopedia of Human Nutrition (Fourth Edition), Academic Press, Elsevier.

Alankarage, D., Juhasz, A.L. (2023): Contributions of contamination sources to soil lead concentrations of a smelter-affected community in South Australia, Australia. Environmental Advances 13(6):100434.

Alkhanjaf, A.A.M., Sharma, S., Sharma, M., Kumar, R., Arora, N.K., Kumar, B., Umar, A., Baskoutas, A., Mukherjee, T.K. (2024): Microbial strategies for copper pollution remediation: Mechanistic insights and recent advances. Environmental Pollution 346: 123588.

Benítez-Fernández, N.C., Pérez-Legaspi, I.A., Rubio-Franchini, I. (2023): Transfer of lead through different trophic levels: Microalgae (*Nannochloropsis oculata*), rotifer (*Brachionus plicatilis*), and prawn (*Macrobrachium rosenbergii*). Revista Internacional De Contaminación Ambiental 39: 405-416.

Bhavani, R.V., Sharma, S., Singh, K.P. (2024): Health impacts associated with heavy metals exposure. pp 34-45. In: Bhavani, R.V., Sharma, S., Singh, K.P. (eds.), Heavy metal contamination in the environment. 1st Edition. CRC Press.

Briant, N., Freydier, R., Araújo, D., Delpoux, S., Elbaz-Poulichet, F. (2022): Cu isotope records of Cu-based antifouling paints in sediment core profiles from the largest European Marina, The Port Camargue. Science of The Total Environment 849: 157885.

Collado-López, S., Betanzos-Robledo, L., Téllez-Rojo, M.M., Lamadrid-Figueroa, H., Reyes, M., Ríos, C., Cantoral, A. (2022): Heavy metals in unprocessed or minimally processed foods consumed by humans worldwide: A scoping review. International Journal of Environmental Research and Public Health 19(14): 8651.

Comber, S., Deviller, G., Wilson, I., Peters, A., Merrington, G., Borrelli, P., Baken, S. (2023): Sources of copper into the European aquatic environment. Integrated Environmental Assessment and Management 19(4):1031-1047.

DeForest, D.K., Brix, K.V., Adams, W.J. (2007): Assessing metal bioaccumulation in aquatic environments: The inverse relationship between bioaccumulation factors, trophic transfer factors, and exposure concentration. Aquatic Toxicology 84: 236-246.

DSME (Decree of the State Minister for the Environment) No. 51 of 2004 concerning standards of seawater quality (2004): State Minister for the Environment of the Republic of Indonesia, Jakarta.

Elmas, S., Skipper, K., Salehifar, N., Salehifar, N., Jamieson, T., Andersson, G.G., Nydén, M., Leterme, S.C., Andersson, M. (2021): Cyclic copper uptake and release from natural seawater - a fully sustainable antifouling technique to prevent marine growth. Environmental Science & Technology 55(1): 757-766.

FAO (Food and Agriculture Organization) (1983): Compilation of legal limits for hazardous substances in fish and fishery products, FAO Fishery Circular No. 464, pp. 5-100.

FAO (Food and Agriculture Organization) (1989): Evaluation of certain food additives and the

contaminants mercury, lead, and cadmium, WHO Technical Report, Series No. 505.
Francisco, A.P., Aride, P.H.R., de Souza, A.B., Polese, M.F., Lavander, H.D., Gomes, L.C. (2020): Toxicity of copper in *Epinephelus marginatus* (Perciformes; Serranidae) after ingestion of contaminated food. Bulletin of Environmental Contamination and Toxicology 105(5): 711-714.
Galanakis, C.M. (2024): The future of food. Foods 13(4): 506.
Gil, F., Olmedo, P. (2023): Food safety heavy metals and metalloids. pp. 351-361. In: Caballero, B. (ed.), Encyclopedia of Human Nutrition, 1-4, Academic Press, Elsevier.
Hara, H. (2022): Introduction to serial reviews: Copper biology in health and disease. Journal of Clinical Biochemistry and Nutrition 71: 1.
Hossen, Md.F., Hamdan, S., Rahman, Md.R. (2014): Cadmium and lead in blood cockle (*Anadara granosa*) from Asajaya, Sarawak, Malaysia. The Scientific World Journal 2014: 924360.
Hsu, E., Durning, C.J., West, A.C., Park, A.-H.A. (2021): Enhanced extraction of copper from electronic waste via induced morphological changes using supercritical CO2. Resources Conservation and Recycling 168: 105296.
Hudson, E., Kulessa, B., Edwards, P., Williams, T., Walsh, R.P.D. (2018): Integrated hydrological and geophysical characterisation of surface and subsurface water contamination at abandoned metal mines. Water, Air, and Soil Pollution 229(8): 256.
INS (Indonesian National Standards) (2008): Indonesian National Standards 6989.59 of 2008, concerning water and wastewater – Part 59: Wastewater Sampling Method. 2008. National Standardization Agency, Jakarta.
Jomová, K., Alomar, S.Y., Nepovimová, E., Kuča, K., Valko, M. (2024): Heavy metals: toxicity and human health effects. Archives of Toxicology 99: 153-209.
Karanth, S., Benefo, E.O., Patra, D., Pradhan, A.K. (2023): Importance of artificial intelligence in evaluating climate change and food safety risk. Journal of Agriculture and Food Research 11: 100485.
Khamidulina, H.H., Tarasova, E.V., Rinchindorzhieva, E.A., Proskurina, A.S., Egiazaryan, A.R., Zamkova, I.V., Dorofeeva, E.V., Shvykina, S.A., Rabikova, D.N., Nikolaeva, N.I., Filin, A.S., Lebedeva, D.A. (2021): Highlights of international regulation of lead, cadmium, mercury and arsenic contents in food. Toxicological Review 1: 2-13.
Little, S.H., Vance, D., McManus, J., Severmann, S., Lyons, T.W. (2017): Copper isotope signatures in modern marine sediments. Geochimica et Cosmochimica Acta 212: 253-273.
Lobo, J., Costa, P.M., Caeiro, S., Caeiro, S., Martins, M., Reis Ferreira, A.M., Caetano, M., Cesário, R., Vale, C., Costa, M.H. (2010): Evaluation of the potential of the common cockle (*Cerastoderma edule* L.) for the ecological risk assessment of estuarine sediments: bioaccumulation and biomarkers. Ecotoxicology 19(8): 1496-1512.
Machado, J.C., Maltez, L. (2021): Comparing chronic and acute heavy metal poisoning: Mechanisms, clinical profiles, and management strategies. International Journal of Molecular Biology and Biochemistry 3(2): 1-3.
Mahary, A., Effendi, I., Hendrik, H., Darwis, D. (2023): Strategy for development of blood cockles (Anadara granosa) cultivation in Batubara Regency, North Sumatra, Indonesia. AACL Bioflux 16(3): 1636-1647.
Mandal, G.C., Mandal, A., Chakraborty, A. (2023): The toxic effect of lead on human health. Human Biology and Public Health 3: 1-11.
Martin, N.H., Trmcic, A., Hsieh, T.-H., Boor, K.J., Wiedmann, M. (2016): The evolving role of

coliforms as indicators of unhygienic processing conditions in dairy foods. Frontiers in Microbiology 7: 1549.
Maurya, A., Kesharwani, L., Mishra, M.K. (2018): Analysis of heavy metal in soil through atomic absorption spectroscopy for forensic consideration. International Journal for Research in Applied Science & Engineering Technology (IJRASET) 6(6): 1188-1192.
MER (Minister of Environment Regulation) (2004): Minister of Environment Regulation of the Republic of Indonesia Number 5 of 2014 concerning Seawater Quality Standards. Ministry of Environment of the Republic of Indonesia. Jakarta, Indonesia.
MER (Minister of Environment Regulation) (2014): Minister of Environment Regulation of the Republic of Indonesia Number 5 of 2014 concerning Waste Water Quality Standards. Ministry of Environment of the Republic of Indonesia. Jakarta, Indonesia.
Miller, S.A., Anderson, B., Falci, K.J. (1983): U.S. Food and Drug Administration Regulatory Strategies for Lead in Foods: Past, Present, and Future. pp. 20-25. Springer, Berlin, Heidelberg.
Min, K.S., Kee, K.P., Tien, S.K., Heng, L.Y., Surif, S. (2011): Analisis proksimat dan logam berat dalam tisu kerang (*Anadara granosa*) di beberapa tapak akuakultur di semenaniung Malaysia. Sains Malaysiana 40(2): 139-146.
Mishra, S., Tirkey, N., Mishra, S. (2024): Chronic and acute health impacts, including neurological disorders, development abnormalities, carcinogenicity, and organ damage. pp. 124-156. In: Singh, V., Kumar, A., Mishra, V., Rai, S.N. (ed.), Heavy Metal Contamination in the Environment Health Impacts and Potential Remediation Approaches. 1st Edition. CRC Press.
Mohamed, C.A.R., Theng, T.L., Ahmad, Z. (2006): 210 Po and 210 Pb in cockle tissues in the west coast of Peninsula Malaysia. Journal of Nuclear and Related Technologies 3(1&2): 69-75.
Mukherjee, S., Paramanik, M., Paramanik, S., Dasmodak, S., Rajak, P., Ganguly, A. (2024): A silent threat to environmental health and its journey toward sustainable management. Acid mine drainage. pp. 493-518. In: Banerjee, A., Jhariya, M.K., Raj, A., Mechergui, T. (eds.), Ecosystem management: climate change and global sustainability. Chapter 15. Scrivener Publishing LLC.
O'Connor, D., Hou, D., Ok, Y.S., Lanphear, B.P. (2020): The effects of iniquitous lead exposure on health. Nature Sustainability 3(2): 77-79.
Okewale, I.A., Grobler, H. (2023): Assessment of heavy metals in tailings and their implications on human health. Geosystems and Geoenvironment 2(4): 100203.
Olubanjo, K., Osibanjo, O., Chidi, N. (2015): Evaluation of Pb and Cu contents of selected component parts of waste personal computers. Journal of Applied Sciences and Environmental Management 19(3): 470-477.
Padmiswari, A.A.I.M., Wulansari, N.T., Antari, N.W.S., Damayanti, I.A.M., Indrayoni, P., Indrawan, G.S. (2021): The effectiveness of soaking duration on blood cockles (*Anadara granosa*) with activated charcoal towards reducing metals lead (Pb). International Journal of Health & Medical Sciences 4(3): 304-308.
Panghal, A., Thakur, A., Deore, M.S., Goyal, M., Singh, C., Kumar, J. (2024): Multimetal exposure: Challenges in diagnostics, prevention, and treatment. Journal of Biochemical and Molecular Toxicology 38(6): e23745.
Patočka, J., Kuca, K. (2016): Lead exposure and environmental health. Military Medical Science Letters 85(4): 147-163.

Peng, C., Zhao, X., Han, Y., Shi, W., Liu, S., Liu, G. (2015): Toxic effects of chronic sub-lethal Cu2+, Pb2+ and Cd2+ on antioxidant enzyme activities in various tissues of the blood cockle, *Anadara granosa*. Journal of Residuals Science and Technology 12(3): 125-131.

Permata, Y.M., Liesna, A.T., Rangkuti, F.M., Insyra, K., Dayanti, Y. (2023): Proximate composition of *Anadara granosa* and *Paphia undulata*. Indonesian Journal of Pharmaceutical and Clinical Research 6(1): 01-05.

Poggere, G.C., Gasparin, A., Barbosa, J.Z., Melo, G.W., Corrêa, R.S., Motta, A.C.V. (2023): Soil contamination by copper: sources, ecological risks, and mitigation strategies in Brazil. Journal of Trace Elements and Minerals 4: 100059.

Poudel, K., Ikeda, A., Fukunaga, H., Brune Drisse, M., Onyon, L., Gorman, J., Laborde, A., Kishi, R. (2023): How does formal and informal industry contribute to lead exposure? A narrative review from Vietnam, Uruguay, and Malaysia. Reviews on Environmental Health 39(2): 371-388.

Qian, N., Boyle, E.A., Zhou, L., Tanzil, J., Chen, Q., Zhang, S., Chen, M. (2023): 3. Spatial-temporal variability and sources of lead (Pb) in the Indian Ocean and Asian Marginal Seas. Journal of Geophysical Research: Oceans 128: e2022JC019222.

Rahman, M.M., Hajar, S., Yunus, K.B. (2020): Comparative analysis of chemical composition of some commercially important fishes with an emphasis on various Malaysian diets. Open Chemistry 18(1): 1323-1333.

Rice, E.W., Bridgewater, L. (2012): Standard methods for water and waste water. American Public Health Association, 22nd edition. American Public Health Association. Washington, D.C.

Rikta, S.Y., Rahaman, Md.S., Rahman, Md.M., Tareq, S.M. (2016): Lead polluted hotspot: environmental implication of unplanned industrial development. Present Environment and Sustainable Development 10(1): 51-60.

Riza, S., Gevisioner, G., Suprijanto, J., Widowati, I., Putra, I., Effendi, I. (2021): Farming and food safety analysis of blood cockles (*Anadara granosa*) from Rokan Hilir, Riau, Indonesia. AACL Bioflux 14(2): 804-812.

Rozirwan, N., Nugroho, R.Y., Diansyah, G., Putri, W.A.E., Agussalim, A. (2023): Phytochemical composition, total phenolic content and antioxidant activity of *Anadara granosa* (Linnaeus, 1758) collected from the east coast of South Sumatra, Indonesia. Baghdad Science Journal 20(4): 6.

Sánchez-Marín, P., Durán, R., Beiras, R. (2019): In vivo oral bioavailability of Pb sequestered in metal rich granules in bivalves. Ecotoxicology and Environmental Safety 181: 330-335.

Sani, A.H., Amanabo, M. (2021): Lead: A concise review of its toxicity, mechanism and health effect. GSC Biological and Pharmaceutical Sciences 15(1): 55-62.

Schmitt, O.J., Andriolo, J.L., Silva, I.C.B., Tiecher, T.L., Chassot, T., Tarouco, C.P., Lourenzi, C.R., Nicoloso, F.T., Marchezan, C., Casagrande, C.R., Drescher, G.L., Kreutz, M.A., Brunetto, G. (2022): Physiological responses of beet and cabbage plants exposed to copper and their potential insertion in human food chain. Environmental Science and Pollution Research 29(29): 44186-44198.

SEPA (Swedish Environmental Protection Agency) (2000): Environmental Quality Criteria – Lakes and Watercourses. Report 5050.

Singh, C., Shekhar, A., Singh, R. (2023). Neurotoxic effect of lead: a review. pp. 33-50. In: Kumar, N., Jha, A.K. (eds.), Lead toxicity: challenges and solution. Environmental Science and Engineering. Springer, Cham.

SNI 06-6992.3-2004 (2004): Sedimen - Bagian 3: Cara uji timbal (Pb) secara destruksi asam dengan spektrofotometer serapan atom (SSA). Standar Nasional Indonesia. Badan Standarisasi Nasional. Jakarta. Pp 9.

SNI 06-6992.5-2004 (2004): Sedimen - Bagian 3: Cara uji timbal (Pb) secara destruksi asam dengan spektrofotometer serapan atom (SSA). Standar Nasional Indonesia. Badan Standarisasi Nasional. Jakarta. Pp 9.

Sofiana, M.S.J., Safitri, I., Nurhidayanti (2024): Occurrence of lead (Pb) metal in water, sediment, and bioaccumulation in giant mudskipper (Boleopthalmus: Gobiidae) from the Pemangkat Mangrove Area West Kalimantan. Jurnal Ilmiah PLATAX 12(1): 345-357.

Srisuksawad, K., Prasertchiewchan, N. (2007): Experimental studies on the bioaccumulation of selected heavy metals and radionuclides in the blood cockle *Anadara granosa* of the Bang Pakong estuary. Environmental Bioindicators 2(4): 253-263.

Teng, J., Yu, X.-Z. (2023): The effect of different heavy metals on human health. Highlights in Science Engineering and Technology 74: 875-880.

Tu, N.P.C., Ha, N.N., Dong, N.V., Nhan, D.T., Tri, N.N. (2022): Heavy metal levels in blood cockle from south Vietnam coastal waters. New Zealand Journal of Marine and Freshwater Research 58(1): 145-154.

Ulinuha, D., Perwira, I.Y. (2023): Bioakumulasi timbal (Pb) pada bivalvia (*Anadara antiquata, Anadara granosa* dan *Perna viridis*) dari perairan Lekok, Pasuruan. Journal of Marine and Aquatic Sciences 8(2): 179-185.

USEPA (United State Environmental Protection Agency) (2004): Guidelines for Water Reuse. United State Agency for International Development, Washington, DC. p 450.

Verma, R., Patel, M., Shikha, D., Mishra, S. (2023): Assessment of food safety aspects and socioeconomic status among street food vendors in Lucknow city. Journal of Agriculture and Food Research 11: 100469.

Vetlényi, E., Rácz, G. (2020): The physiological function of copper, the etiological role of copper excess and deficiency. Orvosi Hetilap 161(35): 1488-1496.

Wang, X., Zhang, M., Cao, H., Dar, M.I., Ali, S. (2022): Transfer of copper (Cu) in the soil–plant–mealybug–ladybird beetle food chain. Insects 13(9): 761.

Yap, C.K., Saleem, M., Tan, W.S., Syazwan, W.M., Azrizal-Wahid, N., Nulit, R., Ibrahim, M.H., Mustafa, M., Rahman, M.A.A., Edward, F.B., Arai, T., Cheng, W.H., Okamura, H., Ismail, M.S., Kumar, K., Avtar, R., Al-Mutair, K.A., Al-Shami, S.A., Subramaniam, G., Wong, L.S. (2022): Ecological–health risk assessments of copper in the sediments: A review and synthesis. Pollutants 2(3): 269-288.

Yona, D., Sari, S.H.J., Iranawati, F., Fathur Rayyan, M., Rini, N.M. (2020): Heavy metals accumulation and risk assessment of *Anadara granosa* from eastern water of Java Sea, Indonesia. IOP Conference Series: Earth and Environmental Science 416: 012007.

Zalewska, T., Danowska, B., Wilman, B., Saniewski, M., Iwaniak, M., Bork-Zalewska, J., Marciniewicz-Mykieta, M. (2024): copper as a complex indicator of the status of the marine environment concerning climate change. Water 16(17): 2411.

Zhao, D., Wang, L., Zhao, F. (2024): Toxic metals and metalloids in food: current status, health risks, and mitigation strategies. Current Environmental Health Reports 11: 468-483.

Zitoun, R. (2018): A delicate balance between copper necessity and toxicity. Junctures 19: 93-98.