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Trace metal concentrations in the edible tissues of fishery products: Human health risk assessment in the Guelma region (Algeria)

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ABSTRACT

The present study aimed to assess the potential health risks to the population of the Guelma region associated with the consumption of seafood products in the context of possible marine metal contamination with five heavy metals (Cd, Cu, Cr, Fe, and Ni) in the muscle tissues of 11 commercially important seafood species sampled from the eastern Algerian coast, and representing different taxonomic groups, namely mollusks, crustaceans, and fish. The samples were analyzed for heavy metals using a flame atomic absorbance spectrophotometer of the Perkin Elmer precisely AAnalyst 400type. The application of PCA revealed significant differences in metal accumulation among aquatic organisms. Mollusks were identified as the most contaminated group, confirming their suitability as bioindicators of environmental pollution. Fish exhibited the lowest levels of contamination, while crustaceans showed a specific affinity for copper. THQ, HI, and CR were assessed for both adults and children. The results highlighted that exposure doses of most elements for human consumption were within the threshold limit, and consequently were safe for non-carcinogenic and carcinogenic health risks.

Keywords: trace metal elements, seafood products, health, risk indices, Algeria.

INTRODUCTION

The metallic contamination of marine ecosystems has become a particular area of interest, debate, and widespread concern around the world (Ayberk et al., 2004; Belabed et al., 2017; Osman et al., 2025; Ouali et al., 2018; Zeghdoudi et al., 2024). Heavy metals in aquatic systems may arise from both natural sources such as rock weathering, volcanic eruptions, erosion, and other geological events, and anthropogenic sources, like mining, fossil fuel combustion, industrial agricultural activities, and urban wastewater discharges (Ikhsani et al., 2025). Ayberk et al. (2004) reported that semi-enclosed seas, including the Mediterranean Sea, are more susceptible to pollution impacts due to their long coastlines relative to their sea surface area and the slow renewal of water masses. It's the case with the Algerian coast, which is generally recognized as highly urbanized and industrialized, leading to enhanced trace elements in sediments and various organisms (Belabed et al., 2017; Cayabo et al., 2025; Ikhsani et al., 2025; Ouali et al., 2018).

Seafood species includes fish, gastropods, crustacean shellfish, and bivalve molluscan shellfish have the abilities to accumulating toxic trace elements residues in their tissues like chrome (Cr), copper (Cu), nickel (Ni), iron (Fe), arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg) (Ikhsani et al., 2025; Ouali et al., 2018; Zeghdoudi et al, 2024). Heavy metals mainly enter fish muscle, and other marine organisms through contaminated water, sediments, and food webs. When their concentrations exceed the tolerance limits, they will eventually pose an earnest problem regarding public health safety (Storelli et al., 2005), because of their persistence, toxicity, and biomagnification (Díaz et al., 2025; Mehouel and Fowler, 2022; Nakib et al., 2026). In marine organisms, various factors, such as length and weight, environmental conditions, season, location, distribution, environmental preference, trophic level, feeding habits, age, sex, and exposure duration to metals, can directly or indirectly influence the accumulation of heavy metals (Arulkumar et al., 2017).

Seafood plays an important role in the global diet due to its richness in essential nutrients and polyunsaturated fatty acids with cardioprotective effects (Garofalo et al., 2025; Ikem and Garth, 2022; Kerdoun et al., 2024). However, in Algeria, consumption remains low (≈ 3–4 kg/capita/year), well below the global average (> 20 kg/capita/year) (FAO, 2022). Numerous international studies have reported contamination of marine organisms by trace metals, sometimes exceeding recommended limits, with variable risks to human health (Almafrachi et al., 2025; Hussein et al., 2023). In Algeria, findings are contrasting: some studies indicate an overall low health risk (Kerdoun et al., 2024), while others report concerning exceedances, particularly for lead, cadmium, and mercury in certain species and regions (Mehouel and Fowler, 2022; Nakib et al., 2026; Ouali et al., 2018).

Most existing studies have focused on the contamination of fish by trace metals collected directly from fishing sites, which are widely regarded as reliable bioindicators of aquatic ecosystem quality. However, fishery products marketed in local markets remain poorly investigated, despite potential variations related to their origin and storage conditions. This gap limits the accurate assessment of dietary exposure and associated health risks. Therefore, the present study aims to quantify trace metal elements (Fe, Ni, Cd, Cr, and Cu) in several species consumed in Guelma (Algeria) and to evaluate the associated health risks across different age groups.

MATERIALS AND METHODS

Sampling and sample preparation

A total of 189 fishery product samples were collected for this study, comprising 50 fish, 79 bivalve and cephalopod mollusks, and 60 crustaceans. The samples were obtained from local fish markets between April and June 2025. According to the fishermen, the seafood sold in these markets originates from the coastal areas of Annaba, El Kala, Skikda, and Collo. These species were selected for several reasons, notably their abundance during the study period and their regular consumption by the local population. For each batch, biological (scientific name, size class, weight range, trophic levels) and ecological (Habitats) characteristics of the studied species is summarized in Table 1.

All collected samples were promptly put in an ice box and transported to the laboratory. Thereafter, all samples were carefully washed first with tap water and then rinsed with de-ionized water to remove any surface and skin contamination. Afterward, the total length and body weight of each sample were measured using a digital balance (accuracy of 0.01 g) and a digital caliper (accuracy of 1 mm), after these measurements, the samples were washed again prior to dissection. Approximately 200 g of edible tissues (muscle without skin, whole soft tissues) from each batch were collected, homogenized, and analyzed separately. Thereafter, the samples were cut into small pieces and packed up in clean, labeled airtight ziplock plastic bags, and then stored at − 20 °C until further processing. Samples were subsequently freeze-dried (CHRIST Alpha 1-2 LDplus lyophilizer, Germany) for two days. The dried samples were weighted to determine the ratio of moisture content using to calculate health risk assessment. Next, the dried samples were crumbled and pulverized thoroughly with a porcelain mortar and pestle. The resulting powder was sieved through 1 mm mesh.

Analyses of heavy metals

Freeze-dried subsamples were subjected to wet digestion. Briefly, one gram of the sample was taken into a clean glass beaker using an analytical balance. 5 ml of 65% nitric acid (HNO_3), and 2 ml of 30% hydrogen peroxide H_2O_2 was gradually added, the mixture was kept overnight in a

Table 1. Biological and ecological data on the studied species

Scientific name	Size class (mm)	Weight range (g)	Counts per size class	Feeding behavior	Habitat
Sardenilla aurita	171–227	58.7–93.8	20	Omnivorous, tending toward carnivory	Coastal waters; Sandy bottoms; seagrass beds.
Pagellus erythrinus	210–230	100–130	5	Benthic invertivore	Demersal; Sandy and muddy detrial bottoms
Pagrus pagrus	185–246	135–255	5	Benthic varnivore (predator)	Demersal; rochy, Sandy, gravel substrates.
Boops boops	203–230	77–118	5	Omnivorous, partly planktivorous	Pelagic-neritic water column
Sparus aurata	196–234	120–140	5	Benthic carnivore	Coastal lagoons; Sandy and muddy bottoms seagrass beds
Diplodus sargus	234–287	212–329	5	Omnivorous to carnivorous	Coastal, Rocky substrates seagrass
Thunnus thynnus	1950–2470	101000–190000	5	Piscivorous top predator,	Oceanic, pelagic (open waters)
Parapenaeus longirostris	61.7–130	4.64–8.64	30	Omnivore/detritivore	Demersal; muddy and sandy bottoms
Aristeus antennatus	80.1–123	4.87–7.3	30	Benthic predator	Deep-sea benthic
Donax trunculus	24–34.48	13.77–19	74	Filter feeder (phytoplankton-based)	Benthic; Sandy beaches.
Loligo vulgaris	110–130	35–75	5	Active carnivorous predator	Neritic coastal waters, demersal-pelagic.

chemical hood for pre-digested, as a consequence, prevent foaming during the subsequent digestion process, Afterward, they were heated (130–200 °C) on an electric hot plate, until the solution evaporated slowly and became completely clear. After cooling to ambient temperature, the digests were diluted to 25 mL with de-ionized water and filtered through a 0.45 mm nitrocellulose syringe filter before storage at 4 °C until further analysis.

All reagents were of analytical grade. To prevent any sources of metal contamination, all glassware and bottles were soaked in 10% nitric acid and then rinsed well with distilled water before use. The determination of heavy metals was carried out by a flame atomic absorbance spectrophotometer of the Perkin-Elmer, precisely AANALYST400 type, in which acetylene gas and air were used as fuel and oxidizer, respectively, set with the parameters recommended by the manufacturer (Elmer, 2008). The mean recovery of the investigated elements from the reference material was 95% ± 10%, and the relative standard deviation (RSD) of all replicate samples was less than 10%. The measurements were performed in the laboratory of Industrial Analysis and Materials of the University 8 May1945. Each sample matrix was analyzed in triplicate to determine the average metal value.

The concentrations were calculated according to the following equation:

$$C = R\ X \left(\frac{D}{W}\right) \tag{1}$$

where: C is the metal concentration (mg/kg) dry weight; R is the digital scale of AAS Reading; D is the sample dilution and W is the sample weight.

Human health risks assessment

Non-carcinogenic health risk

The non-carcinogenic risk for each metal through fish consumption was assessed by the target hazard quotient (THQ). The THQ in the study area was calculated following the guidelines recommended by USEPA (1989) using the specified formula:

$$THQ = \frac{EF \times ED \times FIR \times \times CF \times C}{RfD \times WAB \times TA} \times 10^{-3} \tag{2}$$

where: EF and ED represent the exposure frequency (365 days/year) and the average lifetime duration (70 years), respectively; FIR: the ingestion rate of marine organisms (g/person/day), which is generally 9.7 and 0.027 g /person/day for fish, and shellfish respectively (Belhadj et al., 2025; Mehouel et al., 2019); CF is the conversion factor to convert dry weight to wet weight depending on moisture content of each species; *C* is the metal concentration (mg/Kg); 10^{-3} was the unit conversion factor, *RfD* (mg/ kg day^{-1}) is the reference oral doses which are based on 0.001, 0.003, 0.04, 0.02, and 0.7 mg/kg/day for Cd, Cr, Cu, Ni, and Fe, respectively (US EPA., 1989). WAB is the average body weight for 30 kg and 70 kg for children and adult, respectively (Kerdoun et al., 2024). TA is the average exposure time (365 days/year**ED*).

These indices provide a quantitative framework for risk characterization. A ratio that is greater than one (i.e., THQ >1) implies that the exposed population may be at risk (US EPA., 2000). Conversely, a THQ value less than 1 or equal to 1.0 (i.e., THQ ≤1), indicates no adverse effect from the consumption of fish.

Hazard index (HI)

The exposure to more than one pollutants may result in additive effects (Ikem and Garth, 2022). The hazard index (HI) was also calculated as the arithmetic sum of each THQ values:

$$HI = THQ_{(Cd)} + THQ_{(Cu)} + THQ_{(Cr)} + THQ_{(Ni)} + THQ_{(Fe)} \tag{3}$$

HI ≤1.0 value implies that insignificant adverse effects are predicted, and if HI >1.0, then chronic toxic effects are probable (Ikem and Garth, 2022).

The carcinogenic risk

The risk of cancer was estimated as the probability of an individual developing cancer over their lifetime, as a result of exposure to potential carcinogens. Not all trace metals have carcinogenic effects. Among the measured metals, Cd and Cr are known to cause a cancer risk. The lifetime cancer risk (CR) was calculated by multiplying the daily dose by the cancer slope factor (CSF) derived from the response-dose curve for toxicant ingestion. The acceptable risk levels of CR ranged from 10^{-6} to 10^{-4}. The model formula is as follows:

$$TR = \frac{EF \times ED \times FIR \times \times CF \times C \times CSF}{WAB \times TA} \times 10^{-3} \tag{4}$$

Since CSF values (mg/kg/day) of Cr and Cd used in this study were: Cd (6.3) and Cr (CSF = 0.5) (US EPA., 1989).

Statistical analysis

Statistical analyses were performed using R software (version 4.3.1). Initially, the normality of heavy metal concentration distributions in mollusks, crustaceans, and fish samples was assessed using the Shapiro–Wilk test. Subsequently, comparisons of metal concentrations were carried out both between taxonomic groups (mollusks, crustaceans, and fish) and among species within each group using the non-parametric Kruskal–Wallis test, followed by appropriate post hoc tests when significant differences were detected. Furthermore, principal component analysis (PCA) was applied to the dataset in order to examine the relationships between metal concentrations and the studied zoological groups, as well as to identify potential affinities at the species level. This multivariate statistical method was used to reduce the dimensionality of the data while retaining the main sources of variability. The analysis was performed on the correlation matrix of the standardized variables to ensure comparability among metals. PCA enabled the identification of the main factors explaining data variability and facilitated the visualization of associations between metals and biological groups (fish, crustaceans, and mollusks), as well as differences among species. The PCA was performed using the FactoMineR pachage (Husson et al., 2020). All statistical results were considered significant at $p < 0.05$.

RESULTS

Variations in TM concentrations in the muscle tissues of selected seafood species

The mean concentrations of trace metals (Fe, Cu, Cd, Cr, and Ni) measured in the edible tissues of 11 fishery products species: seven (7) fishes, two (2) crustaceans, two (2) bivalve and cephalopod mollusks, are presented in Table 2.

Iron

The results obtained from analyzed samples (all species combined) show that mean iron concentrations ranged from (1.68 ± 0.03) mg/kg to

(168.53 ± 2.55) mg/kg in mollusks; (2.03± 0.15) mg/kg to (18.5 ± 0.22) mg/kg in crustaceans and (3.73 ± 0.11) mg/kg to (44.97 ± 1.71) mg/kg in fish (Table 2). According to the zoological group, no significant differences were observed between three organism categories (Kruskal-Wallis chi-squared =0.7426, 2 d.f., p=0.6898) (Figure 1). At three groups of fishery products, the mean concentrations for the Fe metal followed the order: mollusks > fish > crustaceans (Figure 1). At the species level, the statistical analyses, using test of Kruskal-Wallis showed a very highly significant difference in Fe concentrations among species (p=0.0004) (Table 2). The highest concentrations were observed in mollusks (*D.trunculus*), followed by fishes (*S.aurata*; *S.aurita*) and, lastly, crustaceans *(P.longirostris*) (Table 2, Figure 1). Overall, the mean concentrations of Fe (considering all species) decreased in the following order: *D.trunculus* > *S.aurata* > *S.aurita* > *P.longirostris* > *T.thynnus* > *P.erythrinus* > *B.boops* > *D.sargus* > *P.pagrus* > *A.antennatus* > *L.vulgaris*. Unlike toxic heavy metals, no strict maximum permissible limits have been established for iron in fish muscle by international organizations such as FAO/WHO.

Cadmium

In the current investigation, Cd was detected in all samples assessed, except *A.antennatus, P.pagrus* and *P.erythrinus*. Cd concentrations varied significantly among the three groups of organisms (Kruskal-Wallis chi-squared = 6.3823, 2 d.f., p = 0.041). Dunn's post hoc test revealed that fish and mollusks exhibited significant differences in Cd concentrations (p = 0.05). Similarly, crustaceans and mollusks differ significantly (p = 0.03), whereas no significant difference was detected among Crustacean and fish groups (p = 1) (Figure 2).

The mean Cd concentration varied from below the detection limit levels to 0.34 mg/kg levels. The highest mean Cd concentration (Table 2) was found in *D. trunculus* (0.34 ± 0.01 mg/kg). According to both national (JO n°: 25, 2011), and international limit (European Commission Regulations N°. 1881/2006), the maximum permissible levels of cadmium are 0.5 mg/kg in crustaceans, and 1mg/kg for bivalve mollusks flesh, respectively. Based on the concentrations obtained, Cd concentration in the edible parts of crustacean and mollusk groups was lower than the standard criteria. However, cadmium concentrations found in fish were above the international guideline (EC N°. 1881/2006) limit (0.05 mg/kg in fish muscle).

Taking into account cadmium levels according to zoological groups measured in the muscles of the analyzed species, a ranking can be established in decreasing order as follows: mollusks > crustaceans > fish (Figure 2). Irrespective of the zoological groups, the ranking is as follows: *D.trunculus* > *S.aurita* > *S.aurata* > *P.longirostris* > *L.vulgaris* > *T. thynnus* > *B.boops* > *D. sargus* (Figure 2).

Table 2. Mean and standard deviation (mean ± SD) of Cu, Cr, Cd, Fe, and Ni concentration (mg/kg dw) in the target species

Zoological groups	Species	Cd	Cu	Cr	Fe	Ni
Mollusks	*L.vulgaris*	0.19 ± 0.03	12.08 ± 0.29	0.66±0.02	1.68 ± 0.03	BDL
	D.trunculus	0.34 ± 0.01	7.71 ± 0.78	1.27±0.08	168.53 ± 2.55	0.90 ± 0.05
Crustaceans	*A.antennatus*	BDL	2.09±0.25	0.79±0.11	2.03± 0.05	BDL
	P.longirostris	0.22 ± 0.03	10.69 ± 0.26	0.8±0.11	18.5 ± 0.22	0.05 ± 0.03
Fish	*S.aurita*	0.28 ± 0.04	3.54 ± 0.29	0.58±0.05	43.39 ± 0.22	BDL
	D.sargus	0.1 ± 0.02	3.95 ± 0.78	0.43±0.05	5.11 ± 0.55	0.45 ± 0.08
	T.thynnus	0.18 ± 0.02	3.75 ± 0.51	0.52±0.03	13.43 ± 0.18	BDL
	S.aurata	0.23 ± 0.05	4.58 ± 0.29	0.78±0.05	44.97 ± 1.71	BDL
	B.boops	0.17 ± 0.03	0.64 ± 0.01	0.52±0.04	5.33 ± 0.07	BDL
	P.pagrus	BDL	0.55 ± 0.02	0.41±0,08	3.73 ± 0.11	BDL
	P.erythrinus	BDL	0.24 ± 0.02	0.29 ± 0.06	6.63 ± 0.28	BDL
P	value of *P* among species	0.001	0.0005	0.001	0.0004	0.0004

Note: The abbreviation "*BDL*" denotes metal below detection limit in the respective species.

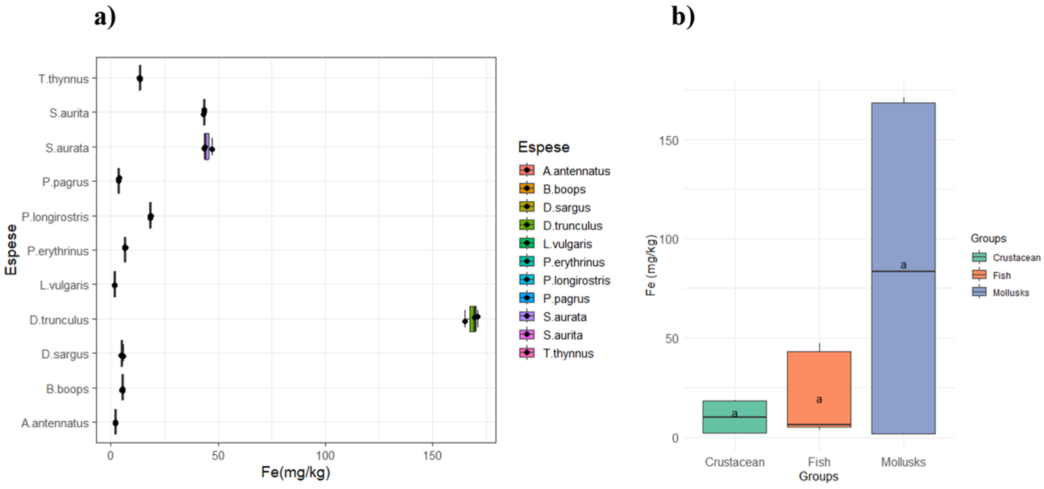

Figure 1. Boxplot demonstrating iron concentrations: (a) across seafood species (median: line inside the box; box: first and third quartiles; whiskers: minimum and maximum), (b) comparative bioaccumulation patterns among zoological groups (Letters represent the results of Kruskall Walis and Dunn test. Different letters represent a significant difference (p-value<0.05) among groups, while equal letters mean here is no significant difference)

Nickel

Of all the heavy metals assessed in this study, nickel was the least prevalent, with eight samples below the detection limit (Table 2). No significant differences were observed among major taxonomic groups (Kruskal-Wallis chi-squared = 5.0758, 2 d.f., p = 0.0790), but a very highly significant difference was found between species (p = 0.0004). For nickel, with the exception of fish (*D. sargus*), mollusk (*D. trunculus*), and crustacean (*P. longirostris*), whose average levels are respectively (0.45 ± 0.08; 0.90 ± 0.05; 0.05 ± 0.03) mg/kg. In general, the accumulation of Ni in tissues of seafood products is as follows: mollusks > crustaceans >fish.

The Food and Agriculture Organization (FAO.,1983) recommends a limit of Ni in seafood of 70 mg/kg; EC (No. 1881/2006) set the permissible levels at 40 mg/kg for fish; whereas FAO/WHO (2005) recommends limits of 3.7 mg/kg for crustacean species. Accumulation of Ni in all seafood species below the FAO, and both EC and FAO/WHO.

Copper

Unlike cadmium and nickel, assessed in the present study, copper was detected in all species. Higher Significant differences between organism groups were observed (Kruskal-Wallis chi-squared = 13.995, 2 d.f., p = 0.0009). with pairwise comparisons showing significantly higher concentrations in mollusks than in the fish group (p = 0.0004) (Figure 3).

According to the FAO (Nauen, 1983), the permissible limit for Cu concentration for fish and shellfish is 30 mg/kg. In our study, the concentration of Cu ranged from 0.225 to 12.5 mg/kg, considering all species. The maximum mean concentrations of Cu were Found in *L.vulgaris*. Among the fish species, the maximum mean concentrations of Cu were recorded in *S. aurata,* and the minimum in *P. erythrinus*. However, in the crustacean group, *P. longirostris* comprised the maximum mean concentrations of Cu (10.69 ± 0.26 mg/kg) (Table 2). Compared with fish species, mollusk and crustacean groups had Markedly higher concentrations of copper, in which Cu exhibited highly significant variation between all species (P = 0.0005). In general, the accumulation of Cu in tissues of seafood products is as follows: mollusks >crustaceans> fishes (Figure 4). According species ranking is as follows: *L.vulgaris* > *P.longirostris* > *D.trunculus* > *S.aurata* > *D.sargus* > *T.thynnus* > *S.aurita* > *A.antennatus* > *B.boops* > *P.pagrus* > *P.erythrinus* (Figure 4).

The Cu concentration found in all fish, mollusks, and crustaceans in this study were below the FAO guideline values. In contrast, its levels in crustacean groups except *A. antennatus* exceeded the EC (N°. 1881/2006) limit of 5 mg/kg.

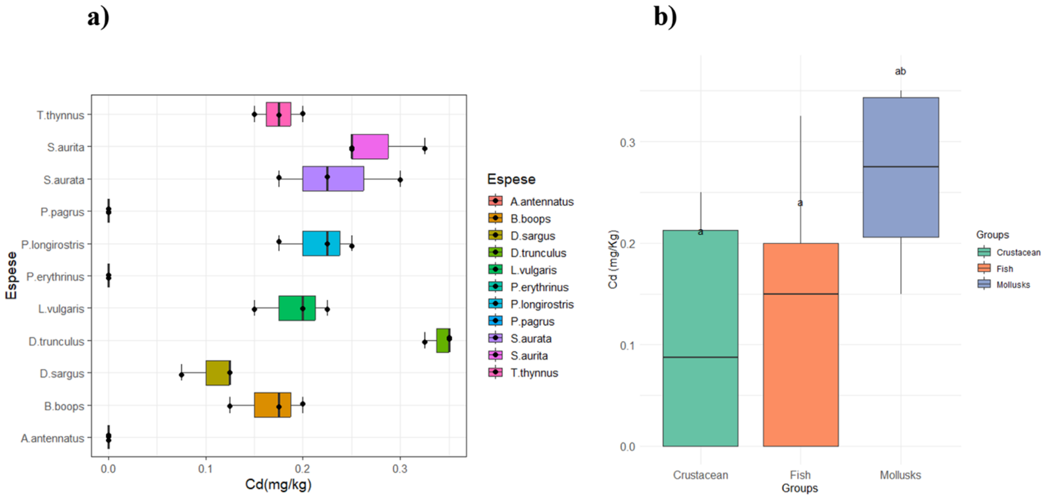

Figure 2. Boxplot demonstrating cadmium concentrations: (a) across seafood species (median: line inside the box; box: first and third quartiles; whiskers: minimum and maximum), (b) comparative bioaccumulation patterns among zoological groups (Letters represent the results of Kruskall Walis and Dunn test. Different letters represent a significant difference (p-value<0.05) among groups, while equal letters mean there is no significant difference)

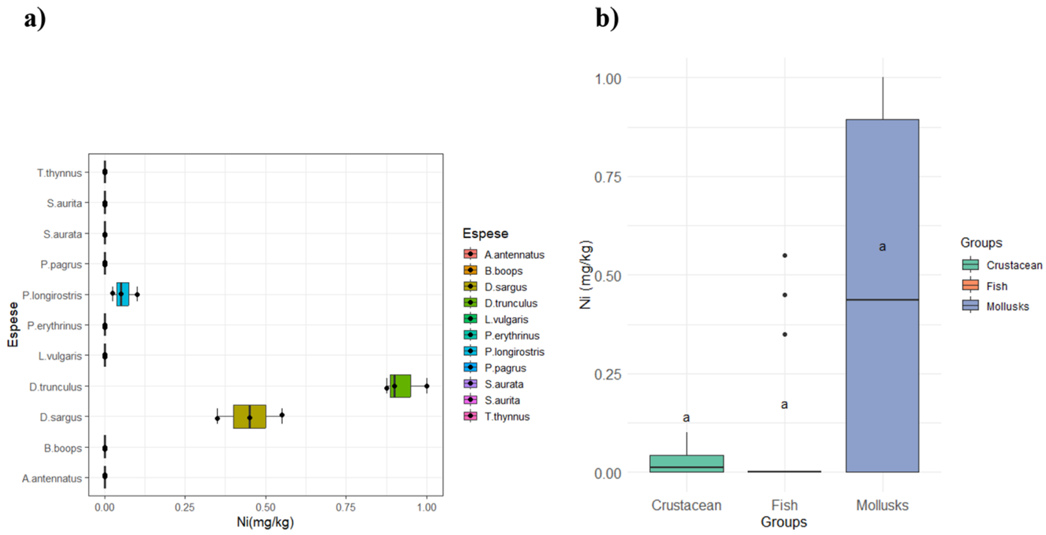

Figure 3. Boxplot demonstrating nickel concentrations: (a) across seafood species (median: line inside the box; box: first and third quartiles; whiskers: minimum and maximum), (b) comparative bioaccumulation patterns among zoological groups (Letters represent the results of Kruskall Walis and Dunn test. Different letters represent a significant difference (p-value<0.05) among groups, while equal letters mean there is no significant difference)

Chromium

Chromium was detected in all species with mean concentrations and ranges varying among species (Table 2). The concentration of Cr was found to vary from 0.225 to 1.35 (mg/kg dw) in selected seafood species (Figure 5). According to the Kruskal-Wallis test, mean concentrations differed significantly among the three organism groups (Kruskal-Wallis chi-squared = 13.995, 2 d.f., p = 0.0009), with highest concentrations measured in mollusks (*D.trunculus*) and the lowest in fish (*P. erythrinus*) (Table 2; Figure 5). Although crustacean Cr concentrations were lower than those of mollusks, but higher than those of fish, no significant differences were observed between the crustacean and mollusks categories were observed (p = 0.399) (Figure 5). However, Dunn's post hoc test revealed significantly higher Cr concentrations in mollusks than in the fish group (p = 0.0004). In addition, the Kruskal-Wallis test showed highly

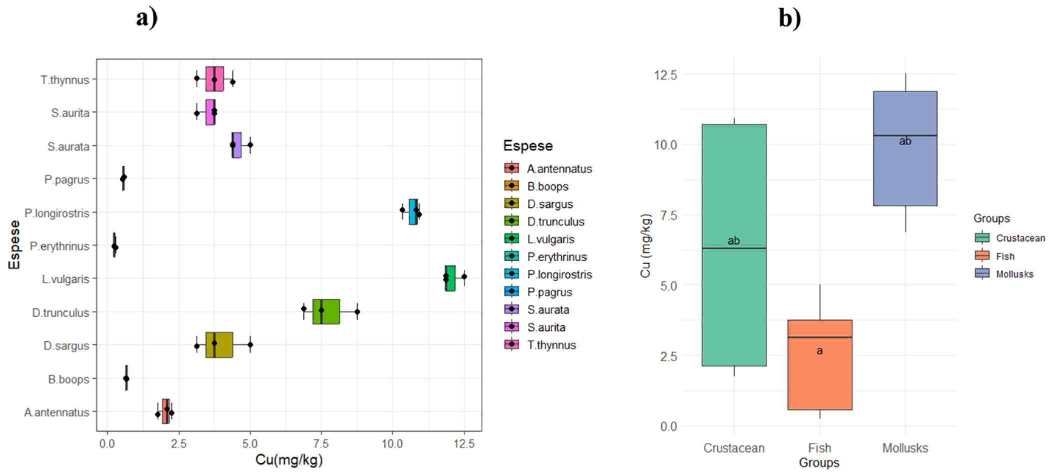

Figure 4. Boxplot demonstrating copper concentrations: (a) across seafood species (median: line inside the box; box: first and third quartiles; whiskers: minimum and maximum), (b) comparative bioaccumulation patterns among zoological groups (Letters represent the results of Kruskall Walis and Dunn test. Different letters represent a significant difference (p-value<0.05) among groups, while equal letters mean there is no significant difference)

significant difference in Cr concentrations between the different species (p = 0.001). In general, the accumulation of Cr in tissues of seafood products is as follows: mollusks > crustaceans > fishes (Figure 5). The species ranking is as follows: *D.trunculus* > *P.longirostris* > *A.antennatus* > *S.aurata* > *L.vulgaris* > *S.aurita* > *T.thynnus* > *B.boops* > *D.sargus* >*P.pagrus* > *P.erythrinus* (Figure 5).

The Cr concentration was lower compared to the international guideline values, where the recommended permissible concentration for Cr for seafood is 12 and 13 mg/kg from the FAO (1983) and USFDA (1993), respectively.

Assessment of trace metal variability in seafood muscle tissues by principal component analysis

In the present study, the PCA was used to recognize the distribution and relationships of trace metal elements (Fe, Cd, Cr, Cu, and Ni) within the target groups selected (fish, mollusks, crustacean) (Figure 6). PCA results revealed that the first two principal components collectively explained for approximately 84.7% of the total information in this study, indicating a satisfactory representation of the dataset. The first and the

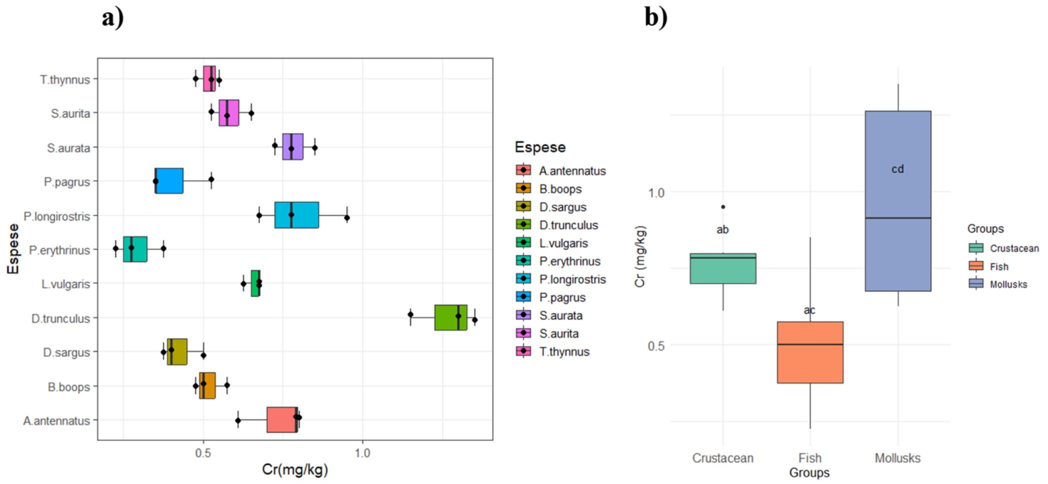

Figure 5. Boxplot demonstrating chromium concentrations: (a) across seafood species (median: line inside the box; box: first and third quartiles; whiskers: minimum and maximum), (b) comparative bioaccumulation patterns among zoological groups (Letters represent the results of Kruskal-Wallis and Dunn test. Different letters represent a significant difference (p-value<0.05) among groups, while equal letters mean there is no significant difference)

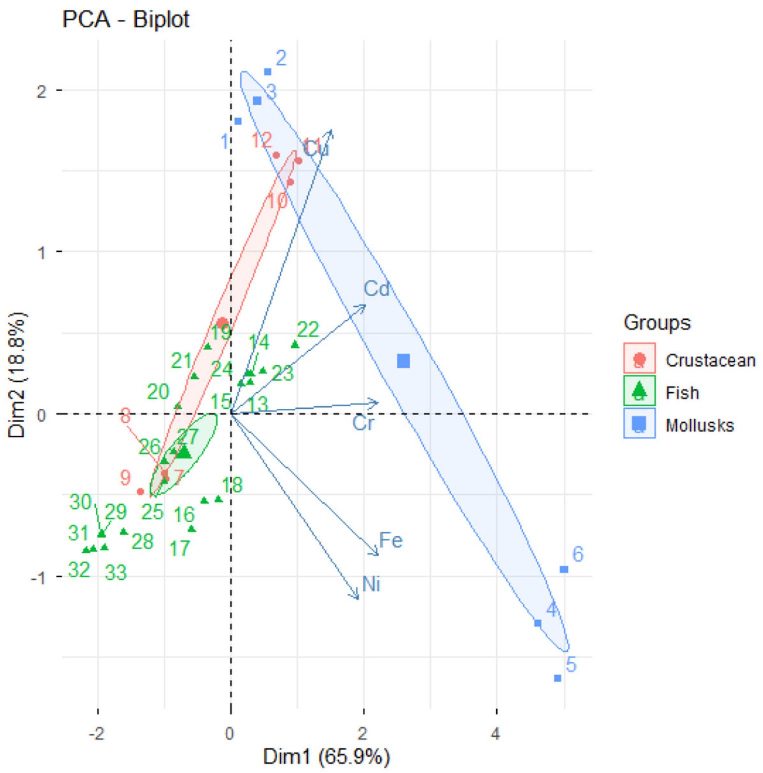

Figure 6. Rotated component loading plot for five trace metal elements in target groups (mollusks, crustaceans, fish)

second (Dim1, Dim 2) principal component accounted for 65.9% and 18.8% of the variability, respectively. However, the first principal component (Dim1) was mainly influenced by positive loadings with Fe (r = 0.906), Cr (r = 0.900), Cd (r = 0.822), and Ni (r = 0.783), reflecting a gradient of overall metal contamination. Samples located on the positive side of this axis were characterized by higher concentrations of these metals, whereas those on the negative side exhibited lower levels.

The second principal component (Dim2) was mainly driven by Cu (r = 0.717), which opposed Fe and Ni along this axis, suggesting differences in accumulation patterns among the elements.

The projection of samples onto the factorial plane revealed a clear separation across the three biological groups. Mollusks were predominantly distributed along the positive side (2.64) of Dim1, indicating elevated concentrations of Cd, Cr, Fe, and Ni. Crustaceans were mainly positioned along the positive side (0.56) of Dim2, showing a stronger association with Cu. In contrast, fish samples were clustered on the negative side (-0.71) of Dim1, reflecting lower overall metal concentrations.

Human health risk assessment of heavy metal concentration in consumed marine species

Target hazard quotient

The THQ and HI values of the metals in question are summarized in Table 3. Results are presented separately for different age consumers within the target species.

Overall, the findings revealed that THQ and Hi values for individual trace elements in all marine organisms selected for this investigation remained below the safety threshold of 1 for both adults and children. Among individual trace elements, and for all species and both age groups, Cr exhibited the highest THQ values compared to other metals. Values reached 0.008 in adults and 0.019 in children following consumption of *S. aurata*. In terms of the HI, which represents the cumulative exposure to all trace elements studied, the highest values were also recorded in *S. aurata*, with 0.01 for adults and 0.024 for children. Overall, the HI values among assessed species decreased in the following order*: S. aurata* > *S. aurita* > *T. thynnus* > *B. boops* > *D. sargus* > *P.pagrus* > *P.erythrinus* > *D.trunculus* > *P.longirostris* > *A. antennatus* > *L.vulgaris*. In

Table 3. Target hazard quotient (THQ) and hazard index (HI) values for heavy metals in edible tissues of fishery products (adult and children)

Groups	Species	Sex	Target hazard quotient (THQ)					Hi
			Cd	Cu	Cr	Fe	Ni	
Mollusks	*L.vulgaris*	Adult	1.39E-07	2.21E-07	1.61E-05	1.76E-07	-	1.67E-05
		Child	3.25E-07	5.16E-07	3.76E-05	4.1E-07	-	3.89E-05
	D.trunculus	Adult	2.75E-07	1.56E-07	3.43E-05	1.95E-05	3.56E-06	5.78E-05
		Child	6,43E-07	3.64E-07	8.00E-05	4.55E-05	8.32E-06	1.35E-04
Crustaceans	*A. antennatus*	Adult	-	4.84E-08	2.44E-05	2.68E-07	-	2.47E-05
		Child	-	1.13E-07	5.69E-05	6.26E-06	-	5.76E-05
	P.longirostris	Adult	2.04E-07	2.47E-07	2.47E-05	2.45E-06	2.31E-07	2.78E-05
		Child	4.75E-07	5.77E-07	5.76E-05	5.71E-07	5.4E-07	6.49E-05
Fish	*S. aurita*	Adult	0.000097	3.07E-05	0.006698	0.002147	-	0.008973
		Child	0.000226	7.15E-05	0.015628	0.005011	-	0.020936
	D. sargus	Adult	0.000108	3.01E-05	0.00437	0.000223	0.000838	0.005569
		Child	0.000252	7.02E-05	0.010196	0.000519	0.001956	0.012994
	T. thynnus	Adult	6.98E-05	3.64E-05	0.006725	0.000744	-	0.007576
		Child	0.000163	8.49E-05	0.015692	0.001737	-	0.017677
	S.aurata	Adult	7.33E-05	3.65E-05	0.008287	0.002048		0.010444
		Child	1.71E-05	8.51E-05	0.019335	0.004778	-	0.024369
	B. boops	Adult	5.42E-05	5.1E-06	0.005524	0.000243	-	0.005826
		Child	1.26E-05	1.19E-05	0.01289	0.000566	-	0.013595
	P. pagrus	Adult	-	4.38E-06	0.004356	0.00017	-	0.00453
		Child	-	1.02E-05	0.010163	0.000396	-	0.01057
	P. erythrinus	Adult	-	1.91E-06	0.003081	0.000302	-	0.003385
		Child	-	4.46E-06	7.19E-05	0.000704	-	0.000781

Note: (-) denotes metal below detection limit in the respective species.

contrast to mollusk and crustacean groups (with higher metal concentrations in their tissues), fish exhibited the highest THQ and HI values.

Carcinogenic risk assessment

CR was calculated only for Cd and Cr based on their established carcinogenic potency slope factors. The estimated CR values for these two elements from all investigated species consumption for both adult and children are summarized in Table 4.

According to the results, the carcinogenic risk values of Cd found in the selective organisms ranged from 8.77E-10 to 6.81E-07 and from 2.05E-09 to 1.59E-06 for both adult, and children respectively. Across all invertebrate species; *D. trunculus* recorded the highest values (1.74E-09 for adult; 4.05E-09 for children). In contrast to mollusk and crustacean groups, fish exhibited markedly higher cumulative risk values overall. Among seven fish species assessed, the highest CR was recorded for *D. sargus* (6.81E-07 for adult, 1.59E-06 for children). Carcinogenic risk associated with chromium consistently exceeded that for cadmium across all investigated species and population groups. Chromium associated CR values were raged from 2.42E-08 to 1.24 E-05, and 5.64E-08 to 2.9E-05 for both age groups (adult, and children respectively). *S. aurata* exhibited the highest Cr related CR values (1.24E-05 for adult, 2. 9E-05 for children), while the lowest values were observed in *L. vulgaris* (2.42E-08 for adult, 5.64E-08 for children).

DISCUSSION

The present study aims to quantify trace metals in the muscle tissue of fishery products (mollusk, crustacean, and fish) collected from the eastern Algerian coast. Furthermore,

Table 4. Carcinogenic risk (CR) values of heavy metals from different marine organisms

Groups	Species	Carcinogenic risk (Cd)		Carcinogenic risk (Cr)	
		Adult	Child	Adult	child
Mollusks	*L. vulgaris*	8.77E-10	2.05E-09	2.42E-08	5.64E-08
	D. trunculus	1.74E-09	4.05E-09	5.14E-08	1.2E-07
Crustaceans	*A. antennatus*	-	-	3.66E-08	8.53E-08
	P. longirostris	1.28E-09	2.99E-09	3.70E-08	8.64E-08
Fish	*S. aurita*	6.11E-07	1.43E-06	1.01E-05	2.34E-05
	D. sargus	6.81E-07	1.59E-06	6.55E-06	1.53E-05
	T. thynnus	4.39E-07	1.03E-06	1.01 E-05	2.35E-05
	S. aurata	4.61E-07	1.08E-06	1.24E-05	2.9E-05
	B. boops	3.41E-07	7.97E-07	8.29E-06	1.93E-05
	P. pagrus	-	-	6.53E-06	1.52E-05
	P. erythrinus	-	-	4.62E-06	1.08E-05

Note: (-) denotes metal below detection limit in the respective species.

it seeks to evaluate the potential health risks associated with their consumption among the population of Guelma.

Overall, based on their biological accumulation, the following hierarchy can be established among the three zoological groups (mollusks > crustacean > fish) and the five metals studied (Fe> Cu > Cr > Cd > Ni) (Table 5). This order could be attributed to several factors, like environmental parameters (pH, temperature, salinity), living habits, migration, feeding strategies, as well as, size, and caught area, metal regulation capacity, affinity for specific organs in marine organisms (Liu et al., 2019; Liu et al., 2020; Tanhan et al., 2022; Zeghdoudi et al., 2024).

The concentrations of heavy metals (Cu, Cr, Cd, Pb, and Fe) measured in the investigated marine species are presented in Table 5.

The comparison with previously published studies indicates that the concentrations obtained in the present study are generally within the range of values reported in other regions worldwide, including Morocco, Turkey, Egypt, and Portugal. However, slightly higher levels reported in some areas may be attributed to increased anthropogenic activities such as industrial discharge and urban effluents. The observed differences among species are consistent with biomagnification processes and species-specific ecological characteristics, including feeding habits and trophic position. Overall, the results suggest a moderate level of contamination in the study area, comparable to global trends, while highlighting the influence of both environmental and biological factors on metal accumulation.

Iron

Overall, Fe showed the highest concentration across all assessed elements in the edible tissues of marine fishery products. The average Fe concentration was approximately 6.70, 45.20, 178, and 219.07 folds higher than the average concentration of Cu, Cr, Cd, and Ni, respectively. The highest Fe concentration was observed in mollusks, especially in benthic bivalves *D.trunculus* (168.53 ± 2.55 mg/kg). Our results are much lower than those found by Türk Çulha et al., (2022) in the Black Sea, Turkey, where related species, the mussel "*Mytilus galloprovincialis*" reached a concentration of 441.42 (mg/kg dw). However, they are lower than those reported Guendouzi et al., (2020) in the southwestern Mediterranean Collo, Skikda, Algeria in the same species "*Mytilus galloprovincialis*", which attained 282.43 ug/g dw. It has also been reported that mussels preferentially accumulate metals Pb, Cd, Ni, Co, and Fe from surrounding sediments. These results may explain the higher Fe concentration observed in *D.trunculus* collected from the Collo coast, where metal contamination in sediments is comparatively higher (Guendouzi et al., 2020). In addition, the higher accumulation of trace metals in mollusks compared with other groups is usually related to their benthic habitat and filter-feeding behavior, which increases their exposure to metal

Table 5. Concentrations of heavy metals found in the marine organisms of different marine zones in the world

Species	Unit	Heavy metal levels, mean and/or (min-max)					Location	Reference
		Cu	Cr	Cd	Ni	Fe		
Donax trunculus	µg/g dw	10.52	1.42	0.29	1.60	-	Agadir Bay, Morocco	(Idardare et al., 2011)
	mg/kg ww	26.53	0.44	0.09	0.006	120.57	Black Sea, Bulgaria	(Peycheva et al., 2023)
	mg/kg dw	6.87–8.75	1.15–1.35	0.32–0.35	0.87–1	170.95–165	Eastern Algerian Coast	Present study
Loligo vulgaris	µg/g dw	3.99	-	-	-	66.11	Gulf of Mersin, Turkey	(Külcü et al., 2014)
	mg/kg dw	11.87–12.5	0.62–0.67	0.15–0.22	BDL	1.65–1.72	Eastern Algerian Coast	Present study
Parapenaeus longirostris	µg/g dw	-	1.38–3.44	0.44–0.67	-	-	Gulf of Mersin, Turkey	(Ayas et al., 2016)
	µg/g dw	100–125	-	0.4-0.9	-	-	northeast Algeria	(Abdennour et al., 2000)
	mg/kg dw	10.32–10.92	0.67–0.95	0.17–0.25	0.02- 0.1	18.25–18.77	Eastern Algerian Coast	Present study
Aristeus antennatus	mg/kg dw	0.0118	-	BDL	-	-	Mediterranean coast of Algiers	(BENMOHAND et al., 2024)
	mg/kg dw	1.75–2.24	0.61–0.8	BDL	BDL	2–2.11	Eastern Algerian Coast	Present study
Thunnus thynnus	mg/kg ww	7.06	3.33	0.27	1.07	94.93	Canary island	(Vásquez-Domínguez et al., 2025)
	mg/kg dw	3.12–4.37	0.47–0.55	0.15–0.2	BDL	13.2–13.65	Eastern Algerian Coast	Present study
Sparus aurata	mg/kg ww	0.428	0.035	-	-	1.58	Aveiro region, Portugal	(El Deghel et al., 2026)
	mg/kg dw	4.37–5	0.72–0.85	0.17–0.3	BDL	43.62–47.37	Eastern Algerian Coast	Present study
Pagrus pagrus	µg/g ww	1.05	0.07	0.06	0.48	15.30	Mediterranean coast, Damietta, North Egypt	(Monier et al., 2023)
	mg/kg dw	0.52–0.57	0.35–0.52	BDL	BDL	3.6–3.87	Eastern Algerian Coast	Present study
Boops boops	µg/g ww	0.030	0.310	0.010	0.200	6.380	Iskenderun bay, Turkey	(Doğan et al., 2023)
	mg/kg dw	0.62–0.65	0.47–0.57	0.12–0.2	BDL	5.25–5.42	Eastern Algerian Coast	Present study
Pagellus erythrinus	-	8.29	-	-	13.75	-	Gulf of Arzew, Algeria	(Inal et al., 2024)
	mg/kg dw	0.22–0.27	0.22–0.37	BDL	BDL	6.42–7.02	Eastern Algerian Coast	Present study
Sardinella aurita	µg/g ww	0.24	0.10	0.06	0.32	19.72	Mediterranean coast, Damietta, North Egypt	(Monier et al., 2023)
	mg/kg dw	3.12–3.75	0.52–0.65	0.25–0.32	BDL	43.07–43.6	Eastern Algerian Coast	Present study

Note: the abbreviation *“BDL”* denotes metal below detection limit in the respective species; “*dw*” indicates dry weight; “*ww*” indicates wet weight; (-) indicates metal not measured.

contaminated sediments and suspended particles (Gafar et al., 2025).

Furthermore, trace metal elements in crustacean group exhibited considerably lower concentration than that of other marine organism categories. Among the assessed crustacean species, Fe concentration in *Parapenaeus longirostris* (18.5 mg/kg dw) was comparatively higher than that in *Aristeus antennatus* (2.03 mg/kg dw). These finding revealed that even close taxa species may exhibit different metal accumulation pathways, as reported in previous studies (Baki et al., 2018; Q. Liu et al., 2018, 2019). For instance, the Fe concentrations in crustacean species were lower than the related studies at Gulf of Skikda (Southern Mediterean sea, Algeria) with a concentration of 25.11 mg/kg in *Parapenaeus longirostris* (Nakib et al., 2026).

Based on the results of this study, Fe concentrations in the muscle of seven fish species followed a decreasing order: *S.aurata* (44.97 mg/kg) > *S.aurita* (43.39 mg/kg) > *T.thynnus* (13.43 mg/kg)> *P.erythrinus* (6.63 mg/kg) > *B.boops* (5.33 mg/kg)> *D.sargus* (5.11 mg/kg) > *P.pagrus* (3.73 mg/kg). Furthermore, some studies, such as those by Bachouche et al., (2017); Külcü et al., (2014); and Lozano-Bilbao et al., (2023) have demonstrated Fe concentration of 323.4 mg/kg, 80ug/g, 177ug/g dw in *Thunnus thynnus*, *Boops boops*, and in the muscle of demersal *Mullus barbatus*, respectively, these concentrations were higher than the Fe levels obtained in this study. However, the concentration observed in the present study were higher than the data reported by El Deghel et al., (2026) for *S.aurata*, and *B. boops*. In addition, the highest levels observed in *S.aurata* compared to other fish species is likely attributable to habitat preferences, metabolism, and physiological traits of each species. Plankton feeders, such as sardines, generally contain more elements than other fish species, including *Sardinella* spp. preying mostly upon copepods (Ali et al., 2025). Zooplankton are considered primary consumers, primarily accumulate pollutants from their surroundings and play a vital role in connecting lower and higher trophic levels. Zooplankton are principally exposed to these contaminants through their diet of phytoplankton and other organic matter (Dey et al., 2024). Over time, metals present in their diet or dissolved in the water tend to concentrate gradually in zooplankton tissues, and ultimately bioaccumulate in larger filter feeders such as sardines, and *Sparus aurata*.

Cadmium

In the present study, Cd was detected in 81.81% of the samples, with concentrations ranging from BDL values to 0.34 mg/kg. While mollusks and crustaceans remained below international regulatory limits, some fish species exceeded the maximum permissible level established by the European Commission (N°. 1881/2006) (0.05 mg/kg).

The Cd levels observed in *Parapenaeus longirostris* were comparable to those reported by Ben Ameur et al., (2025), but were lower than in more polluted areas such as Annaba Gulf, the Gulf of Mersin, and Iskenderun Bay (Abdennour et al., 2000; Ayas et al., 2016; Firat et al., 2008). Conversely, Cd in *Aristeus antennatus* was below detection limits, consistent with recent findings from the Mediterranean coast of Algiers (Benmohand et al., 2024). The relatively higher Cd levels detected in *Donax trunculus* may be attributed to its benthic and filter-feeding behavior, which enhances exposure to contaminated sediments and suspended particles (Hafsaoui et al., 2016; Secco et al., 2025; Tanhan et al., 2022).

Compared to crustaceans and mollusks, fish generally exhibited higher Cd levels, likely due to multiple uptake methods including gill absorption, ingestion, and trophic transfer (Liu et al., 2019; Ouali et al., 2018; Zeghdoudi et al., 2024). The observed interspecific variability reflects differences in ecology, feeding habits, and local environmental conditions (Makroum et al., 2026). Furthermore, exposure to heavy metals may induce the synthesis of metallothioneins, which helps detoxify metals and accumulate in tissues such as liver and muscle (Tanhan et al., 2022).

Nickel

In the present study, Ni values were below the detection limit (BDL) in nearly all analyzed samples, consistent with previous studies reported by El Deghel et al., (2026) in the Aveiro region (Portugal), and Hossain et al., (2022) in the Lower Meghna River and adjacent areas of Bangladesh. Nevertheless, the concentration detected in the present study for *D.trunculus* (0.90 mg/kg dw) was lower than that reported by Idardare et al., (2011), who recorded a mean concentration of 1.60 (ug/g dw) in the same species from Agadir Bay, Morocco. However, benthic filter feeders positioned at the sediment-water interface can accumulate contaminants directly from sediments, which are influenced by changes in pH, redox conditions, and sediment composition (Dey et al., 2024).

Copper

Numerous studies have reported the accumulation of copper in aquatic organisms at varying concentrations worldwide (Díaz et al., 2025; Monier et al., 2023; Zaghloul et al., 2024).

In the present study, Cu concentrations recorded in *L. Vulgaris* were three times higher than those observed in the present study (Külcü et al., 2014). Ghosn et al., (2020) attributed the relatively high levels of Cu and Zn in mollusks to their physiological requirements.

In crustaceans, Cu levels in *P. longirostris* were approximately 18 times higher than those reported by Ben Ameur et al., (2025), but lower than those found by Abdennour et al., (2000). Conversely, Benmohand et al.,(2024) reported lower accumulation levels in *Aristeus antennatus* compared to our results. The elevated Cu concentrations in crustaceans and mollusks can be explained by the presence of hemocyanin, a copper-containing respiratory protein, which contributes to higher bioaccumulation in these groups compared to fish (Ghosn et al., 2020).

In fish species, the highest levels were recorded in *S. aurata*, whereas the lowest were observed in *P. erythrinus*. Compared to other regions, our values are lower than those reported for *Thunnus thynnus* from the Canary Islands (Lozano-Bilbao et al., 2023), but higher than those recorded for *Boops boops* in Mersin Bay (Külcü et al., 2014). Mean Cu levels *in D. sargus* were higher than those reported in the Tagus River estuary (Caçador et al., 2012), but lower than those observed by Afonso et al., (2017).

Overall, variations in trace metal concentrations among species are influenced by several factors, including feeding habits, duration of exposure, environmental conditions, and habitat preferences. In particular, biomagnification tends to be more pronounced in carnivorous species, followed by omnivores, and is generally higher in benthic organisms than in pelagic ones (Dey et al., 2024).

Chromium

In the present study, the mean Cr concentrations observed in *D. truculus* were lower than those reported by Tan and Kızılkaya, (2019) in Black Sea, Bulgaria. Conversely, higher levels were documented by Peycheva et al., (2023), with concentrations approximately 3.44 times higher than those observed here. However, Cd concentrations achieved in this study are lower than the concentrations reported by Ayas et al., (2016). Variation in Cr accumulation are likely attributed to differences in geographical area. In the present study, *Thunnus thynnus* concentration was particularly low, 10 times lower than those observed of the same species in the Canary island (Lozano-Bilbao et al., 2023). Notably, top predators including carnivorous or omnivorous large fish tend to accumulate higher levels of metals and metalloids due to biomagnification, especially for lipophilic contaminants stored in fatty tissues (Dey et al., 2024). Moreover, the Cr concentration measured in *D.sargus* was higher than the values previously reported by Afonso et al., (2017). In addition, Belhadj et al., (2025) have demonstrated that the accumulation of both essential and non-essential metals in marine organisms is influenced by the existence of these contaminants in the surrounding abiotic (water and sediments), and biotic (algae) environment.

PCA

The application of PCA proved to be an effective approach for identifying patterns of metal distribution and the main factors driving variability within the dataset. The PCA results demonstrated marked differences in metal accumulation among the studied organisms. The strong contribution of Fe, Ni, Cd, and Cr to the first principal component suggests that these elements may share common environmental sources or exhibit similar bioaccumulation behaviors. Mollusks showed the highest levels of metal accumulation, which is consistent with their recognized role as effective bioindicators of aquatic pollution. Their sedentary nature and filter-feeding strategy increase their exposure to both dissolved and particulate contaminants, leading to enhanced accumulation. In contrast, fish exhibited the lowest concentrations of metals. This may be explained by their higher mobility, different trophic positions, and more efficient physiological mechanisms for metal regulation and excretion. Crustaceans displayed an intermediate pattern but were clearly associated with copper along the second principal component. This specific association may be linked to the biological role of copper in crustaceans, particularly as a component of hemocyanin, a copper-containing oxygen-transport protein. Furthermore, the observed correlations between Fe and Ni, as well as between Cd and Cr, suggest potential common sources or similar geochemical behavior in the environment. Conversely, the distinct positioning of Cu indicates a different origin or a specific metabolic regulation. Overall, these findings highlight the influence of ecological and physiological factors on metal accumulation and distribution among aquatic organisms (Liu et al., 2019; Tanhan et al., 2022; Zeghdoudi et al., 2024).

Human health risk assessment of heavy metal concentration in consumed marine species

The health risks posed by of toxic metals from three major taxonomic groups were evaluated using THQ, HI and CR. All metals THQ and HI values were within the threshold limit, suggesting that non-carcinogenic adverse health effects from Cu, Fe, Cd, Ni, and Cr are unlikely with current consumption levels by the local population.

In our study, carcinogenic risk (CR) values related to Cd were negligible for almost all selected species, for both adults and child. Conversely, CR values for Cr were within the acceptable range (10^{-6}–10^{-4}) in over half of the assessed samples in both age groups.

In this study, children consistently showed higher THQ, HI, and CR values than adults across all species. This pattern is mainly due to the higher food intake, lower body weight, and increased vulnerability to contaminants. These results align with previous studies (Hossain et al., 2022; Noman et al., 2022; Salhi et al., 2025).

Unlike mollusk and crustacean groups, which have higher metal concentrations in their tissues, fish exhibited the highest THQ, HI, and CR values. This finding can be attributed to a generally lower ingestion rate with 9.7 g/person/day for fish (Mehouel et al., 2019) versus only 0.027 g/person/day for mollusks and crustaceans (Belhadj et al., 2025; Benhalima et al., 2025), thereby significantly reduces exposure from these groups. This suggests that human health risks depend not only on contaminant levels, but also on consumption habits.

Overall, the toxicological assessment demonstrates that consuming any of the seafood species selected in this study from the eastern Algerian coast, especially near Annaba, El Kala, Skikda, and Collo, does not pose a substantial non-carcinogenic or carcinogenic risk for adults or children under typical consumption patterns. Nevertheless, ongoing monitoring and multi-seasonal assessments are highly advised to ensure seafood safety and protect public health.

CONCLUSIONS

This study provides important insights into the potential health risks associated with seafood consumption in the context of possible marine trace metal contamination. The results clearly demonstrate that metal accumulation varies significantly among seafood groups, with mollusks presenting the highest levels, followed by crustaceans and fish. In fact, the risk of dietary exposure to trace metals is strongly dependent on the type of seafood consumed. Consequently, the consumption of certain species, particularly those with higher accumulation capacity, may pose a greater potential risk to human health, especially in cases of frequent intake.

The results indicated that both the target hazard quotient and hazard index values for all analyzed metals remained below one for both adult and child consumers, suggesting that the population of the Guelma region is not expected to experience non-carcinogenic health risks associated with the consumption of the studied seafood. Regarding carcinogenic risk, the estimated values for chromium were within the acceptable range (10^{-6}–10^{-4}) for more than half of the analyzed samples across both age groups. In contrast, the carcinogenic risk associated with cadmium was found to be negligible for nearly all examined species and consumer categories. Notably, children exhibited slightly higher carcinogenic risk values than adults, which can be attributed to their lower body weight and increased susceptibility to contaminant exposure.

Importantly, this work does not aim to characterize environmental contamination but rather to evaluate its possible implications for consumers. In this context, the study highlights the necessity of adopting a food-oriented risk assessment approach, focusing on edible tissues and consumption habits.

The application of Principal Component Analysis further supported the identification of consumption-related exposure patterns, reinforcing its usefulness as a complementary tool in food safety studies.

This approach is essential to ensure consumer safety and to support informed decision-making regarding seafood consumption in regions potentially exposed to metal contamination.

REFERENCES

1. Abdennour, C., Smith, B. D., Boulakoud, M. S., Samraoui, B., Rainbow, P. S. (2000). Trace metals in marine, brackish and freshwater prawns (Crustacea, Decapoda) from northeast Algeria. *Hydrobiologia*, *432*(1–3), 217–227. https://doi.

org/10.1023/A:1004027204088

2. Afonso, A., Gutiérrez, Á. J., Lozano, G., González-Weller, D., Et., A. (2017). Metals in Diplodus sargus cadenati and *Sparisoma cretense*—A risk assessment for consumers. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-017-0697-4
3. Ali, A. M., Nawareg, M. M., Elgetany, A. H., Bahnasawy, M. H., Hopcroft, R. R., El-Tohamy, W. S. (2025). The seasonal evaluation of heavy metals in sardines from the Mediterranean coast of Damietta, Egypt. *Marine Pollution Bulletin*, *217*, 117972.
4. Almafrachi, H. A. A., Gümüş, N. E., Çorak Öcal, İ. (2025). Heavy metal bioaccumulation in fish: Implications for human health risk assessment in ten commercial fish species from Konya, Türkiye. *International Journal of Environmental Science and Technology*, *22*, 4065–4074. https://doi.org/10.1007/s13762-024-05875-3
5. Arulkumar, A., Paramasivam, S., Rajaram, R. (2017). Toxic heavy metals in commercially important food fishes collected from Palk Bay, Southeastern India. *Marine Pollution Bulletin*, *119*(1), 454–459. https://doi.org/10.1016/j.marpolbul.2017.03.045
6. Ayas, D., Köşker, A. R., Durmuş, M., Bakan, M. (2016). Determination of seasonal changes on some heavy metal (Cd, Pb, Cr) levels of shrimp and prawn species from north-eastern Mediterranean sea, Gulf of Mersin, Turkey. *Journal of Aquaculture Engineering and Fisheries Research*, *2*(2), 42-49.
7. Ayberk, hamza S. A. V. A. Ş., Tolun, L., Pekey, H., Karakaş, D. (2004). Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. *Marine Pollution Bulletin*. https://doi.org/10.1016/J.MARPOLBUL.2003.11.023
8. Bachouche, S., Houma, F., Gomiero, A., Rabah, B. (2017). Distribution and environmental risk assessment of heavy metal in surface sediments and red mullet (*Mullus barbatus*) from Algiers and Bou-Ismail Bay (Algeria). *Environmental Modeling & Assessment*, *22*(5).
9. Baki, M. A., Hossain, Md. M., Akter, J., Quraishi, S. B., Haque Shojib, Md. F., Atique Ullah, A. K. M., Khan, M. F. (2018). Concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island, Bangladesh. *Ecotoxicology and Environmental Safety*, *159*, 153–163. https://doi.org/10.1016/j.ecoenv.2018.04.035
10. Belabed, B.-E., Meddour, A., Samraoui, B., Chenchouni, H. (2017). Modeling seasonal and spatial contamination of surface waters and upper sediments with trace metal elements across industrialized urban areas of the Seybouse watershed in North Africa. *Environmental Monitoring and Assessment*, *189*(6), 265. https://doi.org/10.1007/s10661-017-5968-5
11. Belhadj, H., Aubert, D., Youcef, N. D., Touzout, N. (2025). Assessment of metal pollution index, target hazard quotient and human health risk in some marine organisms collected from the extreme west coast of Algeria. *Oceanological and Hydrobiological Studies*, *54*(4), 268–287. https://doi.org/10.26881/oahs-2025.1.24
12. Ben Ameur, W., Annabi, A., Rania, K., Marini, M. (2025). Assessment of heavy metal contamination and human health risk in Parapenaeus longirostris from coastal Tunisian aquatic ecosystems. *Pollutants*, *5*(3), 23.
13. Benhalima, M., Guendouzi, Y., Boulahdid, M., Radakovitch, O., Angeletti, B., Boudjenoun, M. (2025). Assessment of human health risks associated with the consumption of wild and cultivated *Mytilus Galloprovincialis* from the Southwestern Mediterranean Sea. *Thalassas: An International Journal of Marine Sciences*, *41*(4), 227. https://doi.org/10.1007/s41208-025-00995-0
14. Benmohand, C., Aïnouz, L., Hani, F. A., Zaouani, M., Boudjellaba, S., Akkou, M., Milla, A., Khelef, D. (s. d.). Assessment and analysis of lead, cadmium, zinc, copper in Aristeus antennatus shrimp's from mediterranean coast of Algiers and evaluation of freshness by total volatile basic nitrogen test, before and after freezing. *REDVET-Revista electrónica de Veterinaria*, *25*(2), 2024.
15. Caçador, I., Costa, J. L., Duarte, B., Silva, G., Medeiros, J. P., Azeda, C., Castro, N., Freitas, J., Pedro, S., Almeida, P. R. (2012). Macroinvertebrates and fishes as biomonitors of heavy metal concentration in the Seixal Bay (*Tagus estuary*) : Which species perform better? *Ecological Indicators*, *19*, 184–190.
16. Cayabo, G. D. B., Lim, Y. C., Albarico, F. P. J. B., Chen, C.-F., Chen, C.-W., Dong, C.-D. (2025). Sediment pollutant fractionation and controlling factors of bioaccumulation and ecological risks in coastal benthic ecosystems around Kaohsiung Harbor. *Marine Pollution Bulletin*, *220*, 118461. https://doi.org/10.1016/j.marpolbul.2025.118461
17. Chen, L., Zhang, J., Zhu, Y., Zhang, Y. (2018). Interaction of chromium(III) or chromium(VI) with catalase and its effect on the structure and function of catalase : An *in vitro* study. *Food Chemistry*, *244*, 378-385. https://doi.org/10.1016/j.foodchem.2017.10.062
18. Dey, S., Rajak, P., Sen, K. (2024). Bioaccumulation of metals and metalloids in seafood : A comprehensive overview of mobilization, interactive effects in eutrophic environments, and implications for public health risks. *Journal of Trace Elements and Minerals*, *8*, 100141.
19. Díaz, G. E. E., Orellana, F. R. S., Vega, R. E. Y., Valdiviezo-Rivera, J. S., Ríos-Touma, B. P. (2025).

Trace metal contamination in commercial fish from the Ecuadorian amazon: Preliminary health risk assessment in a local market. *Fishes*, *10*(8). https://doi.org/10.3390/fishes10080392

20. Doğan, S., KILIÇ, E., Uğurlu, E., Duysak, Ö. (2023). Investigation of metal toxicity response and health risk assessment of commonly consumed marine fish species along the Turkish coast. *Ecological Life Sciences*, *18*(1), 8-29.
21. El Deghel, N., Vieira, H. C., Bordalo, M. D., Peuble, S., Gallice, F., Bedell, J.-P. (2026). Metallic trace elements in wild and farmed fish from the Aveiro Region (Portugal). *Marine Pollution Bulletin*, *222*, 118774.
22. EU. Commission Regulation (EC). No. 1881/2006 of 19 December Setting Maximum Levels for Certain Contaminants in Foodstuffs; *Official Journal of the European Communities*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2006; Volume 364, pp. 5–24.
23. FAO. Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Products. In *FAO Fishery Circular*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1983; Volume 464, pp. 5–100.
24. [FAO/WHO] Food and Agriculture Organization/ World Health Organization. 2005. *Exposure Assessment for Chemicals in Food.* Report of the FAO/ WHO Workshop, Annapolis, Maryland, USA; 02–06 May 2005.
25. Firat, Ö., Gök, G., Çoğun, H. Y., Yüzereroğlu, T. A., Kargin, F. (2008). Concentrations of Cr, Cd, Cu, Zn and Fe in crab Charybdis longicollis and shrimp *Penaeus semisulcatus* from the Iskenderun Bay, Turkey. *Environmental Monitoring and Assessment*, *147*(1–3), 117–123. https://doi.org/10.1007/s10661-007-0103-7
26. Gafar, A. M., Beheary, M. S., Mohamed, S. H., Hassan, A. K. (2025). Temporal and spatial variation in some heavy metals levels in water, sediment and bivalve in the Mediterranean Sea. *Egyptian Journal of Aquatic Biology and Fisheries*, *29*(6), 2227–2241.
27. Garofalo, L., Sala, M., Focardi, C., Pasqualetti, P., Delfino, D., D'Onofrio, F., Droghei, B., Pasquali, F., Nicolini, V., Galli, F. S., Scaramozzino, P., Ubaldi, A., Russo, K., Neri, B. (2025). Monitoring of cadmium, lead, and mercury levels in seafood products : A ten-year analysis. *Foods*, *14*(3). https://doi.org/10.3390/foods14030451
28. Ghosn, M., Mahfouz, C., Chekri, R., Ouddane, B., Khalaf, G., Guérin, T., Amara, R., Jitaru, P. (2020). Assessment of trace element contamination and bioaccumulation in algae (*Ulva lactuca*), bivalves *(Spondylus spinosus)* and shrimps (*Marsupenaeus japonicus*) from the Lebanese coast. *Regional Studies in Marine Science*, *39*, 101478. https://doi.org/10.1016/j.rsma.2020.101478
29. Guendouzi, Y., Soualili, D. L., Fowler, S. W., Boulahdid, M. (2020). Environmental and human health risk assessment of trace metals in the mussel ecosystem from the Southwestern Mediterranean. *Marine Pollution Bulletin*, *151*, 110820.
30. Hafsaoui, I., Draredja, B., Lasota, R., Como, S., Magni, P. (2016). Population dynamics and secondary production of *Donax trunculus* (Mollusca, Bivalvia) in the Gulf of Annaba (Northeast Algeria). *Mediterranean Marine Science*, *17*(3), 738. https://doi.org/10.12681/mms.1760
31. Hossain, M. B., Bhuiyan, N. Z., Kasem, A., Hossain, M. K., Sultana, S., Nur, A.-A. U., Yu, J., Albeshr, M. F., Arai, T. (2022). Heavy metals in four marine fish and shrimp species from a subtropical coastal area : Accumulation and consumer health risk assessment. *Biology*, *11*(12). https://doi.org/10.3390/biology11121780
32. Husson, F., Josse, J., Le, S., Mazet, J., Husson, M. F. (2020). Package 'FactoMineR'. Multivariate Exploratory Data Analysis and Data Mining. *Available on CRAN: https://cran. r-proje ct. org/web/packages/Facto MineR/Facto MineR. pdf.*
33. Idardare, Z., Moukrim, A., Chiffoleau, J. F., Alla, A. A. (2011). Trace metals in the clam *Donax trunculus* L. from the Bouadisse sandy beach, discharge zone of a plant sewage outfall in Agadir Bay (Morocco). Proc. of the Fifth International Symposium on Sandy Beaches, Rabat, Morocco. http://www.israbat.ac.ma/wp-content/uploads/2015/02/07%20Idardare.pdf
34. Ikem, A., Garth, J. (2022). Dietary exposure assessment of selected trace elements in eleven commercial fish species from the Missouri market. *Heliyon*, *8*(9), e10458. https://doi.org/10.1016/j.heliyon.2022.e10458
35. Ikhsani, I. Y., Harmesa, H., Budiyanto, F., Thoha, H., Fitriya, N., Kaisupy, M. T., Wibowo, S. P. A., Lestari, L. (2025). Heavy metals contamination in Jakarta Bay sediment: Geoaccumulation assessment and implication for environmental health. *Marine Pollution Bulletin*, *216*, 117983. https://doi.org/10.1016/j.marpolbul.2025.117983
36. Kerdoun, M. A., Alouk, L., Rahmani, F. M., Henni, H. A., Dali, H., Kelai, E., Belkhalfa, H. (2024). Mercury in four common fishes sold in Algeria and associated humans risk. *Food Additives & Contaminants. Part B, Surveillance*, *17*(3), 223–229. https://doi.org/10.1080/19393210.2024.2353709
37. Külcü, A. M., Ayas, D., Köşker, A. R., Yatkin, K. (2014). The Investigation of metal and mineral levels of some marine species from the Northeastern Mediterranean Sea. *Journal of Marine Biology and Oceanography*, *3*(2), 2.
38. l'agriculture, O. des N. U. pour l'alimentation et, agricole, F. I. de développement, Santé, O. mondiale de la, Mondiale, P. A., l'enfance, F. des N.

unies pour. (2022). *Résumé de L'État de la sécurité alimentaire et de la nutrition dans le monde 2022 : Réorienter les politiques alimentaires et agricoles pour rendre l'alimentation saine plus abordable*. Food & Agriculture Org.

39. Liu, Q., Liao, Y., Shou, L. (2018). Concentration and potential health risk of heavy metals in seafoods collected from Sanmen Bay and its adjacent areas, China. *Marine Pollution Bulletin*, *131*, 356–364. https://doi.org/10.1016/j.marpolbul.2018.04.041
40. Liu, Q., Xu, X., Zeng, J., Shi, X., Liao, Y., Du, P., Tang, Y., Huang, W., Chen, Q., Shou, L. (2019). Heavy metal concentrations in commercial marine organisms from Xiangshan Bay, China, and the potential health risks. *Marine Pollution Bulletin*, *141*, 215–226. https://doi.org/10.1016/j.marpolbul.2019.02.058
41. Liu, S., Liu, Y., Yang, D., Li, C., Zhao, Y., Ma, H., Luo, X., Lu, S. (2020). Trace elements in shellfish from Shenzhen, China: Implication of coastal water pollution and human exposure. *Environmental Pollution*, *263*, 114582. https://doi.org/10.1016/j.envpol.2020.114582
42. Lozano-Bilbao, E., Delgado-Suárez, I., Paz-Montelongo, S., Hardisson, A., Pascual-Fernández, J. J., Rubio, C., Weller, D. G., Gutiérrez, Á. J. (2023). Risk assessment and characterization in tuna species of the Canary Islands according to their metal content. *Foods*, *12*(7), 1438.
43. Makroum, A. H., Zakaria, A. I., Elshebrawy, H. A., Sallam, K. I. (2026). Health hazard assessment and cooking effects on toxic metals in marine fish from the mediterranean sea at the Damietta Coast, Egypt. *Scientific Reports*, *16*(1), 1328.
44. Mehouel, F., Bouayad, L., Berber, A., Van Hauteghem, I., Van De Wiele, M. (2019). Analysis and risk assessment of arsenic, cadmium and lead in two fish species (*Sardina pilchardus* and *Xiphias gladius*) from Algerian coastal water. *Food Additives & Contaminants: Part A*, *36*(10), 1515–1521. https://doi.org/10.1080/19440049.2019.1634840
45. Mehouel, F., Fowler, S. W. (2022). Review of the toxic trace elements arsenic, cadmium, lead and mercury in seafood species from Algeria and contiguous waters in the Southwestern Mediterranean Sea. *Environmental Science and Pollution Research International*, *29*(3), 3288–3301. https://doi.org/10.1007/s11356-021-17130-0
46. Mol, S., Karakulak, F., Ulusoy, şafak. (2017). Potential health risks due to heavy metal uptake via consumption of Thunnus thynnus from the northern Levantine Sea. *Toxin Reviews*, *37*, 1–6. https://doi.org/10.1080/15569543.2017.1320804
47. Monier, M. N., Soliman, A. M., Al-Halani, A. A. (2023). The seasonal assessment of heavy metals pollution in water, sediments, and fish of grey mullet, red seabream, and sardine from the Mediterranean coast, Damietta, North Egypt. *Regional Studies in Marine Science*, *57*, 102744. https://doi.org/10.1016/j.rsma.2022.102744
48. Nakib, L., Sellaoui, S., Boumahres, A., Ghanem, Z., Boudaoud, A., Arab, H., Mehennaoui, S. (2026). Bioaccumulation of trace elements (Cd, Hg, Pb, Fe and Zn) in seven fish species, crustaceans and mussels from the Gulf of Skikda, Southern Mediterranean Sea. *Veterinaria Italiana*, *62*(1). https://veterinariaitaliana.izs.it/index.php/VetIt/article/view/3849
49. Nauen, C. E. (1983). *Compilation of legal limits for hazardous substances in fish and fishery products.* https://www.cabidigitallibrary.org/doi/full/10.5555/19841463453
50. Noman, M. A., Feng, W., Zhu, G., Hossain, M. B., Chen, Y., Zhang, H., Sun, J. (2022). Bioaccumulation and potential human health risks of metals in commercially important fishes and shellfishes from Hangzhou Bay, China. *Scientific Reports*, *12*(1), 4634.
51. Official Newspaper of People's Democratic Republic of Algeria (n°: 25,2011)
52. Osman, K. A., Mohamed, H. H. E., Salama, M. S. (2025). Marketing of freshwater and marine fish species in Alexandria City, Egypt: Human health risk of specific metals. *Biological Trace Element Research*, *203*(11), 5693-5709. https://doi.org/10.1007/s12011-025-04596-z
53. Ouali, N., Belabed, B.-E., Chenchouni, H. (2018). Modelling environment contamination with heavy metals in flathead grey mullet *Mugil cephalus* and upper sediments from north African coasts of the Mediterranean Sea. *Science of The Total Environment*, *639*, 156–174. https://doi.org/10.1016/j.scitotenv.2018.04.377
54. Peycheva, K., Panayotova, V., Stancheva, R., Merdzhanova, A., Dobreva, D., Parrino, V., Cicero, N., Fazio, F., Licata, P. (2023). Seasonal variations in the trace elements and mineral profiles of the bivalve species, *Mytilus galloprovincialis*, *Chamelea gallina* and *Donax trunculus*, and human health risk assessment. *Toxics*, *11*(4). https://doi.org/10.3390/toxics11040319
55. Salhi, S., Mellal, M., Chelli, A., Khelifa, R. (2025). Heavy metal contamination and bioaccumulation patterns from a Ramsar Wetland Tributary, Northern Algeria: A Baseline Assessment. *Water*, *17*, 2975. https://doi.org/10.3390/w17202975
56. Secco, S., Cesarini, G., Gallitelli, L., Suaria, G., Paluselli, A., Di Gioacchino, M., Sodo, A., Scalici, M. (2025). Multi-matrix approach to microplastic pollution in the bivalve *Donax trunculus*, sediment and water along the Mediterranean coasts. *Environmental Pollution*, *375*, 126318.
57. Storelli, M. M., Giacominelli-Stuffler, R., Storelli, A., Marcotrigiano, G. O. (2005). Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin

tuna from the Mediterranean Sea: A comparative study. *Marine Pollution Bulletin*, *50*(9), 1004–1007. https://doi.org/10.1016/j.marpolbul.2005.06.041

58. Tanhan, P., Lansubsakul, N., Phaochoosak, N., Sirinupong, P., Yeesin, P., Imsilp, K. (2022). Human health risk assessment of heavy metal concentration in seafood collected from Pattani Bay, Thailand. *Toxics*, *11*(1), 18.
59. Türk Çulha, S., Karaduman, F. R., Çulha, M. (2022). Heavy metal accumulation in molluscs associated with Cystoseira barbata in the Black Sea (Türkiye). *Sustain. Aquat. Res*, *1*, 183–200.
60. USEPA (U.S. Environmental Protection Agency) (1989). *Risk assessment guidance for Superfund. Volume I: Human health evaluation manual (Part A)*. Interim Final. Ofce of Emergency and Remedial Response. EPA/540/1 – 89/002.
61. US EPA (2000). *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 2 Risk Assessment and Fish Consumption Limits Third Edition*. United States Environmental Protection Agency.
62. USFDA (1993). *Food and Drug Administration; Guidance Document for Chromium in Shellfish; U.S.* Food and Drug Administration: Washington, DC, USA.
63. Vásquez-Domínguez, E., Lozano-Bilbao, E., Pascual Alayón, P. J., Hardisson, A., Casañas Machin, I., Paz, S., Gonález-Weller, D., Rubio, C., Gutiérrez, Á. J. (2025). Temporal variations of metals and trace elements in tuna spines from the canary islands from 1990s to 2000s. *Scientific Reports*, *15*(1), 3961.
64. Zaghloul, G. Y., Eissa, H. A., Zaghloul, A. Y., Kelany, M. S., Hamed, M. A., Moselhy, K. M. E. (2024). Impact of some heavy metal accumulation in different organs on fish quality from Bardawil Lake and human health risks assessment. *Geochemical Transactions*, *25*(1), 1. https://doi.org/10.1186/s12932-023-00084-2
65. Zeghdoudi Et Al., F. (2024). Trace metal elements contents of the waters and fish on El-Kala Coastline (El-Tarf- Eastern Algeria). *Egyptian Journal of Aquatic Biology and Fisheries*, *28*(4), 453–468. https://doi.org/10.21608/ejabf.2024.368403