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Research Article.

Trace metals in the Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819) from the central Algerian coast (Southwestern Mediterranean Sea)

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ABSTRACT

Mytilus galloprovincialis is a commonly used bioindicator species for assessing environmental pollution. The aim of this study was to investigate the concentrations of heavy metals, including cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn), in the soft tissues of *Mytilus galloprovincialis* obtained from six areas along the central Algerian coast. Mussel samples were collected in these coastal areas at 0-5 m (surface) between March and April 2020. The study revealed that the highest concentration of zinc with a value of 262.58 mg/kg, followed by Cu (54.69 mg/kg), Pb (7.48 mg/kg), and Cd (5.41 mg/kg). The metal concentrations were ranked as Zn > Cu > Pb > Cd. The toxicological risk assessment parameters linked to the consumption of these mussels shows that the values revealed for the daily exposure dose (DJE) are very low for all the metals analyzed. However, all hazard quotient (DQ) values calculated for the metals analyzed are less than 1 for children and adults. Nevertheless, exposure depends on the dietary habits of the population and continued exposure to these elements can lead to undesirable effects.

KEYWORDS

Trace metals;
Algerian central coasts;
Mytilus galloprovincialis;
Bioaccumulation;
Health risk assessment.

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1. INTRODUCTION

The marine environment offers numerous benefits to people, enabling them to settle there and carry out various activities. As with coastlines around the world, the Algiers coastal zone is a fragile and highly stressed area. The region is subject to a multitude of risks, including but not limited to demographic pressure, the expansion of urban areas, the rapid growth of industry and tourism, and the intensive exploitation of marine resources (Inal *et al.,* 2018). Numerous types of pollutants, including trace metals, are discharged into the area, posing a serious problem for all living organisms (Bachouche *et al.,* 2015; Guendouzi *et al.,* 2020; Boudjemaa *et al.,* 2023; Inal *et al.,* 2026). Trace metals are frequently found to be soluble in the water column or bound to sediment particles. Consequently, these metals have the potential to accumulate in living organisms at concentrations that exceed those present in water (Ramade, 1995; Van Der Oost *et al.,* 2003).

A multitude of methodologies exist for the assessment of the environmental quality of coastal regions. Some of these approaches involve the analysis of seawater, sediment and specific marine organisms (Jitar *et al.,* 2013). The latter is the most effective method because analysing the metals in their tissues provides effective information on the environmental status of sites (Zhou *et al.,* 2008; Varol and Sünbül, 2018) over a long period (long-term memory) (Lagadic *et al.,* 1997). In contrast, seawater provides information over a very short period as it is greatly affected by hydrodynamics and the solubility of trace metal elements (Phillips, 1977).

Bivalve molluscs have long been among the most commonly used marine organisms for environmental biomonitoring (Amiard *et al.,* 1998; Abderrahmani *et al.,* 2021; Bajc and Kirbis, 2019; Azizi *et al.,* 2018, Belmokhtar and Guendouzi, 2024). They are excellent bioindicators of the marine environment (Andral *et al.,* 2011), primarily due to their ability to filter large volumes of seawater, resulting in the bioaccumulation of contaminants at concentrations much higher than those found in seawater.

Mussels are a highly nutritious seafood (Yigit *et al.,* 2018), rich in protein, vitamins and several minerals that are essential for biological processes (Stankovic *et al.,* 2012). In areas where water quality is compromised, the consumption of mussel meat poses a significant health risk to humans. Consequently, the monitoring of trace metal levels in mussels is imperative for safeguarding public health and safety.

The objectives of this study were: (1) to assess the levels of trace metals elements copper, zinc, cadmium and lead, in the soft tissue of mussels, (2) to evaluate the environmental health at different sites; (3) to examine the relationship between the bioaccumulation of trace metals and the condition index; and (4) to assess the toxicological risk associated with mussel consumption on the health of the population.

The *Mytilus galloprovincialis* mussels studied were collected from three bays along the Algerian coast include Bateau Cassé and Algiers port in the Bay of Algiers, Berard and Zeralda in Bou-Ismail Bay, Boudouaou and Figuier in the Bay of Zemmouri. The sites include five (05) naturel mussel beds and one (01) Shellfish Farm (Cultmare in Berard).

2. MATERIALS AND METHODS

2.1. STUDY AREA

The study area was located in the central part of the Algerian coast (Fig. 1). It is delimited to the West by Mount Chenoua (Bou-Ismail Bay) (80 km West of Algiers) and to the East by Tamentfoust (Algiers Bay) (eastern terminus of the Bay of Algiers) (Rabehi *et al.,* 2019). Hydrodynamics on the Algerian coast are characterized by average wave height (between 0.2 and 3 m amplitude). Despite the region's lack of precise hydrodynamic data, the maximum wave height observed over the past ten years is 3 m (Larara *et al.,* 2012; Otmani *et al.,* 2019). Wave heights between 2 and 3 m are only reached in Algeria during specific high-energy, high-energy events such as storms or earthquakes (Yelles-Chaouche *et al.,* 2009; Otmani *et al.,* 2019). General observation of underwater morphology of the study area shows that coastal bottoms are relatively less steep between Bou-Ismail.

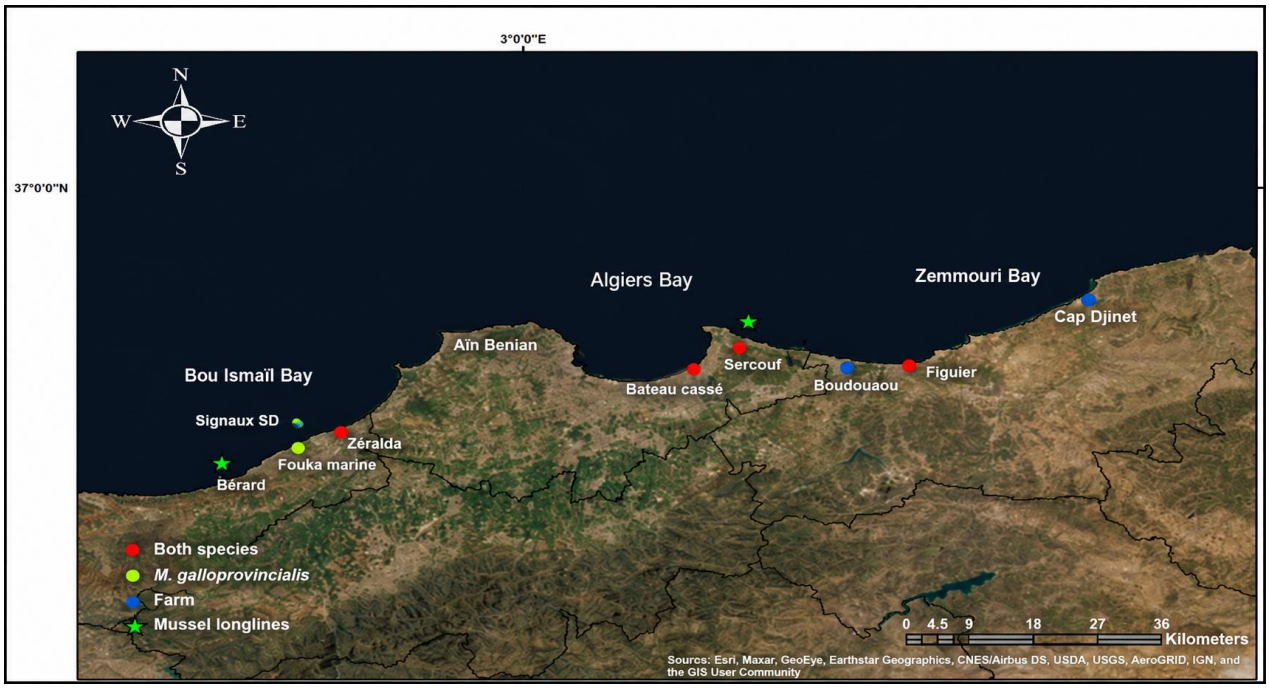

Figure 1. Location of study area and sampling stations

2.2. SAMPLING

Sampling was carried out manually to avoid any contamination, carefully detaching the species from the rock where it was attached by cutting the byssus (except for those from the Cultmare- shellfish farm). For each site, a minimum number of 30 individuals was collected. After there, the samples were stored in plastic freezer bags, labeled (date, sampling location) and transported to the laboratory in a cooler (4 °C), where they were placed in a freezer until treatment and analysis.

2.3. MUSSEL TREATMENT

First, as soon as they are removed from the freezer, the mussels are cleaned of their byssus and any dirt adhering to their shells, and the mussels were weighed using a precision scale.

Morphometric measurements (length, height, and thickness of the individual) were taken using a digital caliper with an accuracy of 0.01 mm. The mussels were dissected using stainless steel scalpels and forceps. The flesh and shells were weighed separately (Carvalho *et al.* 2010).

The condition index (CI) was defined as the ratio of the dry weight of the flesh (g) to the dry weight of the shells (g) (Andral *et al.* 2011; Benedicto *et al.* 2011; Guendouzi *et al.* 2021).

The soft parts were collected in a plastic pillbox with a label on which the observations (date, place of collection) and then put in the freezer (-18°C) with the aim of being lyophilized for the analysis of the trace metals. The metals Zn, Cu, Cd, and Pb were analyzed by flame atomic absorption spectrometry (AAS), following the UNEP/IAEA/FAO method (1990). The results obtained are expressed in µg/g Dry Weight (DW).

2.4. Mussels' quality assessment

Various methods have been developed to assess contamination in fishery and aquaculture products (US EPA, 1998 and ASTEE, 2003). Two approaches are commonly used: the first is based on the relationship between the concentration of the contaminant in the organism and its concentration in the environment (the bioaccumulation factor).

The second approach directly links contamination to the consumer, while also assessing and characterizing the health risk.

2.4.1. Bioaccumulation Factor (BAF)

The bioaccumulation factor (BAF) is the ratio of the concentration of a contaminant in an organism's tissues to its concentration from sediment (Arnot and Gobas, 2006).

$$BAF = Cb/Ce$$

Where Cb = trace element concentration in the species; Ce = environmental concentration (seawater). Both are expressed in mg/kg.

2.4.2. Human Health Risk Assessment

For the present study, the assessment of health risks associated with consuming mussels contaminated by trace metals will follow these steps: Definition of the daily intake admissible values for each metal. Calculation of the estimated dietary intake (EDI) and the target hazard quotient (THQ). Determination of the consumption rate limit (CRL).

The estimated dietary intake EDI

The estimated dietary intake 'EDI' (µg/kg/day) for consumers was calculated using the following formula (EPA, 1992):

$$EDI = \frac{IR \times C}{BW}$$

where C is the trace metal concentration in fish soft parts (µg/g w.w.), IR is the daily ingestion rate [0.01 g/capita/day] www.fao.org, and BW is the body weight: 70 kg for adult, and 28 kg for child. This estimate excludes metal sources given by other meals or drinking water on the same day, so only metal intake from mussel eating is considered.

The target hazard quotient THQ

The target hazard quotient (THQ) is expressed as follows (EPA, 1992):

$$THQ = \frac{EF \times ED \times IR \times C}{RfD \times BW \times AT} \times 10^{-3}$$

where EF: exposure frequency [365 days/year]; ED: exposure duration [365 years]; RfD: oral reference dose, and which for Cd, Pb, Cu, and Zn are 0.001, 0.004, 0.04, and 0.3 [µg/g/day], respectively (EPA, 2016); and AT: averaging time.

THQ value is divided into 5 categories: not significant (THQ ≤1) means there is no risk of non-carcinogenic consequences (e.g., reproductive toxicity, teratogenicity, or liver toxicity) for humans over a lifetime exposure; low (1 < THQ ≤ 10); moderate (10 < THQ ≤ 20); high (20 < THQ ≤ 100) and serious (THQ >100) (Liu *et al.,* 2018; Liu *et al.,* 2017).

The hazard index HI

For the risk assessment of multiple trace metals contained in fishes, the hazard index (HI) was calculated as: $HI = \sum THQ_i$

where THQi is the targeted hazard quotient of an individual trace metal, and n in the present study is 4 (i.e., Cd, Pb, Cu and Zn). If the HI is less than one, the exposed population is deemed to be safe. If the HI ranges from 1 to 5, there may be a potential risk associated with a specific metal in the exposed population (Guendouzi *et al.,* 2020).

Consumption rate limit CRL

The maximum allowed limit for fish consuming for a non-carcinogen determined by using the consumption rate limit (CRL) formula, which can be estimated as follows (Guendouzi *et al.,* 2020; Mortazavi and Fard, 2017):

$$CRL = \frac{(RfD \times BW)}{C} \text{ [kg/day].}$$

3. Results and Discussion

3.1. Biometric Parameters

Quality control in surveillance programs requires the verification of the quality of the mussels *M. galloprovancialis* included in the study through morphometric measurements (length, height, and thickness of the individual) and physiological indices (condition index).

3.1.1. Average Size

The following table summarizes the average sizes of the individuals collected at each sampling station:

Table 1. Average Size of individuals from the different sampling stations

Station	Cultmare	Zeralda	Bateau cassé	Algiers Port	Boudouaou	Figuier
Average Size (mm)	77.20	36.91	40.76	61.47	28.20	40.69

The results show that the average size of mussels collected from the CULTMARE shellfish farm located in Tipaza is the largest (77.20 mm). This exceeds the minimum commercial size for mytilids, which is set at 4 cm, in accordance with Decree No. 20-266 of September 22nd, 2020, establishing the minimum commercial size for fishery resources. While, the mussel individuals collected from the Boudouaou site are the smallest, with an average size of 28.20 mm. However, mussels collected in the port of Algiers have an average size of 61.47 mm, which is significantly larger than the average sizes of mussels sampled from other natural mussel beds (Bateau Cassé, Zeralda, and Figuier) (Fig. 2).

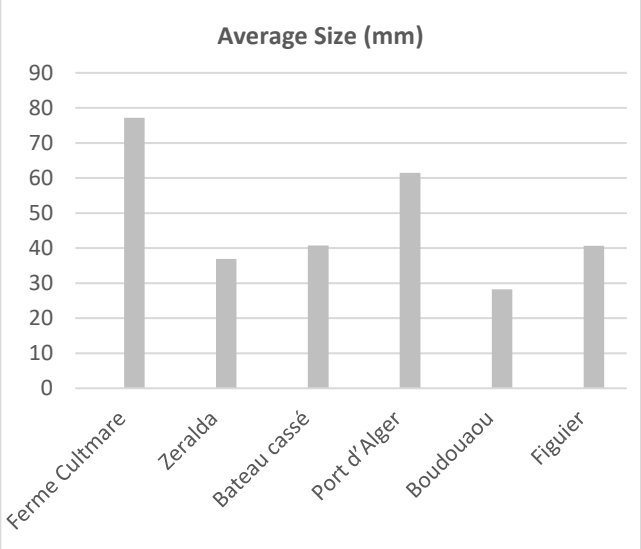

Figure 2. Average size of individuals from the different sampling stations

3.1.2. Condition Index CI

Condition index (CI) is a widely used parameter in ecophysiological studies. It's considered an important clue about the economic value of the species in determining the harvesting period (Acarli *et al.,* 2024). In fact, to evaluate the physiological state, sexual maturity, health status, meat yield, the mussels' growth, and the effects of surrounding environmental stresses, the condition index (CI) was performed. The results shows that the condition index values range between 32.89 and 37.1 with a mean value of 34.44. Its values increased as follows: 32.89 at Figuier < 33.23 at Boudouaou < 33.52 at Zeralda < 34.67 at Algiers port < 35.22 at Bateau cassé < 37.1 at Cultmare Farm (Fig. 3).

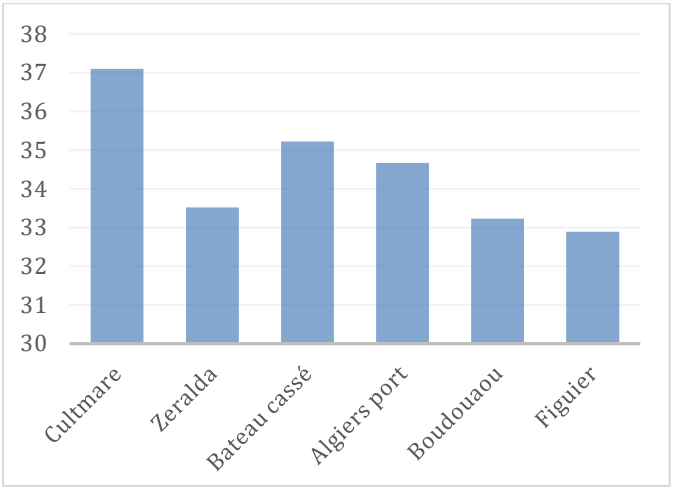

Figure 3. Condition Index values of individuals from the different sampling stations

3.2. Trace Metals Levels

The metal contents analyzed (Cd, Pb, Zn, and Cu) in the soft tissues of the mussels from the different sites are summarized in the table below.

Table 2. Mean and extreme values of trace metals analyze

Metal (µg/g)	Minimum	Maximum	Average	Standard Deviation
Cd	0.081	0.678	0.266	0.234
Pb	0.312	1.918	0.729	0.593
Cu	0.000	53.340	10.382	21.064
Zn	122.568	350.891	199.555	80.530

The results shows that the metal concentrations were ranked as Zn > Cu > Pb > Cd. The minimum value was that of copper with 0 (µg/g) and the maximum was 350.89 (µg/g) for the zinc.

The figure below represents the box plot which allows for the rapid visualization of the distribution, dispersion, and extreme values of the measured levels of trace metals.

The diagrams shows that the means of copper (Cu) and lead (Pb) are out of the box, which means that their concentrations vary widely across the sites. While, those of cadmium (Cd) and zinc (Zn) are inside the boxes, which means that their concentrations are uniform across the sites.

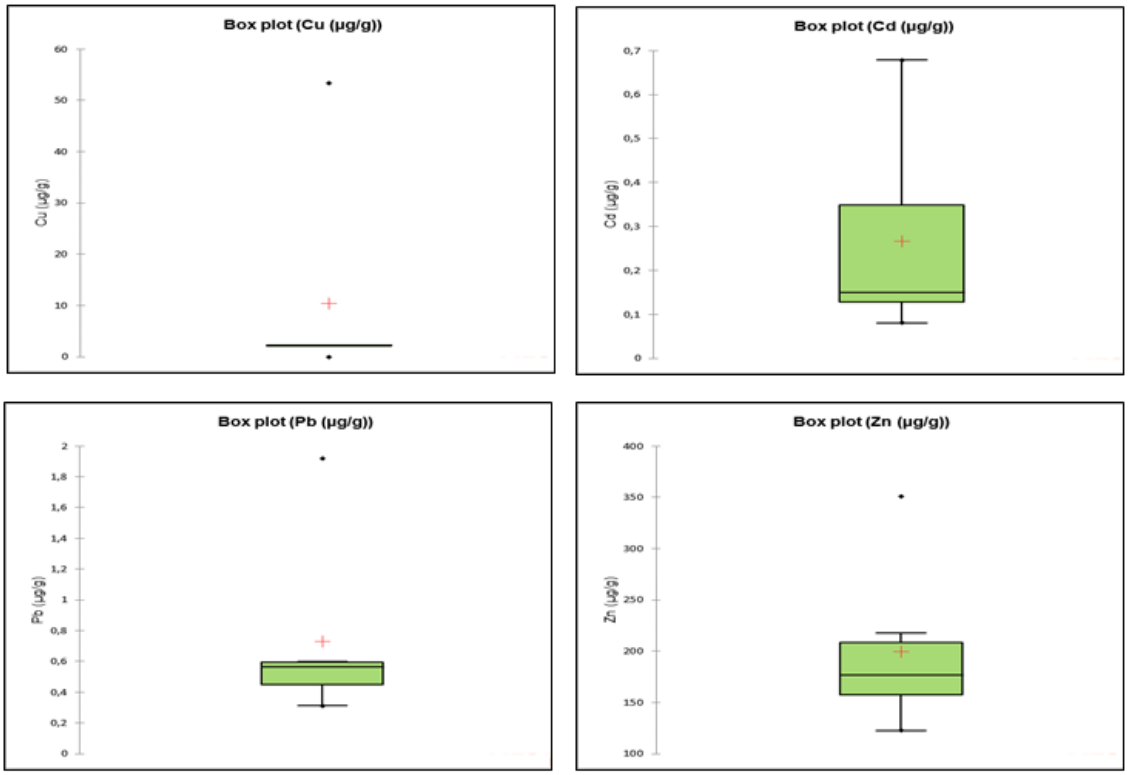

Figure 4. Box plot diagramme of trace matals analysed in the different sites

3.3. Trace Metals Variations

3.3.1. Cadmium

Average cadmium levels vary between 0.06 and 0.69 µg/g dry weight. The lowest concentration (0.15 µg/g dry weight) is recorded in farmed mussels (Cultmare) (size >70 mm). The highest concentration is recorded in the flesh of mussels from the port of Algiers (0.69 µg/g); however, this value is lower than the EEC safety standard (1 µg/g dry weight). Mussels from the Figuier site have fairly high cadmium concentrations (0.4 µg/g). These are close to those recorded in mussels from the port of Algiers.

However, mussels from other sites (Bateau cassé, Zeralda and Boudouaou) show fairly homogeneous and low cadmium levels. They range between 0.12 and 0.15 µg/g.

3.3.2. LEAD

The average lead concentration show variations similar to those of cadmium. Indeed, the highest levels were found in mussels from the port of Algiers (1.92 µg/g). Meanwhile, farmed mussels from the Cultmare farm consistently showed the lowest levels (<0.32 µg/g).

However, the other mussels from the Bateau Cassé, Zeralda, Boudouaou, and Figuier sites showed lead levels ranging between 0.4 and 0.6 µg/g. These levels remain low compared to the standards set by the EEC.

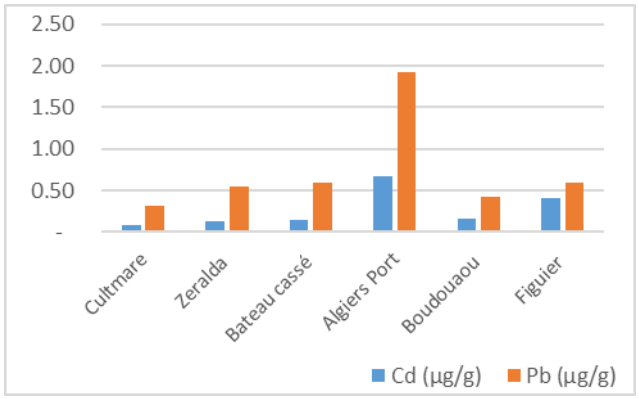

Figure 5. Lead and cadmium content (µg/g) in mussels from different sites

3.3.3. COPPER

The copper (Cu) concentrations found in the soft tissus of the mussels collected from all the study sites are very low. They range between 2.17 and 2.28 µg/g (dry weight). However, an exception is found in the soft tissus of mussels collected from the port of Algiers, with a high concentration of approximately 53.34 µg/g dry weight. This situation observed at the port of Algiers is similar to that of zinc. It can be explained by the large quantities of this element resulting from various port activities.

Thus, this situation highlights the significant affinity that exists between the two essential metals (zinc and copper).

3.3.4. ZINC

Zinc concentrations vary between 122 and 350 µg/g dry weight (DW). They are very consistent across all the study sites, with the exception of the Port of Algiers site, where concentrations far exceed those found at the other sites. The concentration is 350.90 µg/g.

This situation observed at the Port of Algiers can be partly explained by the high quantities of this element in the discharges from various port activities. Furthermore, a fairly high zinc content was recorded in mussels harvested in the Figuier region (Boumerdes). This content can be explained by urban runoff, as the mussel beds at this site are located near a small wadi that carries domestic wastewater from the region's inhabitants directly into the sea.

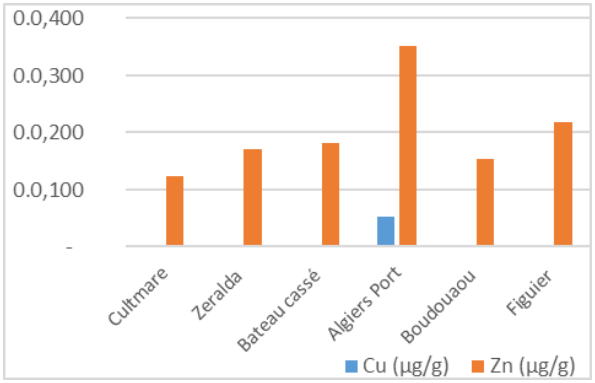

Figure 6. Zinc and copper content (µg/g) in the mussels from the different sites

3.4. Bioaccumulation Factor

The bioaccumulation of trace metals in mussels is the net result of the balance between three main processes: penetration, storage, and excretion of trace elements into the external environment after metal exposure through water, sediment, food, and air (Nef JM.,2002). The BAF values varied between a minimum of 0 observed in the Cultmare farm for the copper and a maximum of 2667 observed in the Algiers port for the copper also. All the maximum values of BAF for the four metals (Cd, Pb, Cu and Zn) were observed in the port of Algiers.

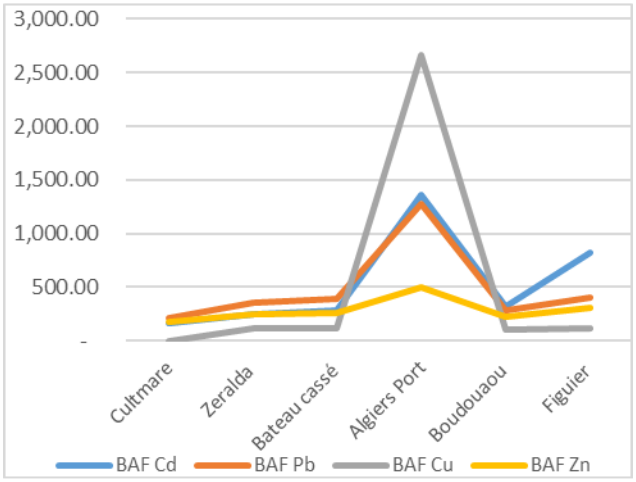

Figure 7. Variation of Bioaccumulation factor values

3.5. Health Risk Assessment

3.5.1. Estimated Dietary Intake

The results show that the Estimated dietary intake values are very low both for adults and children (Fig. 8).

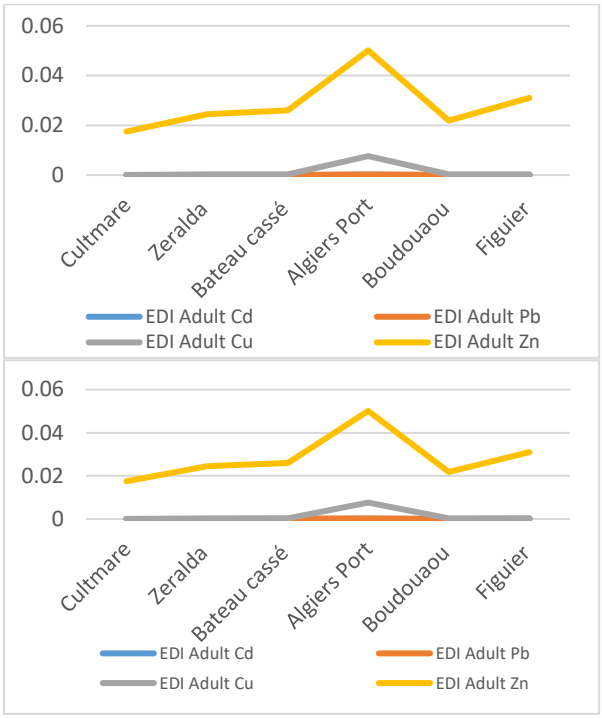

Figure 8. Variation of the Estimated Dietary Intake values for adults and children

3.5.2. Target Hazard Quotient

The results show that the Target hazerd quotient values are very low both for adults and children (Fig. 9).

3.5.1. Hazard Index

The results show that the Hazard index values are low both for adults and children, except that found in the port of Algiers, it exceeds 1. (Fig. 10).

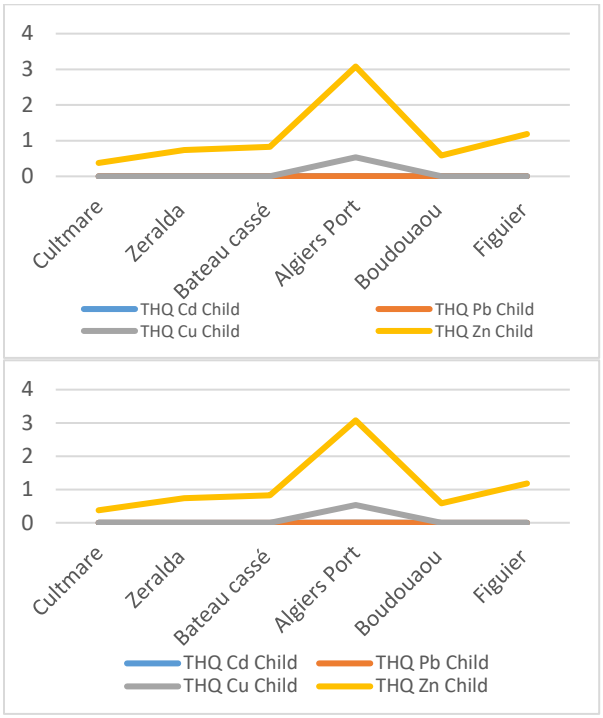

Figure 9. Variation of the Target Hazard Quotient values for adults and children

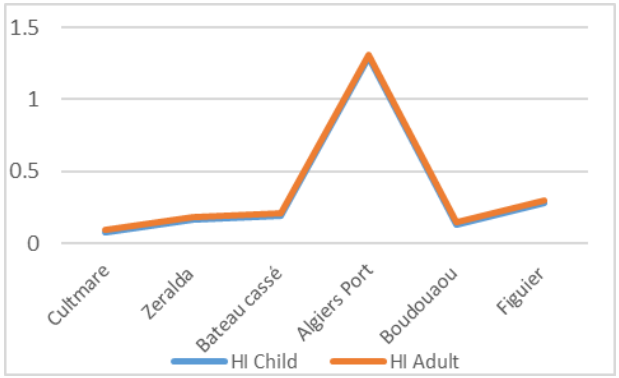

Figure 10. Variation of the Hazard Index values

3.5.2. Consumption Rate Limit

The results show that the Consumption rate limit values are different between all the sampling sites both for adults and children (Fig. 11).

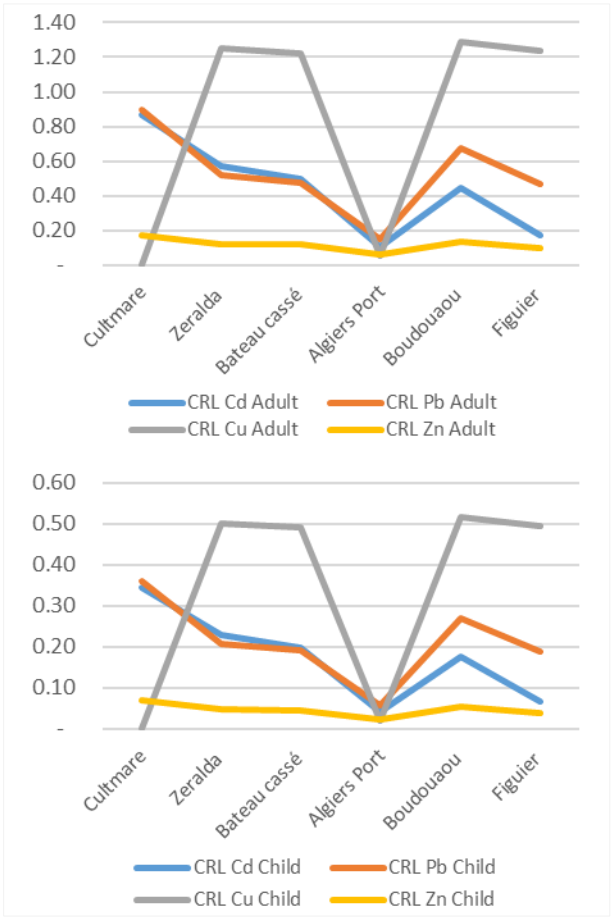

Figure 11. Consumption rate Limit for adults and children

3.6. Trace Metals Correlation

A positives correlations were found between all four metals. İt means that when the concentration of one metal increases in the mussel, the concentration of another metal also rises. These strong correlations can explain that the metals originate from the same human or natural activity or that the mussel absorbs all these contaminants in proportion to their presence in the water. Consequently, an increase in overall filtration (linked to food availability) increases the intake of all the metals simultaneously. Thus, it can be explained that certain metals use the same cellular entry pathways and the activation of these pathways under specific

environmental conditions facilitates the co-entry of several elements. While, some variables such as weight and age influence mussel physiology and cause all metal concentrations to vary in the same direction. İn addition, physicochemical variations of salinity and temperature in the water can alter the bioavailability of most metals simultaneously, facilitating their concurrent uptake.

Table 3. Correlation coefficients

Correlation Coefficients (Pearson) R^2				
Variables	Cd (µg/g)	Pb (µg/g)	Cu (µg/g)	Zn (µg/g)
Cd (µg/g)	1			
Pb (µg/g)	0.904	1		
Cu (µg/g)	0.874	0.988	1	
Zn (µg/g)	0.962	0.972	0.933	1
Determination Coefficients R				
Variables	Cd (µg/g)	Pb (µg/g)	Cu (µg/g)	Zn (µg/g)
Cd (µg/g)	1			
Pb (µg/g)	0.818	1		
Cu (µg/g)	0.763	0.977	1	
Zn (µg/g)	0.925	0.945	0.870	1

3.7. Comparison With Literature

At the national scale, the concentrations of cadmium and lead (Table 4) in mussels collected by Guendouzi (2019) from the Skikda region were found to be minimal, with concentrations of 0.13 and 1.68 mg/kg (d.w.), respectively. The concentrations of Cd and Pb in this study were found to be lower than those documented by Abderrahmani (2023) in the central region and Ben Ali (2017) in the port of Oran. However, the Cd concentrations were found to be comparable to those reported in the study by Rouane Hacene (2013) in the Oran-Mostaganem region. The present study revealed elevated concentrations of copper in comparison to those documented in other studies conducted in disparate regions, including Annaba, Skikda, Oran, and Mostaganem-Oran. With the exception of the study conducted by Ben Ali (2017), in which the most significant Zn level was registered at 541.9 mg/kg, the results of the present study exhibited a high degree of similarity with regard to zinc levels across different regions.

At a regional scale, the Cd concentrations in our study were very low compared to those recorded in Tunisia by Mzoughi and Chouba (2012), in Morocco by Maanan (2008) and in Libya by Galgani (2014). Much higher lead (Pb) content was found in Morocco (Maanan, 2008), while weak levels were registered in Libya (Galgani, 2014). Copper concentrations were very high in this study and in Morocco, whereas weak levels were found in Tunisia (Mzoughi and Chouba, 2012). Our results for zinc were comparable to those found in Tunisia and Morocco, with the lowest levels registered in Libya.

Table 4. Comparison of trace metal results of this study and other studies

Study	Cd	Pb	Zn	Cu	Region
Present study	0.08 - 0.67	0.31 – 1.91	122 - 350	0 - 53.34	Central
Abderrahmani (2023)	0.14 - 1.32	0.37 – 12.56	80 - 262	5.25 – 79.21	Central
Drif (2012)	-	0.14 – 5.95	1.88 – 107.8	1.98 – 6.66	Annaba
Guendouzi (2019)	0.13	1.68	200.94	12.90	Skikda
Ben Ali (2017)	3.71	7.83	541.9	5.28	Port of Oran
Rouane Hacene (2013)	0.50 – 0.82	3 – 15.30	71 - 153	0.8 - 16	Oran-Mostaganem
Maanan (2008)	2.12 – 34.7	0.1 – 26.45	107 - 365	4.55 – 43.1	Safi, Morocco
Mzoughi and Chouba (2012)	0.9 -2.9	0.4 – 0.7	250 - 426	2.9 - 3.9	North of Tunisia
Galgani (2014)	1.21 – 2.42	0.44 – 0.71	141 - 197	3.56 – 4.21	Libya

4. Conclusion

This study assessed the bioaccumulation rate of four metals (Zn, Cu, Cd, and Pb) in mussels collected from six (6) sites along the Algiers coastline.

The results show shows that *M. galloprovincialis* appears to have a greater affinity for Zn and bioaccumulate the four metals in the following decreasing order: Zn > Cu > Cd > Pb.

Then, mussels from the port of Algiers bioaccumulate higher concentrations compared to those from other sites along the Algiers coastline. While, the farmed mussels from the CULTMARE farm (Tipaza) exhibit very low levels of the four analyzed metals.

The study of toxicological risk assessment parameters related to the consumption of these mussels shows that the values revealed for the daily intake of exposure (DIE) are very low for all the metals analyzed. This is true for both adults and children, although the DIE values for children are higher than those revealed for adults in most cases. Also, all hazard quotient (HQ) values calculated for the metals analyzed are less than 1 for both children and adults. Nevertheless, exposure depends on the population's dietary habits, and continuous exposure to these elements can lead to adverse effects.

Therefore, the approach adopted in this study have to be improved in order to allow both the assessment of the sanitary status of shellfish farming areas and the development of scenarios for the evolution of metal contamination. This will provide decision-makers in the fisheries sector with an effective tool for taking predictive measures in the context of sustainable management of the shellfish industry in Algeria.

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