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HEAVY METAL DETERMINATION OF SHARK *Scoliodon laticaudus* IN JOHOR WATERS

(Penentuan Logam Berat daripada Ikan Yu *Scoliodon laticaudus* dalam Perairan Johor)

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Abstract

The sharks from Johor waters were investigated to evaluate certain heavy metal concentrations and their potential human health concerns. This study obtained 25 *Scoliodon laticaudus* as bycatches from the local fishermen's market in Johor and stored them at a low temperature before further analysis. The sharks were divided into gill, muscle, fin, stomach, and liver samples with oven drying at 60˚C. Certain heavy metals (As, Cd, Cr, Cu, Fe, Hg, Pb, and Zn) were then evaluated using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) after the digestion process using nitric acid (HNO_3). This study presented the ascending metal concentration sequences as Fe > Cd > Hg > Pb > Cr > As > Cu > Zn for livers, Cd > Hg > Fe > Pb > Cr > As > Cu > Zn for stomach linings, Cd < Hg < Pb < Fe < Cr < Cu < As < Zn for fins, Hg < Cd < Fe < Pb < Cr < Cu < As < Zn for gills, and Cd < Hg < Fe < Pb < Cr < Cu < As < Zn for muscles. Therefore, the average pollutant load indexes (PLIs) (contamination levels) for livers, stomach linings, fins, gills, and muscles were 3.31, 2.23, 3.15, 2.47, and 3.35, respectively. Based on the PLI values, this study successfully indicated a moderately polluted contamination level.

Keywords: inductively coupled plasma mass spectrometer, pollution load index, pollution, organisms, Straits of Malacca

Abstrak

Ikan yu dari perairan Johor telah dianalisis untuk menilai jumlah logam berat tertentu dan potensi risiko kesihatan terhadap manusia. Kajian ini memperoleh 25 *Scoliodon laticaudus* sebagai tangkapan sampingan dari pasar nelayan tempatan di Johor dan disimpan pada suhu rendah sebelum dianalisis selanjutnya. Ikan yu dibahagikan kepada sampel insang, otot, sirip, perut, hati, dan dikeringkan di dalam ketuhar pada suhu 60°C. Logam berat tertentu (As, Cd, Cr, Cu, Fe, Hg, Pb, dan Zn) dinilai menggunakan spektrometri jisim plasma gadingan aruhan (ICP-MS) selepas proses pencernaan dengan asid nitrik (HNO_3). Kajian ini menunjukkan kepekatan logam menaik iaitu Fe > Cd > Hg > Pb > Cr > As > Cu > Zn untuk hati, Cd > Hg > Fe > Pb > Cr > As > Cu > Zn untuk perut, Cd < Hg < Pb < Fe < Cr < Cu < As < Zn untuk sirip, Hg < Cd < Fe < Pb < Cr < Cu < As < Zn untuk insang, dan Cd < Hg < Fe < Pb < Cr < Cu < As < Zn untuk otot. Oleh itu, purata indeks bebanan pencemaran (PLIs) (tahap pencemaran) untuk hati, perut, sirip, insang, dan otot ialah 3.31, 2.23, 3.15, 2.47, dan 3.35. Kajian ini berjaya menunjukkan tahap pencemaran sederhana berdasarkan nilai PLI.

Kata kunci: spektrometri jisim plasma gadingan aruhan, indeks bebanan pencemaran, pencemaran, organisma, Selat Melaka

Introduction

A crucial and significant habitat for sharks is commonly found in the Malaysian waters of Johor. Nonetheless, Johor is an agricultural and industrial state that discharges a substantial amount of ocean waste [1]. This waste includes heavy metals, which are metallic substances with a considerably higher density than water [2]. Since weight and toxicity are related, heavy metals typically include metalloids (arsenic) and are hazardous at low exposure levels. Although numerous natural events (weathering and volcanic eruptions) greatly influence heavy metal poisoning incidents, human activities are primarily responsible for environmental contamination and human exposure concerns [3]. The largest heavy metal concentrations are generally recorded in apex predators at the top of the food chain. Hence, top predators like elasmobranchs (sharks) are more susceptible to environmental pollution.

The biomagnification and bioaccumulation processes absorb the contaminants in the food chain. For example, sharks acquire greater amounts of Hg (particularly monomethyl mercury) than other fish species, which is the most toxic form of metal [4]. Sharks are frequently the “apex” or top predators in their ecosystems as they have few natural predators. Additionally, sharks’ prey on species in the lower food web levels, aiding the regulation and maintenance of the marine ecological equilibrium. Since these predators directly impact their prey populations, the prey populations of the sharks’ prey are also affected. Most top predators consume diverse foods, and the top predators can switch prey species. This switch enables prey species to survive when certain prey populations are depleted [5].

Scoliodon laticaudus, or spade nose shark, is discovered in the Johor markets, one of the smallest tropical carcharhinid sharks inhabiting shallow coastal waters [6]. Generally, these sharks are observed in coastal and estuarine waters at depths ranging from 10 to 75 m (typically less than 50 m), prefer muddy and sandy substrates, and are commonly found around major freshwater outflows. Other spade nose sharks’ characteristics include a yearly litter of 6 to 20 pups, an early maturity age of two years, and a 4.5-year generation time [7]. Nonetheless, shark-based research in Malaysia still requires further investigation. Moreover, the *Scoliodon laticaudus* species are highly demanded as bycatches in the local markets of Johor. This study determined the heavy metal levels in sharks and the correlation between heavy metals and shark weights using statistical analysis.

Materials and Methods

Sample collection and preparation

A total of 25 *Scoliodon laticaudus* were acquired from the local fishermen in Malaysia (see Figure 1). These sharks were purchased from a port or a market in Johor in March 2022 (see Figure 2), which were bycatches from trawls and gillnets while being sold to the locals. The 25 sharks were labelled and stored at a low temperature in a refrigerator until further use. Initially, the sharks were defrosted, dissected, and analysed in a laboratory. The length and weight of the sharks’ whole bodies were also measured. Subsequently, the gender of the sharks was determined using a clasper. A ceramic knife dissected the sharks into muscle, fin, stomach lining, liver, and gill samples. These organs were transferred into a preheated oven at 60 °C until constant dry weights were achieved. Finally, the organs were homogenised into powder form using a pestle and mortar, and the processing equipment was cleaned with ethanol for each sample [8].

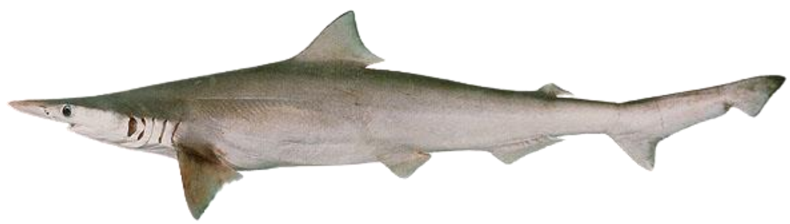

Figure 1. The *Scoliodon laticaudus* or spade nose shark

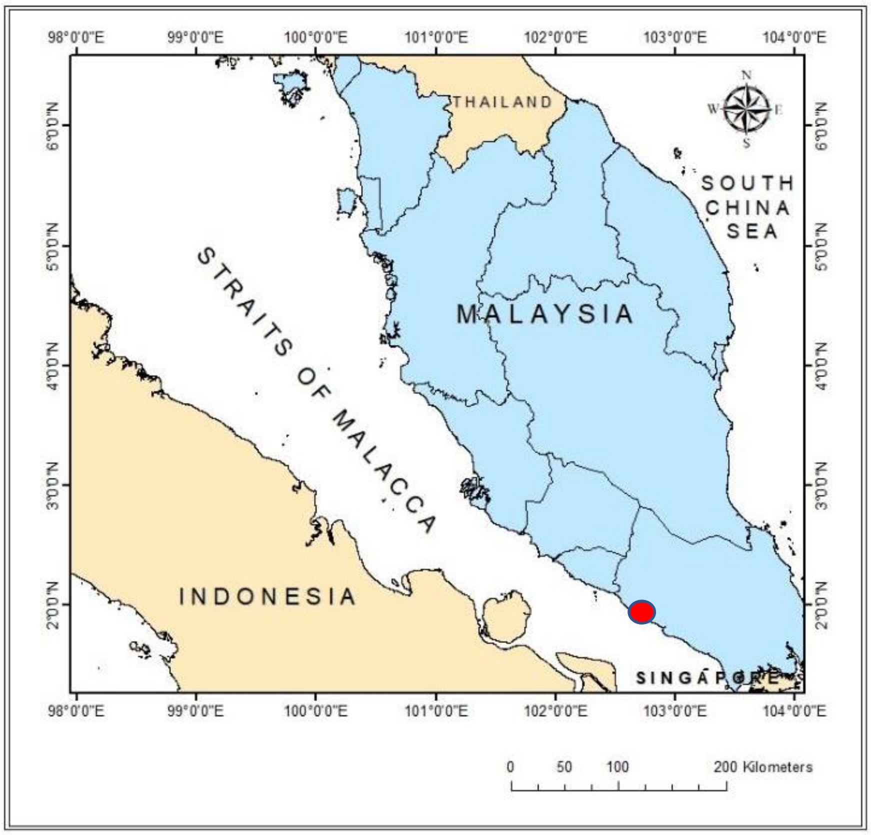

Figure 2. The Johor state map and the Pontian District

Acid digestion technique

The heavy metal contents in the liquid biota samples were measured using the Teflon bomb digestion approach for biological samples. Initially, 0.05 g of the homogenised material was weighed and placed in a 25 mL Teflon beaker containing 1.5 mL of 65% nitric acid (HNO_3) [9]. Since HNO_3 is a strong acid, the approach was conducted within a perchloric fume hood. The Teflon beaker was then tightly sealed to prevent acid leakage throughout the acid digestion process. All Teflon bombs were heated in an oven at 100°C for 8 h to aid digestion [9, 10]. The Teflon bombs were then allowed to cool to room temperature before transferring the solution to separate centrifuge tubes. These tubes were added with deionised water until the 10 mL marks were reached. Simultaneously, the blank and certified reference material samples (DOLT-4 Dogfish liver) were analysed to assess the accuracy of the procedure. Lastly, the Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Mercury (Hg), and Zinc (Zn) heavy metal concentrations were evaluated using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Elan 6000) [11, 12]. Table 1 lists the detection and quantification limits of the ICP-MS instrument.

Table 1. Summary of the detection and quantification limits of the ICP-MS instrument

Metal	**Mass**	**Detection Limits (µg/L)**	**Quantification Limits (µg/L)**
Ar	075	0.590	1.950
Cd	112	0.003	0.010
Cr	052	0.110	0.380
Cu	063	0.210	0.690
Pb	207	0.020	0.050
Fe	055	8.260	27.54
Hg	200	0.006	0.020
Zn	065	0.260	0.850

Data analysis

The Pearson correlation test was utilised to examine the correlation between heavy metal concentrations and shark weights. All analyses used *p*-values less than 0.05 (p <0.05). Meanwhile, the heavy metal contamination levels were evaluated using the pollutant load index (PLI) [13]. No action was necessary if the PLI value was below 50. Otherwise, monitoring was essential if the PLI value was higher than 50. If the PLI value was greater than 100, extreme pollution was indicated, requiring immediate action [14]. An equation is used to calculate XX as follows:

$$PLI = (CF1 \times CF2 \times CF3 \times \cdots \times CFn)^{1/n} \quad (1)$$

where n represents the number of metals.

Results and Discussion

Table 2 tabulates the average length and weight of the *Scoliodon laticaudus*; the maximum weight and length of the shark are 41.3 cm and 295 g, respectively. Meanwhile, the corresponding minimum weight and length were 33 cm and 162 g, respectively. Thus, the shark's average length demonstrated the significant maturity of the sharks [7]. This outcome was supported by Ali and Lim [15] study, which reported that male and female spade nose sharks reached their maturity ranging from 24 to 36 cm and 33 to 35 cm lengths, respectively [15]. When maturity was achieved, an extended survival period for the sharks in the wild was indicated, bioaccumulating a specific number of heavy metals. The weight of the sharks aided in determining the shark's health, which reflected the sharks' condition in their habitat. This factor suggested that the greater the sharks' weight of a certain length, the better their physiological conditions. Consequently, more preys were available for the sharks, which could assess if an ecosystem was healthy or contaminated [16, 17].

Tissue samples reveal the highest Zn and Cu concentrations, which Zn is a required metallic trace element for microbes, plants, animals, and humans. Although Cu and Zn are key minerals offering substantial health benefits and are necessary for metabolic synthesis, they are still potentially toxic metals. For example, Cu is vital as an enzyme cofactor and in Fe consumption [18]. Conversely, excessive Cu in the fish system (particularly in sharks) can harm organs and systems while suppressing the immune system [19]. Another example involves Zn as a crucial inorganic trace element in regulating numerous physiological activities, including defence mechanisms, growth performance, immune system, and radical and free ion resistances [20]. Nonetheless, high Zn concentrations produce deaths in fish by causing damage to the gill tissues. Stress and death are also induced due to the continuously lethal concentrations [21]. Thus, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) established the Joint FAO/WHO Expert Committee on Food Additives (JECFA). In JECFA, standards were developed for evaluating the safety of chemicals in foods that were compatible with current risk assessment concepts while considering toxicology advancements and other relevant fields [22].

Table 2. Size parameter summary of the *Scoliodon laticaudus*

Parameter	Length (cm)	Weight (g)
Average	37 ± 2.29	202.9 ± 34.13
Min	33.0	162
Max	41.3	295

Table 3. Summary of the permissible heavy metal limits by WHO

Heavy Metals	WHO (mg/kg)
Cd	0.05
Pb	0.02
Cr	2.00
As	0.12
Zn	0.05
Hg	0.05
Fe	-
Cu	30.0

Significant As concentrations are observed in tissue samples due to pesticides (agricultural, fertiliser, and animal feeding activities) in the captured shark areas [23, 24]. Since As compounds are predominantly soluble, they are more likely to accumulate in seafood [25]. On the contrary, these amounts should not cause a concern considering the As ratio in less organic fishes to pure organic fishes was low [26]. Although As is the third-highest heavy metal concentration and a non-essential element, necessary precautions are still required. As is detrimental to the locals' health if these sharks are consumed. **Tables 4** to **8** summarise the heavy metal concentrations in the gill, muscle, liver, stomach lining, and fin samples, respectively. The mean, minimum, and maximum heavy metal concentrations were recorded, and standard errors or deviations accompanied the mean values. As the sharks were obtained from the same environment, the weight-dependent heavy metal concentrations were most likely determined by the sharks' physical states. Additionally, strong physical conditions with greater lipid tissue contents produced a relative dilution of the stored contaminants in the organs [17, 27].

Table 4. Summary of metal concentrations in spade nose sharks (gills)

Sample	Metal Concentrations in Gills (µg/g dry wt.)							
	Cr	Fe	Cu	Zn	Cd	Pb	As	Hg
Average	5.91 ± 3.53	4.19 ± 2.06	20.02 ± 10.74	193.72 ±74.13	1.45 ± 2.89	4.48 ± 11.67	25.67 ± 56.53	1.35 ± 2.66
Min	1.90	0.16	7.26	98.68	0.43	1.27	14.00	0.48
Max	14.43	7.34	36.87	343.31	2.89	11.67	56.53	2.66

Table 5. Summary of metal concentrations in spade nose sharks (muscles)

Sample	Metal Concentrations in Muscles (μg/g dry wt.)							
	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**	**Hg**
Average	5.47 ± 5.32	2.80 ± 2.02	19.77 ± 10.31	108.02 ± 35.77	0.96 ± 0.27	2.81 ± 1.00	21.68 ± 8.84	1.76 ± 0.63
Min	1.34	0.74	6.17	61.11	0.56	1.40	11.19	0.92
Max	17.64	8.04	42.06	165.17	1.26	4.72	41.22	3.05

Table 6. Summary of metal concentrations in spade nose sharks (fins)

Sample	Metal Concentrations in Fins (μg/g dry wt.)							
	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**	**Hg**
Average	5.97 ± 1.91	5.67 ± 2.01	30.74 ± 21.83	353.54 ± 134.55	1.76 ± 0.85	4.48 ± 2.02	29.45 ± 14.90	2.15 ± 0.99
Min	3.97	2.54	7.80	126.78	0.57	1.73	15.07	0.08
Max	9.38	10.18	70.40	562.20	3.52	8.62	71.12	3.80

Table 7. Summary of metal concentrations in spade nose sharks (stomach linings)

Sample	Metal Concentrations in Stomach Linings (μg/g dry wt.)							
	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**	**Hg**
Average	9.36 ± 3.41	4.37 ± 2.59	71.56 ± 43.19	779.32 ± 291.64	2.72 ± 1.55	6.27 ± 2.22	40.05 ± 13.07	3.77 ± 1.75
Min	3.79	0.38	27.15	446.85	0.96	3.61	21.12	2.17
Max	15.79	10.30	168.13	1428.42	6.51	11.63	64.57	8.16

Table 8. Summary of metal concentrations in spade nose sharks (livers)

Sample	Metal Concentrations in Livers (μg/g dry wt.)							
	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**	**Hg**
Average	13.78 ± 8.29	0.92 ± 0.56	57.42 ± 27.51	1019.62 ± 523.21	3.40 ± 1.81	5.67 ± 2.25	40.04 ± 14.90	5.18 ± 3.12
Min	4.88	0.09	16.70	317.07	0.89	2.35	17.58	1.51
Max	39.12	2.10	107.61	2079.52	6.98	9.75	67.38	12.60

The lowest Hg content was measured in the gill samples, and the heavy metal distributions in the muscles and internal organs were influenced by environmental pollution [28, 29]. The liver sample also absorbed large quantities of ecological pollutants, which was important for pollutant storage, redistribution, detoxification, and transformation [30, 31]. In addition, the liver and stomach samples contained larger heavy metal amounts than other tissue samples. These heavy metal amounts in tissue samples could vary depending on several factors, such as size, gender, dietary habits, and environment. Furthermore, lower metal absorptions were produced due to the decreased free metal ion activities as salinity increased [32]. Table 9 presents the correlation coefficient interpretations from Mukaka's and Schober et al. studies [33, 34]. Meanwhile, Figures 3 to 7 depict the coefficient correlation curves between shark weights and heavy metal concentrations.

The Cu and Pb concentrations were low in gill tissues (see Figure 3), and their concentrations did not vary significantly with body weights. In contrast, the correlations between Cr and Cd concentrations and shark weights were not statistically significant. The correlation coefficients for Zn, As, Hg, and Fe were less than 0.3, indicating a substantial relationship between shark weights and heavy metal concentrations. In the muscle samples (see Figure 4), a very weak correlation was recorded for all metals between shark weights and heavy metal concentrations. Although the correlation coefficient values for Cr, Fe, Zn, Cd, Pb, As, and Hg were less than -0.2, the values remained in the negative regions (see Figure 5). This outcome suggested that the heavy metal concentrations acquired no significant changes. Likewise, Cu concentration increased slightly with shark weight, which was deemed insignificant.

Table 9. Summary of the correlation coefficient interpretations

Size of Correlation	Interpretation
0.90 to 1.00 (-0.90 to -1.00)	Very high positive (negative) correlation
0.70 to 0.90 (-0.70 to -0.90)	High positive (negative) correlation
0.50 to 0.70 (-0.50 to -0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (-0.30 to -0.50)	Low positive (negative) correlation
0.00 to 0.30 (0.00 to -0.30)	Negligible correlation

In the stomach tissue samples (see Figure 6), the Fe, Cu, Pb, Hg, Zn, and As exhibited significant changes in weight as their concentrations increased. On the contrary, Cr and Cd revealed weak positive and negative significances, respectively. A moderate correlation between Cr and shark weight was also computed in the liver tissue samples (see Figure 7). This result occurred due to the increased sample weight when the Cr concentration decreased. Interestingly, Hg, Cd, and Zn produced corresponding correlation values of -0.32, -0.37, and -0.3, thus indicating significant changes in shark weights and heavy metal concentrations. Lastly, the low Pb, As, and Fe concentrations were deemed insignificant.

The impacts of multiple external aspects (such as the marine environment) and internal factors (fish carcass features) can induce variations in metal accumulations and inter-metal correlations among fish species, locations, and seasons. Generally, the size-age effect on metal content is a well-established study whereby Hg content increase with size and age (particularly in predatory fishes). Nevertheless, this characteristic is not observed in all metals. Certain metals, such as Cr, Cu, Fe, Cd, As, and Pb, have inverse associations with the size or age of the fish. Hence, heavy metal concentrations vary by species, location, and tropic level, generating challenging comparison and interpretation processes [35]. Moreover, negative correlations are more common than positive ones, making it difficult to explain them [36].

All the coefficient values in gills for Cr-Zn, Cu-Cd, Fe-Cd, Fe-Zn, Cu-Cd, Zn-Cd, Cd-As, and Pb-Hg were between 0.5 and 0.7 (see Table 10). Subsequently, all the coefficient values for muscles for Cr-Fe, Cr-Cu, Fe-Zn, Fe-Cd, Fe-Pb, Fe-As, Fe-Hg, and Cu-As were low or negative (see Table 11). Meanwhile, all the coefficient values in fins for Fe-Zn, Fe-Cd, Fe-Hg, Zn-Cd, Cd-Hg, Pb-Hg, and As-Hg were between 0.5 and 0.9 (see Table 12). Alternatively, all the correlation coefficient values for the stomach tissues for Fe-Cu, Fe-Zn, Fe-Pb, Fe-Hg, Cu-Pb, Cu-Hg, Zn-Pb, Zn-Hg, and P-Hg were from 0.5 to 0.9 (see Table 13). Finally, all the correlation coefficient values in liver tissues for Cr-Fe, Cr-Cu, Cr-Zn, Cr-Pb, Cr-As, Cr-Hg, Fe-Cu, and Fe-Cd were low (see Table 14).

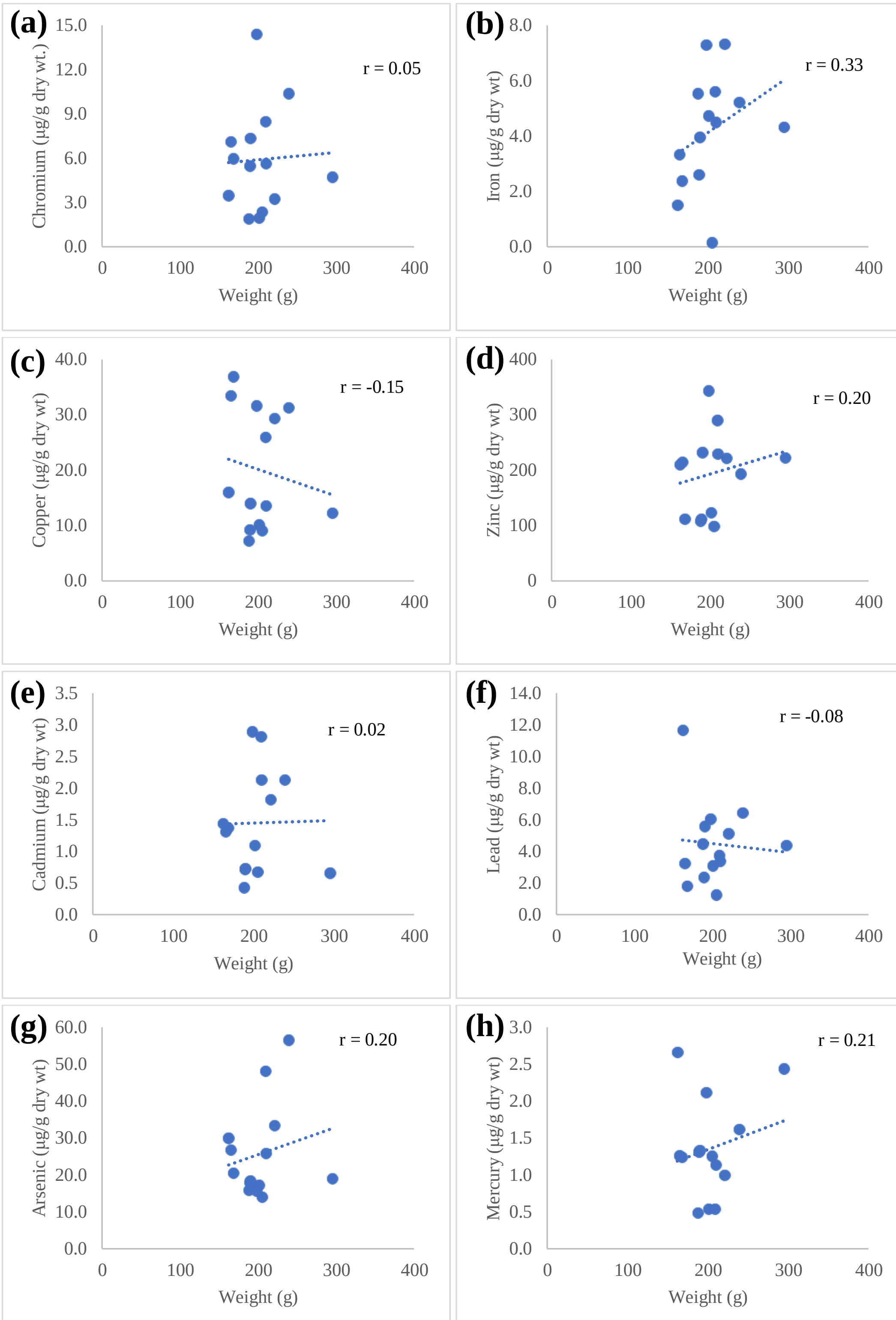

Figure 3. Graphs indicating the correlations (*r*-values) between shark weights (*n* = 25) with (a) Cr, (b) Fe, (c) Cu, (d) Zn, (e) Cd, (f) Pb, (g) As, and (h) Hg concentrations in gills

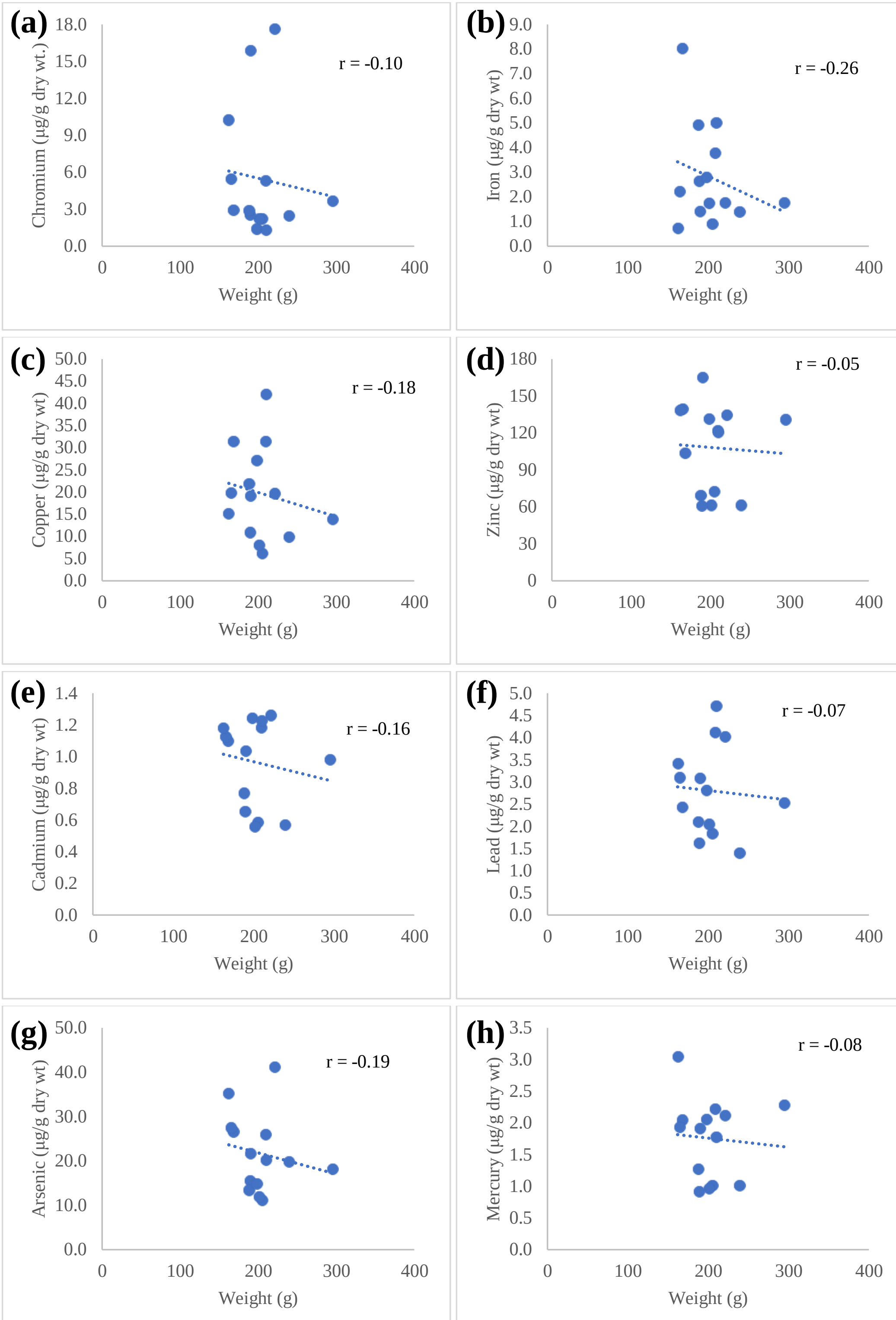

Figure 4. Graphs indicating the correlations (*r*-values) between shark weights (*n* = 25) with (a) Cr, (b) Fe, (c) Cu, (d) Zn, (e) Cd, (f) Pb, (g) As, and (h) Hg concentrations in muscles

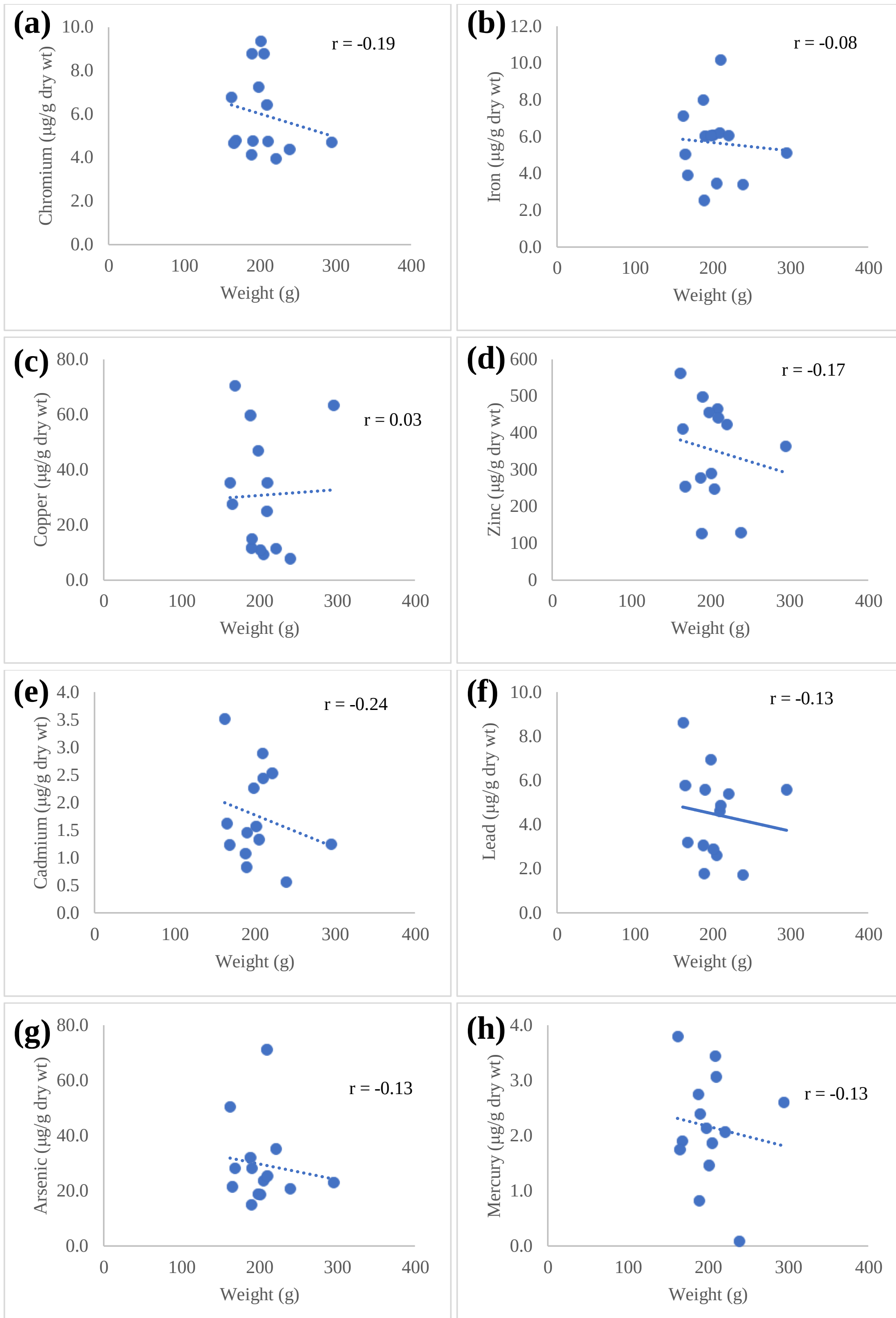

Figure 5. Graphs indicating the correlations (*r*-values) between shark weights (n = 25) with (a) Cr, (b) Fe, (c) Cu, (d) Zn, (e) Cd, (f) Pb, (g) As, and (h) Hg concentrations in fins

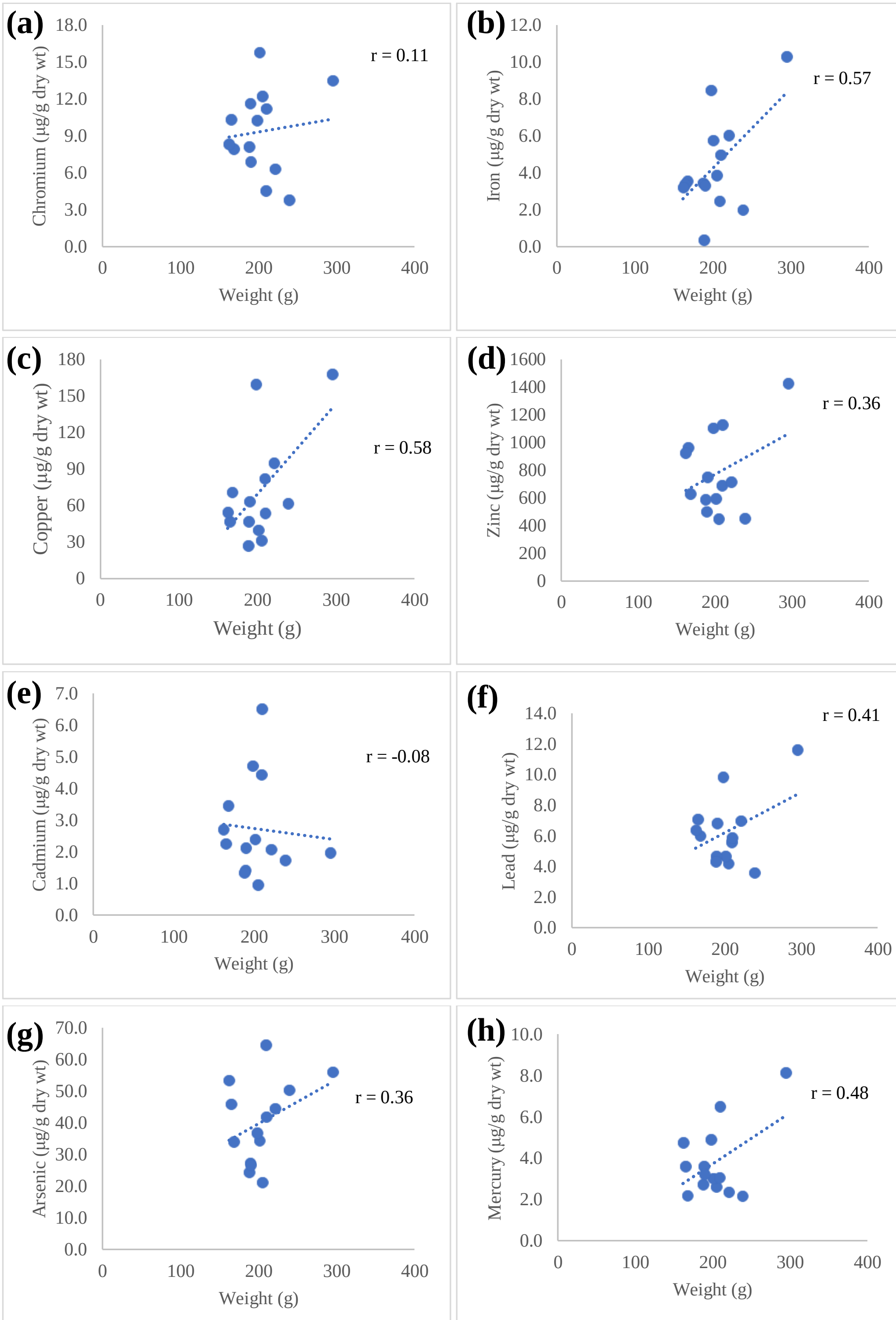

Figure 6. Graphs indicating the correlations (*r*-values) between shark weights (n = 25) with (a) Cr, (b) Fe, (c) Cu, (d) Zn, (e) Cd, (f) Pb, (g) As, and (h) Hg concentrations in stomach linings

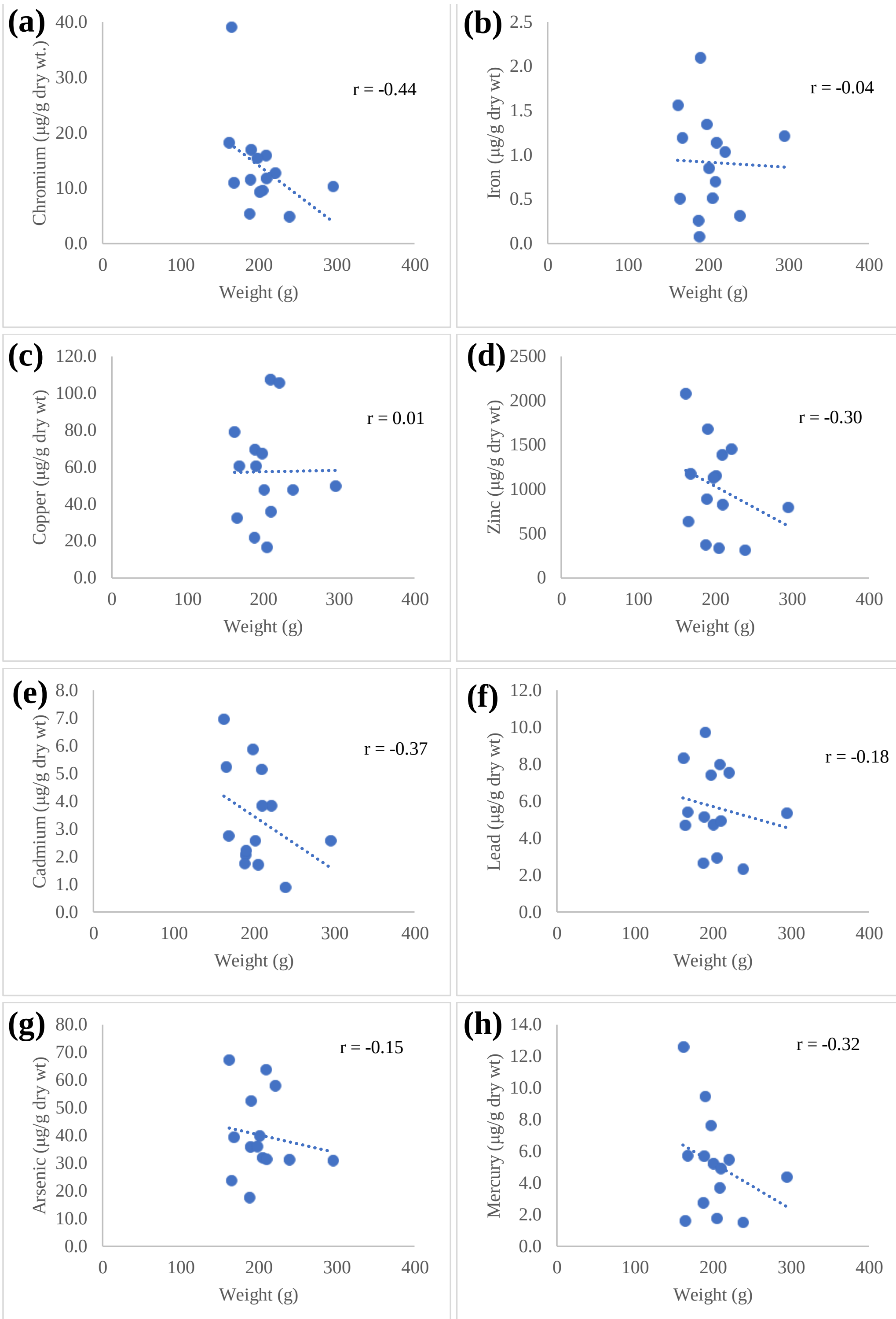

Figure 7. Graphs indicating the correlations (*r*-values) between shark weights (*n* = 25) with (a) Cr, (b) Fe, (c) Cu, (d) Zn, (e) Cd, (f) Pb, (g) As, and (h) Hg concentrations in livers

Table 10. Summary of the correlation coefficient values of heavy metals in gills

	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**
Fe	0.410						
Cu	0.616	0.318					
Zn	0.716	0.576	0.427				
Cd	0.702	0.535	0.636	0.744			
Pb	0.161	0.137	0.066	0.429	0.229		
As	0.335	0.282	0.483	0.333	0.586	0.313	
Hg	0.294	-0.219	0.096	0.344	0.047	0.602	-0.042

Table 11. Summary of the correlation coefficient values of heavy metals in muscles

	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**
Fe	-0.350						
Cu	-0.058	0.723					
Zn	0.617	-0.091	0.433				
Cd	0.416	0.257	0.735	0.857			
Pb	0.419	0.153	0.724	0.714	0.851		
As	0.718	-0.023	0.249	0.587	0.670	0.599	
Hg	0.458	0.029	0.418	0.830	0.850	0.660	0.702

Table 12. Summary of the correlation coefficient values of heavy metals in fins

	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**
Fe	-0.310						
Cu	-0.383	0.264					
Zn	-0.208	0.645	0.152				
Cd	0.033	0.580	0.018	0.838			
Pb	-0.197	0.481	0.266	0.916	0.769		
As	-0.129	0.312	0.055	0.526	0.686	0.357	
Hg	-0.152	0.709	0.422	0.807	0.768	0.687	0.692

Table 13. Summary of the correlation coefficient values of heavy metals in stomach linings

	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**
Fe	0.435						
Cu	0.036	0.777					
Zn	0.298	0.736	0.694				
Cd	-0.053	0.220	0.274	0.474			
Pb	0.231	0.812	0.889	0.877	0.238		
As	-0.328	0.192	0.434	0.451	0.350	0.350	
Hg	0.462	0.628	0.571	0.900	0.389	0.714	0.351

Table 14. Summary of the correlation coefficient values of heavy metals in gills

	Cr	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**As**
Fe	0.144						
Cu	0.059	0.284					
Zn	0.223	0.732	0.727				
Cd	0.613	0.380	0.462	0.606			
Pb	0.334	0.770	0.731	0.913	0.598		
As	0.085	0.517	0.836	0.884	0.499	0.804	
Hg	0.073	0.761	0.456	0.878	0.504	0.776	0.655

Positive correlation coefficients implied that the potentially exposed and bioaccumulated tissue samples originated from the same source. Likewise, the Malacca Strait included waste from both terrestrial and marine sources. For example, the vessels in the areas were accompanied by accident-related platform activities. Therefore, the heavy metal contamination of fish in Johor was likely caused by urban activities [37, 24]. The predatory fish in this study acquired a higher trophic level while accumulating more heavy metals. Since carnivorous fish are active swimmers, these fishes mostly ingest fingerlings, shrimps, and zooplankton. These activities can result in large heavy metal accumulations in the body. Furthermore, the surroundings and dietary habits determine the heavy metal accumulations. Another concern lies in fishes with steady growth rates that inhabit contaminated settings, which stabilise the heavy metal accumulations [38].

Based on present data, the livers contained the highest metal concentrations than other tissue samples, and contaminants tend to concentrate in tissues with high lipid content. This outcome suggested that sharks possessed high lipid concentrations in their livers. Similarly, other elasmobranchs also accumulated pollutants [26]. Table 15 lists the results following the calculated average PLI values in Table 14. The overall average results indicated that the samples were moderately contaminated and that no immediate action was necessary for the research region.

Table 15. Summary of the PLI values in this study

Tissue Sample	**PLI**
Gills	3.31
Muscles	2.23
Fins	3.14
Stomach Linings	2.47
Livers	3.35

Conclusion

This study successfully demonstrated the heavy metal concentrations in tissue samples, which were ascending. The orders were Hg < Cd < Fe < Pb < Cr < Cu < As < Zn for gills, Cd < Hg < Fe< Pb < Cr < Cu < As < Zn for muscles, Cd < Hg < Pb < Fe < Cr < Cu < As < Zn for fins, Cd < Hg < Fe < Pb < Cr < As < Cu < Zn for stomach linings, and Fe < Cd < Hg < Pb < Cr < As < Cu < Zn for livers. The livers acquired the most heavy metals, while Zn was the highest among all tissue samples. Furthermore, shark size was not the only factor determining heavy metal concentrations. Several factors involving eating habits, environment, gender, and species type, could influence heavy metal concentrations. Consequently, this study concluded that no immediate action was required based on the PLI values. Nevertheless, considerable precautions were still needed as most bioaccumulated heavy metals originated from the same source.

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