Heavy Metal Concentrations in Captured Marine Fishes of Peninsular Malaysia and Estimation of Target Hazard Quotient through Dietary Intake

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ABSTRACT

Fish is a staple food in countries with direct access to the ocean, including Malaysia. However, in the Malaysian diet, fish also represents the main source of heavy metals, especially in commercial fishes. In this study we determined the concentrations of four heavy metals (arsenic, cadmium, mercury and lead) in fish and estimated target hazard quotient (THQ) values for local consumers. The concentrations of heavy metals in marine fishes, (*Decapterus* spp., *Nemipterus* spp. and *Rastrelliger* spp.) from three fish landing jetties in West (West PM) and East Peninsular Malaysia (East PM) were determined. Heavy metals in fish muscle samples were extracted using acid-microwave digestion and determined by inductively coupled-plasma mass spectrometry (ICP-MS). One-way ANOVA was performed to test for temporal and genus variation. *Nemipterus* spp. in East PM contained significantly higher ($p<0.05$) levels of arsenic (As, 1,030 to 3,140 $ng \cdot g^{-1}$ ww) and mercury (Hg, 113 to 790 $ng \cdot g^{-1}$ ww) than the other two genera, suggesting a greater ability to retain these two heavy metals. *Nemipterus* spp. in Tok Bali (TB), East PM alone showed consistently high levels of As and Hg in 2017 and 2018, which exceeded the concentration allowed by Malaysian Food Act 1983 (Amendment) (No. 3) Regulations 2014. Based on these results, local consumers in TB were interviewed to gather information for the computation of THQ. The THQ values for As were greater than 1 in all studied fishes, whereas THQ for Hg only exceeded 1 in *Nemipterus* spp. Thus, THQ values indicate the potential health risk of consuming these types of fishes, particularly in TB.

Keywords: Arsenic, Estimated daily intake, Mercury, *Nemipterus* spp.

INTRODUCTION

Food security from fisheries is achieved when the supply is sufficient and safe for the population. The human population growth projection is predicted to rise from 2.4 to 9.7 billion by 2050 (United Nations, 2015), certainly leading to higher food demand for fisheries resources. In addition, fish represented as much as 86 % of the diet of consumers in 2014 (Jennings *et al*., 2016). Therefore, the measurement of contaminants in fish is absolutely necessary to ensure that consumers (especially humans) do not exceed safe levels in their diets. Chemicals such as pesticides, heavy metals and persistent organic pollutants can accumulate in fish and pose a public health risk (Jennings *et al*., 2016). Dietary exposure to methylmercury, for instance, has been shown to have neurotoxic effects in humans (Sunderland, 2007). Heavy metals in pregnant mothers also can be transferred to the foetus, which was demonstrated in the case of mercury contamination in Minamata Bay, Japan (Eto *et al*., 1992).

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Heavy metals are among the most ubiquitous contaminants in the aquatic environments, and heavy metals can potentially be accumulated in fish. Concentrations of heavy metals in the water or sediments do not necessarily pose toxicological risk, but the portion that is bioavailable to fish can cause detrimental impacts (Angeli *et al*., 2013). For this reason, fish are considered as good indicators for environmental quality besides providing us, as the top consumer, the contamination status of our own food (Trevizani *et al*., 2019).

Fish is also an important food commodity in Malaysia. Between 60 and 70 % of the protein in the diet of Malaysians is derived from various species of fish (Lihan *et al*., 2006). *Decapterus* spp., *Nemipterus* spp. and *Rastrelliger* spp. are three popular and commercially important genera of fishes in Malaysia (Jamaluddin *et al*., 2010; Amira *et al.*, 2016; Hashim *et al*., 2017). Their spawning seasons peak from May to July in Peninsular Malaysia (Gambang *et al*., 2003; Khandaker *et al*., 2015; Rahman and Samat, 2021). These fishes accounted for 34 % of total marine fish landings in 2015, which implies their demand and contribution to the food supply in Malaysia (Shaari and Mustapha, 2018).

These fishes are harvested from four major fishing grounds, known as West PM, East PM, Sarawak and Sabah. The demand for fish is generally higher in Peninsular Malaysia (PM) than Sarawak and Sabah as a result of higher population density. Over 80 % of the population is concentrated in West PM, along with industrial development, tin reserves, plantations and ports (Mazlan *et al*., 2005). Yusoff *et al*. (2006) reported that approximately 76 coastline reclamation projects occurred along West PM. Due to uncontrolled discharges from electronic and semiconductor industries, rivers in Perak, Selangor, Penang and Malacca are polluted with mercury and arsenic (Sany *et al*., 2019). Although East PM is less populated than West PM, oil-and-gas-related industries are developing rapidly along the coast of East PM (Shazili *et al*., 2006). For that reason, the majority of pollutants in East PM comes from sewage, industrial wastes and hydrocarbons as well as agricultural runoff (Mashitah *et al*., 2012).

Along with industrial development, environmental pollutants such as heavy metals are becoming a significant issue in Malaysia. Among these heavy metals, arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) are well known global contaminants and appear on the EPA hazardous substances priority list due to significant environmental and public health concerns (World Health Organization, 2006). Arsenic is commonly produced as a waste during heavy metal processing, and is found in fungicides and wood preservatives (Shirazi *et al*., 2011), whereas Cd is produced through steel and plastic processing, and is used in galvanized pipes and fertilizers (Yoshimoto *et al*., 2016). Both As and Cd are carcinogenic in humans, causing liver and bladder cancer (Yunus *et al*., 2020), and can cause kidney disease and fragile bones (Perera *et al*., 2016). Mercury generally enters the environment through pesticides, discarded batteries and paper industry wastes (Mokhtar *et al*., 2015); meanwhile, Pb is contributed from paints, pesticides, and burning of coal (Abbas *et al*., 2016). Overexposure to Hg had been linked to neurological and behavioral disorders (Aldroobi *et al*., 2013), while Pb can damage the nervous system and kidneys (Kamaruzzaman and Ong, 2009).

The occurrence of these non-essential heavy metals in protein sources such as fish creates a regional problem because they are non-biodegradable. For instance, the level of Cd and Pb in green-lipped mussels (Yap *et al*., 2002) and As in mangrove snails (Cheng and Yap, 2015) in West PM were found exceeding the permissible level of the Malaysian Food Act 1983. Rahman *et al*. (1997) also measured high Hg levels in fish and squid samples from West PM, which were linked to industrial sources and agricultural activities. The content of As in farmed sea bass (Alia *et al*., 2020) and anchovies (Nurulnadia *et al*., 2021) in East PM also has surpassed the permissible limit of the Malaysian Food Act 1983. These contaminated food sources pose a health risk to consumers, while also alarming residents living near the pollution sources (Poon *et al*., 2016). The consumption of fish is one of the important routes of heavy metal uptake in humans (Kaneko and Ralston, 2007), hence the concentrations in fish can be used to predict human health risks. Estimated daily intake (EDI) of heavy metals and total hazard quotient (THQ) formulas are mostly employed in the prediction of human health risk through consumption of fish (Nurulnadia *et al*., 2021).

Hajeb *et al*. (2008) demonstrated a positive correlation between heavy metal concentrations in humans and the rate of consumption. The effect of gender on the accumulation of heavy metals attracted our attention, as Hajeb *et al*. (2008) reported higher levels of Hg in adult females than males, whereas in children, the trend is the opposite (Llop *et al*., 2013). Thus, gender and age somehow contribute to the different rates of accumulation of heavy metals in the human body, and these factors warrant further investigation.

This study compared heavy metal concentrations in fishes from West and East PM during 2017-2018. The potential health hazard from the consumption of fish was also calculated using the THQ formula according to the age and gender of consumers.

MATERIALS AND METHODS

Fish samples (*Decapterus* spp., *Nemipterus* spp. and *Rastrelliger* spp.) were collected from three fish landing jetties of West PM (Batu Maung, Pantai Remis, and Kuala Selangor) and another three jetties of East PM (Kuantan, Kuala Besut, and Tok Bali) as shown in Figure 1. The identification of fish genera was based on Lim and Ahmad (2015) and Atan *et al*. (2010).

Fish samples were collected randomly depending on availability, as indicated in Table 1

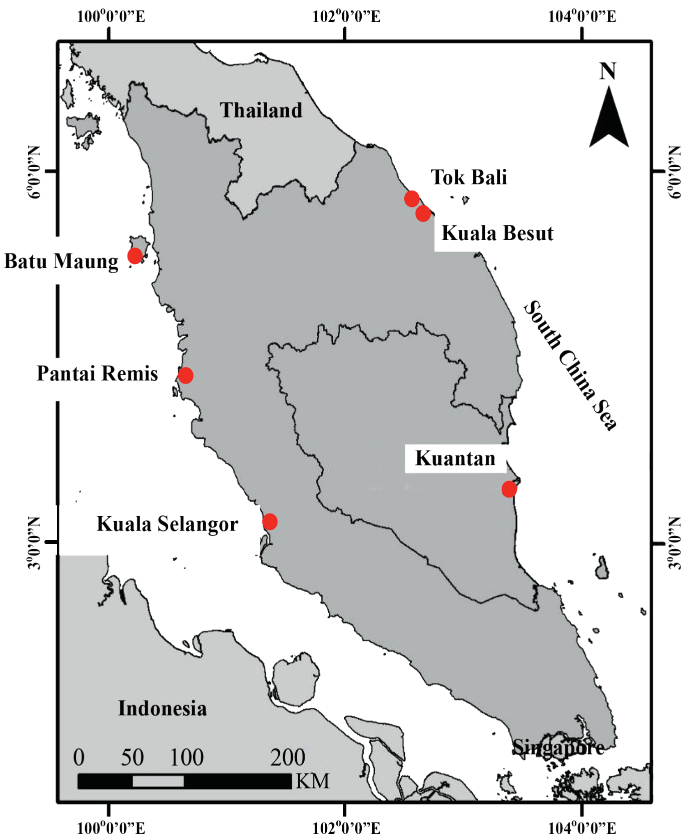


Figure 1. Map of sampling locations in Peninsular Malaysia; Batu Maung (BM), Pantai Remis (PR), Kuala Selangor (KS), Kuantan (KTN), Kuala Besut (KB) and Tok Bali (TB).

(n = 5 to 22). Sampling was conducted from March 2017 to October 2018. These jetties are managed by the Fisheries Development Authority of Malaysia (LKIM), and most of the landed fish were caught by local fishing vessels within Malaysian waters. These jetties were selected because most of the catch is sold for local consumption only. Samples were stored in an ice chest (4 °C) and transported to the Fisheries Research Institute laboratory at Batu Maung. Specimens were measured for total length and weighed, with the following ranges: 18-22 cm and 60-110 g for *Decapterus* spp., 16-28 cm and 60-180 g for *Nemipterus* spp., and 15-25 cm and 40-170 g for *Rastrelliger* spp. (Figure 2). These fish genera were chosen for study because they are the most commonly caught and available at the selected jetties.

Heavy metals (As, Cd, Hg, Pb) in the muscle flesh from both left and right sides of the fish body were analyzed by digesting (US EPA, 1996) with 65 % nitric acid (Suprapur). Approximately 0.3 g of wet sample was mixed with 6 mL of nitric acid in a Teflon beaker and microwave heated at 180 °C (CEM MARS-6 Microwave Digester) for 1 h. Thirty minutes after heating, the sample was transferred into a centrifuge tube and the volume was brought up to 50 mL with ultra-pure water. The blank (nitric acid) and standard reference samples (Fish Protein Certified Reference Material for Trace Metals DORM-4) were treated in the same manner as the fish samples. The samples were then analyzed using ICP-MS (Agilent CX7500). The recovered percentages ranged from 74.0 % to 94.7 %.

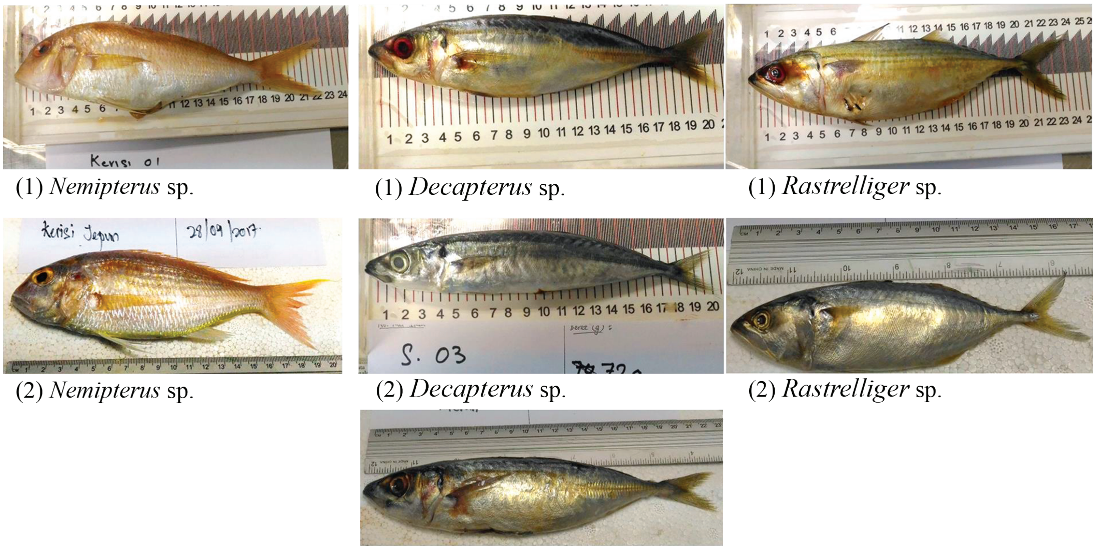
Calculations

Estimated daily intake (EDI) and target hazard quotient (THQ) were used to predict the potential adverse effects of heavy metal uptake through fish consumption. The values of EDI (Edosomwan *et al*., 2019) and THQ (Giri and Singh, 2017) can be obtained by the following equations:

$$\text{EDI} = \text{heavy metal concentration (mg}\cdot\text{kg}^{-1}) \times \text{consumption (kg}\cdot\text{day}^{-1})/\text{body weight (kg)}$$

$$\text{THQ} = \text{EDI/reference dose (mg}\cdot\text{kg}\cdot\text{day}^{-1})$$

Nemipterus spp. *Decapterus* spp. *Rastrelliger* spp.



(1) *Nemipterus* sp. (1) *Decapterus* sp. (1) *Rastrelliger* sp.

(2) *Nemipterus* sp. (2) *Decapterus* sp. (2) *Rastrelliger* sp.

(3) *Decapterus* sp.

Figure 2. Examples of fish specimens tested for heavy metal concentrations: from the left, *Nemipterus* spp., *Decapterus* spp., and *Rastrelliger* spp.

Reference dose is the daily-maximum oral exposure which is anticipated to be without appreciable risk in the general population (Hurt *et al*., 2010). The reference doses for As, Cd, Pb and Hg are 0.0003, 0.001, 0.00357 and 0.0001 $mg \cdot kg^{-1} \cdot day^{-1}$, as published by the US EPA (1997; 2019).

Consumer interviews

A total of 54 consumers within the Tok Bali (TB) area were interviewed in person in order to gather the average daily fish consumption and consumer body weight data. This location was chosen because the concentrations of As and Hg in fish in both sampling years exceeded the permissible levels of the Malaysia Food Act 1983. The calculations were made separately for males (23 students aged 8-17 years and 9 adults aged 19-60) and females (7 students aged 6-13 and 15 adults aged 18-59). The male respondents had higher consumption rates than the female respondents ($kg \cdot day^{-1}$). The average consumption rates for male students (33.5 kg bw) and adults (70.3 kg bw) were 0.10 and 0.12 $kg \cdot day^{-1}$, respectively, while the average consumption rates for female students (23.4 kg bw) and adults (64.3 kg bw) were 0.062 and 0.065 $kg \cdot day^{-1}$, respectively.

Data analyses

One-way ANOVA was used for data analyses, whereby either year of sampling, genus of fish or sampling location (West and East PM) was considered as the source of variation. The analyses were done by pooling those data. Mean As and Hg concentrations were compared among the three fish genera and between the two sampling locations using Tukey-Kramer. The results were considered significant when $p<0.05$. The analyses were performed in Microsoft Excel 2019 and XLSTAT 2019 which were licensed to Universiti Malaysia Terengganu.

RESULTS AND DISCUSSION

Heavy metals in fish of West and East Peninsular Malaysia

Heavy metal concentrations in fish samples collected at each landing jetty are presented in Table 1. Levels of As, Cd, Hg and Pb in *Decapterus* spp. were below the permissible amounts stated by the Malaysia Food Act 1983, except for As in KB. The same limit of As is used by Food Standards Australia New Zealand (FSANZ, 2020). The average As values were 2,400±492 and 2,250±537 $ng \cdot g^{-1}$ ww during 2017 and 2018, respectively. Levels of As and Hg in *Nemipterus* spp. from East PM also exceeded the limits of the Malaysia Food Act 1983, especially Hg in the year of 2017. These Hg concentrations (all less than 1,000 $ng \cdot g^{-1}$ ww), however, are considered safe in consumed fish based on the limits by FSANZ (2004). Mercury values decreased to safe levels in *Nemipterus* spp. samples from KTN and KB the following year, but remained high in TB (574±267 and 778±69 $ng \cdot g^{-1}$ ww in 2017 and 2018, respectively). These results suggest the presence of As and Hg at alarming levels in East PM. Arsenic and Hg are commonly produced from metal smelting, and are contained in paints, pesticides and batteries (Shirazi *et al*., 2011; Mokhtar *et al*., 2015). These kinds of industries currently operate near the coastal area of East PM (Nurul *et al*., 2016; Yusoff *et al*., 2018; Zainul Armir *et al*., 2021), and thus are potential sources of As and Hg in this area. Herbicides such as disodium methyl arsenate (Hammid *et al*., 2013; Goh *et al*., 2015), which are commonly applied in oil palm plantations in Malaysia, also contain As. Thus, agriculture could be another contributor of As in the environment. Sultan *et al*. (2011) identified a small enrichment of Hg in the surface sediments of East PM, but it was similar to regional background levels, and not likely due to anthropogenic input. However, this is not the case for these heavy metals in *Decapterus* spp. and *Nemipterus* spp., since As and Hg are non-essential elements for fish. If these commercial fish species were to be frequently consumed by humans over a long term, health risks such as cancer and neurological disorders (Aldroobi *et al*., 2013; Yunus *et al*., 2020) would be elevated. Levels of both As and Hg, however, are below the maximums permitted by the Food and Agriculture Organization (Codex Alimentarius Commission, 2017) for marine fish such as tuna and sea bream.

The one-way ANOVA indicated no temporal differences in heavy metal concentrations ($p>0.05$) (Figure 3), suggesting that the inputs and uptake of these heavy metals in targeted fishes during both years were similar. However, one-way ANOVA among the three genera of fish revealed significantly higher values ($p<0.05$) of As and Hg in *Nemipterus* spp. than in the others (Figure 4). This suggests that demersal fishes such as *Nemipterus* spp. are exposed to higher levels of heavy metals and/or can accumulate higher levels of heavy metals than pelagic types (*Decapterus* spp. and *Rastrelliger* spp.) (Naccari *et al*., 2015). *Nemipterus* spp. are known as predacious carnivores and tend to feed in the bottom sediments as evidenced by the presence of benthic organism in their stomachs (Tonnie *et al*., 2018). Sediment is known as the ultimate sink of pollutants, hence fish that feed on the bottom sediment have high opportunity to accumulate heavy metals from their diet (Nurulnadia *et al*., 2014).

Table 1. Concentrations of As, Cd, Hg and Pb (mean±SD) in ng•g^{-1} wet weight with comparison to levels permitted Malaysian Food Act 1983.

Fish landing jetty		As (ng•g^{-1} ww)		Cd (ng•g^{-1} ww)		Hg (ng•g^{-1} ww)		Pb (ng•g^{-1} ww)	
		2017	2018	2017	2018	2017	2018	2017	2018
Decapterus spp.									
West PM	BM, n = 22	1100±415	1090±414	11.6±4.69	13.6±7.45	na	na	83.5±10.3	69.2±9.93
	PR, n = 8	391±193	674±474	6.71±5.53	16.9±8.76	30.8±12.8	31.0±13.3	79.4±23.0	77.0±8.37
	KS, n=22	9.14±3.59	9.20±3.64	1.33±0.76	0.65±0.14	0.41±0.06	0.43±0.11	0.13±0.02	0.13±0.02
East PM	KTN, n = 6	1410±513	1335±511	34.7±8.14	32.2±9.49	15.9±6.53	13.3±6.10	121±22.0	109±22.9
	KB, n = 12	**2400±492**	**2250±537**	35.4±6.67	34.0±7.64	87.7±13.4	88.4±13.0	119±20.6	103±23.0
	TB, n = 22	639±122	602±156	23.1±7.80	22.6±8.19	71.7±4.4	70.2±5.03	110±9.97	103±15.0
Nemipterus spp.									
West PM	BM, n = 21	1340±538	926±266	5.44±1.39	6.25±2.04	131±69.2	122±45.3	81.2±14.6	79.3±16.2
	PR, n = 8	798±153	926±170	7.01±1.85	8.78±1.85	165±23.8	35.9±3.29	89.2±9.34	67.4±9.34
	KS, n = 22	18.3±7.43	18.7±2.49	0.38±0.36	1.33±0.23	5.32±1.31	8.84±1.17	0.07±0.03	0.12±0.04
East PM	KTN, n = 5	1030±82.9	1160±82.9	6.13±2.05	7.90±2.05	**790±80.9**	113±10.9	141±36.3	119±36.3
	KB, n = 22	**2940±347**	1890±556	27.5±1.67	59.6±15.0	**531±339**	296±66.1	89.5±11.9	675±57.6
	TB, n = 22	**2890±406**	**3140±825**	28.3±4.25	5.72±1.99	**574±267**	**778±68.5**	89.5±11.9	144±31.9
Rastrelliger spp.									
West PM	BM, n = 21	408±184	462±160	11.6±4.69	10.4±5.73	21.8±10.3	23.2±9.53	80.80±7.50	61.7±6.64
	PR, n = 8	111±47.5	105±45.0	6.71±5.53	7.05±5.88	11.5±4.92	11.60±4.90	84.90±5.71	80.1±6.49
	KS, n = 22	2.04±1.31	1.92±1.17	1.33±0.76	0.70±0.25	1.65±0.99	0.48±0.30	0.45±0.24	0.36±0.21
East PM	KTN, n = 5	96.3±42.7	84.5±42.7	14.0±12.1	14.7±12.1	6.96±3.26	7.08±3.26	139±20.2	129±20.2
	KB, n = 7	255±118	202±74.2	15.2±13.4	12.7±12.1	32.8±12.3	31.7±14.0	137±18.7	119±20.2
	TB, n = 20	597±141	520±141	18.5±7.31	17.4±7.31	36.0±7.45	32.9±7.45	116±22.6	98.3±22.6
Permissible level Malaysian Food Act 1983		2000		1000		500		2000	

Note: BM-Batu Maung; PR-Pantai Remis; KS-Kuala Selangor; KTN-Kuantan; KB-Kuala Besut; TB-Tok Bali; n-number of fish samples; na-data not available; bold values indicate concentrations exceeding the permissible level

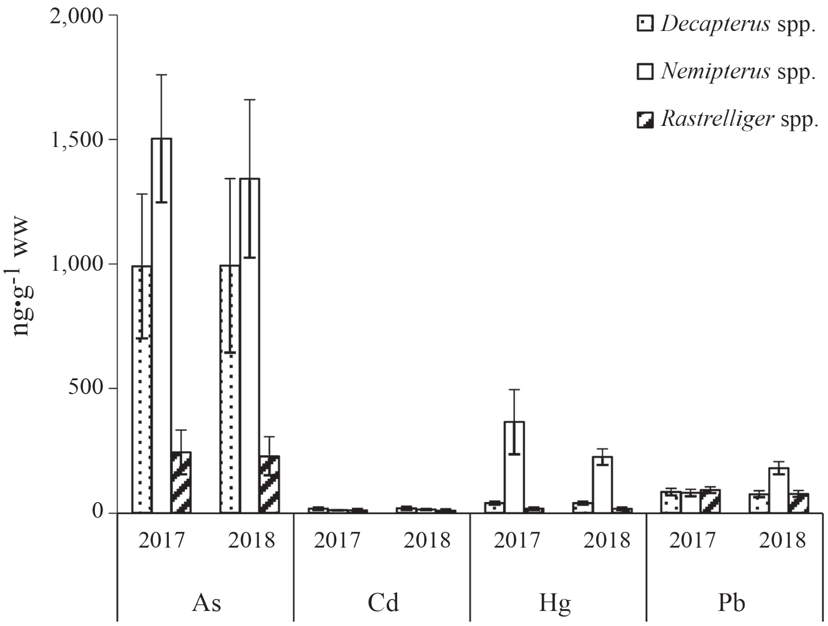


Figure 3. Mean heavy metal concentrations in three fish genera harvested in Malaysian wheavyaters. One-way ANOVA showed no temporal difference concentrations.

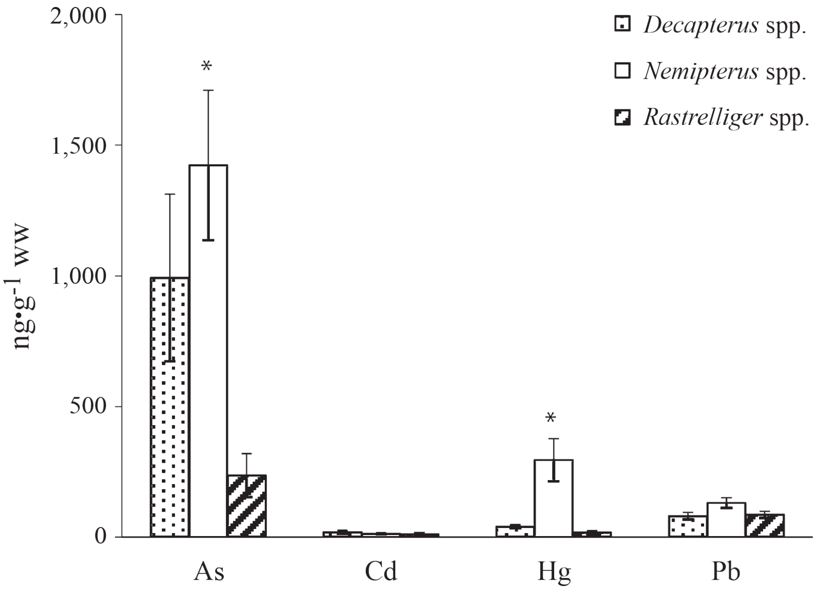


Figure 4. Mean heavy metal concentrations in three fish genera harvested in Malaysian waters. Asterisks (*) indicate significantly higher As and Hg in *Nemipterus* spp. than in the other two genera.

The concentrations of the four heavy metals in *Rastrelliger* spp. were below the permissible limits (Table 1), and hence safe for human consumption. Considering the fish landing locations, the values of As and Hg in *Decapterus* spp. and *Nemipterus* spp. from East PM were significantly higher ($p<0.05$) than those from West PM (Figure 5). These results were similar to two recent studies of heavy metals in fish sampled from East PM (Alia *et al*., 2020; Nurulnadia *et al*., 2021). Therefore, these two heavy metals have accumulated substantially in fishes caught from the South China Sea.

Estimated daily intake (EDI) and target hazard quotient (THQ) for Tok Bali

The EDI (Figure 6a and 6b) and THQ (Figure 7a and 7b) values were calculated for each fish genus to assess the human health risk specifically for TB. In general, a THQ greater than 1 indicates potential health concern (Naughton and Petroczi, 2008), but does not emphasize any particular health risk.

The EDI values for the three fish genera ranged from 0.00003 to 0.0094 $mg \cdot kg^{-1} \cdot day^{-1}$ for both As and Hg (Figure 6a and 6b). The World Health Organization (2019) defines 0.002 $mg \cdot kg^{-1} \cdot day^{-1}$ bw as the maximum acceptable human intake of As in food. The EDI values for As exceeded this guideline in *Nemipterus* spp. for all age and gender groups, suggesting a potential health risk to the consumer. The THQ is commonly reported as the total of all heavy metals in a study (Siddiqui *et al*., 2019; Nurulnadia *et al*., 2021). In this study, the calculation was conducted according to age (student or adult) and gender classifications. One-way ANOVA showed no significant differences either for age or gender ($p>0.05$) of the consumers. The THQ values for As exceeded 1 (THQ>1) in all fish genera, indicating a potential health hazard (Figure 7a). The levels of As and Hg in this study were reported as the total of their forms. However, As exists in several forms in natural environments, with inorganic arsenite and arsenate as the most toxic among the available species. The organic forms of monomethylarsenic acid and dimethylarsenic acid are much less toxic than inorganic As, while other organic species such as arsenobetaine, arsenoribosides and arsenocholine are non-toxic (Shrain *et al*., 1999; Peshut *et al*., 2008). Owing to the different characteristics of each As species, the effects on humans may be underestimated or overestimated when determined from the total As value. Therefore, the investigation of As in fish should be broadened to speciation for better estimating the effects on the consumer as well as inputs to the environment.

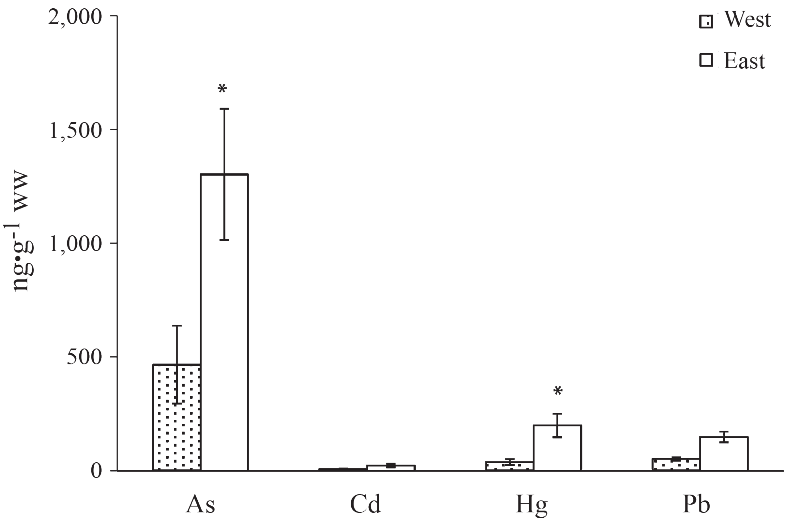


Figure 5. Mean heavy metal concentrations in fish harvested in Malaysian waters. Asterisks (*) indicate significantly higher As and Hg in East PM than in West PM.

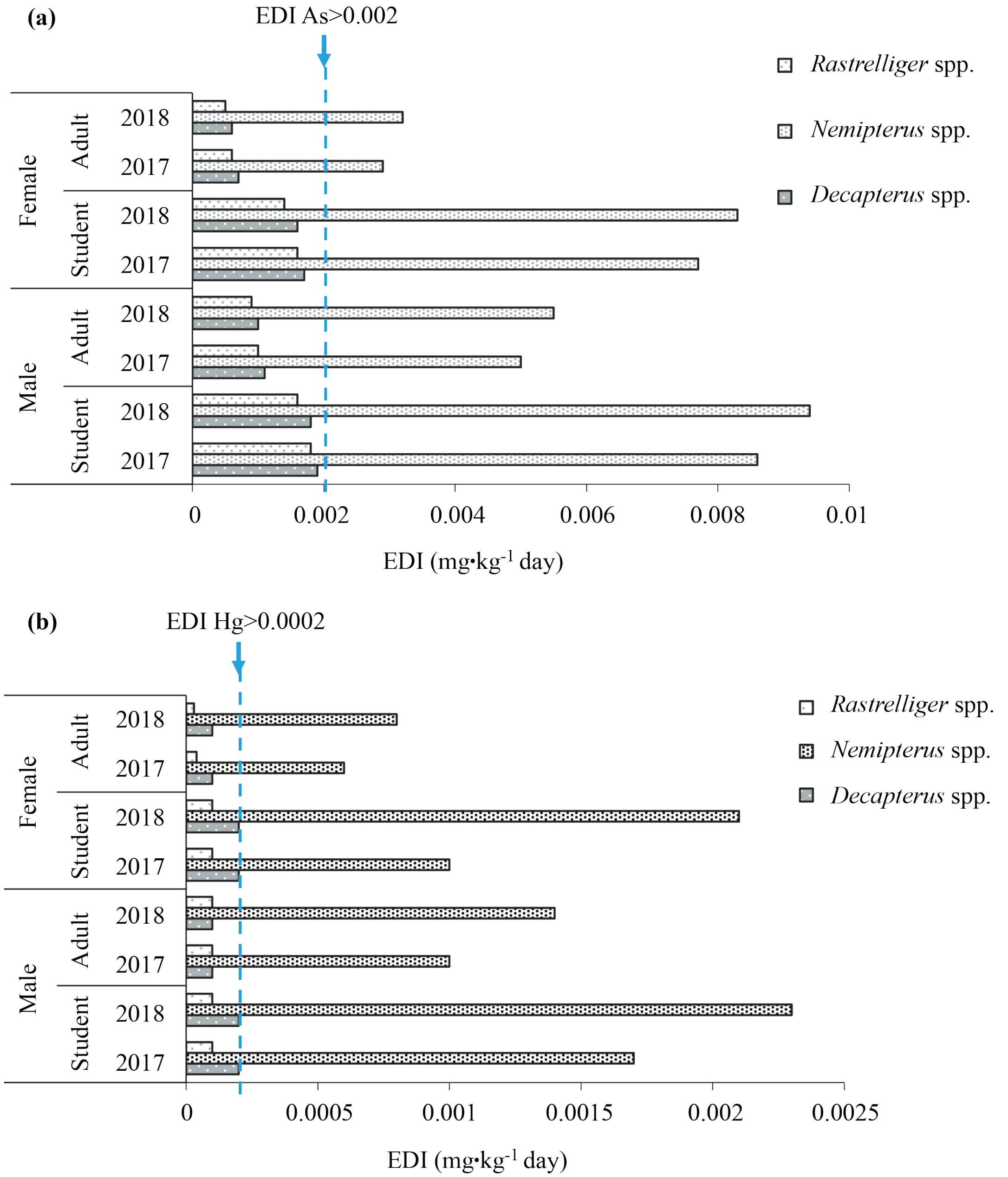


Figure 6. Estimated daily intake (EDI) of (a) arsenic (As) and (b) mercury (Hg) values for three fish genera from Tok Bali (TB), Malaysia.

Note: Male students: age 8-17; male adults: 19-60; female students: 6-13; female adults: 1-59.

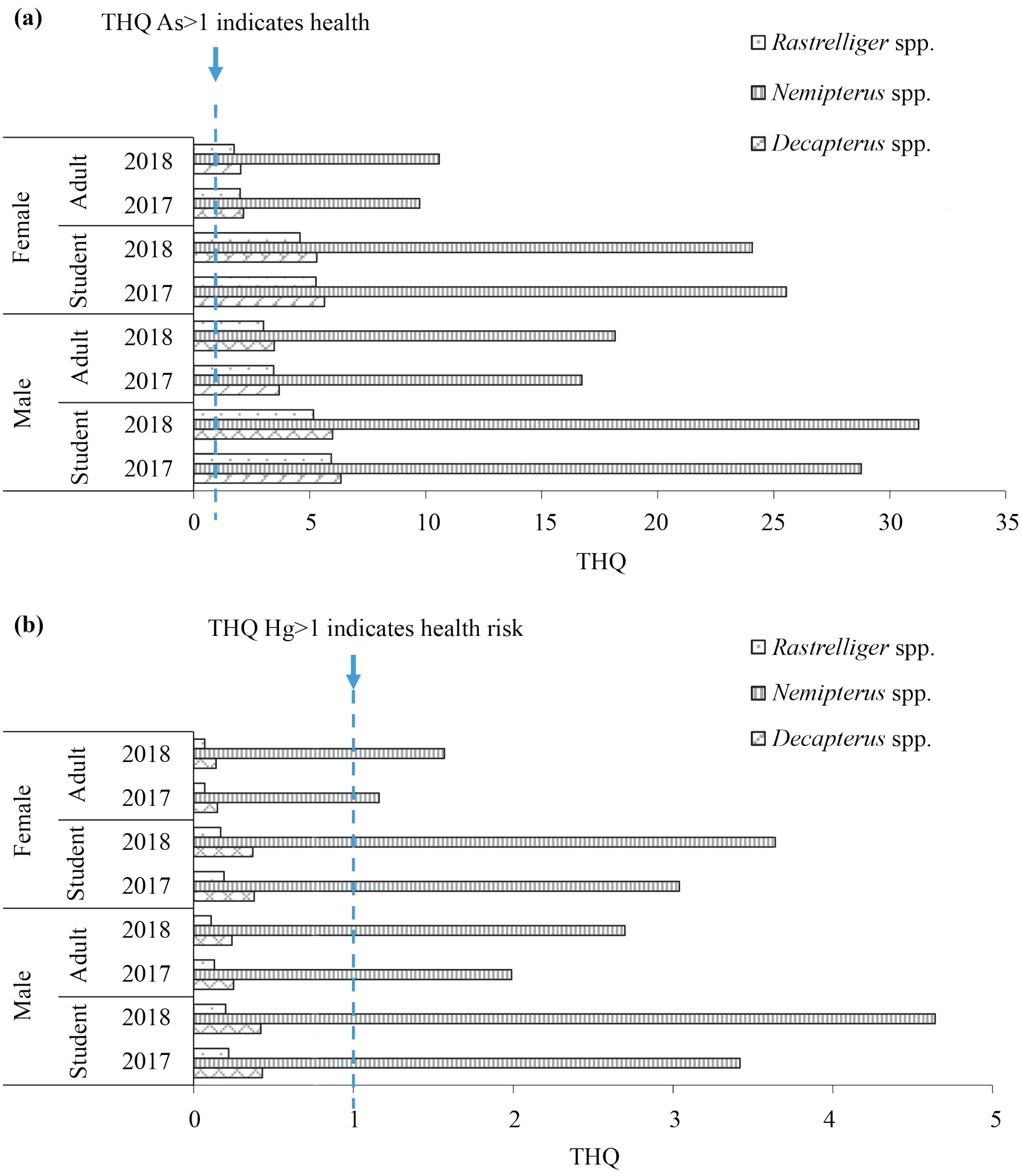


Figure 7. Total hazard quotient (THQ) values for (a) arsenic (As) and (b) mercury (Hg) from three fish genera from Tok Bali (TB), Malaysia.

Note: Male students: age 8-17; male adults: 19-60; female: 6-13; female adults: 18-59.

Currently, a tolerable Hg intake recommendation is only available for methyl Hg (Jones, 1999; European Commission, 2006). The European Food Safety Authority has set the tolerable weekly intake of methyl Hg at 1.3 $\mu g \cdot kg^{-1}$ bw which is equivalent to 0.0002 $mg \cdot kg^{-1} \cdot day^{-1}$ bw (EFSA, 2012). According to this consumption rate, the concentration of Hg in *Nemipterus* spp. exceeds the guideline value (Figure 6b). The *Nemipterus* spp. in this study may contain both inorganic and methyl Hg. Therefore, conclusions cannot be drawn based on this comparison alone. Similar to EDI, the THQ values for Hg also exceeded 1 in *Nemipterus* spp. (Figure 7b). Mercury in fish is normally reported as total Hg or methyl Hg content. Methyl Hg is the most toxic, as it is considered a neurotoxic agent (Storelli *et al*., 2005). The US Food and Drug Administration, Japan and European countries have set safe limits based on the total Hg concentration, similar to this study. Based on the maximum levels permitted by Japan (400 $ng \cdot g^{-1}$ ww) and Europe (500 $ng \cdot g^{-1}$ ww; Storelli *et al*., 2005), Hg in *Nemipterus* spp. is too high and therefore not safe for human consumption. Therefore, action should be taken to determine the concentration in the other fish species, and consumers of this genus should be made aware of this finding, particularly those in the TB area.

CONCLUSION

The concentrations of four heavy metals (As, Cd, Hg, Pb) were measured in *Decapterus* spp., *Nemipterus* spp., and *Rastrelliger* spp. collected from East and West Peninsular Malaysia. These are the three most common fishes sold in local markets, hence the heavy metals were determined to evaluate potential health risks to local consumers. Concentrations of Cd and Pb were below levels permitted by the Malaysia Food Act 1983 for all three fish genera, and therefore are not a concern. For *Rastrelliger* spp., concentrations of As and Hg were also within safe levels for consumption. However, As and Hg in *Nemipterus* spp. from all landing jetties in East PM as well as As in *Decapterus* spp. from one site (KB) exceeded permissible levels, and indicated potential health risks to the consumers of these species. In addition, concentrations of these two heavy metals were significantly higher in fish from East PM than West PM, suggesting potential contribution of these heavy metals along the South China Sea coast. The THQ values for As in all fish genera, and for only Hg in *Nemipterus* spp. exceeded 1 (THQ>1), indicating a potential health hazard to the consumer.

Nevertheless, to draw a conclusion based on overall heavy metal contamination and total hazard quotient from three genera of marine fishes might be misleading. Hence, future studies should consider a wider variety of marine organisms at several trophic levels, as well as trace the potential sources of heavy metals using mathematical models, particularly in the East PM area. Since the income of fishermen could be impacted by unclear and incomplete information on health risks, this study should only be considered a first step in evaluating the amount of riskposed by heavy metals in products from the local fishery.

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LITERATURE CITED

Abbas, A., A.M. Al-Amer, T. Laoui, M.J. Al-Marri, M.S. Nasser, M. Khraisheh and M.A. Atieh. 2016. Heavy metal removal from aqueous solution by advanced carbon nanotubes: Critical review of adsorption applications. **Separation and Purification Technology** 157: 141-161.

Aldroobi, K.S.A., A. Shukri, S. Bauk, E.M.A. Munem and A.M. Abuarra. 2013. Determination of arsenic and mercury level in scalp hair from a selected population in Penang, Malaysia using XRF technique. **Radiation Physics and Chemistry** 91: 9-14.

Alia, T.T.N., L.S. Hing, S.F. Sim, S. Pradit, A. Ahmad and M.C. Ong. 2020. Comparative study of raw and cooked farmed sea bass (*Lates calcarifer*) in relation to metal content and its estimated human health risk. **Marine Pollution Bulletin** 153: 111009. DOI: 10.1016/j.marpolbul.2020.111009.

Amira, F.S., M.M. Rahman, Y. Kamaruzzaman, K.C.A. Jalal, M.Y. Hossain and N.S. Khan. 2016. Relative abundance and growth of male and female *Nemipterus furcosus* population. **Sains Malaysiana** 45(1): 79-86.

Angeli, J.L.F., T.H. Trevizani, A.P. Ribeiro, E.C. Machado, R.C.L. Figueira, B. Market, S. Fraenzle and S. Wuenschmann. 2013. Arsenic and other trace elements in two catfish species from Paranaguá Estuarine Complex, Paraná, Brazil. **Environmental Monitoring and Assessment** 185: 8333-8342.

Atan, Y., H. Jaafar and A.R.A. Majid. 2010. **Ikan Laut Malaysia: Glosari Nama Sahih Species Ikan [Marine Fish of Malaysia: Glossary Authentic Name of Fish Species].** Dewan Bahasa dan Pustaka, Kuala Lumpur, Malaysia. 290 pp.

Cheng, W.H. and C.K. Yap. 2015. Potential human health risks from toxic metals via mangrove snail consumption and their ecological risk assessments in the habitat sediment from Peninsular Malaysia. **Chemosphere** 135: 156-165.

Codex Alimentarius Commission. 2017. **General standard for contaminants and toxins in food and feed (CODEX STAN 193-1995). FAO: Rome, Italy.** https://www.fao.org/fileadmin/user_upload/livestockgov/documents/1_CXS_193e.pdf. Cited 2 Jan 2022.

Edosomwan, E.U., M.O. Ainerua and D.O. Izevbizua. 2019. Heavy metals levels in dried fish consumed in Benin and Warri Metropolis; levels and health risk assessment. **African Scientist** 17(2): 93-96.

EFSA Panel on Contaminants in the Food Chain (CONTAM). 2012. Scientific opinion on the risk for public health related to the presence of mercury and methylmercury in food. **EFSA Journal** 10(12): 2985. DOI: 10.2903/j.efsa.2012.2985.

Eto, K., S. Oyanagi, Y. Itai, H. Tokunaga, Y. Takizawa and I. Suda. 1992. A fetal type of Minamata disease. **Molecular and Chemical Neuropathology** 16(1): 171-186.

European Commission. 2006. Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. **Official Journal of European Union** 364: 365-324.

Food Standards Australia New Zealand (FSANZ). 2004. **Mercury in fish-Background to the mercury in fish advisory statement.** https://www.foodstandards.gov.au/publications/Documents/mercury%20in%20fish%20-%20further%20info.pdf. Cited 2 Jan 2022.

Food Standards Australia New Zealand (FSANZ). 2020. **Maximum levels for arsenic in food.** https://www.foodstandards.gov.au/consumer/chemicals/arsenic/Pages/default.aspx. Cited 2 Jan 2022.

Gambang, A.C., H.B. Rajali and D.A.U.D. Awang. 2003. **Overview of biology and exploitation of the small pelagic fish resources of the EEZ of Sarawak, Malaysia. Fisheries Research Institute.** http://www1.sarawak.com.my/org/frisb/publication/pelagic2003.pdf. Cited 6 Nov 2021.

Giri, S. and A.K. Singh. 2017. Human health risk assessment due to dietary intake of heavy metals through rice in the mining areas of Singhbhum Copper Belt, India. **Environmental Science and Pollution Research** 24(17): 14945-14956.

Goh, Y.K., K.L. Wong, C.H. Lai, S.Y. Tan and T. Nazir. 2015. Control of *Mucuna bracteata* Dc. Ex. Kurz legume covers with herbicides in oil palm plantation: Spraying volume and frequency. **Oil Palm Bulletin** 70: 1-7.

Hajeb, P., J. Selamat, A. Ismail, F.A. Bakar, J. Bakar and H.N. Lioe. 2008. Hair mercury level of coastal communities in Malaysia: A linkage with fish consumption. **European Food Research and Technology** 227(5): 1349-1355.

Hammid, A.N.A., A. Kuntom, R. Ismail and N. Pardi. 2013. Determination of arsenic in palm kernel expeller using microwave digestion and graphite furnace atomic absorption spectrometry method. **International Journal of Basic and Applied Science** 1(3): 641-649.

Hashim, M., M.F. Aziz, R.B. Hassan and M.S. Hossain. 2017. Assessing target strength, abundance, and biomass for three commercial pelagic fish species along the East coast of Peninsular Malaysia using a Split-Beam echo sounder. **Journal of Coastal Research** 33(6): 1448-1459.

Hurt, S., J. Ollinger, G. Arce, Q. Bui, A.J. Tobia and B. van Ravenswaay. 2010. **Dialkyldithiocarbamates (EBDCs).** In: Hayes' Handbook of Pesticide Toxicology (ed. R. Krieger), pp. 1689-1710. Academic Press, University of California, Berkeley, USA.

Jamaluddin, J.A.F., A.T. Ahmad, S. Basir, M.A. Rahim and S.A.M. Nor. 2010. *Rastrelliger* systematics inferred from mitochondrial cytochrome *b* sequences. **African Journal of Biotechnology** 9(21): 3063-3067.

Jennings, S., G.D. Stentiford, A.M. Leocadio, K.R. Jeffery, J.D. Metcalfe, I. Katsiadaki, Auchterlonie, N.A., S.C. Mangi, J.K. Pinnegar, T. Ellis, E.J. Peeler, T. Luisetti, C. Baker-Austin, M. Brown, T.L. Catchpole, F.J. Clyne, S.R. Dye, N.J. Edmonds, K. Hyder, J. Lee, D.N. Lees, O.C. Morgan, C. M. O'Brien, B. Oidtmann, P.E. Posen, A.R. Santos, N.G.H. Taylor, A.D. Turner, B.L. Townhill and D.W. Verner-Jeffreys. 2016. Aquatic food security: insights into challenges and solutions from an analysis of interactions between fisheries, aquaculture, food safety, human health, fish and human welfare, economy and environment. **Fish and Fisheries** 17(4): 893-938.

Jones, D.W. 1999. Exposure or absorption and the crucial question of limits for mercury. **Journal of the Canadian Dental Association** 65(1): 42-46.

Kamaruzzaman, Y. and M.C. Ong. 2009. Geochemical proxy of some chemical elements in sediments of Kemaman river estuary, Terengganu, Malaysia. **Sains Malaysiana** 38(5): 631-636.

Kaneko, J.J. and N.V. Ralston. 2007. Selenium and mercury in pelagic fish in the central north Pacific near Hawaii. **Biological Trace Element Research** 119(3): 242-254.

Khandaker, M.U., K. Asaduzzaman, S.M. Nawi, A.R. Usman, Y.M. Amin, E. Daar, D.A. Bradley, H. Ahmed and A. A. Okhunov. 2015. Assessment of radiation and heavy metals risk due to the dietary intake of marine fishes (*Rastrelliger kanagurta*) from the straits of Malacca. **PLoS One** 10(6): e0128790. DOI: 10.1371/journal.pone.0128790.

Lihan, T., N. Ismail, M.A. Mustapha and S.A. Rahim. 2006. Kandungan logam berat dalam makanan laut dan kadar pengambilannya oleh penduduk di Tanjung Karang, Selangor [Heavy metal content in seafood and uptake rate by the residents in Tanjung Karang, Selangor]. **Malaysian Journal of Analytical Sciences** 10(2): 197-204.

Lim, A.P.K. and A. Ahmad. 2015. **Panduan Mengenali Species Ikan Marin (Guide to Identification of Marine Fish Species).** Department of Fisheries Malaysia. Perpustakaan Negara Malaysia, Putrajaya, Malaysia. 50 pp.

Llop, S., M.J. Lopez-Espinosa, M. Rebagliato and F. Ballester. 2013. Gender differences in the neurotoxicity of metals in children. **Toxicology** 311(1-2): 3-12.

Mashitah, S.M., N.A.M. Shazili and M.K.A. Rashid. 2012. Elemental concentrations in brown seaweed, *Padina* sp. along the east coast of Peninsular Malaysia. **Aquatic Ecosystem Health and Management** 15(3): 267-278.

Mazlan, A.G., C.C. Zaidi, W.M. Wan-Lotfi and B.H.R. Othman. 2005. On the current status of coastal marine biodiversity in Malaysia. **Indian Journal of Marine Sciences** 34(1): 76-87.

Mokhtar, N.F., A.Z. Aris and S.M. Praveena. 2015. Preliminary study of heavy metal (Zn, Pb, Cr, Ni) contaminations in Langat river estuary, Selangor. **Procedia Environmental Sciences** 30: 285-290.

Naccari, C., N. Cicero, V. Ferrantelli, G. Giangrosso, A. Vella, A. Macaluso, F. Naccari and G. Dugo. 2015. Toxic metals in pelagic, benthic and demersal fish species from Mediterranean FAO zone 37. **Bulletin of Environmental Contamination and Toxicology** 95(5): 567-573.

Naughton, D.P. and A. Petróczi. 2008. Heavy metal ions in wines: Meta-analysis of target hazard quotients reveal health risks. **Chemistry Central Journal** 2(1): 1-7.

Nurul, A.H., B.M.T. Shamsul and I. Noor Hassim. 2016. Assessment of dust exposure in a steel plant in the eastern coast of peninsular Malaysia. **Work** 55(3): 655-662.

Nurulnadia, M.Y., J. Koyama, S. Uno, A. Kito, E. Kokushi, E.T. Bacolod, K. Ito and Y. Chuman. 2014. Accumulation of endocrine disrupting chemicals (EDCs) in the polychaete *Paraprionospio* sp. from the Yodo River mouth, Osaka Bay, Japan. **Environmental Monitoring and Assessment** 186(3): 1453-1463.

Nurulnadia, M.Y., N.M.A. Nik-Nurasyikin, K.H. Ling, B.M. Zahid, G. Adiana and B.I. Nurlemsha. 2021. Metal concentrations in fresh and salt-dried anchovy, *Encrasicholina devisi*, and estimation of target hazard quotient for consumers in Kuala Terengganu. **Regional Studies in Marine Science** 41: 101595. DOI: 10.1016/j.rsma.2020.101595.

Perera, P.C.T., T.V. Sundarabarathy, T. Sivananthawerl, S.P. Kodithuwakku and U. Edirisinghe. 2016. Arsenic and cadmium contamination in water, sediments and fish is a consequence of paddy cultivation: Evidence of river pollution in Sri Lanka. **Achievements in the Life Sciences** 10(2): 144-160.

Peshut, P.J., R.J. Morrison and B.A. Brooks. 2008. Arsenic speciation in marine fish and shellfish from American Samoa. **Chemosphere** 71(3): 484-492.

Poon, W.C., G. Herath, A. Sarker, T. Masuda and R. Kada. 2016. River and fish pollution in Malaysia: A green ergonomics perspective. **Applied Ergonomics** 57: 80-93.

Rahman, M.M. and A.F. Samat. 2021. Reproductive cycle, sexual maturity and fecundity of *Nemipterus furcosus* (Valenciennes, 1830). **Aquaculture and Fisheries** 6(4): 424-431.

Rahman, S.A., A.K. Wood, S. Sarmani and A.A. Majid. 1997. Determination of mercury and organic mercury contents in Malaysian seafood. **Journal of Radioanalytical and Nuclear Chemistry** 217(1): 53-56.

Sany, S.B.T., M. Tajfard, M. Rezayi, M.A. Rahman and R. Hashim. 2019. **The west coast of Peninsular Malaysia.** In: World Seas: An Environmental Evaluation (ed. C. Sheppard), pp. 437-458. Academic Press, The University of Warwick, Coventry, UK.

Shaari, N.R. and M. Mustapha. 2018. Predicting potential *Rastrelliger kanagurta* fish habitat using MODIS satellite data and GIS modeling: A case study of exclusive economic zone, Malaysia. **Sains Malaysiana** 47(7): 1369-1378.

Shazili, N.A.M., K. Yunus, A.S. Ahmad, N. Abdullah and M.K.A. Rashid. 2006. Heavy metal pollution status in the Malaysian aquatic environment. **Aquatic Ecosystem Health and Management** 9(2): 137-145.

Shirazi, S.M., Z. Ismail, S. Akib, M. Sholichin and M.A. Islam. 2011. Climatic parameters and net irrigation requirement of crops. **International Journal of Physical Sciences** 6(1): 15-26.

Shrain, A., B. Chiswell and H. Olszowy. 1999. Speciation of arsenic by hydride generation-atomic absorption spectrometry (HG-AAS) in hydrochloric acid reaction medium. **Talanta** 50: 1109-1127.

Siddiqui, E., K. Verma, U. Pandey and J. Pandey. 2019. Metal contamination in seven tributaries of the Ganga River and assessment of human health risk from fish consumption. **Archives of Environmental Contamination and Toxicology** 77(2): 263-278.

Storelli, M.M., A. Storelli, R. Giacominelli-Stuffler and G.O. Marcotrigiano. 2005. Mercury speciation in the muscle of two commercially important fish, hake (*Merluccius merluccius*) and striped mullet (*Mullus barbatus*) from the Mediterranean Sea: Estimated weekly intake. **Food Chemistry** 89(2): 295-300.

Sultan, K., N.A. Shazili and S. Peiffer. 2011. Distribution of Pb, As, Cd, Sn and Hg in soil, sediment and surface water of the tropical river watershed, Terengganu (Malaysia). **Journal of Hydro-environment Research** 5(3): 169-176.

Sunderland, E.M. 2007. Mercury exposure from domestic and imported estuarine and marine fish and shellfish in U.S. seafood markets. **Environmental Health Perspectives** 115: 235-242.

Tonnie, N., M.A. Hena, M.H. Idris, A.H. Rajaee, S.M.N. Amin and M.H. Nesarul. 2018. Food and feeding habits of *Nemipterus japonicus* and *Nemipterus peronii* from coastal water of Bintulu, Sarawak, South China Sea. **Journal of Environmental Biology** 39(5): 857-864.

Trevizani, T.H., C. Domit, M.C. Vedolin, J.L.F. Angeli and R.C.L. Figueira. 2019. Assessment of metal contamination in fish from estuaries of southern and southeastern Brazil. **Environmental Monitoring and Assessment** 191(5): 1-16.

United Nations. 2015. **World Population Prospects: The 2015 Revision.** https://population.un.org/wpp/Publications/Files/WPP2015_DataBooklet.pdf. Cited 2 Jan 2022.

United States of Environmental Protection Agency (US EPA). 1996. **EPA method 3052: Microwave assisted acid digestion of siliceous and organically based matrices.** https://www.epa.gov/sites/production/files/2015-12/documents/3052.pdf. Cited 9 Jun 2020.

United States of Environmental Protection Agency (US EPA). 1997. **Mercury study report to congress health fffects of mercury and mercury compounds.** https://www.epa.gov/sites/production/files/2015-09/documents/volume5.pdf. Cited 9 Jun 2020.

United States of Environmental Protection Agency (US EPA). 2019. **Regional screening level (RSL) summary table (TR=1E-06 THQ =1.0).** https://semspub.epa.gov/work/HQ/197414.pdf. Cited 9 Jun 2020.

World Health Organization. 2019. **Preventing disease through healthy environments: exposure to arsenic: a major public health concern (No. WHO/CED/PHE/EPE/19.4. 1). World Health Organization.** https://apps.who.int/iris/bitstream/handle/10665/329482/WHO-CED-PHE-EPE-19.4.1-eng.pdf. Cited 2 Dec 2021.

World Health Organization. 2006. **Guidelines for Drinking-Water Quality. First Addendum to Third Edition, vol. 1. World Health Organization, Geneva.** https://apps.who.int/iris/bitstream/handle/10665/43428/9241546964_eng.pdf. Cited 6 Nov 2021.

Yap, C.K., A. Ismail, S.G. Tan and H. Omar. 2002. Correlations between speciation of Cd, Cu, Pb and Zn in sediment and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia. **Environment International** 28(1-2): 117-126.

Yoshimoto, N., M. Takaoka, T. Fujimori, K. Oshita, N. Sakai and S.A.S. Abd Kdir. 2016. Substance flow analysis of mercury in Malaysia. **Atmospheric Pollution Research** 7(5): 799-807.

Yunus, K., M.A. Zuraidah and A. John. 2020. A review on the accumulation of heavy metals in coastal sediment of Peninsular Malaysia. **Ecofeminism and Climate Change** 1(1): 21-35.

Yusoff, F.M., M. Shariff and N. Gopinath. 2006. Diversity of Malaysian aquatic ecosystems and resources. **Aquatic Ecosystem Health and Management** 9(2): 119-135.

Yusoff, N.M., S.N. Jaafar, N.A.M. Shazili, N.N.N.M. Azmi and M.S.A. Hassan. 2018. Assessment of metals concentration in tilapia (*Oreochromis* sp.) and estimation of daily intake by Malaysian. **Malaysian Journal of Analytical Sciences** 22(4): 594-604.

Zainul Armir, N.A., S. Zakaria, R.A. Begum, N.M. Ariff, N. Chamhuri, J. Harun, N.M. Talib and M.A. Kadir. 2021. Factors affecting industrial localization of timber mills in Peninsular Malaysia by econometric and spatial analysis. **Environment, Developmentand Sustainability** 1-18. DOI: 10.1007/s10668-021-01760-y.