Concentrations of Selected Heavy Metals in Fish Organs of Chub Mackerel (*Scomber japonicus*), Zawia, Libya

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Abstract

Heavy metal contamination threatens coastal ecosystems and seafood safety, especially near industrial areas. This study measured lead (Pb), zinc (Zn), and cadmium (Cd) concentrations in the liver, gills, and muscles of chub mackerel (*Scomber japonicus*) from an industrial site near the Zawia oil refinery and a reference site at Dila on the Libyan coast. Three fish per site were collected in each of the four months (June, August, October, and December 2024). Tissues were oven-dried, digested by microwave-assisted acid digestion, and analyzed by inductively coupled plasma mass spectrometry (ICPMS), and concentrations are reported in mg/kg dry weight. Based on mean concentrations across the four months. Zn and Cd followed the order liver > gills > muscle at both sites, while, Pb was highest in the gills and lowest in the muscle. Most metal tissue combinations peaked in August and were lowest in December. Zn levels in all tissues, Pb levels in the gills and muscle, and Cd levels in the liver were higher at the refinery site in every month, whereas Pb levels in the liver and Cd levels in the gills and muscle showed no consistent difference between sites. Mean liver Cd was nearly twice as high at the refinery as at Dila (1.23 vs 0.65 mg/kg). Muscle, the edible tissue, had the lowest concentrations. Muscle Cd (maximum 0.070 mg (which is roughly the daily recommended amount)/kg) was below the EU limit for mackerel (0.10 mg/kg wet weight) in all samples, and muscle Pb exceeded the EU limit (0.30 mg/kg wet weight) only in one refinery sample from October, and only before conversion from dry to wet weight. These results suggest that industrial activity near the refinery contributes to metal accumulation in fish that EU support continued monitoring of industrial discharge.

Key words: Heavy metals; *Scomber Japonicus*; Bioaccumulation; ICP-MS, Zawia; Libya.

1. Introduction

The marine ecosystem supports biodiversity and plays an important role in ensuring food security for people. In recent years, it has been compromised by increasing human activities, such as industrial and agricultural discharges and municipal waste, resulting in the buildup of pollutants, mainly heavy metals (El-Sharkawy *et al*., 2025), even at minimal concentrations. Dense elements classified as heavy metals are some of the most dangerous pollutants in marine environments because of their ability to bioaccumulate and transfer through food chains (Tchounwou *et al.,* 2012). Because they are physiochemically stable, they are difficult to remove of from the marine ecosystem and slowly build up in biological tissue (El-Sharkawy *et al.,* 2025).

Fish are an important protein source for humans, and consuming contaminated fish can expose consumers to neurological, renal, and cardiovascular effects, as well as carcinogenic effects of some metals (Jaishankar *et al.,* 2014; Djedjibegovic *et al.,* 2020). Lead (Pb) and Cadmium (Cd) are on the World Health Organization 's list of chemicals of major public health concern, while, zinc (Zn) is an essential element that may cause adverse effects at excessive exposure levels (World Health Organization, 2011). Fish are also widely used

as bioindicators of the environmental status of water bodies (Younis *et al.,* 2024). Metal concentrations in fish tissues vary with species, geographic location, and the level of surrounding pollution (Dinesh Kumar et al., 2025), as well as with physiological factors such as age, sex, and metabolic capacity (Brázová *et al.,* 2025).

Concern is increasing along the Mediterranean and Libyan coasts regarding the pollution of the marine environment by coastal industrial activities, which threaten fish quality and the health of local consumers (Maeyouf *et al.,* 2025). Basically, the marine ecosystem around the Zawia oil refinery is exposed to petroleum-related and wastewater discharges, which may lead to the accumulation of Pb, Zn, and Cd in fish. Chub mackerel (*Scomber japonicus*) is a vital, (for the most part) nutritious, and commonly consumed species in the Zawia area, where human and industrial activities are expanding. However, data on metal concentrations in its tissues are scarce, especially near industrial zones such as the Zawia refinery.

This study provides updated heavy metal data from two contrasting sites: an industrial site near the Zawia oil refinery and a reference site at Dila. The objectives were to compare Pb, Zn, and Cd concentrations in the liver, gills, and muscle of chub mackerel and compare the Pb and Cd concentrations in the edible muscle with EU maximum limits (set for Pb and Cd but not for Zn) as a screening-level assessment of the implications for seafood safety.

2. Materials & Methods

2.1 Study area and sampling:

The study was conducted along the coastal area of Zawia, Libya, at two environmentally distinct sites: an industrial site near the Zawia oil refinery and a reference site at Dila. At each site, three chub mackerel (*Scomber japonicus*) were collected over four sampling months (June, August, October, and December 2024), giving 24 fish in total. Samples were placed in clean polyethylene bags, kept on ice, and transported immediately to the laboratory, where they were stored at -20 °C until analysis.

2.2 Sample preparation and digestion:

Fish were dissected to obtain liver, gills, and muscle tissues. The tissues were oven-dried at 80 ℃ for 48 h until a constant weight was achieved, then ground into a fine powder using a ceramic mortar and pestle. Approximately 0.5 g of each tissue sample was digested with 5 mL nitric acid (HNO_3) and 2 mL hydrogen peroxide (H_2O_2) using a microwave digestion system (Milestone Start D, Italy) at 150 ℃ for 20 min. Digested samples were cooled for 35 min and diluted with deionized water to 50 mL for muscle and gill tissues and 25 mL for liver tissues, then filtered through 0.45 µm Whatman filter paper (Whatman International Ltd.). Deionized water was used throughout all dilution steps.

2.3 Instrumental analysis and quality control:

Pb, Zn, and Cd concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS; ELAN 9000, PerkinElmer, USA) at the Wadi Massin Environmental Technologies Laboratory, Tripoli, Libya. Concentrations are reported in mg/kg dry weight. Accuracy was verified using a certified reference material (CRM) by comparing the measured values with the certified concentrations. Quality control also included procedural blanks, duplicate samples, and internal standards. The recovery for all three metals ranged from 90% to 110%.

2.4 Comparison with regulatory limits:

Regulatory limits for fish apply to the edible muscle and are expressed per kg of wet weight. Therefore, only muscle was compared with the limits in Commission Regulation (EU) 2023/915: Pb 0.30 mg/kg and Cd 0.10 mg/kg for mackerel (European Commission, 2023). Because dry-weight concentrations are higher than the wet-weight concentrations of the same tissue, directly comparing dry-weight values with these limits is

conservative. The dry weight value above the limit was then interpreted by converting it to wet weight (C_wet = C_dry × (100 − % moisture) / 100) using the moisture content of fish muscle (Cresson *et al.,* 2017). With this conversion, the October refinery Pb value (0.70 mg/kg dry weight) falls below 0.30 mg/kg wet weight only if the muscle moisture exceeds 57.14% (1 − 0.30/0.70). No regulatory limits exist for fish liver or gills; therefore, these tissues were compared between sites and months and with published studies.

2.5 Statistical analysis:

Concentrations were presented descriptively. No inferential tests were performed; therefore, differences among sites, sampling months, and tissues are therefore described qualitatively and were not tested for statistical significance.

3. Results

3.1 Overview of tissue distribution:

Pb, Zn, and Cd were quantified in the liver, gills, and muscle of chub mackerel at both sites during all four sampling months (Table 1-2, Figures 1-2). Zn was the most abundant metal in every tissue at both sites. Zn and Cd were presented in the order liver > gills > muscle at both sites, whereas Pb was highest in the gills, followed by the liver, and then the muscle.

3.1.1 Dila site:

Concentrations at Dila (Table 1) were generally highest in August and lowest in December. **Liver**: Pb levels increased from 0.30 mg/kg in June to 0.70 mg/kg in August and then fell to 0.02 and 0.01 mg/kg in October and December, respectively. Zn peaked at 2.1 mg/kg in August (1.9 mg/kg in June) and declined to 1.0 mg/kg by December. Cd peaked at 1.20 mg/kg in August and fell to 0.20 mg/kg in December. **Gills:** Pb peaked at 0.39 mg/kg in August (0.35 mg/kg in June) and declined to 0.20 mg/kg in December. Zn peaked at 2.3 mg/kg in August. Cd was irregular; it was highest in June (0.90 mg/kg), dropped sharply in August (0.11 mg/kg), rebounded in October (0.60 mg/kg), and reached its lowest value in December (0.10 mg/kg). **Muscle**: muscle had the lowest concentrations of the three tissues. Pb peaked at 0.12 mg/kg in August and was 0.03 and 0.02 mg/kg in October and December, respectively. Zn peaked at 0.45 mg/kg in August. Cd peaked at 0.070 mg/kg in August, was 0.010 mg/kg in October, and was not detected in December.

Table 1. Concentrations (mg/kg dry weight) of chub mackerel from the Dila site 2024.

Tissue and metal	June	August	October	December	Mean
Liver Pb	0.30	0.70	0.02	0.01	0.26
Liver Zn	1.9	2.1	1.5	1.0	1.63
Liver Cd	0.70	1.20	0.50	0.20	0.65
Gills Pb	0.35	0.39	0.29	0.20	0.31
Gills Zn	1.8	2.3	1.3	0.9	1.58
Gills Cd	0.90	0.11	0.60	0.10	0.43
Muscle Pb	0.09	0.12	0.03	0.02	0.07
Muscle Zn	0.39	0.45	0.34	0.25	0.36
Muscle Cd	0.020	0.070	0.010	ND	0.025

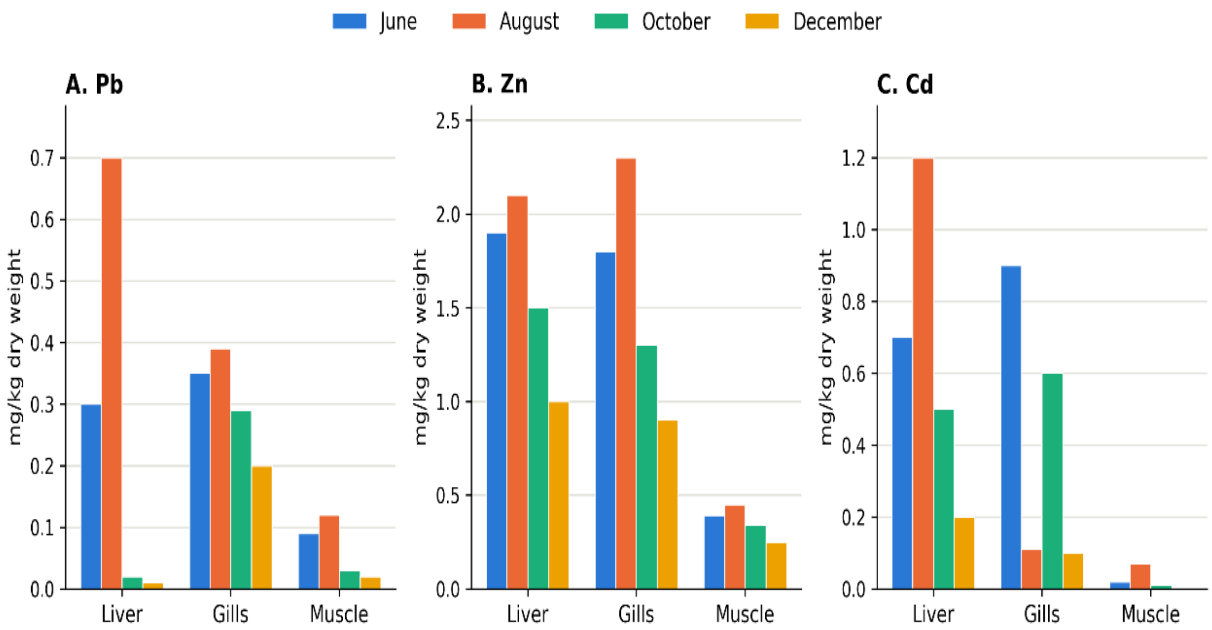


Figure 1: Concentrations (mg/kg dry weight) of (A) Pb, (B) Zn, and (C) Cd in the liver, gills, and muscle of chub mackerel from the Dila site in June, August, October, and December 2024.

3.1.2 Zawia refinery site:

Liver: Pb was highest in June (0.80 mg/kg), fell to 0.13 mg/kg in August, and remained at 0.30 mg/kg and 0.10 mg/kg in October and December. Zn peaked at 2.9 mg/kg in August, 2.2 mg/kg in June, and declined to 1.3 mg/kg by December. Cd was markedly elevated throughout; it peaked at 1.90 mg/kg in August and was 0.60 mg/kg at its lowest in December. Gills: Pb rose from 0.39 mg/kg in June to 0.45 mg/kg in August, was 0.32 mg/kg in October, and fell to 0.27 mg/kg in December. Zn peaked at 2.9 mg/kg in August. Cd was low from June to October (0.10-0.25 mg/kg) and rose to 0.60 mg/kg in December, its highest value. Muscle: Concentrations were again the lowest overall. Pb showed an isolated peak of 0.70 mg/kg in October, compared with 0.11-0.20 mg/kg in the other months. Zn peaked at 0.50 mg/kg in August and declined to 0.30 mg/kg by December. Cd was highest in June (0.070 mg/kg), then 0.015 mg/kg in August, 0.050 mg/kg in October, and 0.010 mg/kg in December (Table 2).

Table 2. Concentrations (mg/kg dry weight) of chub mackerel from the Zawia refinery site 2024.

Tissue and metal	June	August	October	December	Mean
Liver Pb	0.80	0.13	0.30	0.10	0.33
Liver Zn	2.2	2.9	1.9	1.3	2.08
Liver Cd	1.40	1.90	1.00	0.60	1.23
Gills Pb	0.39	0.45	0.32	0.27	0.36
Gills Zn	2.3	2.9	1.8	1.2	2.05
Gills Cd	0.12	0.25	0.10	0.60	0.27
Muscle Pb	0.11	0.20	0.70	0.20	0.30
Muscle Zn	0.42	0.50	0.38	0.30	0.40
Muscle Cd	0.070	0.015	0.050	0.010	0.036

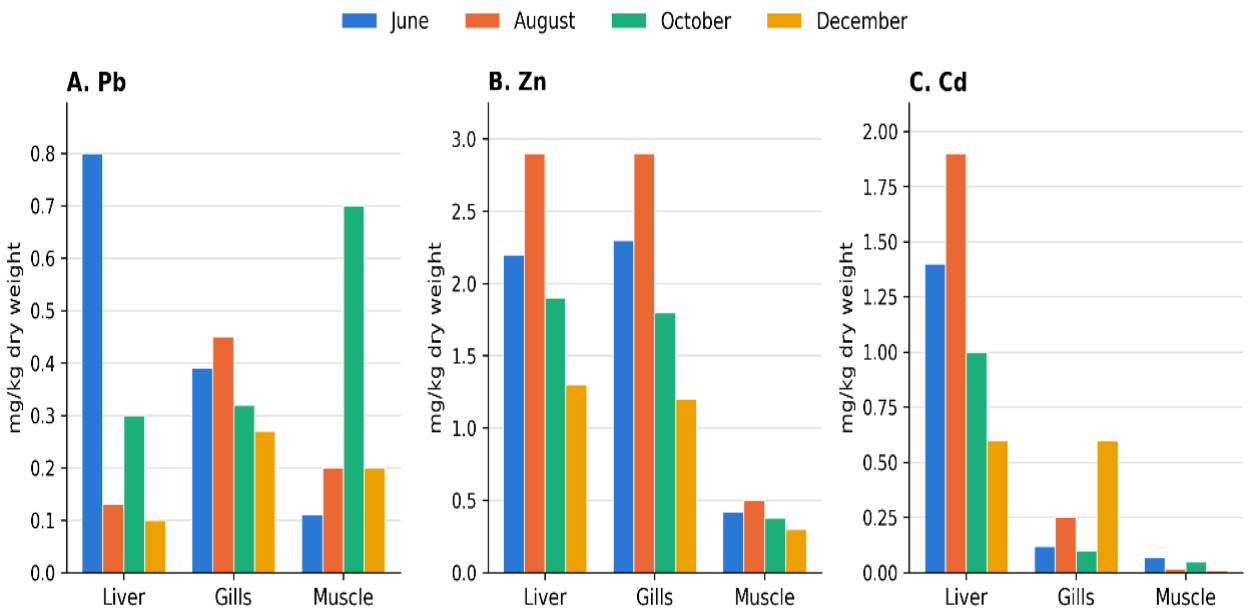


Figure 2. Concentrations (mg/kg dry weight) of (A) Pb, (B) Zn, and (C) Cd in the liver, gills, and muscle of chub mackerel from the Zawia refinery site in June, August, October, and December 2024.

3.2 Comparison of muscle with regulatory limits

Muscle was compared with the EU limits for Pb (0.30 mg/kg wet weight) and Cd in mackerel (0.10 mg/kg wet weight) (European Commission, 2023). Muscle Cd never exceeded 0.070 mg/kg dry weight at either site, so it was below the Cd limit in all samples, regardless of moisture content. Muscle Pb was 0.20 mg/kg or lower in every sample, except the refinery sample from October (Tables 2 and 3). This value exceeds the Pb limit on a dry weight basis. With muscle moisture above 57.14%, it falls below 0.30 mg/kg wet weight, and therefore, no sample is expected to exceed either limit. Liver and gills were not compared with limits because none exist for these in fish.

Table 3. The highest muscle concentration at each site compared was with the EU limit.

Metal (EU limit, wet weight)	Site	Highest value (dry weight)	Above limit if compared directly?	Below the limit after conversion to wet weight?
Cd (0.10 mg/kg)	Dila	0.070 mg/kg (August)	No	Yes
Cd (0.10 mg/kg)	Refinery	0.070 mg/kg (June)	No	Yes
Pb (0.30 mg/kg)	Dila	0.12 mg/kg (August)	No	Yes
Pb (0.30 mg/kg)	Refinery	0.70 mg/kg (October)	Yes	Yes, if moisture exceeds 57.14%

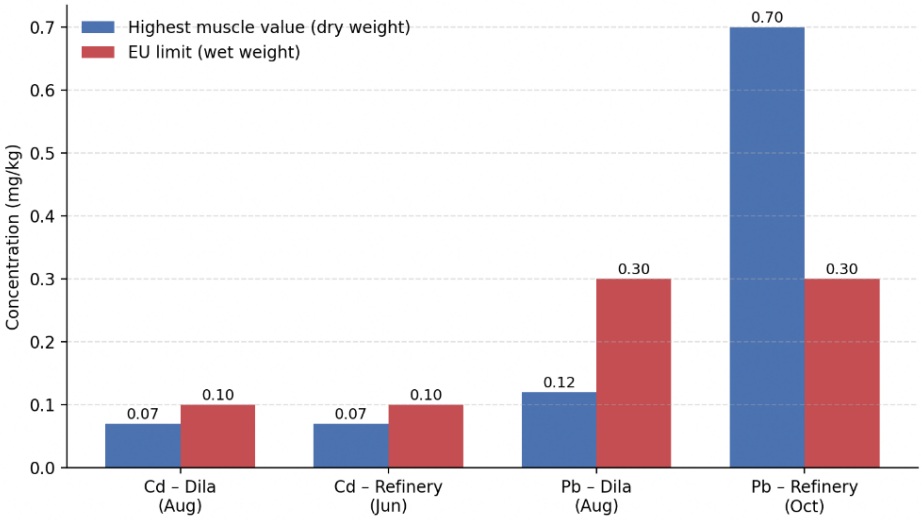


Figure3. Highest muscle concentration at each site compared with the EU limit.

3.3 Comparison between sites:

The refinery site had higher concentrations of Zn in all three tissues, Pb in the gills and muscle, and Cd in the liver than Dila in every month. (Tables 1, 2, and 4). The difference was largest for liver Cd (mean 1.23 vs 0.65 mg/kg) and muscle Pb (0.30 vs 0.07 mg/kg). The pattern was not uniform. Liver Pb was higher at Dila in August (0.70 vs 0.13 mg/kg), and gill Cd was higher at Dila in June and October (0.90 vs 0.12 and 0.10 mg/kg), which gave a higher Dila mean (0.43 vs 0.27 mg/kg). Muscle Cd was higher at Dila in August (0.070 vs 0.015 mg/kg) and at the refinery in the three months (Tables 1, 2 and 4).

Table 4. Mean concentrations (mg/kg dry weight) at the two sites

Tissue and metal	Dila mean	Refinery mean	Is the refinery higher in all four months?
Liver Pb	0.26	0.33	No (Dila higher in August)
Liver Zn	1.63	2.08	Yes
Liver Cd	0.65	1.23	Yes
Gills Pb	0.31	0.36	Yes
Gills Zn	1.58	2.05	Yes
Gills Cd	0.43	0.27	No (Dila higher in June and October)
Muscle Pb	0.07	0.30	Yes
Muscle Zn	0.36	0.40	Yes
Muscle Cd	0.025	0.036	No (Dila higher in August)

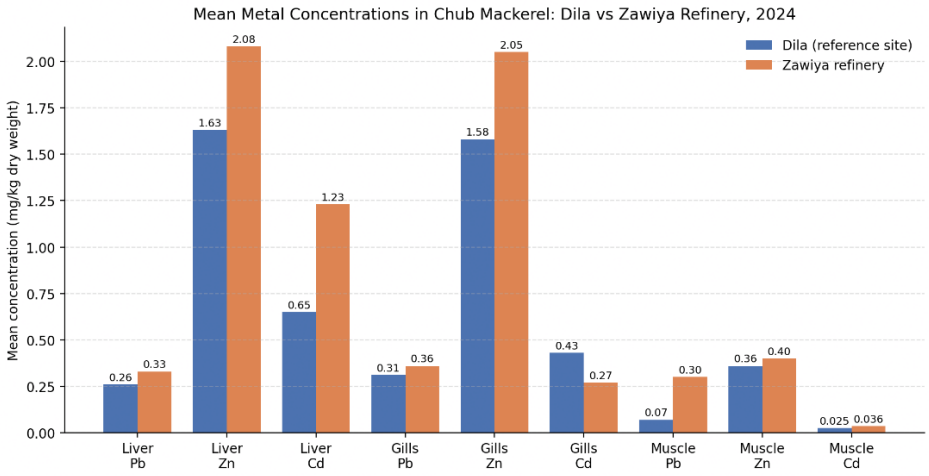


Figure4. Mean concentrations (mg/kg dry weight) at the two sites.

4. Discussion:

4.1 Tissue-specific accumulation:

Zn and Cd concentrations were highest in the liver and lowest in muscle at both locations, whereas Pb levels peaked in the gills. Typically, pelagic fish exhibit higher metal concentrations in the liver than in the muscle. Chub mackerel and various species were documented along the Moroccan Atlantic coast (Afandi *et al.,* 2018) and in Iskenderun Bay within the eastern Mediterranean (Ersoy & Çelik, 2009)**.** Within Libyan waters, fish sourced from Tripoli port exhibited the highest Cd levels in the liver, whereas Zn concentrations were elevated in the gills and skin (Okbah *et al.,* 2018). In red mullet and common pandora from the Zilten coast, the accumulation of Pb and Cd was highest in the liver, followed by gills, gonads, and lowest in muscle, whereas Zn levels were lowest in muscle (Ighwela *et al.,* 2021). Fish from the Zwitina oil-contaminated region exhibited the highest metal concentrations in the gills for certain species and in the liver for others, while muscle contained the least (Bahanaswy, 2009). Our Pb pattern, showing gills at or above the liver, aligns with this reliance on species and metal, potentially indicating the gills' direct interaction with water. The liver is metabolically engaged and gathers more metal than muscle (Ploetz *et al.,* 2007), and metal-binding metallothionein in the liver enables it to retain significant quantities (Roesijadi, 1996). Accumulation typically aligns with the functional role of each organ (Uysal *et al.,* 2011). On a dry weight basis, our liver Cd (0.65-1.23 mg/kg) and muscle Cd (0.025-0.036 mg/kg) were significantly lower than those in chub mackerel from the Moroccan upwelling region (50.07 and 0.198 mg/kg dry weight), where Cd sources were linked to upwelling and phosphate industry discharges (Afandi *et al.,* 2018). Consequently, the Cd burden in our fish is relatively low compared to that in fish from Cd-enriched waters.

4.2 Differences between sites (Zawia oil refinery and Dila):

Zn levels in all tissues, Pb in the gills and muscle, and Cd in the liver were elevated at the refinery site each month. This aligns with the inputs related to refineries. A recent analysis of the Zawia refinery found offshore petroleum hydrocarbons at a level of up to 43 mg/L and an increase in nickel and vanadium, suggesting refinery origins (Rtemi *et al.,* 2026), yet it did not mention Pb, Zn, or Cd in fish. Metal buildup in fish has also been associated with oil pollution at Zwitina, showing species dependency and elevated levels in fish residing near sediments (Bahanaswy, 2009), with industrial operations focused in coastal cities like Zawia. Since water and sediment were not examined, our data cannot assign the metals to a specific source. A study of coastal sediments in Tripoli, Khoms, and Misurata showed no risk of metal pollution (Hassan & Elssaidi, 2015), but since Zawia

was not included, local baseline data are necessary. The contrast on the site was inconsistent. Liver Pb and gill and muscle Cd did not show any consistent variation between locations. Chub mackerel is a sociable, mobile species that consumes small pelagic fish as adults (Afandi *et al.,* 2018), allowing individual fish to combine exposure over a broad region and obscure local variations. Every monthly value is based on three fish, and the unique October spike in refinery muscle Pb (0.70 mg/kg dry weight compared to 0.11-0.20 mg/kg in other months) might indicate occasional exposure or a solitary fish.

4.3 Temporal variation:

Most metal-tissue combinations peaked in August and were lowest in December. In Iskenderun Bay, trace metals in muscle were highest in spring and summer, and Zn was highest in summer (Ersoy & Çelik, 2009). In contrast, the maximum Pb in that study occurred in autumn, whereas our Pb peaks were mostly in June or August. Other studies have found no clear seasonal pattern in mackerel muscle in the Moroccan upwelling area (Afandi *et al.,* 2018) and significant seasonal and regional variation among Zwitina fish (Bahanaswy, 2009). Seasonal effects on metal content in chub mackerel have also been reported (Aktan & Tekin-Özan, 2012; Bae & Lim, 2012). Seasonal differences in tissue metals are generally attributed to growth and reproductive cycles and water temperature (Ersoy & Çelik, 2009), and to water circulation and upwelling intensity (Afandi *et al.,* 2018). With four months one year and three fish per month, our seasonal pattern should be regarded as preliminary.

5. Conclusion:

Chub mackerel from the Zawia coast accumulated Zn and Cd in the order liver > gills > muscle, with Pb highest in the gills on average. Zn in all tissues, Pb in gills and muscle, and Cd in the liver were higher near the refinery site than at Dila, and most concentrations peaked in August. Muscle, the edible tissue, had the lowest concentrations, and no muscle sample was expected to exceed the EU limits for Cd or Pb. Muscle Pb exceeded the EU limit only in one refinery sample from October (0.70 mg/kg dry weight), and only before conversion to wet weight; after conversion, it fell below 0.30 mg/kg if muscle moisture exceeded 57.14%. Because only three fish were analysed per site and month and no statistical tests were applied, the differences described here are descriptive. Larger samples, multi-year sampling, water and sediment data, and a formal exposure assessment are needed to confirm these findings.

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