Jurnal Teknologi Perikanan dan Kelautan Vol. 16 No. 4 November 2025: 428-439 *ISSN 2087-4871*
DOI: https://doi.org/10.24319/jtpk.16.428-439 *EISSN 2549-3841*

TEMPORAL AND SPATIAL VARIATIONS OF HEAVY METALS IN SHELLFISH IN BANTEN BAY

VARIASI TEMPORAL DAN SPASIAL LOGAM BERAT PADA KERANG DAN KEPITING DI TELUK BANTEN

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(Received September 10, 2025; Revised November 5, 2025; Accepted November 11, 2025)

ABSTRACT

Banten Bay is a busy water area with diverse activities, including capture fisheries, aquaculture, marine and land transportation, and industry, which are estimated to generate significant amounts of heavy metals that enter the water and accumulate in fish and shellfish. Some fishery commodities commonly found in Banten Bay included shellfish, such as blood cockles, green mussels, mud crabs, and blue swimming crabs. The study aims to monitor heavy metal contamination variations spatially and temporally of the shellfish in Banten Bay. Biota samples were taken for 6 months in Cengkok Coastal Waters (March–August 2019) and 3 months in Bojonegara Coastal Waters (August–October 2020). The heavy metal content was determined using an atomic absorption spectrophotometer (AAS). Pb and Cd concentrations in the flesh of the shellfish (blood cockles, green mussels, mud crabs, and blue swimming crabs) from the Cengkok and Bojonegara Coastal Waters ranged from 0.001 to 0.070 ppm and from <0.001 to 0.030 ppm, respectively. All measured heavy metal concentrations met the BPOM (2018) quality standards. Bioconcentration factors were generally <100, indicating low accumulation levels. Blood cockles, green mussels, and mud crabs from Cengkok Coastal Waters were still safe for consumption in normal amounts, while the consumption of swimming crabs was strictly limited to 0.42 kg/week for adults and 0.11 kg/week for children. The same four species from the Bojonegara Coastal Waters were also considered safe for consumption in normal portions.

Keywords: Banten Bay, blood cockles, blue swimming crabs, green mussels, mud crabs

ABSTRAK

Perairan Pantai Teluk Banten merupakan salah satu wilayah perairan yang cukup ramai dengan aktivitas yang beragam, yang mencakup perikanan tangkap, perikanan budidaya, transportasi, dan industri, yang diperkirakan dapat menghasilkan limbah logam berat di perairan tersebut dan berakumulasi pada kerang dan kepiting. Beberapa jenis komoditas perikanan yang cukup sering ditemukan di Teluk Banten ini adalah kerang dan kepiting yang terdiri atas kerang darah, kerang hijau, kepiting, dan rajungan. Penelitian ini memiliki tujuan mengamati variasi spasial dan temporal kontaminasi logam berat pada kerang dan kepiting di Teluk Banten. Contoh biota diambil selama 6 bulan di Pantai Cengkok (Maret–Agustus 2019) dan 3 bulan di Pantai Bojonegara (Agustus–Oktober 2020). Kandungan logam berat diamati menggunakan *atomic absorption spectrophotometer* (AAS). Kandungan Pb dan Cd pada daging kerang dan kepiting (kerang darah dan hijau, kepiting, dan rajungan) pada perairan Pantai Cengkok dan Bojonegara, secara berturut-turut berkisar 0,001–0,070 ppm, dan <0,001-0,030 mg/kg. Kandungan logam berat tersebut memenuhi baku mutu BPOM (2018). Faktor biokonsentrasi secara umum bernilai <100, yang tergolong ke dalam kategori akumulasi rendah. Kerang darah, kerang hijau, dan kepiting bakau dari Pantai Cengkok masih aman dikonsumsi dalam jumlah yang normal, sedangkan konsumsi rajungan terbatas hanya 0,42 kg/minggu untuk orang dewasa dan 0,11 kg/minggu untuk anak-anak. Keempat biota yang sama dari Pantai Bojonegara masih aman dikonsumsi dalam porsi yang normal.

Kata kunci: kepiting, kerang darah, kerang hijau, rajungan, Teluk Banten

INTRODUCTION

Banten Bay is located north of Serang Regency, approximately 60 km west of Jakarta, with a coastline of 22 km, a diameter of approximately 15 km, and an area of approximately 150 km^2. The bay's waters are relatively shallow, with depths of no more than 12 m, a substrate generally consisting of sandy mud, and relatively high turbidity (Douven *et al.* 2003). The characteristics of Banten Bay's waters are influenced by the Sunda Strait, which produces relatively strong tidal currents near the Java Sea and weaker ones in Banten Bay (Wisha *et al.* 2015).

Currently, the surrounding area of Banten Bay is experiencing rapid development across various sectors (Mawardi and Sarjani 2017). Population growth in the area surrounding the bay has driven a shift in land use into transitional areas, particularly industrial areas (Wisha *et al.* 2015). One of the dominant sectors around the bay is industry, including refined sugar factories, shipyards, and power plants. At least 351 industries are estimated to be contributing to the decline in the environmental quality of water bodies (Farkan *et al.* 2017). Other sources of pollutants include agricultural and plantation waste, as well as domestic waste (Mawardi and Sarjani 2017). The growth of industry and residential areas has led to an increase in the amount of waste that can pollute aquatic environments (Putri *et al.* 2012). The increasing sources of waste pollution from human activities are highly concerning, given that this waste adds to the environmental pollution burden.

Heavy metals are pollutants with significant potential to reduce and damage the environmental carrying capacity. This is a condition that requires vigilance, as heavy metals are accumulative elements, both in sediments and in aquatic organisms. If heavy metals are present in significant quantities, they can impact the biological and ecological aspects of a body of water (Ismarti *et al.* 2017). Of the various types of waste, heavy metal waste is classified as the most dangerous pollutant because it is toxic to the environment and living organisms, including humans (Setiawan 2013).

Heavy metals in marine waters can originate from various human activities, such as mining, household waste disposal, horticulture, and industry (Silalahi *et al.* 2023). The main sources of lead (Pb) come from fuel waste, explosives, oil spills, and the battery industry. Pb pollution also comes from the use of lead as a connecting medium for pipes used in industrial and domestic waste disposal sampling locations, and the use of ship lubricants (Elfidasari *et al.* 2019). In addition to Pb, cadmium (Cd) found in waters can originate from the paint, battery, and electroplating industries. According to Pratiwi (2020), Cd also originates from agricultural and household activities.

Research has been conducted on partial heavy metal content in the edible flesh of blood cockles, green mussels, crabs, and swimming crabs in the waters of Cengkok and Bojonegara Coastal Waters of Banten Bay, i.e., Febrianessa *et al.* (2020), Noviani *et al.* (2020), Dinulislam *et al.* (2021), Melinda *et al.* (2021), Fatryani *et al.* (2022), Nedya *et al.* (2022), Susilowati *et al.* (2022). However, a comprehensive study comparing heavy metal concentrations in the edible flesh of these organisms has never been reported. This study aims to monitor spatial and temporal variations in heavy metal contamination in Banten Bay, and to compare these findings with environmental quality standards and safety levels for consumption, to assess potential pollution risks, and to provide essential baseline information for managing aquatic biota resources.

METHODS

Time and location

Samples of shellfish (blood cockles, green mussels, mud crabs, and swimming crabs) were taken monthly for 9 months, namely March–August 2019 (in the Cengkok Coastal Waters), and August–October 2020 (in the Bojonegara Coastal Waters), Banten Bay (Figure 1). The selection of these two locations represents a polluted area that is surrounded by busy human activities such as agriculture, settlements, and industry, as well as fisheries and aquaculture activities. In addition, these two waters are also the estuaries of the Cibanten, Wadas, and Terate Rivers. A sample analysis of the aquatic biota flesh was carried out in Bio-Macro Laboratory I. Furthermore, the process of destroying the flesh (wet destruction) was carried out in the Dairy Animal Nutrition Laboratory, while the analysis of heavy metal content in the aquatic biota flesh was carried out in the Joint Laboratory, IPB University.

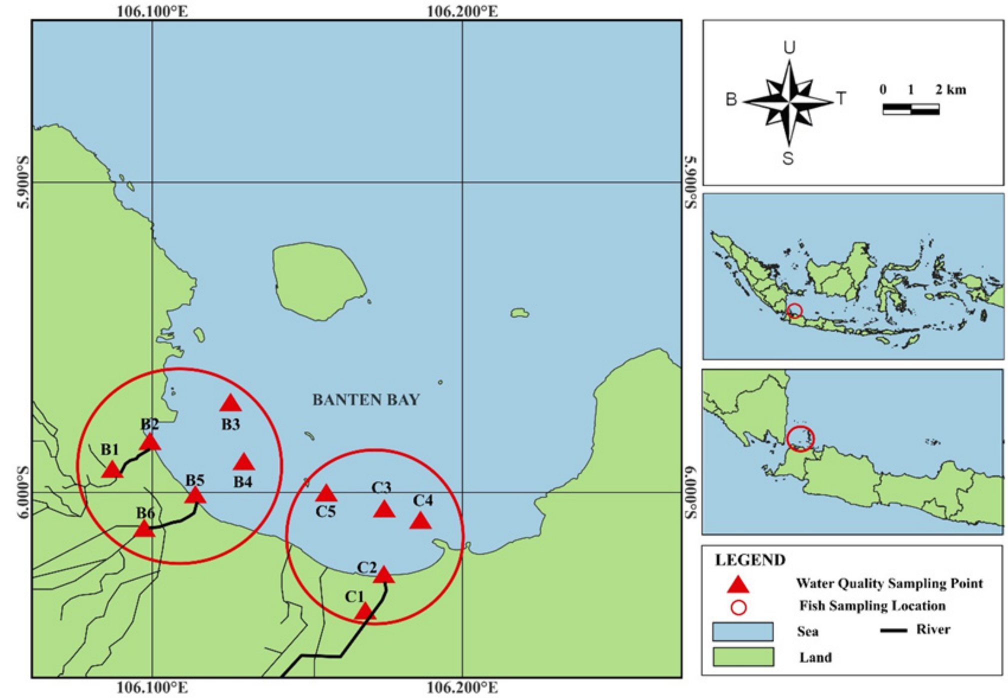

Figure 1. Location of research on heavy metal content in several fishery commodities (blood cockles, green mussels, mud crabs, and swimming crabs) in the Cengkok and Bojonegara Coastal Waters, Banten Bay.

Equipment and materials

The equipment needed in this research included a cool box, ruler, surgical instruments, analytical scales, and an atomic absorption spectrophotometer (AAS), Shimadzu brand type AA-7000, while the materials needed were aluminum foil, nitric acid (HNO_3), perchloric acid ($HClO_4$), and marine biota (blood cockles, green mussels, mud crabs, and swimming crabs).

Data collection

Sample collection and preparation were carried out through a series of activities of capturing biota, measuring length and weight, and collecting flesh from aquatic biota. Aquatic biota were captured using several fishing gears, including rakes (clams), traps (crabs), and gill nets (swimming crabs). Samples of the aquatic biota flesh were placed in a cool box containing ice cubes. The cool box was used to maintain the quality of the samples being analyzed. Blood cockles, green mussels, mud crabs, and swimming crabs were measured for body length using a ruler and weighed using an analytical balance. The biota was dissected, and their flesh was taken as much as 30–50 g. The number of samples captured varied for each type of biota (blood cockles and green mussels, 90–200 individuals, mud crabs ±75 individuals, and swimming crabs 90–180 individuals). Aluminum foil was prepared to wrap the flesh, then stored in a refrigerator to maintain sample quality. The samples that had been taken were labeled and then analyzed in the laboratory, in accordance with APHA (2012).

Heavy metal content in biota flesh and water

Analysis of the heavy metals Pb and Cd in aquatic biota flesh was conducted in two stages: wet digestion and heavy metal content analysis. Sample digestion was carried out using the nitric acid-perchloric acid digestion, which involves adding nitric acid and perchloric acid to separate the fat from the solution (AOAC 2002). The solution was then analyzed for heavy metals spectrophotometrically using an atomic absorption spectrophotometer (AAS) at wavelengths of 217.0 nm and 228.8 nm, respectively.

Data analysis

Descriptive analysis

Descriptive analysis was conducted on the data obtained to determine the presence and quantity of heavy metals in the edible flesh of aquatic organisms. The results of the physical and chemical parameters of the water were compared with quality standards based on Government Regulation of the Republic of Indonesia (PP RI) Number 22 of 2021, while the results of the heavy metal content analysis were compared with quality standards based on the Food and Drug Monitoring Agency (BPOM 2018).

Bioconcentration factor

Bioconcentration factor (BCF) is the ability of organisms to absorb chemicals. This value is obtained by comparing the pollutant content in the water with that in the body of the organism (EPA, 2003):

$$BCF = \frac{Ct}{Cw}$$

Description:
BCF = Bioconcentration factor
Ct = Pollutant concentration value in aquatic organisms (mg/kg)
Cw = Pollutant concentration value in water (mg/L)
The BCF value can be classified according to Esch (1977) as low accumulation (BCF < 100), medium accumulation (100 < BCF ≤ 1000), and high accumulation (BCF > 1000).

Safety level

The safe limit for consuming aquatic biota flesh is calculated using the EPA (2000) formula.

$$CRlim = \frac{RfD \times BW}{Cm}$$

Description:
CRlim = Maximum consumption limit (g/week)
RfD = Reference dose (μg/kg-week)
BW = Body weight (kg)
Cm = Heavy metal concentration in the edible flesh of aquatic organisms (mg/kg)

RESULTS AND DISCUSSION

Physical and chemical parameters of water

The results of observations of water quality conditions, both physical and chemical parameters in the waters of Cengkok and Bojonegara Coastal Waters of Banten Bay, are presented in Table 1. These observation results were then compared using the quality standards from PP RI No. 22 of 2021. All observation results on temperature parameters (28.2–31.2 °C), pH (7–7.8), DO (5.6–9.3 ppm), and Pb (0.002–0.008 ppm) in met the quality standards, while in Bojonegara Coastal Waters only the pH parameters (7–7.9) and Pb (0.002 ppm) still met the quality standards.

Water transparency (0.7–3.75 m) at both locations did not meet the quality standards. This condition may be due to the location of the research site, which is located at the mouth of the Cibanten, Wadas, and Terate rivers, which carry sediment and soil particles from the mainland to the sea (Sugiarti *et al.* 2022). Furthermore, all Cd values (0.002–0.005 ppm) in the water at both locations did not meet quality standards. This is a serious concern, given that Cd content in water significantly impacts the health of living organisms (Riani *et al.* 2017).

Heavy metal content in the flesh of blood cockles, green mussels, mud crabs, and blue swimming crabs

The results showed that the heavy metal content in blood cockles, green mussels, mud crabs, and swimming crabs from Cengkok Coastal Waters (Figure 2) varied significantly compared to samples from Bojonegara Coastal Waters (Table 2). Nevertheless, all concentrations from Cengkok Coastal Waters remain within acceptable limits. However, the highest values (Pb and Cd) in the edible flesh of blue swimming crabs)require caution because long-term accumulation has the potential to fail to meet the standards (marked by the red dotted line in Figure 2).

All analysis results showed that the Pb and Cd content in the flesh of the four biotas from Bojonegara Coastal Waters was relatively low and still met the 2018 BPOM quality standards (Table 2). Most of the Pb and Cd levels also showed low concentration, namely less than <0.005 mg/kg, but only the Pb value in blood coocle reached <0.030 mg/kg. However, the Pb value in the blood cockles (<0.03 mg/kg) was still relatively low and met the 2018 BPOM quality standards (0.20 mg/kg). Therefore, the analysis results (Table 2) indicate that the bioaccumulation of heavy metals in the four biota from Bojonegara Waters is still low.

Bioconcentration factor (BCF)

The BCF values of blood cockles, green mussels, mud crabs, and blue swimming crabs in water are presented in Table 3. Overall, all BCF calculation results fall into the low accumulation level category (<100). The highest BCF value was 54.6 in blood cockles from Cengkok Coastal Waters, which still falls within the low accumulation category.

Safety level

The results of the safety level analysis for shellfish (blood cockles, green mussels, mud crabs, and blue swimming crabs) per adult weight (50 kg) and child weight (15 kg) are presented in Table 4. The consumption limits for these aquatic biotas vary. The highest consumption values for adults and children vary depending on the type of biota consumed.

Bojonegara Coastal Waters

The safe consumption limit for the four biota from Bojonegara Coastal Waters was not considered because the analysis results showed that their heavy metal content still met the BPOM (2018) requirements. If considered, the safe consumption limit could reach a high level, which would not be a practical recommendation. Therefore, the four biota from Bojonegara Coastal Waters are still safe for consumption in normal amounts.

Cengkok Coastal Waters

The consumption safety limits were calculated only for blue swimming crabs from Cengkok Coastal Waters. This is because Cd levels of the blue swimming crabs showed the highest Pb and Cd concentrations among the sampled species and therefore require caution (Figure 2). The consumption of blue swimming crabs is strictly limited to 0.42 kg/week for adults and 0.11 kg/week for children. The other species, both from Cengkok and Bojonegara Coast, remain safe to consume in normal amounts.

Table 1. Physico-chemical parameters of water in the Cengkok and Bojonegara Coastal Waters, Banten Bay.

Month	Temperature (°C)	Transparency (m)	pH	Salinity (‰)	DO (ppm)	Pb (ppm)	Cd (ppm)
Cengkok 2019							
April	30	0.7*	7	33	7.2	0.002	0.002*
May	30.2	1.25*	7.31	34	5.6	0.005	0.004*
June	31.2	1.3*	7.1	35*	7.4	0.002	0.002*
July	30.2	1.26*	7	35*	7.6	0.002	0.002*
August	30.9	1.1*	7.8	30*	7.2	0.002	0.002*
Bojonegara 2020							
August	34.5*	3.75*	7	30*	3.3*	0.002	0.001*
September	33*	3.25*	7	30*	6.5	0.002	0.001*
October	33*	0.85*	7.9	35*	4.6*	0.002	0.001*
Standard (PP RI No. 22 Year 2021)	**28–32**	**>5**	**7–8.5**	**33–34**	**>5**	**0.008**	**0.001**

Note: Data cells whose values did not meet the quality standards according to PP RI No. 22 of 2021 are marked *

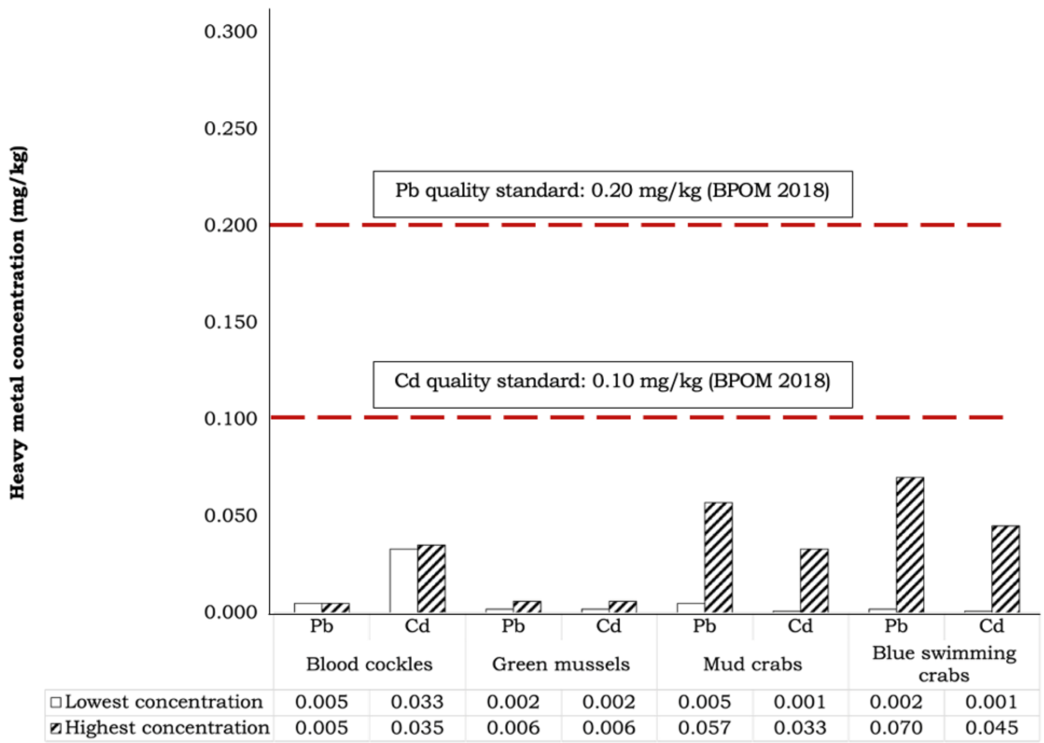

Figure 2. Pb and Cd content in the edible flesh of shellfish in the Cengkok Coastal Waters, Banten Bay, compared with BPOM quality standards (2018).

Table 2. Content values of heavy metals Pb and Cd in the flesh of shellfish (blood cockles, green mussels, mud crabs, and blue swimming crabs) in the Bojonegara Coastal Waters, Banten Bay (in mg/kg).

Heavy metal	Blood cockles	Green mussels	Mud crabs	Blue swimming crabs	BPOM (2018)
Pb	<0.030	<0.003	<0.003	<0.002	0.20
Cd	<0.005	<0.005	<0.005	<0.001	0.10

Table 3. Bioconcentration factors of shellfish (blood cockles, green mussels, mud crabs, and blue swimming crabs) in the Cengkok and Bojonegara coastal waters, Banten Bay.

Heavy metal/ month	Blood cockles		Green mussels		Mud crabs		Blue swimming crabs	
	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd
Cengkok (2019)								
April	2.5	7	4.88	4.61	1.02	3.18	2.5	4.87
May	2.5	47.1	4.88	4.61	0.08	0.01	0.71	5.05
June	2.5	54.6	17.07	3.39	0	0	16.75	2
July	2.5	34.9	17.07	3.39	0.10	0.20	23	0.75
August	2.5	42.5	17.07	3.39	0.01	0.37	29.38	3.64
Bojonegara (2020)								
August	15	5	0	0	15	5	15	5
September	15	5	0	0	15	5	15	5
October	15	5	0	0	15	5	15	5

Table 4. Safety level of several shellfish found in the waters of Cengkok and Bojonegara Coastal Waters, Banten Bay (in kg/week).

Heavy metal/ status	Blood cockles		Green mussels		Mud crabs		Blue swimming crabs	
	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd
Cengkok (2019)								
Adult	-	-	-	-	-	-	1.5	0.42
Children	-	-	-	-	-	-	0.38	0.11
Bojonegara (2020)								
Adult	-	-	-	-	-	-	-	-
Children	-	-	-	-	-	-	-	-

Discussion

Banten Bay is a coastal area that has developed into a diverse area with diverse activities, including residential areas, trade, agriculture, fishing ports, aquaculture, and industry. The area is also a fishing ground for various fish, crabs, and other marine commodities (Dinulislam *et al.* 2021). The various community activities surrounding the bay can contribute to waste entering the waters, making monitoring the aquatic environment in Banten Bay (including heavy metal concentrations in the water and biota) crucial.

Observations of physical and chemical parameters showed varying results and were then compared with the quality standards stipulated in Government Regulation No. 22 of 2021. Most of the temperature, salinity, and DO data at Cengkok Coastal Waters were better than those at Bojonegara Coastal Waters. This can be seen from the data (Table 1), which still meet quality standards. Water quality parameters in a body of water are factors that influence the bioaccumulation and toxicity of certain types of metals present in the water (Riani *et al.* 2017). Rising temperatures accelerate the metabolic rate of aquatic biota, leading to increased bioaccumulation (Amriani *et al.* 2011). Decreasing pH, DO, and salinity lead to increased heavy metal toxicity (Samosir *et al.* 2023). The ideal salinity to support marine life ranges from 28 to 31‰ (Broom 1985). On the other hand, not all water transparency data met the quality standard. However, this still supports the survival of blood cockles, green mussels, mud crabs, and blue swimming crabs because they live on the seabed with muddy substrates (Dinulislam *et al.* 2021; Shofirma *et al.* 2025; Febrianessa *et al.* 2020).

The analysis showed that Cd concentrations in the Cengkok and Bojonegara coastal waters exceed the threshold of 0.001 mg/kg set by PP RI No 22 of 2021, indicating non-compliance with national water quality standards. This very low threshold serves as an early warning mechanism to prevent pollution in aquatic environments, particularly because metal concentrations in water are normally lower due to the influence of water flow and currents. However, analyses of biota from the same locations revealed higher Cd concentrations compared to those detected in the water. This is consistent with the BPOM (2018) standard of 0.100 mg/kg for food products, including aquatic organisms, as the permissible limits for biota differ from those for water. The higher concentrations found in biota reflect the ability of aquatic organisms to accumulate heavy metals through irreversible bioaccumulation, with levels potentially increasing further through biomagnification at the higher trophic levels (Damayanty *et al.* 2023). Although the Cd content in biota remains within acceptable limits for food safety, this represents a different context from environmental water quality regulation. The contrast in permissible limits between water and biota underscores the importance of early detection of contamination through continuous water quality monitoring, so that rising Cd levels can be controlled before causing broader impacts on ecosystems, aquatic organisms, and human health through the food chain (Balali-Mood *et al.* 2021). Therefore, strict and sustained monitoring of water quality is essential to ensure environmental safety and sustainability.

Heavy metal content at Cengkok Coastal Waters tends to be higher than at Bojonegara coastal waters. This may be due to differences in sampling time and location. Sampling at Cengkok Coastal Waters was conducted from March to August, which was a transition season to the dry season (dominant dry season), while samples at Bojonegara Coastal Waters were collected from August to October, which was the dry season to transition season (to rainy season). During the dry season, heavy metal accumulation increases due to low rainfall (Melinda *et al.* 2021). Conversely, the rainy season creates water flow and currents that reduce the tendency for heavy metals to settle in one location (Dinulislam *et al.* 2021). Riani *et al.* (2017) also confirmed that heavy metal dilution occurs more frequently during the rainy season. However, the difference in sampling times at the two locations is a limitation of this study, as it prevents consistent comparisons of the results from both locations.

According to Hidayah *et al.* (2014), heavy metal content in water also influences the bioaccumulation of heavy metals in aquatic organisms. Monthly differences in heavy metal content can be influenced by various factors, including temperature, alkalinity, salinity, and pH, which are all related to heavy metal concentrations in marine biota (Darmono 1995). Furthermore, the concentration of heavy metals in marine biota is also influenced by the organism's activity, habitat conditions, and pollutant concentrations (Ismarti 2016).

One of the wastes entering the waters of Banten Bay is the heavy metals Pb and Cd. Based on observations, Pb and Cd levels in the Cengkok and Bojonegara Coastal Waters, Banten Bay, ranged from 0.001 to 0.070 mg/kg and <0.001 to 0.030 mg/kg, respectively. The presence of these heavy metal concentrations indicates waste likely originating from the Karangantu Fisheries Port, fishermen's housing, and the timber trading port near the biota sampling site (Sugiarti *et al.* 2016).

All Pb content analyses in the biota flesh in this study were low and still meet the BPOM (Indonesian Food and Drug Authority) quality standards (2018). The low Pb content is indicated by a lack of contamination sources or proper waste management in the surrounding environment (Dinulislam *et al.* 2021). Pb content in aquatic biota is thought to originate from the rubber, cosmetics, pipe, battery, cable, and paint industries, pollution from land and water fuel combustion, and oil spills (Jaishankar *et al.* 2014; Ardyanto 2005; Santi *et al.* 2017). Furthermore, Pb also originates from domestic activities or household waste (Nur and Karneli 2015).

The Cd concentrations detected in the biota flesh remained within the BPOM 2018. The levels observed are likely attributable to contamination sources in the surrounding environment. Based on site survey results, Cengkok Coastal Waters is surrounded by agricultural land and residential areas. This is supported by research conducted by Hidayah *et al.* (2014), which explains that high Cd concentrations in the water may originate from residential and agricultural waste. Agricultural practices typically use pesticides and fertilizers, which contribute to water pollution (Dinulislam *et al.* 2021).

The sampling points at both locations were selected based on the potential sources of contamination carried by the Cibanten, Wadas, and Terate Rivers. According to Siaka *et al.* (2016), the closer an organism is to a pollutant source, the higher the concentration of heavy metals absorbed into its body. Maritime transportation routes in Banten Bay are also a contributing factor to increased heavy metal concentrations in the region (Jalius *et al.* 2008). Heavy metals entering the body will reach target organs depending on the type of heavy metal. Sulfide compounds that bind to heavy metals can cause damage or dysfunction to the target organs (Sutrisno *et al.* 2007). Antifouling, as part of activities that produce heavy metal waste, is used to coat ships to prevent them from being infested by organisms so that the ship is not damaged (Sulistiono *et al.* 2018).

The bioconcentration factor (BCF) indicates the accumulation of heavy metals in water, absorbed by organisms through their biological flesh (Hidayah *et al.* 2014). The BCF values in this study fell into the low category. Heavy metal accumulation significantly impacts shellfish survival. One negative impact of heavy metal accumulation is characterized by malformations. According to Jalius *et al.* (2008), heavy metal accumulation also affects green mussel spermatogenesis by slowing meiosis, resulting in reduced or low spermatocyte formation. The bioconcentration factor can be influenced by the organic matter present and deposited at the bottom of the water (Arnot and Gobas 2006; Zhang *et al.* 2014).

The safety level, or safe consumption limit, is determined from the lowest calculated result (Dinulislam *et al.* 2021). Based on the calculations above, blood cockles, green mussels, mud crabs, and blue swimming crabs from Bojonegara Coastal Waters are still safe for consumption in normal portions. Blood cockles, green mussels, and mud crabs from Cengkok Coastal Waters are also still safe for consumption, but the consumption of blue swimming crabs is strictly limited to 0.42 kg/week for adults, which is equivalent to approximately four medium-sized swimming crabs and 0.11 kg/week for children, which is roughly equal to one medium-sized crab. The consumption of blue swimming crabs from Cengkok Coastal Waters poses a high risk if people consume more than the recommended amount. This means that it cannot be consumed daily.

The consumption of food derived from the flesh of marine life containing heavy metals in the waters needs to be limited. This is because marine life contains heavy metals absorbed from the environment (Dinulislam *et al.* 2021). Consuming marine life exposed to excessive amounts of heavy metals continuously in uncontrolled amounts can accumulate in the human body, causing negative toxic effects (Hidayah *et al.* 2014). Toxic levels can cause various diseases such as kidney disease, hypertension, lung disease, liver disease, and others (Istarani and Pandebesie 2014). Safety levels can be used as a reference to avoid negative impacts that arise when consuming edible flesh of aquatic biota containing heavy metals (Barokah *et al.* 2019).

CONCLUSION

Based on the analysis results, the Pb and Cd content in the edible flesh of blood cockles, green mussels, crabs, and swimming crabs in the Cengkok and Bojonegara Coastal Waters, Banten Bay, ranged from 0.001–0.070 mg/kg and <0.001–0.030 mg/kg, respectively. All measured heavy metal concentrations met the BPOM (2018) quality standards. The low levels of heavy metals in Bojonegara coastal waters may be influenced by seasonal factors. Bioconcentration factors were generally <100, indicating low accumulation levels. In addition, several BCF values, such as the unusually high June Pb BCF for green mussels at Cengkok, appear inconsistent with corresponding water concentrations, indicating the need for data verification. To improve transparency, future studies should also include numerical biota metal-concentration tables alongside graphical figures. Blood cockles, green mussels, and mud crabs from Cengkok coastal waters were still safe for consumption in normal amounts, while the consumption of blue swimming crabs is strictly limited to 0.42 kg/week or 420 g/week for adults, which is equivalent to approximately four medium-size swimming crabs and 0.11 kg/week or 110 g/week for children, which is roughly equal to one medium-sized crab. These findings highlight the importance of continued monitoring to detect spatial and temporal changes in heavy metal contamination in Banten Bay. However, the results of this study only represent Cengkok and Bojonegara coastal waters, and not the entire Banten Bay.

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