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Original Article

Zinc in commercial marine fish from Peninsular Malaysia: Biomonitoring, health risks, and UNSDGs' connection

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Abstract
The present study aimed to determine the human health risk (HHR) of zinc (Zn) in forty species of marine commercial fishes sourced from Peninsular Malaysia and available between April and May 2023. These species exhibited concentrations of Zn ranging from 24.1 to 153 mg kg^{-1} dried weight. These values fell below the maximum allowable limits established by seafood safety guidelines, indicating that the fish are valuable sources of the essential element. The Zn target hazard quotient values were below 1, suggesting that consuming fish containing Zn poses no non-carcinogenic risks. Additionally, it was discovered that the computed estimated weekly Zn intake values were lower than the established provisional allowable weekly Zn intake. It can be inferred that ingesting fish from Peninsular Malaysia would not expose consumers to any detrimental consequences regarding Zn levels. Although this is true, on-going surveillance via Fish Watch (biomonitoring of metal pollution using fish) is imperative to safeguard the well-being of consumers who significantly depend on commercial marine fish imported from Peninsular Malaysia. The study contributes to the achievement of the United Nations Sustainable Development Goals, particularly Goal 3 (Good Health and Well-being) by promoting safe consumption, Goal 12 (Responsible Consumption and Production) through sustainable fishing practices, and Goal 14 (Life Below Water) by emphasizing the importance of protecting marine ecosystems.

Keywords: coastal pollution; essential metals; fish consumption; public concerns

1 | INTRODUCTION

Zinc (Zn) has been routinely detected and recorded in commercial seafood in the literature. This may be because Zn, although an important element with significant health advantages are potentially toxic metals (PTMs) when it is ingested more than human health risk (HHR) thresholds (Bosch *et al.* 2016). Roney *et al.* (2005) and Dorsey *et al.* (2021) thoroughly documented the toxicology of Zn; environmental health requirements are also set by World Health Organization (WHO 1998, 2001).

Zinc is an essential micronutrient for fish growth (Chen *et al.* 2008). It aids immune function, tissue maintenance, wound healing, lipid and glucose metabolism, and hormone synthesis. Fish with physiological Zn levels have a protective effect on free radical production. Zinc overload may harm fish cells (Wang *et al.* 2023). In fish, high Zn levels can cause cytotoxicity by competing with other metals for protein binding, causing protein breakdown and dysfunction. Cell membrane structure and cell division and death depend on Zn.

Zinc overexposure from fish consumption can lead to harmful effects on human health, including nausea, vomiting, abdominal cramps, fatigue, dizziness, and neutropenia (Shears and Fletcher 1985; Daniszewski and Konieczny 2013; Innigo-Figueroa *et al.* 2013; Obaidat *et al.* 2015; Zahra and Kalim 2017; Aberoumand and Baesi 2018; Andarani *et al.* 2020; Miao *et al.* 2021; Owoeye 2021). Fish with high Zn levels can accumulate the metal in their tissues, which can then biomagnify through the aquatic food chain, posing a risk to consumers (Liang *et al.* 2014). While zinc is an essential micronutrient crucial for immune function, tissue maintenance, wound healing, and metabolism, excessive amounts can damage fish cells and affect human health. Therefore, monitoring zinc concentrations in fish populations is necessary to protect both environmental and human health (Liu *et al.* 2022).

PTM concentrations in fish from different nations and areas (e.g. Red Sea: Khalaf *et al.* 2012, El-Moselhy *et al.* 2014, Younis *et al.* 2021; India: Kureishy *et al.* 1981, Nair *et al.* 1997; Mohan *et al.* 2012; Pakistan: Raza *et al.* 2003; Ahmed *et al.* 2014; Velusamy *et al.* 2014; Kakar *et al.* 2020; Malaysia: Yap and Al-Mutairi 2022; Indonesia: Takarina *et al.* 2021; Persian Gulf or Iran: Abdolahpur Monikh *et al.* 2013, Abadi *et al.* 2015, Hosseini *et al.* 2015, Agah *et al.* 2016, Janadeleh and Jahangiri 2016; Bangladesh: Rahman *et al.* 2012; Lakshmanasenthil *et al.* 2013; Jahangir Sarker *et al.* 2020; and Tanzania: Mziray and Kimirei 2016) have been studied extensively. Most monitoring data and direct comparisons to food safety requirements for PTMs were discovered in studies published before 2000. Recent marine fish HHR evaluations have used PTM provisional tolerable weekly intake (PTWI) and target hazard quotient (THQ). For instance, Babji et al. (1979) assessed the maximum permissible limits (MPLs) of PTMs (including Zn) in six Peninsular Malaysian marine fish species to food standards. Kureishy *et al.* (1981) monitored six metals in Andaman Sea marine species, including Zn. No seafood safety guidelines were used to compare these amounts. In addition to PTM concentrations, Fathi *et al.* (2013) found that three marine fish species from Mersing, on Peninsular Malaysia's east coast, had estimated daily and weekly intakes of four PTMs (including Zn) far below the PTWI limits. In addition to Zn exceeding food safety regulations, Jahangir Sarker *et al.* (2020) observed that THQ values below one for all fish species suggested no public health hazards. Alipour *et al.* (2021) found a considerable non-carcinogenic danger for Malaysian and Bangladeshi babies and adults.

Malaysia's current per capita fish consumption rate is approximately 52.7 kg annually (Tan *et al.* 2024). This high consumption highlights the importance of continuous monitoring of PTMs in marine fish, as several studies have already been conducted to assess the safety and quality of seafood consumed by the population (Agusa *et al.* 2007; Irwandi and Farida 2009; Ahmad Kamal *et al.* 2012; Rosli *et al.* 2018; Wan Azmi *et al.* 2019). Agusa *et al.* (2005) measured twenty-one trace elements (including Zn) in twelve marine fish species from Malaysian coastal areas. Bigeye scad (*Selar crumenophthalmus*) from Peninsular Malaysia's east coast had seven PTMs, including Zn, which were higher than those from the west. The risk assessment of nine heavy metals in 46 marine fish species from Peninsular Malaysia's coastal waters found that all fish species had THQ values below one, indicating a low non-carcinogenic risk and safety for human consumption. Salam *et al.* (2021) found that Kedah and Selangor citizens who regularly eat torpedo scad (*Megalaspis cordyla*) had a high chronic risk using the THQ value.

The research addresses key knowledge gaps related to Zn concentrations in commercial marine fish, particularly in the context of Peninsular Malaysia. While previous studies have documented potentially toxic metals (PTMs) in fish, most of the data available are outdated, with limited focus on more recent monitoring efforts. Additionally, there is insufficient information on the extent of Zn biomagnification within the aquatic food chain and its subsequent accumulation in fish species sold in local markets. The potential health risks associated with consuming zinc-contaminated fish, especially in relation to Human Health Risk (HHR) thresholds and provisional tolerable weekly intake (PTWI) limits, are poorly understood in Malaysia. This gap is significant given the population's heavy reliance on marine fish as a major protein source, which underscores the need for updated research to assess the risks posed by Zn overexposure.

In light of these gaps, the primary objectives of the research are to determine current Zn concentrations in 40 commercially available marine fish species purchased from Malaysian markets in 2023 and to evaluate the associated health risks. The study aims to conduct a comprehensive HHR using established indicators such as the THQ and PTWI, comparing these values against international food safety standards. Furthermore, the research seeks to assess the biomagnification potential of zinc in the aquatic food chain and identify species with elevated risks. By evaluating both short-term and long-term health effects of Zn overexposure, this study aims to provide insights that will guide future monitoring and regulatory actions to protect public health in Malaysia.

2 | METHODOLOGY

2.1 Sample collection

From March 31 to May 2, 2023, 40 commercial marine fish samples were randomly purchased from Peninsular Malaysian marketplaces of various sources (Table S1). Table S1 demonstrates that fish samples were sourced from a wide range of markets across different states in Peninsular Malaysia, including urban areas such as Kuala Lumpur, coastal regions like Kuantan and Johor Bahru, and more rural areas such as Pekan and Kelantan. This broad geographic coverage reduces the risk of sample bias by ensuring that various fish species from different environmental and market conditions are included. Additionally, markets were selected to represent both inland and coastal locations, reflecting a diverse distribution of fish availability and potential Zn concentrations.

The term "randomly purchased" refers to a simple random sampling approach, where fish samples were randomly selected from different vendors across multiple markets to avoid bias in the selection process. This ensured a representative sample of commercially available fish in the region. Table S1 lists the common name, scientific name, purchase location, and time. The fish samples were immediately frozen at –20°C after collection to preserve their integrity. As the main Zn storage location, all fish samples' edible dorsal muscles were dissected for metal analysis (Yap and Al-Mutairi 2022). In the dissection process, we utilized sterile stainless-steel scalpels and forceps to carefully extract the dorsal muscle tissue from the fish specimens. These instruments were thoroughly cleaned and sterilized between samples to prevent cross-contamination. Fish were categorized using www.fishbase.org, and Mohsin and Ambak (1996) and Matsunuma *et al.* (2011). To verify each fish species' name, family, and niche habitat, the Fishbase web database (https://www.fishbase.org) was used.

2.2 Sample preparation

The samples were put in a refrigerator-safe package with ice right after they were collected to keep them fresh. Ice was used to maintain moisture during shipping. The samples were rinsed with water to get rid of any alien particles. Any water that was left over was soaked up by the fish using a paper towel. An electric scale was used to weigh each fish, and then a ruler was used to measure its length. The fish's length was measured from the front of the upper jaw to the end of its tail. Once this was done, the fish's dorsal muscles were cut open. Ten to 20 g of dorsal muscle were cut out of each fish. According to Rahman *et al.* (2012), the main place where fish store metal is in their muscles.

The specimens were preserved by freezing them and then taken to the laboratory at Universiti Putra Malaysia, where they were put into groups by species to avoid any chance of infection. After that, the samples were put in a freezer until it was time to do the metal tests. The samples are taken out of the freezer in the lab and left to warm up.

The dorsal muscle part of the fish was cut and was measured for its fresh water. The wet samples were dried onto an oven of 60°C for 72 hours. Afterwards, they were measured for their dry weight. This is to determine the water content by measuring the weight loss after drying. After that, a grinder and an agate pestle were used to mix the pieces. The sample powder was kept in plastic bags until further analysis.

2.3 Zinc analysis

The present study analysed three replicates for each fish sample. After precisely weighing 0.50 g of the homogenized dried sample, 5 mL of concentrated nitric acid (HNO3; AnalaR grade, BDH 69%) was added to the digesting vessel. Subsequently, the materials underwent predigestion for one hour at 40°C in a hot block digester. After three hours, the temperature was increased to 140°C to digest the samples fully (Yap *et al.* 2016).

After digestion, the solution was allowed to settle for 30 minutes before being diluted to a final level of 40 mL with distilled water. After filtering the acid digest using filter paper, it was put into pillboxes washed with acid (specifically, Whatman No. 1). The amounts of Zn in the decomposed fish samples were measured using a flame atomic absorption spectrometer (FAAS; Model AA 800, USA), which utilized an air-acetylene flame. The FAAS demonstrated a detection limit of 0.007 mg L^{-1} for Zn. Our analysis found no samples below the detection limit of 0.007 mg L^{-1} for Zn using FAAS. However, in cases where concentrations were below the detection limit, the results were reported as half the detection limit rather than as zero to maintain statistical integrity.

The plastics and glassware were soaked in a solution of 10% nitric acid for a whole night, then rinsed with distilled water and dried before use. The goal is to minimize the possibility of contamination. To provide quality control, the procedural blanks and triplicates of the samples were also analyzed. The procedural blanks were included in every batch of sample digestion to account for any potential contamination from reagents or the environment. Specifically, one blank was processed for every thirty samples during digestion. This regular use of blanks helped ensure the accuracy and reliability of the results. Blanks were used simultaneously in each set of experiments to ensure the accuracy of the results. The Certified Reference Materials (CRM) underwent digestion using the same process. The correctness of the approach was verified using the CRM (Certified Reference Material) of dogfish liver, namely the DOLT-3 provided by the National Research Council Canada. The obtained findings agreed with the confirmed values, indicating the method's capacity to produce consistent results (Zn CRM= 86.6 mg kg^{-1}, Zn measurement = 103 mg kg^{-1} with CV = 1.80%). The recovery yielded good results, ranging from 106 to 119%.

2.4 Zinc data treatment for human health risk assessment

To conduct a human health risk assessment (HHRA), the data on the concentration of Zn, measured on a dry weight (dw) basis, were converted to a wet weight (ww) basis. This conversion was done using a conversion factor specific to each fish species, as indicated in Table S1. Three evaluations were conducted to estimate the Human Health Risk Assessment (HHRA) resulting from the consumption of the fish.

a) Direct comparisons with MPLs: This study utilized three Maximum Permissible Limits (MPLs) of Zn from seafood safety standards. Specifically, the MPLs provided by the Food and Agriculture Organization (FAO 1983), the Ministry of Agriculture, Fisheries and Food (MAFF 2000), and the Malaysian Food Regulation 1985 (MFR 1985) were employed.

b) Estimation of THQ: The initial step to determine the THQ was to calculate the expected daily intake (EDI). EDI refers to calculating the specific metal intake based on the individual's body weight (BW) and rate of fish eating. The calculation was performed according to the following equation:

$$EDI = (Mc \times CR) / BW$$

Where, Mc = Metal concentration in the fish muscles (mg kg^{-1}) on a ww basis. The table labelled S2 provides the water contents of all the fish in the dorsal muscle region and their corresponding conversion factors. Nevertheless, the present study suggested that all the fish species' skin's water content may reach 50%. The giant catfish has been shown to possess a water content of 53.8% in its skin (Sai-Ut *et al.* 2012). Hence, a uniform conversion factor of 0.50 was used for all fish samples in this investigation. CR = Fish consumption rate (100 g $person^{-1}$ day^{-1}) for Malaysian adults based on 2675 respondents (Malay: 76.9%; Chinese: 14.7%; India: 8.4%) (Nurul Izzah *et al.* 2016). BW = Body weight employed was 62 kg for the adult Malaysian population, according to Nurul Izzah *et al.* (2016).

Later, the THQ was calculated using the following equation:

$$THQ = EDI / ORD$$

Where, ORD = Oral Reference Dose. The ORD measures the amount of a harmful substance consumed daily during a person's lifetime without causing any negative health consequences (Idriss and Ahmad 2015). This investigation utilized the ORD values (Zn = 300, µg kg^{-1} day^{-1}) specified by the USEPA regional screening level (US EPA 2021).

c) Comparisons between estimated weekly intake (EWI) and PTWI.

The PTWI was established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA 2010). The risk to human health from fish intake was assessed by calculating weekly metal exposures and comparing the findings to the prescribed PTWI levels. The PTWI, or Provisional Tolerable Weekly Intake, is a measure of the amount of a chemical in food or drinking water that may be safely ingested every week during a person's lifetime without causing any substantial health risks (JECFA 2010).

Consequently, computations were conducted to determine the number of fish from this investigation that surpassed the PTWI limitations. As per the Joint FAO/WHO Expert Committee on Food Additives (JECFA) reports (JECFA 2010; WHO/JECFA 2022), the acceptable weekly intake of Zn is 1.00 mg kg^{-1} body weight (BW). This value was derived by converting the preliminary maximum tolerated daily intake of 1.00 mg/kg BW/day for Zn. Consequently, the PTWI for Zn is 434 mg per week for an adult weighing 62 kg. In order to assess the potential danger of ingesting fish, the Estimated Weekly Intake (EWI) of fish components was determined using the following equation.

$$EWI = EDI \times 7$$

Where, EDI = estimated daily intake calculated earlier. The value was multiplied by 7 to get weekly value.

The comparison of the computed EWI values with the set PTWI limits for a 62 kg adult will decide if the calculated EWI values are lower than the established PTWI for Zn.

3 | RESULTS AND DISCUSSION

Even though there was a total of 40 fish species analyzed for Zn in the present study, for the measurements of body weights and body lengths, the study collected data on 119 individuals from 37 fish species in Peninsular Malaysia. Three species were not included for the two parameters due to human errors. The body wet weights of the fish varied from 3.00 to 4.00 g for *Valumugil seheli* and from 245 to 315 g for *Euthynnus affinis* (Table S2). The study examined a sample of 113 fish individuals from 35 species (excluding five unrecorded species) obtained from various markets and sources in Peninsular Malaysia. The highest body lengths observed varied from 14.7 – 16.4 cm for *Selaroides leptolepis* to 80 – 93 cm for *Trichiurus lepturus* (Table S2).

The analysed samples for Zn concentrations of marine fish consisted of 40 species, which belonged to 19 families. These families were Ariidae (1 species), Anabantidae (1 species), Balastidae (1 species), Belanidae (1 species), Carangidae (12 species), Dorosomatidae (3 species), Drepaneidae (1 species), Epinephelidae (1 species), Haemulidae (2 species), Latidae (1 species), Mugillidae (1 species), Mullidae (1 species), Nemipteridae (1 species), Polynemidae (2 species), Sciaemidae (1 species), Scombridae (6 species), Siganidae (1 species), Sphraemidae (2 species), and Trichiuridae (1 species). These families may be classified into specific niche environments, notably amphidromous and demersal. The following terms are used to describe different types of aquatic organisms: potamodromous, anadromous, oceanodromous, catadromous, demersal, reef-associated, pelagic neritic, tropical, and benthopelagic (Table S2).

3.1 Comparison with food safety guidelines of Zn

The amounts of Zn in the 40 fish species varied from 2.08 to 37.2 mg kg^{-1} ww (24.1 – 153 mg kg^{-1} dw) (Figure 1; Table 1, Table S3). The current Zn levels were found to be lower than the maximum permissible limits (MPLs) recommended by the Food and Agriculture Organization (FAO 1983), the Ministry of Agriculture, Fisheries and Food (MAFF 2000), and the Malaysian Food Regulation 1985 (MFR 1985). The MPLs proposed by these organizations were 40 – 150 mg kg^{-1} ww, 50 mg kg^{-1} ww, and 100 mg kg^{-1} ww, respectively. Consequently, no apparent Zn hazard was linked to consuming commercially purchased fish from Peninsular Malaysia. Comparable results are seen for the fish skin, despite the fact that the Zn levels in the fish skin are higher than those in the fish's muscular tissues (Figure 2).

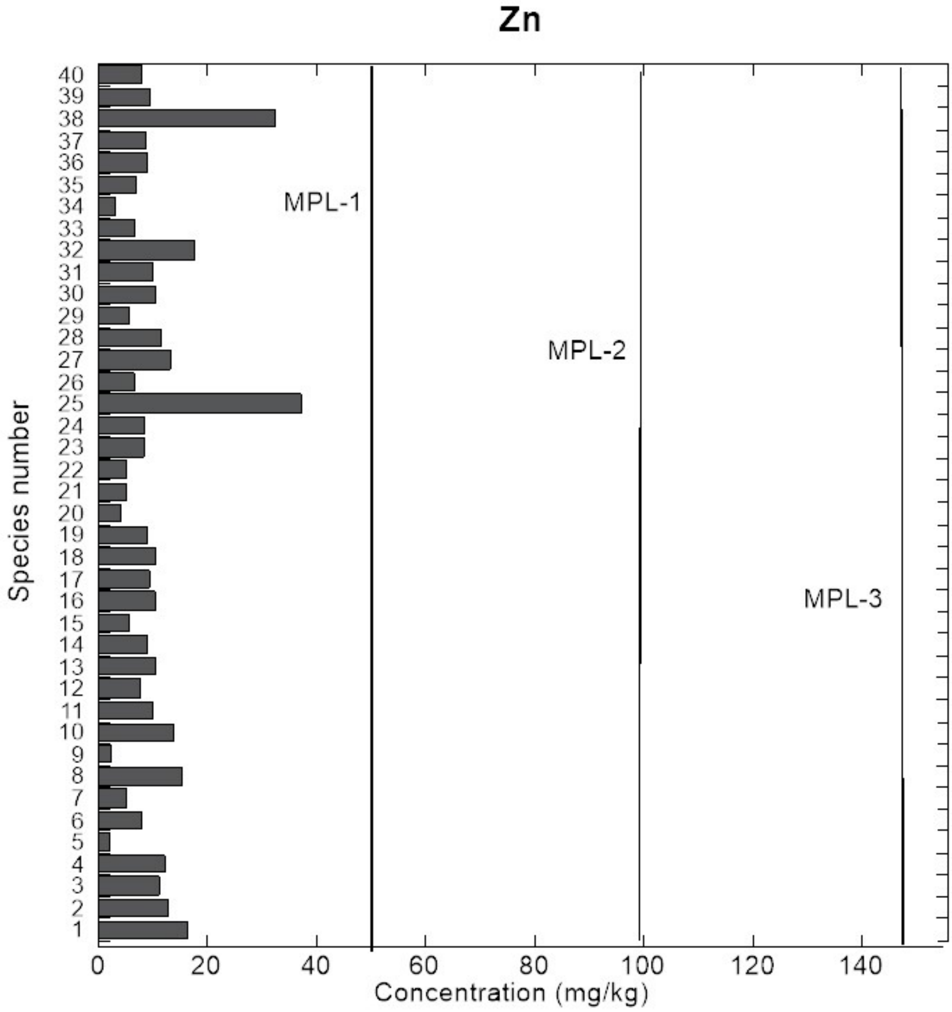

FIGURE 1 Mean concentrations (mean, mg kg^{-1} wet weight) of Zn in 40 commercial marine fish purchased from Peninsular Malaysia. MPL-1 = the Ministry of Agriculture, Fisheries and Food (MAFF 2000); MPL-2 = Malaysian Food Regulation 1985 (MFR 1985); MPL-3 = Food and Agriculture Organization (FAO 1983 missing); Note: 1 = *Abalistes stellaris*; 2 = *Alectis indicus*; 3 = *Alepes melanoptera*; 4 = *Anabas testudineus*; 5 = *Arius arius*; 6 = *Atule mate*; 7 = *Carangoides armatus*; 8 = *Decapterus macrosoma*; 9 = *Drepana punctata*; 10 = *Elagatis bipinnulata*; 11 = *Eleutheronema tetradactylum*; 12 = *Epinephelus tauvina*; 13 = *Escualosa thoracata*; 14 = *Euthynnus affinis*; 15 = *Lates calcarifer*; 16 = *Leptomelanosoma indicum*; 17 = *Megalaspis cordyla*; 18 = *Nemipterus tambuloides*; 19 = *Parastromateus niger*; 20 = *Pennahia argentata*; 21 = *Plectorhinchus flavomaculatus*; 22 = *Pomadasys kakaan*; 23 = *Rastrelliger brancysoma*; 24 = *Rastrelliger kanagurta*; 25 = *Sardinella fimbriata*; 26 = *Scomberoides lysan*; 27 = *Scomberomorus commerson*; 28 = *Scomberomorus guttatus*; 29 = *Selar boops*; 30 = *Selar crumenophthalmus*; 31 = *Selaroides leptolepis*; 32 = *Siganus javus*; 33 = *Sphyaera putnamae*; 34 = *Sphyraena obtusata*; 35 = *Tenualosa toli*; 36 = *Thunnus tonggol*; 37 = *Trichiurus lepturus*; 38 = *Tylosurus crocodilus*; 39 = *Upeneus sulphureus*; 40 = *Valumugil seheli*.

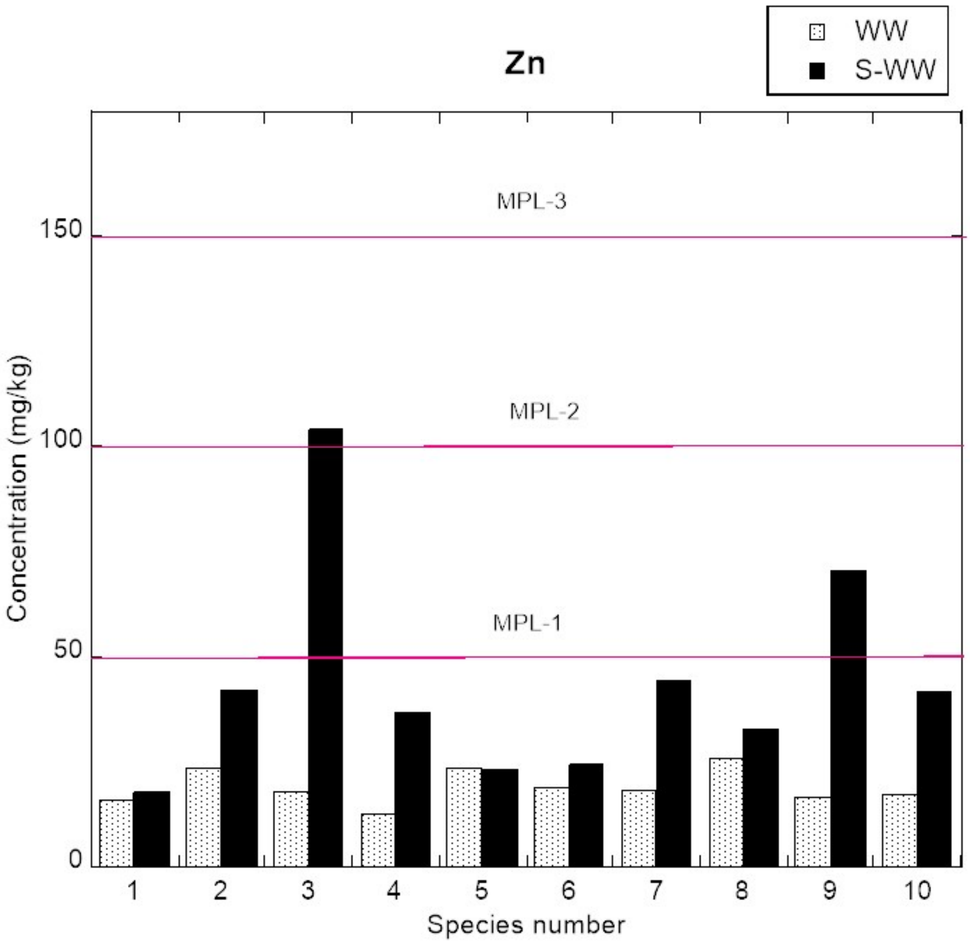

FIGURE 2 Mean concentrations (mean, mg kg^{-1} wet weight of Zn in the dorsal muscles [WW] and skins [S] of 10 commercial marine fish purchased from Peninsular Malaysia. Note: MPL-1 = the Ministry of Agriculture, Fisheries and Food (MAFF 2000); MPL-2 = Malaysian Food Regulation 1985 (MFR 1985); MPL-3= Food and Agriculture Organization (FAO 1983); Note: 1 = *Drepana punctata*; 2 = *Selar crumenophthalmus*; 3 = *Eleutheronema tetradactylum*; 4 = *Pomadasys kakaan*; 5 = *Megalaspis cordyla*; 6 = *Trichiurus lepturus*; 7 = *Siganus javus*; 8 = *Leptomelanosoma indicum*; 9 = *Scomberoides lysan*; 10 = *Tenualosa toli*.

3.2 Comparison with reported Zn concentrations in the different fish species

Zn levels (2.08 – 37.2 mg kg^{-1} ww; 24.1 – 153 mg kg^{-1} dw) (Figure 1; Table 1; Table S3) are higher than those (0.08 – 27.0 mg kg^{-1} ww; 0.34 – 104 mg kg^{-1} dw) for 92 reports of 20 articles (Table 2). Table 3 shows the mean Zn concentrations (mg kg^{-1} dw and ww) in 18 marine fish species reported in the literature. These Zn ranges are wider than those (5.29 – 20.9 mg kg^{-1} ww; 24.1 – 80.5 mg kg^{-1} dw) reported for the 19 Setiu commercial fish from the east coast of Peninsular Malaysia (Yap and Al-Mutairi 2022).

Compared to 16 recorded Zn levels, *R. kanagurta*'s (8.38 mg kg^{-1} ww) is within the range of 2.39 – 27.0 mg kg^{-1} ww. The current Zn level is lower than that (20.93 mg/kg ww) reported from Setiu, the Kunduchi fish market in Dar es Salaam (Tanzania) (27.0 mg kg^{-1} ww). Mersing, Indonesia, Thailand, Bangladesh, Andaman Sea, marine fish Peninsular Malaysia, Pahang coastal waters, Cochin coast (India), Palk Bay (India), Langkawi Island, West coast of Peninsular Malaysia, and Coastal waters off Kochi (India) were lower than the current research (Table 3). Ahmed *et al.* (2014) found that *R. kanagurta* has the highest Zn content (20.6 mg kg^{-1} ww).

Atule mate had a Zn content of 8.07 mg kg^{-1} ww, within the range of 6.72 – 14.1 mg kg^{-1} ww (Table 3). The current Zn level is lower than Setiu (14.1 mg kg^{-1} ww) and Marine fish Peninsular Malaysia (8.49 mg kg^{-1} ww) but greater than Kuala Terengganu (6.72 mg/kg ww). *Selaroides leptolepis* has a Zn level of 10.2 mg kg^{-1} ww, which is within the range (2.64 – 14.1 mg kg^{-1} ww) of four reported (Table 3) of marine fish from Peninsular Malaysia, Pa-hang coastal waters, and West coast.

The Zn content in *D. macrosoma* (58.8 mg kg^{-1} dw; 15.4 mg kg^{-1} ww) exceeds the 4.06 – 10.97 mg kg^{-1} ww of 5 reported (Table 3). The current Zn level is greater than that (10.97 mg kg^{-1} ww) from Setiu, Langkawi, Kuala Terengganu, Gulf of Aqaba (Jordan), and Marine fish Peninsular Malaysia by Khalaf *et al.* (2012) (20.3 mg kg^{-1} dw). Agusa *et al.* (2007) discovered 29.1 mg kg^{-1} dw Zn in *D. macrosoma*. Wan Azmi *et al.* (2019) found that *D. macrosoma* has the greatest Zn concentration (15.9 mg kg^{-1} ww) (Table 3).

TABLE 1 Overall statistics of Zn concentrations (mg kg^{-1} wet weight), estimated daily intake (EDI), target hazard quotient (THQ), and estimated weekly intake (EWI) in the 40 commercial marine fish species purchased from Peninsular Malaysia (*n* = 40).

	DW	WW	EDI	High EDI	THQ	High THQ	EWI	High EWI	PTWI (%)	High PTWI (%)
Minimum	24.05	2.08	3.36	6.72	0.01	0.02	23.5	47.1	0.01	0.01
Maximum	153	37.2	59.9	119	0.20	0.40	420	839	0.10	0.19
Mean	46.1	10.3	16.8	31.8	0.06	0.11	117	235	0.03	0.05
Median	39.6	9.18	14.8	28.7	0.05	0.10	102	204	0.02	0.05
SD	22.7	6.75	11.3	21.9	0.04	0.08	79.3	158	0.02	0.04
Variance	517	45.6	128	478	0.00	0.01	6280	25120	0.00	0.00
SE	3.60	1.07	1.79	3.46	0.01	0.01	12.5	25.1	0.00	0.01
Skewness	2.79	2.44	2.26	2.52	2.27	2.25	2.27	2.27	2.27	2.27
Kurtosis	10.25	6.94	5.60	7.36	5.65	5.60	5.66	5.66	5.66	5.66

Note: SD = standard deviation; SE = standard error. High = 2 times of normal consumption rate. WW = wet weight; DW = dry weight.

TABLE 2 Overall statistics of Zn concentrations (mg kg^{-1} wet weight) (WW) with recalculation of estimated daily intake (EDI), target hazard quotient (THQ), and estimated weekly intake (EWI) in the 20 commercial marine fish species cited from the literature (92 reports of 20 papers) (*n* = 92).

	DW	WW	EDI	High EDI	THQ	High THQ	EWI	High EWI	PTWI (%)	High PTWI (%)
Minimum	0.34	0.08	0.12	0.25	0.00	0.001	0.87	1.74	0.001	0.00
Maximum	104	27.0	43.6	171	0.15	0.29	5971	1194	0.14	0.28
Mean	28.09	6.27	10.12	22.4	0.03	0.07	78.37	156	0.02	0.04
Median	23.20	5.14	8.29	17.4	0.03	0.06	60.91	122	0.01	0.03
SD	18.45	4.46	7.20	21.1	0.02	0.05	73.88	148	0.02	0.03
Variance	340.36	19.92	51.81	446	0.00	0.00	5458	21833	0.00	0.00
SE	1.92	0.47	0.75	2.20	0.00	0.01	7.70	15.4	0.00	0.00
Skewness	1.78	2.15	2.15	4.37	2.14	2.15	4.37	4.37	4.37	4.37
Kurtosis	3.63	5.87	5.87	25.59	5.84	5.85	25.59	25.6	25.6	25.6

Note: SD = standard deviation; SE = standard error. High = 2 times of normal consumption rate. WW = wet weight; DW = dry weight.

TABLE 3 Values of estimated daily intake (EDI) (mg kg^{-1} body weight), target hazard quotient (THQ), and percentages (%) of ratios of estimated weekly intake (EWI) to provisional tolerable weekly intake (PTWI) of Zn in fish (*n* = 92) based on Zn cited data in the literature.

Species	DW	WW	EDI	High EDI	THQ	High THQ	EWI	High EWI	PTWI (%)	High PTWI (%)	Ref.
Alectis indicus	27.89	5.86	9.45	18.90	0.03	0.06	66.16	132.32	0.015	0.030	1
Anabas testudineus	6.47	1.85	2.98	10.06	0.01	0.02	35.20	70.41	0.008	0.016	2
Atule mate	21.50	6.72	10.84	21.68	0.04	0.07	75.87	151.74	0.017	0.035	3
Atule mate	47.72	8.49	13.69	27.39	0.05	0.09	95.85	191.71	0.022	0.044	4
Atule mate	61.17	14.1	22.69	45.39	0.08	0.15	158.85	317.71	0.037	0.073	1
Decapterus macrosoma	29.1	5.82	9.39	18.77	0.03	0.06	65.71	131.42	0.015	0.030	5
Decapterus macrosoma	20.3	4.06	6.55	13.10	0.02	0.04	45.84	91.68	0.011	0.021	6
Decapterus macrosoma	32.30	8.46	13.65	27.29	0.05	0.09	95.52	191.03	0.022	0.044	3
Decapterus macrosoma	60.70	15.9	25.65	51.29	0.09	0.17	179.52	359.03	0.041	0.083	4
Decapterus macrosoma	54.85	10.97	17.69	35.39	0.06	0.12	123.85	247.71	0.029	0.057	1
Epinephelus tauvina	21.60	4.039	6.51	13.03	0.02	0.04	45.60	91.20	0.011	0.021	7
Epinephelus tauvina	19.70	3.684	5.94	11.88	0.02	0.04	41.59	83.19	0.010	0.019	7
Lates calcarifer	17.1	3.42	5.52	11.03	0.02	0.04	38.61	77.23	0.009	0.018	5
Lates calcarifer	15.5	3.1	5.00	10.00	0.02	0.03	35.00	70.00	0.008	0.016	5
Lates calcarifer	15.6	3.12	5.03	10.06	0.02	0.03	35.23	70.45	0.008	0.016	5
Lates calcarifer	21.7	4.79	7.73	15.46	0.03	0.05	54.11	108.22	0.012	0.025	8
Megalaspis cordyla	27.2	6.26	10.10	30.19	0.03	0.07	105.68	211.35	0.024	0.049	5

TABLE 3 Continued.

Species	DW	WW	EDI	High EDI	THQ	High THQ	EWI	High EWI	PTWI (%)	High PTWI (%)	Ref.
Megalaspis cordyla	28.3	6.51	10.50	33.94	0.04	0.07	118.77	237.55	0.027	0.055	5
Megalaspis cordyla	27.9	6.42	10.35	13.29	0.03	0.07	46.52	93.03	0.011	0.021	5
Megalaspis cordyla	35.2	8.10	13.06	20.19	0.04	0.09	70.68	141.35	0.016	0.033	5
Megalaspis cordyla	29.3	6.74	10.87	21.00	0.04	0.07	73.50	147.00	0.017	0.034	5
Megalaspis cordyla	23.6	5.43	8.76	20.71	0.03	0.06	72.48	144.97	0.017	0.033	5
Megalaspis cordyla	20.4	4.69	7.56	26.13	0.03	0.05	91.45	182.90	0.021	0.042	5
Megalaspis cordyla	22.7	5.22	8.42	21.74	0.03	0.06	76.10	152.19	0.018	0.035	5
Megalaspis cordyla	21.3	4.9	7.90	17.52	0.03	0.05	61.31	122.61	0.014	0.028	5
Megalaspis cordyla	22	5.06	8.16	15.13	0.03	0.05	52.95	105.90	0.012	0.024	5
Megalaspis cordyla	45.74	10.52	16.97	15.65	0.06	0.11	54.76	109.52	0.013	0.025	9
Megalaspis cordyla	19.3	4.44	7.16	7.42	0.02	0.05	25.97	51.94	0.006	0.012	10
Megalaspis cordyla	19.95	3.99	6.44	9.68	0.02	0.04	33.87	67.74	0.008	0.016	11
Megalaspis cordyla	7.800	1.560	2.52	14.32	0.01	0.02	50.13	100.26	0.012	0.023	12
Megalaspis cordyla	15	3	4.84	22.58	0.02	0.03	79.03	158.06	0.018	0.036	13
Megalaspis cordyla	35	7	11.29	16.84	0.04	0.08	58.94	117.87	0.014	0.027	14
Megalaspis cordyla	10	2.3	3.71	15.81	0.01	0.02	55.32	110.65	0.013	0.025	14
Megalaspis cordyla	21.1	4.85	7.82	16.32	0.03	0.05	57.13	114.26	0.013	0.026	4
Megalaspis cordyla	17.9	4.12	6.65	5.97	0.02	0.04	20.89	41.77	0.005	0.010	1
Parastromateus niger	0.34	0.077	0.12	0.25	0.00	0.00	0.87	1.74	0.000	0.000	15
Pennahia argentata	2.515	0.42	0.68	1.35	0.00	0.00	4.74	9.48	0.001	0.002	16
Pennahia argentata	1.856	0.31	0.50	1.00	0.00	0.00	3.50	7.00	0.001	0.002	16
Rastrelliger brancysoma	17.4	4.40	7.09	14.18	0.02	0.05	49.63	99.26	0.011	0.023	5
Rastrelliger kanagurta	23.2	6.03	9.73	19.45	0.03	0.06	68.08	136.16	0.016	0.031	5
Rastrelliger kanagurta	15	3.90	6.29	12.58	0.02	0.04	44.03	88.06	0.010	0.020	5
Rastrelliger kanagurta	50.7	13.2	21.26	42.52	0.07	0.14	148.81	297.61	0.034	0.069	5
Rastrelliger kanagurta	21.1	5.49	8.85	17.71	0.03	0.06	61.98	123.97	0.014	0.029	5
Rastrelliger kanagurta	29.3	7.62	12.29	24.58	0.04	0.08	86.03	172.06	0.020	0.040	17
Rastrelliger kanagurta	19.83	4.64	7.48	14.97	0.02	0.05	52.39	104.77	0.012	0.024	18
Rastrelliger kanagurta	80.49	20.93	33.76	67.52	0.11	0.23	236.31	472.61	0.054	0.109	10
Rastrelliger kanagurta	104	27.0	43.55	87.10	0.15	0.29	304.84	609.68	0.070	0.140	19
Rastrelliger kanagurta	15	3.90	6.29	12.58	0.02	0.04	44.03	88.06	0.010	0.020	11
Rastrelliger kanagurta	37.4	9.72	15.68	31.35	0.05	0.10	109.74	219.48	0.025	0.051	12
Rastrelliger kanagurta	24	6.24	10.06	20.13	0.03	0.07	70.45	140.90	0.016	0.032	13
Rastrelliger kanagurta	38.9	10.13	16.34	32.68	0.05	0.11	114.37	228.74	0.026	0.053	20
Rastrelliger kanagurta	38.80	9.08	14.65	29.29	0.05	0.10	102.52	205.03	0.024	0.047	4
Rastrelliger kanagurta	80.49	20.9	33.76	67.52	0.11	0.23	236.31	472.61	0.054	0.109	1
Rastrelliger kanagurta	9.21	2.39	3.85	7.71	0.01	0.03	26.98	53.97	0.006	0.012	1
Rastrelliger kanagurta	26.03	6.09	9.82	19.65	0.03	0.07	68.76	137.52	0.016	0.032	1
Scomberoides lysan	26.800	5.36	8.65	17.29	0.03	0.06	60.52	121.03	0.014	0.028	5
Scomberomorus commerson	17.50	4.03	6.50	13.00	0.02	0.04	45.50	91.00	0.010	0.021	5
Scomberomorus commerson	9.43	2.17	3.50	7.00	0.01	0.02	24.50	49.00	0.006	0.011	21
Scomberomorus commerson	12.52	4.24	6.84	13.68	0.02	0.05	47.87	95.74	0.011	0.022	22
Scomberomorus commerson	37.20	8.56	13.81	27.61	0.05	0.09	96.65	193.29	0.022	0.045	18
Scomberomorus commerson	13.85	4.69	7.56	15.13	0.03	0.05	52.95	105.90	0.012	0.024	4
Scomberomorus commerson	49.60	11.41	18.40	36.81	0.06	0.12	128.82	257.65	0.030	0.059	1
Selar crumenophthalmus	28	7.292	11.76	23.52	0.04	0.08	82.33	164.65	0.019	0.038	5
Selar crumenophthalmus	39.2	6.261	10.10	20.20	0.03	0.07	70.69	141.37	0.016	0.033	5
Selar crumenophthalmus	25.5	8.765	14.14	28.27	0.05	0.09	98.96	197.92	0.023	0.046	5
Selar crumenophthalmus	29.7	5.702	9.20	18.39	0.03	0.06	64.38	128.75	0.015	0.030	5
Selar crumenophthalmus	27	6.641	10.71	21.42	0.04	0.07	74.98	149.96	0.017	0.035	5
Selar crumenophthalmus	35.4	6.037	9.74	19.47	0.03	0.06	68.16	136.32	0.016	0.031	5

TABLE 3 Continued.

Species	DW	WW	EDI	High EDI	THQ	High THQ	EWI	High EWI	PTWI (%)	High PTWI (%)	Ref.
Selaroides leptolepis	11	2.64	4.26	8.52	0.01	0.03	29.81	59.61	0.007	0.014	10
Selaroides leptolepis	22.47	4.49	7.24	14.48	0.02	0.05	50.69	101.39	0.012	0.023	12
Selaroides leptolepis	36.04	7.20	11.61	23.23	0.04	0.08	81.29	162.58	0.019	0.037	4
Selaroides leptolepis	58.78	14.1	22.76	45.52	0.08	0.15	159.31	318.61	0.037	0.073	1
Sphyraena obtusata	22.600	2.124	3.43	22.35	0.01	0.02	78.24	156.48	0.018	0.036	5
Sphyraena obtusata	18.700	1.758	2.84	170.52	0.01	0.02	596.81	1194	0.138	0.275	5
Sphyraena obtusata	73.723	6.93	11.18	17.81	0.04	0.07	62.32	124.65	0.014	0.029	23
Tenualosa toli	83.140	16.63	26.82	53.64	0.09	0.18	187.74	375.47	0.043	0.087	1
Trichiurus lepturus	25.3	5.57	8.98	17.97	0.03	0.06	62.89	125.77	0.014	0.029	24
Trichiurus lepturus	25.96	6.01	9.69	19.39	0.03	0.06	67.85	135.71	0.016	0.031	25
Trichiurus lepturus	42.34	9.31	15.02	30.03	0.05	0.10	105.11	210.23	0.024	0.048	26
Trichiurus lepturus	24.14	5.31	8.56	17.13	0.03	0.06	59.95	119.90	0.014	0.028	1
Valumugil seheli	13	2.600	4.19	8.39	0.01	0.03	29.35	58.71	0.007	0.014	5
Valumugil seheli	17.7	3.540	5.71	11.42	0.02	0.04	39.97	79.94	0.009	0.018	5
Valumugil seheli	15.3	3.060	4.94	9.87	0.02	0.03	34.55	69.10	0.008	0.016	5
Valumugil seheli	17	3.400	5.48	10.97	0.02	0.04	38.39	76.77	0.009	0.018	5
Valumugil seheli	25	5.000	8.06	16.13	0.03	0.05	56.45	112.90	0.013	0.026	5
Valumugil seheli	18.7	3.740	6.03	12.06	0.02	0.04	42.23	84.45	0.010	0.019	5
Valumugil seheli	23.2	4.640	7.48	14.97	0.02	0.05	52.39	104.77	0.012	0.024	5
Valumugil seheli	16.4	3.280	5.29	10.58	0.02	0.04	37.03	74.06	0.009	0.017	5
Valumugil seheli	19.2	3.840	6.19	12.39	0.02	0.04	43.35	86.71	0.010	0.020	5
Valumugil seheli	23.6	4.720	7.61	15.23	0.03	0.05	53.29	106.58	0.012	0.025	5
Valumugil seheli	16.9	3.380	5.45	10.90	0.02	0.04	38.16	76.32	0.009	0.018	5
Valumugil seheli	24.1	4.820	7.77	15.55	0.03	0.05	54.42	108.84	0.013	0.025	27

References: 1 = Yap and Mutairi (2022); 2 = Sarker *et al.* (2020); 3 = Ong *et al.* (2018); 4 = Wan Azmi *et al.* (2019); 5 = Agusa *et al.* (2007); 6 = Khalaf *et al.* (2012); 7 = Ahmad and Al Ghais (1996); 8 = Krishnamurthi and Nair (1999); 9 = Fathi *et al.* (2013); 10 = Kamaruzzaman *et al.* (2011); 11 = Nair *et al.* (1997); 12 = Nurnadia *et al.* (2013); 13 = Praveena and Lin (2015); 14 = Salam *et al.* (2019); 15 = Tabezar *et al.* (2023); 16 = Takarina *et al.* (2021); 17 = Arulkumar *et al.* (2017); 18 = Irwandi and Farida (2009); 19 = Mziray and Kimirei (2016); 20 = Rejomon *et al.* (2010); 21 = Ahmed *et al.* (2014); 22 = Gu *et al.* (2015); 23 = Jaziri *et al.* (2022); 24 = Anandkumar *et al.* (2018); 25 = Rahman *et al.* (2012); 26 = Velusamy *et al.* (2014); 27 = Krishnamurti and Nair (1999).

Scomberomorus commerson had a greater Zn content (13.2 mg kg^{-1} ww) than 6 published reports (2.17 – 11.4 mg kg^{-1} ww) (Table 3). The Zn level is greater than in Koh Kong (Cambodia), Marine fish Peninsular Malaysia, Langkawi Island, Karachi Coast, and Zhongsha. The literature reports 19 Zn levels, and *M. cordyla*'s (13.2 mg kg^{-1} ww) is within the range (2.30 – 10.5 mg kg^{-1} ww). The Zn level is greater than in Setiu, Langkawi, Port Dickson, Kelantan, Cambodia, Thailand, Marine fish Peninsular Malaysia, Pahang coastal waters, Mersing, Karachi Fish Harbour (Pakistan), Cochin coast (India), and West coast of Peninsular Malaysia (Table 3). The literature reports 5 – 9 mg kg^{-1} ww of Zn in *T. lepturus* (Table 3), whereas its current level is 8.67 mg kg^{-1} ww. The current Zn content is greater than Setiu (5.31 mg kg^{-1} ww) but lower than Mumbai Harbour.

Based on 46 marine fish species collected from Fisheries Development Authority of Malaysia major fish landing ports and Peninsular Malaysia wholesale markets, Wan Azmi *et al.* (2019) found D. macrosoma had the highest Zn concentration (15.9 mg kg^{-1} ww) and *Otolithoides biauritus* the lowest (2.30 mg kg^{-1} ww). Babji *et al.* (1979) found 2.30 – 6.50 mg kg^{-1} ww Zn in six Peninsular Malaysian fish species taken at six locations. Neither of the six species was among the 19 from the present research. North Sumatra fish had Zn levels of 2.97 to 11.5 mg kg^{-1} ww (Simanjuntak *et al.* 2012). Çelik and Oehlenschläger (2004) found Zn values of 2.38 to 9.73 mg kg^{-1} ww in 49 commercial fish species from the eastern Mediterranean Sea (Izmir Outer Bay, Homa Lagoon/Izmir, and Mersin Bay). Tuzen (2009) found 38.8 – 93.4 mg kg^{-1} ww Zn in 10 Black Sea fish species.

According to Arulkumar *et al.* (2017), *P. pelagicus* has the greatest Zn content (55.1 mg kg^{-1} ww), followed by *S. brevimana* (52.1 mg kg^{-1}) and *S. aculeate* (42.8 mg kg^{-1}). El-Moselhy *et al.* (2014) found Zn ranges from 1.17 to 12.0 mg kg^{-1} ww in fourteen benthic and pelagic fish species from three important landing places (Shalateen, Hurghada, and Suez) in the Egyptian Red Sea. *Arius thalassinus* and *J. belangeri* had Zn values of 30.2 to 13.1

mg kg^{-1} dw (Bashir *et al.* 2013). *Megalaspis cordyla* exhibited the lowest mean Zn concentration (17.5 mg kg^{-1} dw) in a Malaysian eastern coast (Fathi *et al.* 2013). Kamaruzzaman *et al.* (2010) discovered Zn level of 12.0 mg kg^{-1} dw (*S. leptolepis*) to 25.0 mg kg^{-1} dw (*R. kanagurta*) in Pahang coastal waters.

Anandkumar *et al.* (2018) found Zn, ranged between 16.9 and 71.0 mg kg^{-1} dw, in fish muscles of seven Miri coast marine fish species. In a study on Langkawi, Malaysia, all fish species had higher Zn concentrations than other metals, with muscle Zn concentrations ranging from 34.3 to 49.4 mg kg^{-1} dw (Irwandi and Farida 2009). Irwandi and Farida (2009) also reported that Pulau Tuba fish had Zn levels of 34.3 (*R. kanagurta*) to 49.4 mg kg^{-1} (*Lutjanus johnii*). Rejomon *et al.* (2010) found that Zn levels in the muscle tissue of different fish species ranged from 24.4 to 79.3 mg kg^{-1} dw and 37.4 to 84.3 mg kg^{-1} dw for fish collected off Mangalore and Kochi, respectively, with *Lates cal-carifer* having the highest concentration and *R. kanagurta* and *Cyanoglossus macrostomus* having the lowest.

In Kapar fish samples, Bashir *et al.* (2013) discovered Zn of 18.3 and 20.5 mg kg^{-1} dw in *J. belangeri* and *A. thalassinus* muscles, respectively. In Mersing fish samples, *J. belangeri* and *A. thalassinus* muscles had 13.1 mg kg^{-1} and 30.2 mg kg^{-1} dw Zn contents, respectively. Kalay *et al.* (1999) found 14.1 – 33.5 mg kg^{-1} dw Zn in Mediterranean Sea fish. In Bangladeshi fish from the Meghna River estuary, Jahangir Sarker *et al.* (2020) found Zn values of 39.5 – 180 mg kg^{-1} dw. Dural Eken *et al.* (2007) found 8.27 – 75.4 mg kg^{-1} dw Zn in three marine fish species captured in Turkey's Tuzla Lagoon. In 1990, tuna (*Thunnus thynnus*) muscle tissue from the northwest Atlantic Ocean had a mean Zn content of 12.0 to 25.0 mg kg^{-1} dw (Hellou *et al.* 1992).

3.3 THQ and EWI of Zn

The computed values of EDI, THQ, and EWI, derived from the present investigation and the mentioned Zn data in the literature for marine fishes, are displayed in Table S4. The table in this study provides an overview of the Zn concentrations (mg kg^{-1} ww), EDI, THQ, and EWI in the 40 commercial fish purchased from Peninsular Malaysia. Additionally, Figure 3 specifically displays the THQ values of the 40 commercial fish analysed in this study. Figure 4 presents the total heavy metal content (THQ values) of Zn in the dorsal muscles and skins of 10 commercially obtained marine fish from Peninsular Malaysia.

The Zn THQ values of 40 fish species examined in this study varied between 0.01 and 0.20 (Table 1). The reported Zn THQ values from 92 sources across 20 articles varied between 0.001 to 0.15 (Table 2). The Zn readings for all fish species were below 1, suggesting a low non-carcinogenic risk of Zn and confirming their safety for human consumption. This also indicates the lack of a public health threat from Zn exposure.

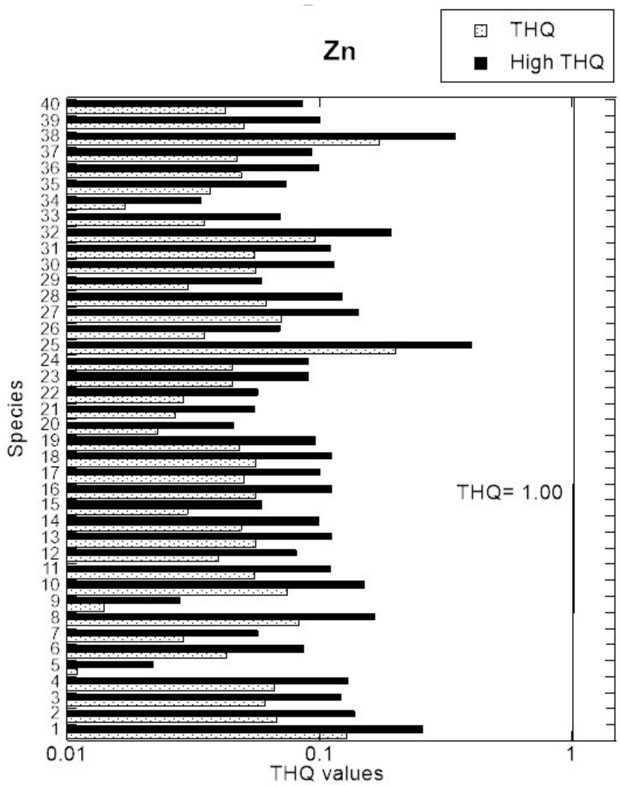

FIGURE 3 Target hazard quotient (THQ) values of Zn in 40 commercial marine fish purchased from Peninsular Malaysia. Note: High THQ values indicate two times consumption of the normal consumption rate. Note: 1 = *Abalistes stellaris*; 2 = *Alectis indicus*; 3 = *Alepes melanoptera*; 4 = *Anabas testudineus*; 5 = *Arius arius*; 6 = *Atule mate*; 7 = *Carangoides armatus*; 8 = *Decapterus macrosoma*; 9 = *Drepana punctata*; 10 = *Elagatis bipinnulata*; 11 = *Eleutheronema tetradactylum*; 12 = *Epinephelus tauvina*; 13 = *Escualosa thoracata*; 14 = *Euthynnus affinis*; 15 = *Lates calcarifer*; 16 = *Leptomelanosoma indicum*; 17 = *Megalaspis cordyla*; 18 = *Nemipterus tambuloides*; 19 = *Parastromateus niger*; 20 = *Pennahia argentata*; 21 = *Plectorhinchus flavomaculatus*; 22 = *Pomadasys kakaan*; 23 = *Rastrelliger brancysoma*; 24 = *Rastrelliger kanagurta*; 25 = *Sardinella fimbriata*; 26 = *Scomberoides lysan*; 27 = *Scomberomorus commerson*; 28 = *Scomberomorus guttatus*; 29 = *Selar boops*; 30 = *Selar crumenophthalmus*; 31 = *Selaroides leptolepis*; 32 = *Siganus javus*; 33 = *Sphyaera putnamae*; 34 = *Sphyraena obtusata*; 35 = *Tenualosa toli*; 36 = *Thunnus tonggol*; 37 = *Trichiurus lepturus*; 38 = *Tylosurus crocodilus*; 39 = *Upeneus sulphureus*; 40 = *Valumugil seheli*.

The Zn EWI values of 40 fish species in this study varied between 23.5 and 420 (Table 1). The Zn EWI values, obtained from 92 published sources across 20 articles, varied between 0.87 and 597 (Table 2). The study found that the percentages of EWI to the PTWI varied between 0.001% and 0.10% for 40 different fish species (Table 1). The proportions of EWI to the PTWI were reported in 92 studies from 20 articles, with values ranging from 0.001% to 0.14% (Table 2). Figure 5 presents the percentages of EWI to PTWI of Zn in 40 commercially obtained marine fish from Peninsular Malaysia. Figure 6 provides the percentages (%) of EWI to PTWI of Zn in the dorsal muscles and skins of 10 commercially harvested marine fish. The results indicated that all the computed EWI values were much lower than the defined PTWI of Zn (7000 µg kg^{-1} BW week^{-1}). Thus, according to the FAO/WHO JECFA recommendations, the eating of the researched fishes would not have any harmful effects of Zn on consumers in terms of the fish's muscles and skin.

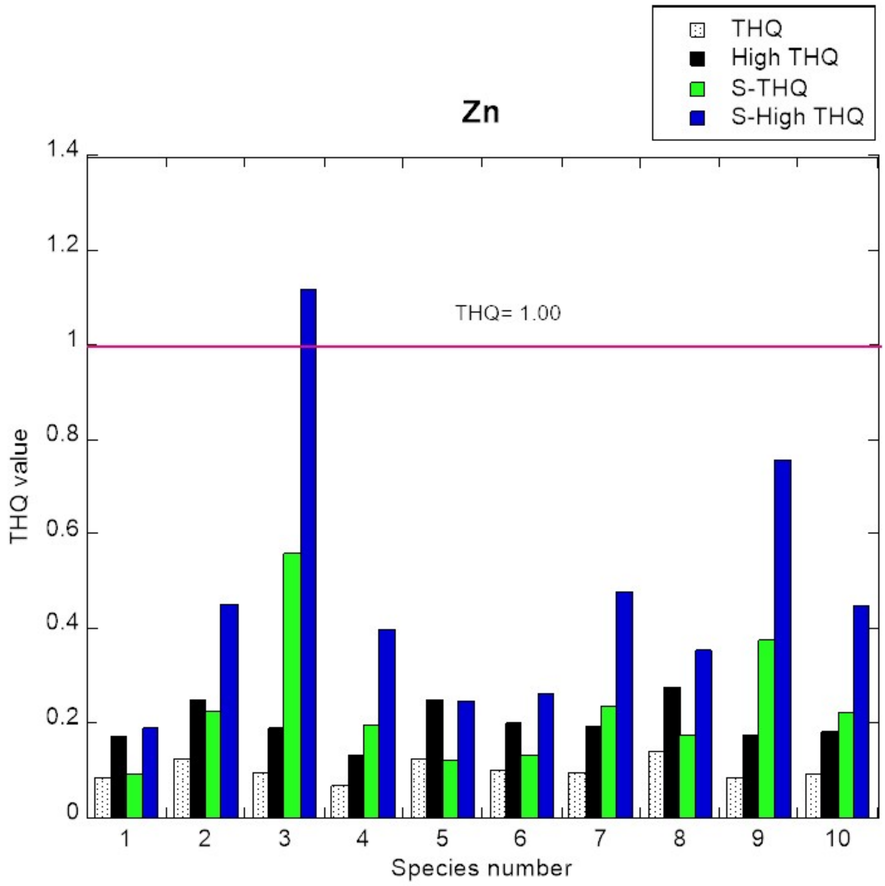

FIGURE 4 Target hazard quotient (THQ) values of Zn in the dorsal muscles and skins [S] of 10 commercial marine fish purchased from Peninsular Malaysia. Note: High THQ values indicate two times consumption of the normal consumption rate. Note: 1 = *Drepana punctata*; 2 = *Selar crumenophthalmus*; 3 = *Eleutheronema tetradactylum*; 4 = *Pomadasys kakaan*; 5 = *Megalaspis cordyla*; 6 = *Trichiurus lepturus*; 7 = *Siganus javus*; 8 = *Leptomelanosoma indicum*; 9 = *Scomberoides lysan*; 10 = *Tenualosa toli*.

Wan Azmi *et al.* (2019) documented the EWI of Zn to be between 7.3 and 15.9 µg kg^{-1} BW week^{-1}. The estimated hazard quotient (HQ) indicated that the HQ values were below 1, suggesting that consuming fish from Peninsular Malaysia has a minimal non-cancer risk to people. The research conducted by Peycheva *et al.* (2016) revealed that their HQ values for Zn (ranging from 0.0005 to 0.0010) were comparatively lower than the values observed in our investigation.

Ates *et al.* (2015) documented the EDI and EWI values of Zn for commercially significant fish species that are ingested by adult individuals in Turkey. These numbers were approximated based on the assumption that an individual with a body weight of 70 kg will consume 20 g of fish per day, which is equivalent to 140 g of fish each week. The estimated EWI values for 8 commercially important fish species taken from the Aegean and Mediterranean oceans varied from 532 to 7490 µg 70kg^{-1} BW week^{-1}. These values were much lower than the suggested PTWI values of 7000 µg kg^{-1} BW week^{-1} (JECFA 2010), with the exception of *Serranus scriba*, which had a value of 7490 µg 70kg^{-1} BW week^{-1}. Nevertheless, the Zn EWI values were significantly below the PTWI of 490,000 µg kg^{-1} BW week^{-1} for the average adult weighing 70 kg (JECFA 2010).

The estimated daily dietary consumption levels for total Zn are 5.6 – 10 mg day^{-1} for babies and children aged 2 months to 11 years, 12.3 – 13.0 mg day^{-1} for children aged 12 – 19 years, and 8.8 – 14.4 mg day^{-1} for people aged 20 – 50 years (WHO 2001). The daily dietary Zn consumption in this nation typically varies between 5.2 and 16.2 mg. The National Academy of Sciences has determined that the Recommended Dietary Allowance (RDA) for Zn is 11 mg per day for males. The equivalent dosage for an average adult male (70 kg) is 0.16 mg kg^{-1} BW day^{-1}, which is equal to eleven mg every day. A Recommended Dietary Allowance (RDA) of 8 mg day^{-1}, or 0.13 mg kg^{-1} of body weight for an average adult female (60 kg), was determined to account for the lower average weight of women compared to males. Infants (2 – 3 mg day^{-1}) and children (5 – 9 mg day^{-1}) are advised to consume less Zn due to their lower typical body weights (Roney *et al.* 2005).

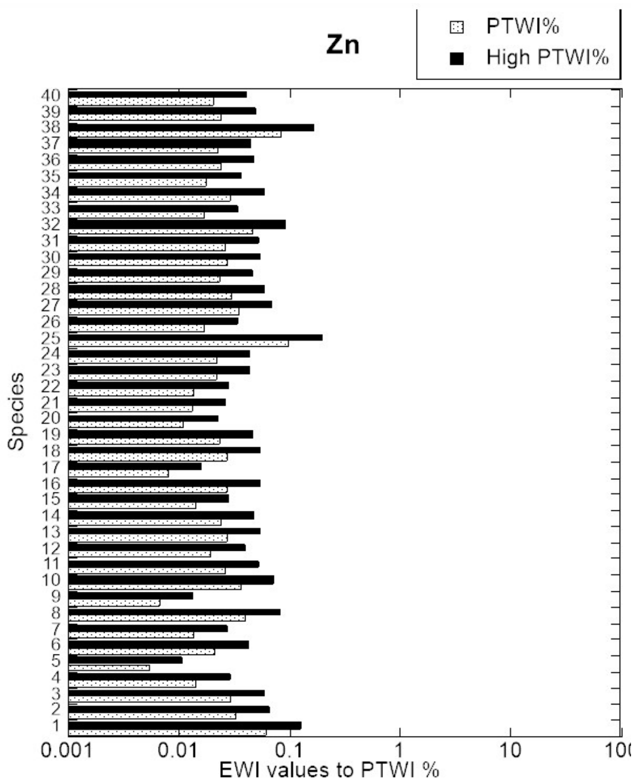

FIGURE 5 Percentages (%) of estimated weekly intake (EWI) to provisional tolerable weekly intake (PTWI) of Zn in 40 commercial marine fish purchased from Peninsular Malaysia. Note: High PTWI values indicate two times consumption of the normal consumption rate. Note: 1 = *Abalistes stellaris*; 2 = *Alectis indicus*; 3 = *Alepes melanoptera*; 4 = *Anabas testudineus*; 5 = *Arius arius*; 6 = *Atule mate*; 7 = *Carangoides armatus*; 8 = *Decapterus macrosoma*; 9 = *Drepana punctata*; 10 = *Elagatis bipinnulata*; 11 = *Eleutheronema tetradactylum*; 12 = *Epinephelus tauvina*; 13 = *Escualosa thoracata*; 14 = *Euthynnus affinis*; 15 = *Lates calcarifer*; 16 = *Leptomelanosoma indicum*; 17 = *Megalaspis cordyla*; 18 = *Nemipterus tambuloides*; 19 = *Parastromateus niger*; 20 = *Pennahia argentata*; 21 = *Plectorhinchus flavomaculatus*; 22 = *Pomadasys kakaan*; 23 = *Rastrelliger brancysoma*; 24 = *Rastrelliger kanagurta*; 25 = *Sardinella fimbriata*; 26 = *Scomberoides lysan*; 27 = *Scomberomorus commerson*; 28 = *Scomberomorus guttatus*; 29 = *Selar boops*; 30 = *Selar crumenophthalmus*; 31 = *Selaroides leptolepis*; 32 = *Siganus javus*; 33 = *Sphyaera putnamae*; 34 = *Sphyraena obtusata*; 35 = *Tenualosa toli*; 36 = *Thunnus tonggol*; 37 = *Trichiurus lepturus*; 38 = *Tylosurus crocodilus*; 39 = *Upeneus sulphureus*; 40 = *Valumugil seheli*.

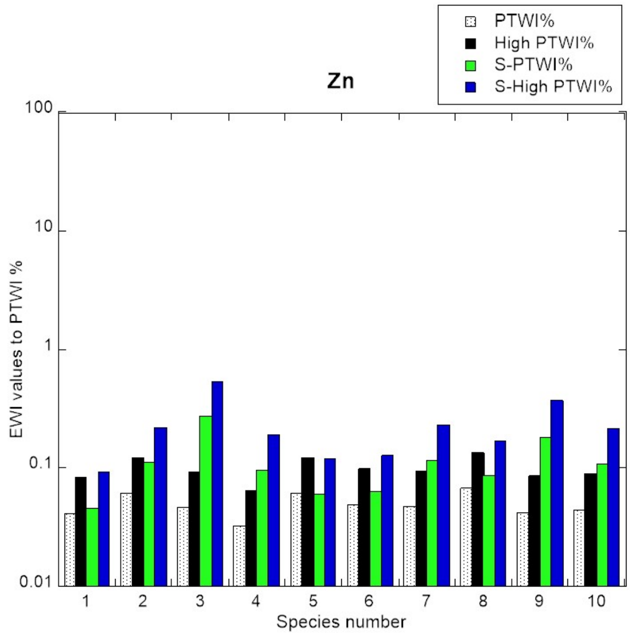

FIGURE 6 Percentages (%) of estimated weekly intake (EWI) to provisional tolerable weekly intake (PTWI) of Zn in the dorsal muscles and skins [S] of 10 commercial marine fish purchased from Peninsular Malaysia. Note: High THQ values indicate two times consumption of the normal consumption rate. Note: 1 = *Drepana punctata*; 2 = *Selar crumenophthalmus*; 3 = *Eleutheronema tetradactylum*; 4 = *Pomadasys kakaan*; 5 = *Megalaspis cordyla*; 6 = *Trichiurus lepturus*; 7 = *Siganus javus*; 8 = *Leptomelanosoma indicum*; 9 = *Scomberoides lysan*; 10 = *Tenualosa toli*.

3.4 Relationships of metal concentrations and body size of fish

The associations between metal concentrations and body lengths, as well as body weight, in the 36 species of commercial marine fish obtained from Peninsular Malaysia are presented in Figure 7. In general, there are no significant differences ($p > 0.05$) between the levels of Zn and body size (length and weight). The literature indicates that these correlations are incongruous (Chi *et al.* 2007; Singh *et al.* 2007; Satheeshkumar *et al.* 2011; Saghali *et al.* 2014; Gu *et al.* 2015)

In their study, Wan Azmi *et al.* (2019) discovered that there was no statistically significant distinction ($p > 0.05$) in the relationship between the levels of Zn and the length of fish bodies in 46 different species of marine fish found in the coastal waters of Peninsular Malaysia. Bashir *et al.* (2013) similarly discovered strong positive correlations ($p < 0.05$) between the overall length and weight of fish and the amounts of heavy metals.

Yi and Zhang (2012) conducted a study using linear regression analysis to examine the relationships between fish size (length and weight) and metal concentrations in seven fish species collected from the Yangtze River in China. Generally, they discovered that there were positive correlations between fish sizes and metal levels, except for mercury and chromium levels in the size of catfish and yellow-head catfish, which exhibited negative associations. Canli and Atli (2003) examined the correlation between the dimensions of fish (length and weight) and the levels of metal present in the tissues of six different fish species collected from the northeastern region of the Mediterranean Sea. They determined that, save from a few instances, there was no significant correlation between metal concentrations and fish size.

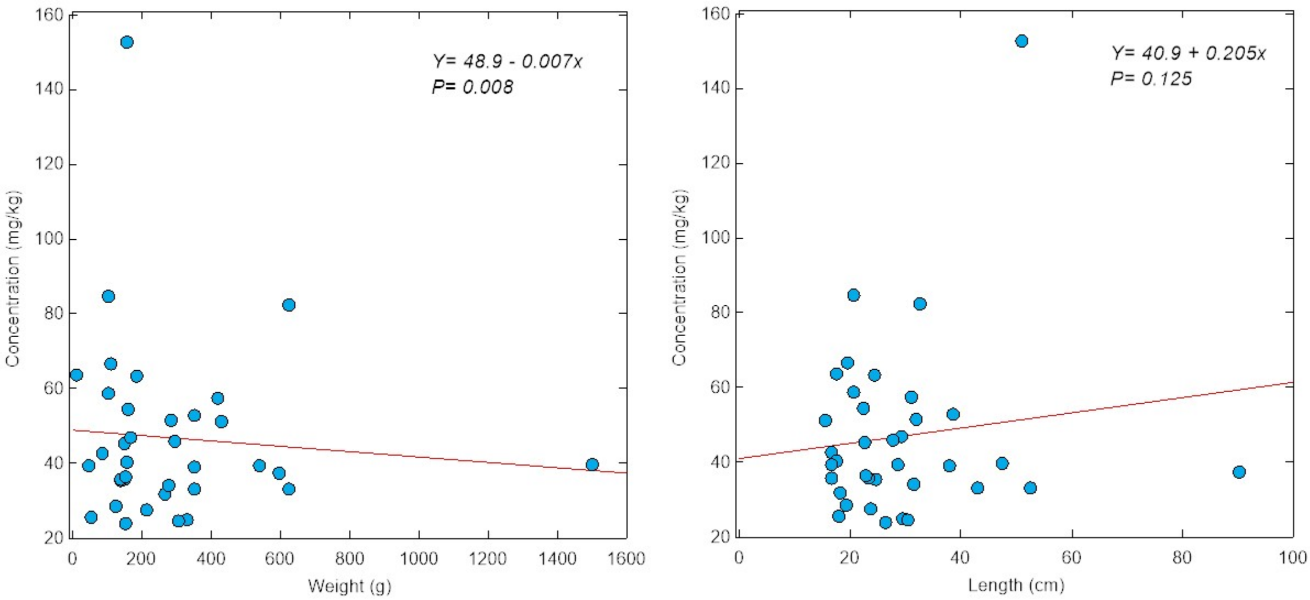

FIGURE 7 Relationships between Zn concentrations (mg kg^{-1} dry weight) and body lengths (cm) and body wet weight (g) in the 36 species of commercial marine fish purchased from Peninsular Malaysia. n = 36.

3.5 Connection to UNSDGs

The presence of Zn in commercial marine fish from Peninsular Malaysia is discussed with regard to biomonitoring, health risks, and its connection to the United Nations Sustainable Development Goals (UNSDGs). The study contributes to the achievement of the UNSDGs, particularly Goal 3 (Good Health and Well-being) by promoting safe consumption, ensuring that zinc levels in fish pose no health risks to consumers. Additionally, the study supports Goal 12 (Responsible Consumption and Production) by advocating for sustainable fishing practices through ongoing monitoring of metal contamination. Finally, the study addresses Goal 14 (Life below Water) by emphasizing the importance of protecting marine ecosystems, using fish as bioindicators to prevent metal pollution and conserve marine biodiversity.

(a) Goal 3: Good Health and Well-being: The findings of this study directly contribute to achieving UNSDG 3, which focuses on ensuring healthy lives and promoting well-being for all. By assessing Zn levels in commercial marine fish, this study emphasizes the safety of fish consumption from Peninsular Malaysia, ensuring that Zn intake remains below harmful levels. As zinc is an essential micronutrient, the study reassures consumers that the levels found in these fish species are both safe and beneficial for health (Rosli *et al.* 2018; Azmi *et al.* 2019; Yap and Al-Mutairi 2022). As proposed through initiatives like Fish Watch, continuous monitoring ensures the sustainability of public health efforts by preventing potential metal accumulation risks, thereby supporting long-term human health and well-being (Effah *et al.* 2021).

Analyzing Zn levels in commercial marine fish from Peninsular Malaysia is crucial for ensuring food safety and public health. Previous studies have reported varying levels of heavy metals, including Zn, in fish from different regions of Malaysia (Yunus *et al.* 2015; Anandkumar *et al.* 2018). For instance, a study on fish from the east coast of Peninsular Malaysia found that Zn concentrations were below the maximum permissible limits set by seafood safety guidelines (Yunus *et al.* 2015). Similarly, another study on fish from the Miri coast concluded that the levels of Zn and other elements in the edible muscle tissues were safe for consumers (Anandkumar *et al.* 2018). These findings suggest that marine fish from Peninsular Malaysia are generally a good source of essential elements like Zn, with concentrations well within acceptable limits for human consumption.

(b) Goal 12: Responsible Consumption and Production

The sustainable management of marine resources is a crucial aspect of achieving the UNSDG 12, which emphasizes the need for responsible consumption and production patterns (Garcia and Rosenberg 2010; Alleway *et al.*

2023). By monitoring the levels of trace metals, such as Zn, in commercially important fish species, this study contributes to the promotion of sustainable seafood consumption and production practices.

Trace metals, including zinc, are commonly found in the marine environment, and their bioaccumulation in fish can pose potential health risks to consumers. Monitoring these metals in commercially available fish is essential to ensure that seafood products entering the market adhere to safety standards, thereby promoting responsible consumption (Bosch *et al.* 2016; Primost *et al.* 2017). Additionally, this research aligns with the goal of encouraging the sustainable harvesting of marine species, as it provides valuable information on contamination levels of these important food resources (Feng *et al.* 2020).

The emphasis on on-going biomonitoring of trace metal levels in fish also supports responsible consumption practices by ensuring consumers are well-informed about the quality and safety of the fish they purchase. This, in turn, can drive the seafood industry towards more sustainable production methods, as consumers demand products that meet high safety and quality standards (Bosch *et al.* 2016; Primost *et al.* 2017; Yap and Al-Mutairi 2022; Feng *et al.* 2020).

(c) Goal 14: Life below Water: Ensuring the health and preservation of marine ecosystems is a crucial component of the UNSDG 14, which aims to conserve and sustainably use the oceans, seas, and marine resources (Noman *et al.* 2022). One approach to addressing this goal is through biomonitoring, where key indicator species are employed to track the state of the marine environment. The present study contributes to sustainable marine resource management by utilizing fish as bioindicators to monitor Zn pollution in marine environments (Yunus *et al.* 2015; Majed *et al.* 2019). By monitoring Zn levels and ensuring they remain within safe limits, the study helps preserve marine biodiversity and prevent contamination from escalating to harmful levels (Primost *et al.* 2017; Feng *et al.* 2020).

Fish have been recognized as effective bioindicators due to their ability to accumulate heavy metals, including Zn, from their surrounding environment (Majed *et al.* 2019). Additionally, the study's focus on Zn pollution is significant, as trace metals like Zn are essential for the growth and development of marine organisms but can become lethal if present beyond a certain threshold. The findings of this study provide valuable information for understanding the species-specific patterns of metal accumulation in fish, which can inform the development of targeted conservation measures to protect both the environment and human consumers of seafood.

On-going surveillance and monitoring of trace metal pollution, as suggested by the study, promote the conservation of marine ecosystems and help maintain a balance between human consumption and environmental sustainability. By addressing Zn contamination and safeguarding marine biodiversity, the study aligns with global efforts to achieve the target set by SDG 14.

This integration of UNSDGs 3, 12, and 14 showcases the multifaceted impact of the study, addressing human health, responsible consumption, and the preservation of marine ecosystems, all of which are interconnected for the achievement of sustainable development. In conclusion, while the levels of Zn in commercial marine fish from Peninsular Malaysia were found to be within safe limits, on-going monitoring and research are essential to ensure the continued safety and sustainability of marine fish as a vital source of nutrition. This will further support the achievement of the UNSDGs, ensuring that fish remain a safe and sustainable food source while protecting marine environments for future generations.

3.6 Connection to ESG

The monitoring of Zn levels in commercially consumed marine fish is of paramount importance due to its essentiality, research needs, and implications for human health and safety (Figure 8). From the perspective of essentiality, regular monitoring of Zn in fish is deemed necessary, as fish is a significant source of protein and an essential micronutrient for the human body (Cambia *et al.* 2019). Additionally, the ecotoxicological impacts of Zn in commercial fish populations require further research, supported by governance and Environmental, Social, and Governance (ESG) considerations (Yap and Al-Mutairi 2022). Undoubtedly, human safety and well-being, manifested through potential health risks associated with excessive zinc consumption from fish products, is a major driving force to continue research on this essential micronutrient.

Connecting the assessment of Zn risk to ESG factors highlights the importance of efficient control and monitoring of Zn levels in fish populations for both ecological sustainability and human well-being (Zamborain-Mason *et al.* 2023). Monitoring zinc contamination in edible fish aligns with the targets of ESG initiatives, ensuring that businesses adopt responsible and sustainable practices (Bosch *et al.* 2016; Jothi *et al.* 2018; Yap and Al-Mutairi 2022).

Therefore, it is important to consider the potential dangers associated with an excessive quantity of Zn in fish and take necessary steps to mitigate these risks by vigilant monitoring and efficient management. In summary, increased levels of Zn in fish might pose a possible risk to human health when consumed as part of the aquatic food chain. Therefore, it is crucial to continuously monitor and assess the levels of Zn in commonly consumed seafood species in order to precisely determine the potential health risks associated with consuming fish.

FIGURE 8 The conceptual importance of Zn monitoring in the commercial marine fish from the points of essentiality, research needs, and safety and health.

4 | CONCLUSIONS

In sum, the ranges of Zn concentrations in the edible muscles and skin parts of commercial marine fish purchased from Peninsular Malaysia were below the MPLs and THQs for all species were below 1. This indicated no non-carcinogenic risks of Zn for consumers. It was also found that the calculated values of EWI were below than PTWI of Zn. Even though the EWI of the population was lower than PTWI levels, excessive fish consumption could lead to adverse effects on human health. More research on physiological and ecological factors is proposed to further understand the processes affecting the accumulation of Zn in fish species. In the future, a continuous monitoring program using a validated questionnaire should be implemented to acquire data on the actual consumption rates of each fish species among local populations. This information is crucial in determining the chances of developing non-carcinogenic or chronic systemic effects of Zn after consuming each species. Finally, using Fish Watch, incorporating ESG, it is suggested that Zn contamination of commercial marine fish species be monitored regularly to ensure the safety of commercial marine fish purchased from Peninsular Malaysia.

By considering the interconnectedness of health, environmental sustainability, and the UNSDGs, holistic solutions can be established to support the overarching goals of promoting a sustainable and healthy future for all. Therefore, continued research and monitoring are critical to ensure the safety and sustainability of marine fish as a vital source of nutrition while upholding the principles of the UNSDGs 3, 12, and 14.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptualization, CKY and KAA-M; methodology and validation, CKY and KAA-M; formal analysis, CKY; investigation, CKY; resources, KAA-M; data curation, CKY; writing—original draft preparation, CKY; writing—review and editing, CKY and KAA-M. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of the study will be made available on a reasonable request from the corresponding author.

SUPPLEMENTARY INFORMATION

Supplementary data to this article can be found online at https://doi.org/10.17017/j.fish.746.

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