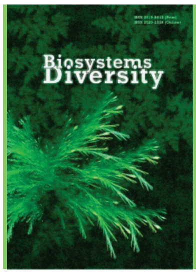

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Assessment of metal trace elements in the echinoderm *Paracentrotus lividus* from the North-Eastern coast of Algeria

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The echinoderm sea urchin *Paracentrotus lividus* Lamarck, 1816 (Echinodermata, Echinoidea) is a good species to be used in environmental and toxicology research, in particular as a heavy metal bio-indicator. Our study's objective is to evaluate the amounts of Zn, Pb, Fe, and Cu in sea urchin specimens collected from the coast of Skikda (Northeast Algeria) in order to validate the fact that sea urchins are good indicators of metal pollution and can be used effectively for environmental biomonitoring. To realize our objectives, three sampling sites were chosen based on suspected forms and sources of contamination. The main physicochemical parameters of the seawater were measured to determine their quality. 15 specimens of urchins in each station were obtained from exposed rocky surfaces and transported to the laboratory. Before dissection, the biometric parameters and the total wet weight were determined. The soft organs (gut and gonads) of individuals were separated and utilized to evaluate the levels of heavy metals. The condition index and metal indices were also determined. Our study confirmed that *P. lividus* may be considered a valuable bioindicator of heavy metal contamination in marine ecosystems. The results show that the amounts of heavy metals differed significantly between stations. Samples taken from the Larbi Ben M'hidi station showed greater amounts of Pb, Zn, and Cu. These amounts are above the recommended limits for fish and aquatic animals. Also, the heavy metals found in sea urchins vary depending on the physicochemical parameters, trace metals in the seawater, and the individual biometric parameters. These higher concentrations of metals in seawater and in *P. lividus* individuals at the Larbi Ben M'hidi station are largely caused by the construction of a massive oil industry complex and terminal with several refineries and petrochemical units near this station, as well as by a considerable amount of domestic wastewater. Finally, to avoid this metallic pollution risk, it is necessary that permanent controls be imposed as soon as possible. Urban and industrial wastes must be treated before being released, in the hope of reducing future metal concentrations.

Keywords: sea urchin; bioindicator; heavy metals; marine pollution; Skikda; Mediterranean Sea.

Introduction

Heavy metal pollution is a pressing issue that requires all communities concerned to maintain a certain level of quality in their water resources. Since metallic pollutants are poorly metabolised (unlike organic pollutants), they can enter the food chain and build up in living matter. Above a certain level, all heavy metals are toxic (Kucuksezgin et al., 2006). When the concentration of essential metallic trace elements (e.g., zinc) exceeds a specific acceptable level, they might have toxic effects similar to non-essential ones (e.g., lead) (Chiffoleau et al., 2001; Lafabrie et al., 2007).

Recent research indicates that the quality of our aquatic ecosystems is declining, which seems to be caused by massive and anarchic pollution from both natural organic matter and synthetic industrial products (Yilmaz & Yilmaz, 2007). This pollution causes an increase in heavy metals such as zinc, lead, cadmium, and copper in coastal waters (Mok et al., 2023). The toxicity of metals also depends on the state of other physicochemical water parameters, such as temperature, pH, salinity, organic matter, nitrate and nitrite, etc. The pollution appears to affect all compartments of the ecosystem and is one of the causes of marine pollution (Berg et al., 2009).

The coastal areas of the Mediterranean Sea are exposed to serious pollution problems due to demographic pressure, the growth of urban areas associated with a rapid expansion of industry, tourism, and the intensive exploitation of marine resources (Kostianoy & Carpenter, 2018). Indeed, multiple studies have documented a rise in pollution all along Algeria's coastline (southwest of the Mediterranean Sea).This pollution is a combination of several factors, of which industrial discharges and untreated urban wastewater represent the most important factors (Bencheikh et al., 2022).

Bioindicators are organisms that can be used to evaluate an ecosystem's health and detect any potential natural or induced imbalances (Chiarelli et al., 2019). Bioindicator species must meet a number of criteria: be sedentary, abundant, have a compatible life duration, wide geographical distribution, high accumulation of substances, and ease of collection (Goldberg & Bertine, 2000). The sea urchin *Paracentrotus lividus* is an excellent bioindicator due to its easy collection, widespread distribution, and high resistance to pollutants. The animal is one of those most commonly used to examine the health of an aquatic environment (Gharred et al., 2015; Savriama et al., 2015; Ternengo et al., 2018). The species has been the subject of several works in Algeria, the most significant of which deal with its biology, ethology, and growth (Dermeche et al., 2012; Belkhedim et al., 2014). Concerning the bioaccumulation of metals, some research was carried out in the central and western coastal zones of Algeria (South-Western Mediterranean) (Guendouzi et al., 2017; Rouane-Hacene et al., 2018). In the eastern region of the country, there have been no studies on metal bioaccumulation in sea urchins. The main aim of the present work was to evaluate the quality of the aquatic ecosystem in the Gulf of Skikda, northeastern Algeria, by determining for the first time the bioaccumulation of four heavy metals (zinc, lead, iron, and copper) in the soft parts of the echinoderm *P. lividus* at three different stations. This work aims to validate the fact that sea urchins are good indicators of metal pollution and can be used effectively for environmental biomonitoring. We also contributed to the evaluation of physico-chemical parameters in the surface waters of three study sites in an attempt to determine a correlation between those factors and the level of heavy metals detected in sea urchins. Finally, we compared our local results with earlier research published from other Mediterranean regions.

Materials and methods

The study was conducted on the Mediterranean coast of Skikda in northeastern Algeria. Along the Skikda Gulf, three sampling sites were chosen based on suspected sources of contamination (Fig. 1). The main factors utilised for selecting the study sites were differences in the forms and amounts of pollution. These stations are: Collo (S1), 36°58' N 6°35' E, the most westerly site, which is located far from any industrialised area but is mostly impacted by pollution from urban wastewater and agricultural activities; Larbi Ben M'hidi (S2), 36°53' N 6°58' E, in the Bay of Skikda City, was chosen because it is exposed to significant household and industrial wastes (from Skikda City, an oil terminal, and a large oil industrial complex); and El Marsa (S3), 37°01' N 7°15' E, a rural area with a small fishing port, seems to be less impacted by pollution than other sites. At the three sampling sites, the main physicochemical parameters of the seawater were measured at the same time to find out about the quality of the water. Throughout the study, samples were taken in labelled plastic bottles, kept in coolers at 4 °C, and transported to the laboratory. pH, temperature, organic matter, salinity, dissolved oxygen, phosphate, nitrate, nitrite, zinc, lead, copper, iron, and cadmium levels were all measured according to standard methods recommended by Rodier (1996).

In each locality, 15 adult sea urchins were collected by scuba diving between March and May 2018. Specimens of different diameters were obtained from exposed rocky surfaces with a steel instrument. On the same day, they were transported to the laboratory in plastic boxes filled with water taken from the sampling site and then frozen at –10 °C until dissection. A total of 45 urchins were utilized to determine biometric parameters and metal assessments.

In the laboratory, the height (H) and diameter (D) of every individual's test were determined with a caliper (0.01 mm accuracy). Before dissection, the total wet weight (TWW) of every urchin was determined.

Later, the soft parts of urchins were separated from the rest of the body with stainless steel equipment. A 0.01 g precision balance was used to measure the soft flesh wet weight (SFWT) and the test dry weight (TDW). Then, separated soft parts (gonads and gut) from the urchins' bodies were placed in Petri dishes and dried for 3 hours at 110 °C to a constant weight. Once the drying was complete, we measured the soft flesh dry weight (SFWD) for a calculation of the metal indices.

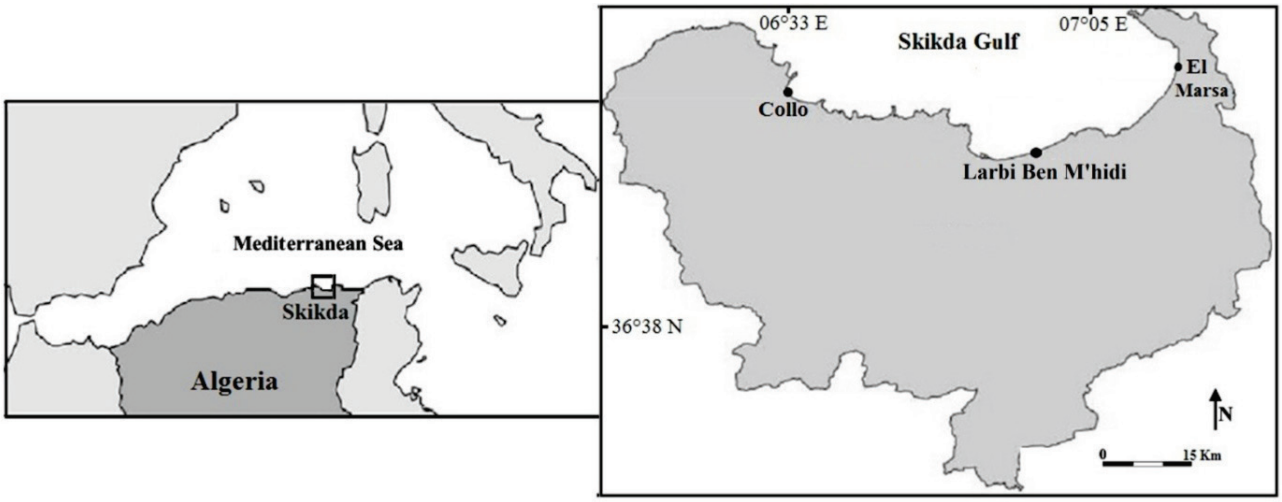

Fig. 1. Sampling sites in the Gulf of Skikda, Northeastern Algeria

After that, we placed the soft parts of the urchins in a muffle oven first for 15 minutes at 450 °C, and then they were moistened with nitric acid (HNO_3) and returned to the oven at 350 °C for 1.5 hours. The samples were then finely ground using an agate mortar. The quantity of the biological material used varied between 0.5 g and 1 g of dry weight. The samples were diluted with 1% nitric acid to a volume of 25 mL, cooled to room temperature, and stored fresh in labelled tubes until analysis. Four heavy metal levels (Zn, Pb, Fe, and Cu) were measured using an AURORA TRACE Al 1200 atomic absorption spectrometer. It is a method for analysing sediments and biological material that is used to examine trace amounts of heavy metals. Except as otherwise noted, all heavy metal levels were given in milligrams per kilogram of dry weight. The concentrations of heavy metals (Table 1) at all stations are compared with the International Atomic Energy Agency standards for metal contamination of fish tissue IAEA-407 (Wyse et al., 2003).

The Condition Index (CI) was used to calculate the urchins' physiological status. The CI is determined using the following formula: CI = (Soft Flesh Wet Weight / Total Wet Weight) × l00.

According to Richir and Gobert (2014), the MTW Index, which is the ratio of metal content to test weight, was calculated to assess the availability of metals using the following formula: MTWI = MCST × (SFWD / TDW), where MCST indicates the concentration of metal in soft tissues, in mg/kg dw and TDW is the test dry weight (g).

Table 1
Recommended levels of the trace elements studied, according to the International Atomic Energy Agency IAEA-407 for contamination in fish tissue (Wyse et al., 2003)

Element	Concentration[1], mg/kg	Std Deviation, mg/kg	95% Confidence interval, mg/kg	N[2]
Copper	3.28	0.40	3.20–3.36	90
Iron	146	14	143–149	71
Lead	0.12	0.06	0.10–0.14	61
Zinc	67.1	3.8	66.3–67.9	93

Note: [1] mean values are expressed on a dry-weight basis; [2] number of accepted laboratory means.

We calculated means and standard deviations for the various parameters studied. The normality of the data was checked using the Shapiro-Wilk test. To evaluate whether there were any significant variations in the levels of heavy metal across the stations, a one-way analysis of variance (ANOVA) with a Tukey post-test was utilised with $P<0.05$. In our situation, we used principal component analysis (PCA) to evaluate the possible correlations between biometric data, metal concentrations, and indices. All of these analyses were run on Windows using the Statistica 10 software (Stat Soft, Inc., USA).

Results

The average, minimum, and maximum values of the physicochemical parameters and heavy metals of the coastal waters obtained at the three study sites (Collo, Larbi Ben M'hidi, and El Marsa) in the Gulf of Skikda are presented in Table 2. A one-way analysis of variance (ANOVA) was employed to compare means, followed by a post-hoc Tukey test. A significant difference is marked by the superscript letters a, b, and c at the 0.05 significance level.

Results indicate that there was no significant difference ($P > 0.05$) in temperature, pH, salinity, nitrite, zinc, and iron levels between the three studied stations. However, the ANOVA results showed a significant difference in dissolved oxygen levels between stations (S1 and S2) and (S2 and S3), with no significant difference between stations S1 and S3. These results suggest that station 2 had a higher dissolved oxygen level compared to stations 1 and 3.

Regarding organic matter level, there was no significant difference between stations (S1 and S2) and (S1 and S3), but there was a significant difference between stations S2 and S3. Similarly, there was no significant difference between the nitrate levels of stations (S1 and S2) and (S2 and S3), but stations S1 and S3 exhibited a significant difference.

In terms of phosphate, lead, copper, and cadmium levels, no significant difference was found between stations (S1 and S3). Nonetheless, a disparity in levels was detected between stations (S1 and S2) and (S2 and S3). According to the results, station 2 had the highest concentrations of these elements.

Table 2
Spatial variation of physicochemical parameters and heavy metal concentrations of water collected from three sites in Skikda Gulf

Parameter	S1	S2	S3	ANOVA	
				F-value	P-value
Temperature, °C	19.27 ± 2.23^{a} [16.1–21.0]	19.38 ± 2.84^{a} [17.7–22.6]	18.93 ± 2.37^{a} [15.6–21.1]	0.04	0.964
pH	7.44 ± 0.10^{a} [7.31–7.55]	7.65 ± 0.16^{a} [7.47–7.85]	7.39 ± 0.06^{a} [7.29–7.44]	4.22	0.051
Salinity, g/L	35.22 ± 0.35^{a} [34.8–35.65]	35.69 ± 0.39^{a} [35.33–36.14]	34.88 ± 0.49^{a} [34.22–35.4]	3.85	0.062
Dissolved oxygen, mg/L	5.45 ± 0.30^{a} [5.13–5.87]	4.85 ± 0.23^{b} [4.59–5.12]	5.66 ± 0.19^{a} [5.43–5.88]	11.71	0.003
Organic matter, mg/L	74.80 ± 4.25^{ab} [69.9–80.01]	85.0 ± 8.11^{a} [75.05–93.51]	69.63 ± 5.29^{b} [62.06–73.4]	6.56	0.017
Nitrate, mg/L	2.60 ± 0.29^{a} [2.31–2.91]	2.20 ± 0.21^{ab} [1.94–2.40]	2.09 ± 0.14^{b} [1.98–2.30]	5.63	0.026
Nitrite, mg/L	0.015 ± 0.005^{a} [0.01–0.02]	0.03 ± 0.01^{a} [0.01–0.05]	0.02 ± 0.008^{a} [0.01–0.03]	1.91	0.204
Phosphate, mg/L	0.098 ± 0.04^{b} [0.068–0.15]	0.23 ± 0.06^{a} [0.169–0.315]	0.12 ± 0.04^{b} [0.064–0.152]	9.09	0.007
Zinc, µg/L	3.55 ± 0.23^{a} [3.22–3.74]	3.63 ± 0.28^{a} [3.25–3.90]	3.18 ± 0.20^{a} [3.01–3.47]	4.02	0.057
Lead, µg/L	0.84 ± 0.26^{b} [0.55–1.14]	1.79 ± 0.28^{a} [1.47–2.14]	0.53 ± 0.13^{b} [0.37–0.67]	30.34	0.001
Copper, µg/L	0.85 ± 0.13^{b} [0.70–1.02]	1.38 ± 0.33^{a} [1.19–1.89]	0.66 ± 0.14^{b} [0.47–0.82]	10.84	0.004
Iron, µg/L	19.79 ± 0.36^{a} [19.47–20.17]	20.13 ± 0.24^{a} [19.89–20.47]	20.06 ± 0.15^{a} [19.88–20.23]	1.83	0.215
Cadimium, µg/L	0.01 ± 0.004^{b} [0.01–0.02]	0.02 ± 0.008^{a} [0.019–0.037]	0.01 ± 0.001^{b} [0.009–0.013]	9.10	0.007

Notes: S1 – Collo, S2 – Larbi Ben M'hidi, S3 – El Marsa; n = 15; values are averages ± standard deviations; minimum and maximum values are indicated between brackets; according to the Tukey test, values with the same letter are not significantly different.

The levels of heavy metals analysed (zinc, lead, iron, and copper) using atomic absorption spectrophotometry in the soft parts of *P. lividus* from three sampling stations in the Skikda Gulf (Collo, Larbi Ben M'hidi, and El Marsa) are presented in Table 3. Except for Fe, the Larbi Ben M'hidi station (S2) recorded the highest metal levels from urchin samples (Table 3). In terms of zinc levels, no significant difference was noted between stations S1 and S3, while a significant difference was detected between stations (S1 and S2) and (S2 and S3), with station 2 exhibiting the highest content. For lead and copper, ANOVA analysis followed by Tukey's post hoc test revealed a significant difference among the three stations. Station 2 had the highest content of these elements, followed by Station 1 and Station 3 in last position (Table 3). Regarding iron levels, a significant difference was noted among the three stations. Station 3 displayed the highest iron content, followed by Station 2 and Station 1.

Zinc and lead concentrations in all stations exceeded the International Atomic Energy Agency's maximum permitted level for zinc contamination in fish tissue, IAEA-407 (Table 1). For copper, only levels at the Larbi Ben M'hidi station exceeded the IAEA's maximum allowed limit for copper contamination in fish tissue. On the other hand, no station's iron concentration went above the International Atomic Energy Agency's maximum permitted level (Table 1).

Table 3
Metal concentrations (mg/kg dw) in the soft parts of urchins *Paracentrotus lividus* collected from three Skikda Gulf sites

Metal	S1	S2	S3	ANOVA		Metals in decreasing order
				F-value	P-value	
Zinc	119.86 ± 12.64^{b} [95.0–135.0]	175.73 ± 18.05^{a} [144.0–210.0]	109.21 ± 14.99^{b} [71.0–130.0]	83.67	< 0.001	S2 > S1 > S3
Lead	1.88 ± 0.35^{b} [0.93–2.32]	5.13 ± 1.11^{a} [3.17–7.10]	1.16 ± 0.21^{c} [0.77–1.49]	142.93	< 0.001	S2 > S1 > S3
Copper	2.29 ± 0.32^{b} [1.34–2.71]	3.62 ± 0.30^{a} [2.99–4.12]	1.87 ± 0.23^{c} [1.47–2.17]	146.81	< 0.001	S2 > S1 > S3
Iron	48.79 ± 7.09^{c} [37.0–60.1]	60.77 ± 7.93^{b} [47.9–74.0]	69.58 ± 8.36^{a} [57.1–81.0]	26.72	< 0.001	S3 > S2 > S1

Notes: values are averages ± standard deviations; n = 15 for each station; minimum and maximum values are indicated between brackets.

Based on the biometric data collected during the study period, we found that the individuals with the largest test diameters (D) were collected at the Collo station with a mean of 4.18 ± 0.62 cm (values ranging from 3.17 to 5.45 cm), while the smallest diameters were recorded on the Larbi Ben M'hidi coast (3.65 ± 0.37, 3.09–4.14 cm). The population of El Marsa measured an average size (3.79 ± 0.44, 3.10–4.87 cm, Fig. 2a). A slight difference was recorded for test diameters between the study stations ($F_{2,42} = 4.61$, $P = 0.016$), with significant differences between the stations (S1 and S2) and (S1 and S3).

The same results were observed for test heights (H), with the largest being observed in the Collo population (1.98 ± 0.21 cm), while the smallest were in the Larbi Ben M'hidi population (1.63 ± 0.19 cm, Fig. 2b). Test heights varied significantly between the three study stations ($F_{2,42} = 10.53$, $P = 0.0002$). According to the Tukey test, a significant difference was detected between the stations (S1 and S2). The biometric parameters (D and H) of our urchins are listed in descending order as follows: S1 > S3 > S2.

Individuals at Collo station had the largest mean condition index (CI) with 21.46 ± 3.54 (with a minimum of 12.95 and a maximum of 24.10). The lowest CI is observed at Larbi Ben M'hidi station, with an average of 18.20 ± 3.72 (ranging from 10.05 to 23.1, Fig. 2c). During the whole study period, the condition index of sea urchins showed slight variation according to the study stations ($F_{2,42} = 3.88$, $P = 0.028$), with a significant difference detected between the stations (S1 and S2).

The different values of the metal content/test weight index (MTWI) of the urchin populations in the three stations are presented in Figure 3. The highest mean value of Zn/TWI was found in individuals from Larbi Ben M'hidi station with 2.46 ± 0.86 mg/kg dw (ranging from 1.58 to

4.85 mg/kg dw). The lowest mean values were recorded at El Marsa station, with 1.51 ± 0.38 mg/kg dw (ranging from 0.95 to 2.35 mg/kg dw). The Zn/TW Index varied significantly between the study stations (F = 10.09, P = $2.6*10^{-4}$). The decreasing order of metal indexes was as follows: S2 > S1 > S3, with a significant difference between the stations (S2 and S1) and (S2 and S3) (Fig. 3a).

The Pb/TW Index decreased significantly between stations as follows: S2 > S1 > S3 (F = 51.89, P = <0.001), with a high significant difference between the stations (S2 and S1) and (S2 and S3) (Fig. 3b). The highest mean value of Pb/TWI in S2 was 0.071 ± 0.02 mg/kg dw (ranging from 0.039 to 0.119 mg/kg dw), and the lowest mean level recorded in El Marsa station was 0.016 ± 0.005 mg/kg dw (ranging from 0.0084 to 0.027 mg/kg dw) (Fig. 3b). As with the previous values of MTWI, the value of the Cu/TWI decreased significantly with stations as follows: S2 > S1 > S3 (F = 17.46, P = <0.001), with a significant difference between the stations (S2 and S1) and (S2 and S3) (Fig. 3c). The highest mean value was 0.051 ± 0.010 mg/kg dw in Larbi Ben M'hidi station, and the lowest mean level was 0.026 ± 0.008 mg/kg dw in El Marsa station (Fig. 3c).

Only Fe/TWI shows a high value in El Marsa station, with an average of 0.97 ± 0.24 mg/kg dw (ranging from 0.65 to 1.46 mg/kg dw) (Fig. 3d). Fe/TW Index values of the Fe index decreased slightly with stations, as follows: S3 > S2 > S1 (F = 3.40, P = 0.043), with a significant difference between the stations (S3 and S1).

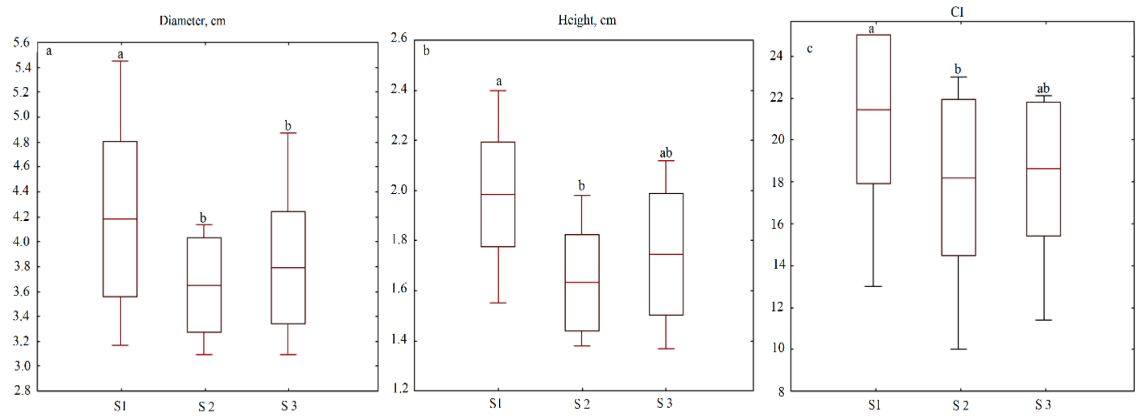

Fig. 2. Spatial variation of biometric parameters of sea urchins from Skikda Gulf: *a* – diameter, *b* – height, *c* – condition index; n = 15 for each station; the mean in the boxes is represented by a horizontal line; the ends of the box indicate the value of mean ± SD; the whiskers extend from the box's ends to indicate the min-max values; letters [a], [b], and [c] show statistically differences in metals between the three stations (Tukey test)

Table 4 analysed with PCA is an 11-variable matrix (biometric data, metal concentrations, and metal indices) measured on three sites of the Gulf of Skikda. With coefficients up to 0.90, analysis performed on these variables revealed a highly significant correlation between the values of metal indexes and the levels of metal concentrations that corresponded. In addition, we found a significant correlation between test height and Zn, Pb, and Cu levels and a slightly significant correlation between test diameter and Fe level.

Discussion

The echinoderm sea urchin is a very abundant species that is the subject of ever-expanding fishing activities in the waters of Algeria (Soualili et al., 2008). Several ecological studies have confirmed that the animal is an excellent indicator of metal pollution and can accumulate metals based on the amount of contamination in the aquatic ecosystem (Warnau et al., 1998; Soualili et al., 2008).

The present study examined the amounts of Zn, Pb, Fe, and Cu in *P. lividus* samples obtained from three distinct stations from the Skikda Gulf in the northeast of Algeria In order to evaluate the quality of the aquatic ecosystem. The results obtained for the physicochemical parameters and heavy metal concentrations reflect the quality of the environment at the study stations. The temperatures recorded at all stations are related to the sampling periods. Overall, the average temperature of the seawater surface layer is affected by the meteorological conditions (Luo et al., 2022). The observed values reveal that the pH of the seawater is slightly alkaline in all the studied stations. These values are close to the pH values of the sea water, which are 8.3. The small variations in pH recorded in these areas are associated with the alkalizing action of the seawater. The salinity of the seawater shows variations depending on the study sites and is comparable to those found in the same region in previous work (Luo et al., 2022). Dissolved oxygen (DO) is one of the common indicators of pollution levels. The drop-in (DO) in S2 can be explained by excessive inputs of biodegradable organic matter discharged from the sewers of Skikda City and discharges from the port and industrial activity. The high amounts of phosphates, nitrates, and nitrites and the five heavy metals measured at station S2 are also explained by the large discharge of urban and industrial wastewater without any treatment.

Table 5 compares our data with other results reported for *P. lividus* in other geographical areas of the Mediterranean. In the same region, no comparison can be made for heavy metal concentrations, as no reliable data are available. At Station 2, our mean concentration of zinc is lower than those found in urchins from Sidi Mejdoub in Mostaganem, NW Algeria (Guendouzi et al., 2017); Sidi-Fredj, Tamentfoust, and Algiers Beach (Soualili et al., 2008); different sites in Corsica, France (Ternengo et al., 2018); and Agios Thomas and Koronisia in Greece (Strogyloudi et al., 2014).

Table 4
Correlation matrix between biometric parameters, metal concentrations and indices

Parameter	D	H	CI	ZN/TWI	PB/TWI	CU/TWI	Fe/TWI	Zn	Pb	Cu
H	0.276	1	–	–	–	–	–	–	–	–
CI	0.175	0.122	1	–	–	–	–	–	–	–
ZN/TWI	0.110	–0.084	–0.064	1	–	–	–	–	–	–
PB/TWI	–0.053	–0.329*	–0.128	0.737***	1	–	–	–	–	–
CU/TWI	0.083	–0.181	–0.156	0.907***	0.822***	1	–	–	–	–
Fe/TWI	0.109	–0.026	–0.120	0.550***	0.203	0.466**	1	–	–	–
Zn	–0.231	–0.308*	–0.137	0.541***	0.688***	0.514***	–0.174	1	–	–
Pb	–0.216	–0.412**	–0.173	0.457**	0.887***	0.580***	–0.121	0.830***	1	–
Cu	–0.192	–0.343*	–0.220	0.473**	0.765***	0.668***	–0.170	0.835***	0.888***	1
Fe	–0.336*	–0.251	–0.214	–0.112	–0.106	–0.175	0.451**	–0.004	–0.037	–0.147

Note: significant correlation: * P < 0.05, ** P < 0.01, *** P <0.001.

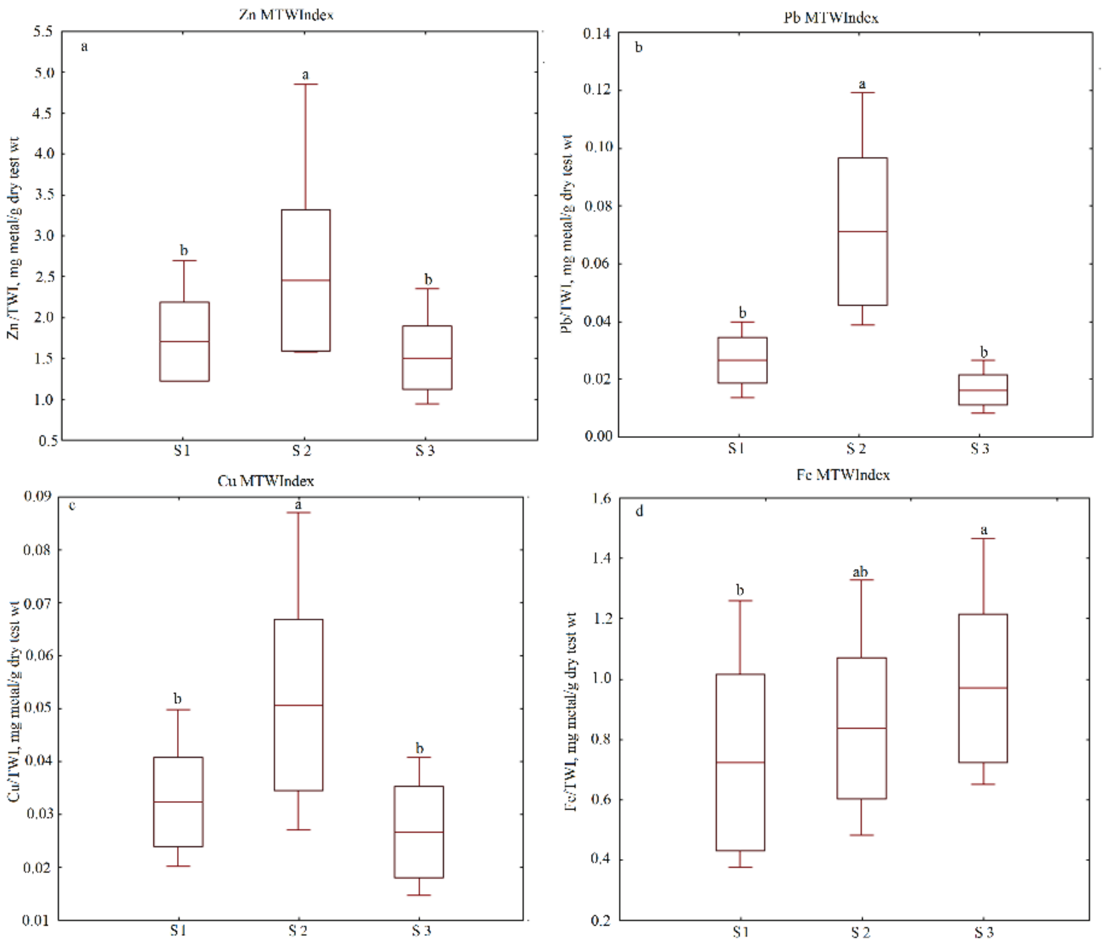

Fig. 3. Spatial variations of the MTW Index in *P. lividus* from Skikda Gulf: *a* – Zn/TWI, *b* – Pb/TWI, *c* – Cu/TWI, *d* – Fe/TWI

Table 5
Metal concentrations in urchin samples from other sampling areas in the Mediterranean

Country	Sampling area	Heavy metal concentrations, mg/kg dry weight				Source
		Zn	Pb	Fe	Cu	
Algeria	Mostaganem Sidi Mejdoub	232.63 ± 20.17	2.85 ± 0.82	–	3.56 ± 2.04	Guendouzi et al. (2017)
	Mostaganem Willis	120.33 ± 18.51	4.51 ± 1.91	–	3.43 ± 1.67	
	Algiers Bateau Cassé	155.72 ± 19.89	5.13 ± 1.32	–	3.45 ± 1.19	
	Oran Harbour	114.93 ± 3.59 (93.9–173.1)	6.08 ± 0.30 (3.3 4–6.10)	–	8.82 ± 0.58 (3.6–13.2)	Rouane-Hacene et al. (2018)
	Ain Defla	66.23 ± 2.11 (44.2–92.1)	4.85 ± 0.30 (2.5–8.45)	–	3.18 ± 0.18 (1.8–5.5)	
	Hadjaj	56.22 ± 1.33 (44.0–68.7)	3.59 ± 0.20 (1.68–6.0)	–	2.45 ± 0.10 (1.1–3.9)	
	Algiers Beach	385.5 ± 344.1	6.14 ± 3.46	73.8 ± 35.5	2.84 ± 0.97	Soualili et al. (2008)
	Tamentfoust	538.2 ± 324.3	1.5 ± 1.72	113 ± 37.6	2.49 ± 0.47	
	Sidi-Fredj	366.9 ± 178.3	0.68 ± 0.12	71.1 ± 54.8	3.42 ± 0.85	
France	Ajaccio1	201.82 ± 54.30	0.17 ± 0.02	115.08 ± 15.62	4.56 ± 0.17	Ternengo et al. (2018)
	Ajaccio2	304.12 ± 76.44	0.50 ± 0.26	95.21 ± 11.84	4.09 ± 0.12	
	Saint Florent2	192.23 ± 78.61	0.09 ± 0.01	237.88 ± 45.96	3.46 ± 0.17	
	Bonifacio1	195.16 ± 42.68	0.16 ± 0.02	59.49 ± 11.89	3.65 ± 0.13	
Italy	SicilyDéfirent sites	–	4.61 (1.28–20.74)	–	3.76 (0.02-24.17)	Salvo et al. (2014)
	Caprara	117 ± 33	–	23 ± 9	2.5 ± 0.05	Pinsino et al. (2008)
	Pianosa	68 ± 45	–	36 ± 27	3.3 ± 1	
	Apulia	157.13 ± 47.91 (103.8–249.9)	0.86 ± 0.67 (0.10–2.65)	183.6 ± 165.4 (48.6-622.7)	5.19 ± 2.68 (1.9–14.6)	Storelli et al. (2001)
Spain	BalearicIslands Mallorca	40.3 (5.7–74.5)	3.0 (0.8–6.7)	–	4.9 (1.6–7.5)	Deudero et al. (2007)
Greece	Agios Thomas	851 ± 485 (193–1874)	–	236 ± 206 (46–815)	7.5 ± 12.2 (2.7–58.8)	Strogyloudi et al. (2014)
	Koronisia	215 ± 467 (5–1774)	–	249 ± 201 (68–880)	5.3 ± 1.7 (2.6–9.6)	
	Mytikas	152 ± 260 (19–1024)	–	146 ± 102 (44–355)	3.8 ± 2.5 (2.1–11.8)	

Notes: mean ± SD; minimum and maximum values are indicated between parentheses if available.

Most of these sampling areas have a medium-to-high contamination level. Zinc concentrations in S2, on the other hand, are higher than those reported by Rouane-Hacene et al. (2018) in Hadjaj and Oran Harbour in NW Algeria, as well as Deudero et al. (2007) in Mallorca, Spain, and Pinsino et al. (2008) in Caprara and Pianosa, Italy. Our lead levels in Station 2 are comparable to those found by Guendouzi et al. (2017) in Bateau Cassé near Algiers; they are higher than those found in Sidi Mejdoub and Willis in Mostaganem (Guendouzi et al., 2017). However, our Pb values are lower than concentrations in Oran Harbour (Rouane-Hacene et al., 2018) and Algiers Beach (Soualili et al., 2008). Cooper concentrations in S2 are lower than those of Rouane-Hacene et al. (2018) in Oran Harbour or those of Strogyloudi et al. (2014) in Agios Thomas, Greece, similar to the results given by Guendouzi et al. (2017) but higher than those of Soualili et al. (2008).

In seeking to explain the strong presence of these elements in Larbi Ben M'hidi station, we might consider the domestic waste of Skikda city and the contributions of industrial and domestic discharges in several wadis, especially the Saf-Saf wadi. In addition, the construction of a massive oil industry complex, an oil terminal with several refineries and petrochemical units one km from Station 2, is responsible for several metal discharges.

Station 1 (Collo) is the medium-contaminated site, even though it contains significant concentrations of heavy metals. Our results for zinc are higher compared to those of Pinsino et al. (2008) and Rouane-Hacene et al. (2018) from Italy and Algeria, respectively. Our lead levels are higher than those from the Apulian coast in Italy (Storelli et al., 2001), and all stations in Corsica (Ternengo et al., 2018). This situation is directly related to the use of chemicals in intensive agricultural activities (fertiliser, organometallic pesticides), and domestic discharges in Wadi Guebli in particular. Iron and copper concentrations are lower compared to most other Mediterranean stations shown in Table 5.

The present study showed that Station 3 (El Marsa) was the least polluted area. Zinc, lead, and copper concentrations are lower compared to all other Mediterranean stations presented in Table 5 with some exceptions (the results of Deudero et al. (2007), Pinsino et al. (2008), and Rouane-Hacene et al. (2018) for zinc, and the results of Storelli et al. (2001); Soualili et al. (2008), and Ternengo et al. (2018) for lead). The fact that Station 3 is located in a very rural region and is far from both significant industrial and domestic sources of pollution may help to explain this situation. The notable exception at this station is the elevated iron values compared to the other two stations studied. However, the large iron values obtained do not exceed those of most other Mediterranean stations or even the recommended values of trace elements indicated by the IAEA for iron contamination in fish tissue IAEA-407 (Wyse et al., 2003).

In our study, we observed a significant decrease in biometric parameters at S2. The explanation is that the sea urchins are exposed to high metal pollution in the seawater at this station, which may affect their growth. This hypothesis, which confirms the link between the high metal load and the physiological disturbance of populations, has been confirmed by previous studies in several Mediterranean areas (Soualili et al., 2008; Dermeche et al., 2012; Rouane-Hacene et al., 2018). Usually, in unpolluted environments characterised by good conditions, the growth of sea urchins is relatively high (Savriama et al., 2015; Rouane-Hacene et al., 2018). Our results, in accordance with several authors, have also shown that the biometric parameters of marine organisms are excellent biomarkers that give information on environmental quality and the state of the animals. These parameters are still useful for biomonitoring and marine surveillance.

In our study, we used the metal content/test weight index (MTWI) suggested by Richir & Gobert (2014). This index was used later by Richir & Gobert (2016) on *Mytilus galloprovincialis* populations on the French south coast to test a possible effect of dry weight of flesh and shell length on the accumulation of heavy metals. The study showed a significant impact of mussel shell biometry on the accumulation of trace metals in their soft body parts. The same results were found by Rouane-Hacene et al. (2015), with a significant influence of trace metal content and metal indexes in mussels from the Algerian coast.

McClintock et al. (2022) examined the relationship between body size of coastal sea urchins *Lytechinus variegatus* from the Gulf of Mexico in the United States and concentrations of trace elements. They found that the concentrations of three elements decreased significantly with increasing test diameter. In the echinoderm *Paracentrotus lividus* from the Algerian coast, only the study by Rouane-Hacene et al. (2018) on the west coast showed that this method is effective in examining the availability of trace metals in the marine environment. Our study on the Algerian east coast confirmed the results obtained by Rouane-Hacene et al. (2018) with a correlation between the contents of metallic trace elements searched in the study stations and the associated metallic indices' values, indicating the bioavailability of environmental metals.

Conclusion

Our study confirmed that *P. lividus* can be considered a valuable bioindicator of heavy metal contamination in marine ecosystems. These heavy metal contaminations vary according to the physicochemical parameters and metallic trace elements of the seawater. A correlation between the biometric parameters of the sea urchin and the concentrations of metals in the soft parts of the body was obtained by calculating the trace element pollution index.

Furthermore, industrial and anthropogenic activity in the Larbi Ben M'hidi station, as compared to Collo and El Marsa stations, was reflected in higher concentrations of metals in seawater and accumulated in the *P. lividus* individuals. Finally, to avoid the risk of this metallic pollution at Larbi Ben M'hidi station, it is necessary that permanent controls should be imposed as soon as possible. Urban and industrial wastes must be treated before being released, in order to reduce future metal concentrations. Moreover, future studies should examine the correlation between the origin of sea urchin decline and high concentrations of toxic metals, as proven by several previous studies, for better preservation of biodiversity and the marine ecosystem.

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References

Belkhedim, L., Dermeche, S., Chahrour, F., & Boutiba, Z. (2014). Physiological indices and reproduction in the sea urchin *Paracentrotus lividus* (Lamarck, 1816) Echinodermata Echinoidae in the west coast of Algeria. International Journal of Recent Research and Applied Studies, 18(2), 173–181.

Bencheikh, Z., Refes, W., Brito, P. M., Prodocimo, M. M., Gusso Choueri, P. K., Choueri, R. B., & Oliveira Ribeiro, C. A. (2022). Chemical pollution impairs the health of fish species and fishery activities along the Algeria coastline. Mediterranean Sea. Environmental Monitoring and Assessment, 194, 497.

Berg, L. R., Hassenzahl, D. M., & Raven, P. H. (2009). Environnement. Editeur De Boek Superieur, Brussels.

Chiarelli, R., Martino, C., & Roccheri, M. C. (2019). Cadmium stress effects indicating marine pollution in different species of sea urchin employed as environmental bioindicators. Cell Stress and Chaperones, 24, 675–687.

Chiffoleau, J., Auegr, D., Chartier, E., Michel, P., Truquet, I., Ficht, A., Gonzalez, J. L., & Romana, L. D. (2001). Spatiotomporal changes in cadmium contamination in the Seine Estuary (France). Estuaries, 24, 1029–1040.

Dermeche, S., Chahrour, F., & Boutiba, Z. (2012). Evaluation of the toxicity of metal pollutants on embryonic development of the sea urchin *Paracentrotus lividus* (Lamarck, 1816) (Echinodermata, Echinoidea). Biodiversity Journal, 3(3), 165–172.

Deudero, S., Box, A., March, D., Valencia, J. M., Grau, A. M., Tintore, J., & Benedicto, J. (2007). Temporal trends of metals in benthic invertebrate species from the Balearic Islands, Western Mediterranean. Marine Pollution Bulletin, 54, 1545–1558.

Geraci, F., Pinsino, A., Turturici, G., Savona, R., Giudice, G., & Sconzo, G. (2004). Nickel, lead, and cadmium induce differential cellular responses in sea urchin embryos by activating the synthesis of different HSP70s. Biochemical and Biophysical Research Communications, 322, 873–877.

Gharred, T., Ezzine, I. K., Naija, A., Rayena Bouali, R., & Jebali, J. (2015). Assessment of toxic interactions between deltamethrin and copper on the fertility and developmental events in the Mediterranean sea urchin, *Paracentrotus lividus*. Environmental Monitoring and Assessment, 187, 193–200.

Goldberg, E. D., & Bertine, K. K. (2000). Beyond the mussel watch-new directions for monitoring marine pollution. Science of the Total Environment, 247(2–3), 165–174.
Guendouzi, Y., Soualili, D. L., Boulahdid, M., Boudjenoun, M., & Mezali, K. (2017). Seasonal variation in bioavailability of trace metals in the echinoid *Paracentrotus lividus* (Lamarck, 1816) from Algerian coastal waters: Effect of physiological indices. Regional Studies in Marine Science, 14, 112–117.
Kostianoy, A. G., & Carpenter, A. (2018). History, sources and volumes of oil pollution in the Mediterranean Sea. Handbook of Environmental Chemistry, 83, 9–31.
Kucuksezgin, F., Kontas, A., Altay, O., Uluturhan, E., & Darilmaz, E. (2006). Assessment of marine pollution in Izmir Bay: Nutrient, heavy metal and total hydrocarbon concentrations. Environment International, 32, 41–51.
Lafabrie, C., Pergent, G., Kantin, R., Pergent-Martini, C., & Gonzalez, J. L. (2007). Trace metals assessment in water, sediment, mussel and sea grass species-validation of the use of *Posidonia oceanica* as a metal biomonitor. Chemosphere, 68(11), 2033–2039.
Luo, M., Zhang, Y., Li, H., Hu, W., Xiao, K., Yu, S., Zheng, C., & Wang, X. (2022). Pollution assessment and sources of dissolved heavy metals in coastal water of a highly urbanized coastal area: The role of groundwater discharge. Science of the Total Environment, 807, 151070.
McClintock, J. B., Amsler, M. O., Angus, R. A., & Edwards, R. A. (2022). Variation in trace element concentrations with size in sea urchin skeletal components. Journal of Shellfish Research, 41(2), 277–281.
Mok, W. J., Ghaffar, M. A., Noor, M. I. M., Lananan, F., & Azra, M. N. (2023). Understanding climate change and heavy metals in coastal areas: A macroanalysis assessment. Water, 15, 891.
Pinsino, A., Della Torre, C., Sammarini, V., Bonaventura, R., Amato, E., & Matranga, V. (2008). Sea urchin coelomocytes as a novel cellular biosensor of environmental stress: A field study in the Tremiti Island Marine Protected Area, Southern Adriatic Sea, Italy. Cell Biology and Toxicology, 24, 541–552.
Richir, J., & Gobert, S. (2014). A reassessment of the use of *Posidonia oceanica* and *Mytilus galloprovincialis* to biomonitor the coastal pollution in trace elements: New tools and tips. Marine Pollution Bulletin, 89, 390–406.
Richir, J., & Gobert, S. (2016). An ecophysiological discussion of trace element bioaccumulation in cultured *Mytilus galloprovincialis*. Belgian Journal of Zoology, 146(1), 53–61.
Rodier, J. (1996). The analysis of the water: Natural waters, residual waters, sea water. 8th ed. Dunod, Paris.
Rouane-Hacene, O., Boutiba, Z., Belhaouaria, B., Guibbolini-Sabatier, M., Francour, P., & Risso-de Faverney, C. (2015). Seasonal assessment of biological indices, bioaccumulation and bioavailability of heavy metals in mussels *Mytilus galloprovincialis* from Algerian west coast, applied to environmental monitoring. Oceanologia, 57, 362–374.
Rouane-Hacene, O., Boutiba, Z., Benaissa, M., Belhaouari, B., Francour, P., Guibbolini-Sabatier, M. E., & Risso-De Faverney, C. (2018). Seasonal assessment of biological indices, bioaccumulation, and bioavailability of heavy metals in sea urchins *Paracentrotus lividus* from Algerian west coast, applied to environmental monitoring. Environmental Science and Pollution, 25, 11238–11251.
Salvo, A., Potortì, A. G., Cicero, N., Bruno, M., Turco, V. L., Bella, G. D., & Dugo, G. (2014). Statistical characterisation of heavy metal contents in *Paracentrotus lividus* from Mediterranean Sea. Natural Product Research, 28, 718–726.
Savriama, Y., Stige, L. C., Gerber, S., Pérez, T., Alibert, P., & David, B. (2015). Impact of sewage pollution on two species of sea urchins in the Mediterranean Sea (Cortiou, France): Radial asymmetry as a bioindicator of stress. Ecological Indicators, 54, 39–47.
Soualili, D. L., Dubois, P., Gosselin, P., Pernet, P., & Guillou, M. (2008). Assessment of seawater pollution by heavy metals in the neighbourhood of Algiers: Use of the sea urchin, *Paracentrotus lividus*, as a bioindicator. Journal of Marine Science, 65, 132–139.
Storelli, M. M., Storelli, A., & Marcotrigiano, G. O. (2001). Heavy metals in the aquatic environment of the Southern Adriatic Sea, Italy: Macroalgae, sediments and benthic species. Environment International, 26, 505–509.
Strogyloudi, E., Pancucci–Papadopoulou, M. A., & Papadopoulos, G. L. (2014). Metal and metallothionein concentrations in *Paracentrotus lividus* from Amvrakikos Gulf (Ionian Sea – Greece). Environmental Monitoring and Assessment, 186, 5489–5499.
Ternengo, S., Marengo, M., El Idrissi, O., Yepka, J., Pasqualini, V., & Gobert, S. (2018). Spatial variations in trace element concentrations of the sea urchin, *Paracentrotus lividus*, a first reference study in the Mediterranean Sea. Marine Pollution Bulletin, 129, 293–298.
Warnau, M., Biondo, R., Temara, A., Bouquegneau, J. M., Jangoux, M., & Dubois, P. (1998). Distribution of heavy metals in the echinoid *Paracentrotus lividus* from the Mediterranean *Posidonia oceanica* ecosystem: Seasonal and geographical variations. Journal of Sea Research, 39, 267–280.
Wyse, E. J., Azemard, S., & Mora, S. J. (2003). Report on the world-wide intercomparison exercise for the determination of trace elements and methylmercury in fish homogenate. IAEA-407, IAEA/AL/144 (IAEA/MEL/72), IAEA, Monaco.
Yilmaz, A. B., & Yilmaz, L. (2007). Influences of sex and seasons on levels of heavy metals in tissues of green tiger shrimp (*Penaeus semisulcatus* de Hann, 1844). Food Chemistry, 101, 1696–1701.