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Mercury and risk assessment from consumption of crustaceans, cephalopods and fish from West Peninsular Malaysia

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ABSTRACT

Mercury (Hg) is a toxic element and has no known biological functions in humans. This study measured total Hg and methyl mercury (MeHg) concentrations in commonly consumed fish and seafood as well as to estimate the risk of Hg contamination through seafood consumption by Malaysians. The concentrations of total Hg and MeHg in 8 species of crustaceans ($n = 15$), 5 species of cephalopods ($n = 12$), and 29 species of fish ($n = 78$) from West Peninsular Malaysia are reported. Total mercury concentrations in crustaceans, cephalopods and fish were 0.033 ± 0.033 µg/g, 0.040 ± 0.025 µg/g and 0.106 ± 0.128 µg/g wet weight respectively. The proportion of methyl mercury in fish was 81–99% with a mean of 93 ± 5% (n = 15). Significantly higher mercury concentrations were observed in demersal fish, fish on higher trophic level and fish with body length of > 20 cm. All fish and seafood were below the Malaysian Food Regulations of 0.5 µg/g wet weight mercury for fish and fishery products and 1.0 µg/g wet weight mercury for predatory fish. The consumption of fish from certain seafood species, however, should be taken into consideration to ensure that the Provisional Tolerable Weekly Intake (PTWI) of MeHg does not exceed 1.6 µg/kg body weight/week.

1. Introduction

Fish are an important source of protein providing essential fatty acids; docosahexaenoic acid and eicosapentaenoic acid which aid to reduce cholesterol levels and incidence of heart disease [1]. Although fish is beneficial to human health, human exposure to Hg can occur primarily through consumption of fish and is a public health concern worldwide [2]. About 95% of the MeHg in ingested fish is absorbed into the bloodstreams of humans and within 4–14 h, peak blood MeHg concentrations are reached [3]. MeHg can cross plasma membranes more readily than inorganic Hg species and can cross the blood-brain barrier and the placenta [4]. Low-dose Hg exposure in fetuses, infants and children is associated with developmental delays, learning disabilities and possibly behavioral problems [5].

In Malaysia, fish and other seafood (molluscs and crustaceans) have always been a popular choice of protein for most of the population compared to other sources of protein such as pork, chicken, beef and mutton. Statistics in the year 2000 showed that per capita food supply from fish and fishery products was 58 kg per person [6].

Metal and metalloid concentrations in fish and other biota has been reported in different coastal areas in Malaysia [7] as well as from local wholesale markets in commonly consumed fish [8]. In general, metal/metalloid concentrations in fish increase with size and length [9]. Fish from the top of the food chain (secondary carnivores) usually have higher metal/metalloid concentrations compared to non-predatory fish [10].

Consumption of fish and seafood is the major route of exposure to Hg in humans with top predator fish containing considerably elevated concentrations of Hg due to bioaccumulation and biomagnification [10]. Realizing the importance of fish as a commodity among Malaysian population, assessment of Hg and MeHg concentrations in fish and other seafood is necessary in order to ensure that seafood can be safely consumed by the public and do not pose a significant health risk. Guidelines for MeHg concentrations in predatory fish are 1.0 µg/g wet weight while for non-predatory fish are 0.5 µg/g wet weight as stipulated under the Fourteenth Schedule of Regulation 38, Malaysian Food Regulation 195 (Food Act 1983, (Act 281) and Regulations 2006) and JECFA (2006). The "tolerable intake" is widely used to describe "safe"

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levels of intake; and can be expressed on either a daily basis (TDI or tolerable daily intake) or a weekly basis (TWI or tolerable weekly intake). PTWI is the maximum amount of a contaminant to which a person can be exposed per week over a lifetime without an unacceptable risk of health effects [11].

This study measured the total Hg and MeHg concentrations in commonly consumed fish and other seafood (crustaceans, cephalopods) of West Peninsular Malaysia to estimate the risk of Hg contamination through seafood consumption by Malaysians. While other studies have measured Hg concentrations in muscle and liver of fish [12,13], this study focused only on edible muscle tissues as they provide a reliable measure of long term Hg exposure and bioaccumulation. To assess risk of consumption of fish and other seafood, mercury concentrations were compared to Malaysian Food Regulation guidelines and PTWIs.

2. Materials and methods

2.1. Collection of crustaceans, cephalopods and fish

All crustaceans, cephalopods and fish for this study were obtained from West Peninsular Malaysia. Two wholesale markets in Perak and Selangor and a fish complex in Selangor were selected for this study. Wholesale markets sell seafood to consumers. Fish complexes accept and market fish to wholesale markets. Visits to fish complexes and wholesale markets were conducted between June to December 2009. Fish and seafood were obtained according to the time the fish landed at the fish complex while purchase of fish at the wholesale markets was done between 12 am to 2 am.

A total of 105 samples comprising 29 species of fish, 8 species of crustaceans and 5 species of cephalopods were collected from selected wholesale market and fish landing sites in Peninsular Malaysia. The samples consisted of 15 pelagic fish (Carangidae and Scrombidae) and 14 demersal fish (Lutjanidae, Latidae, Dasyatidae, Sciaenidae, Nemipteridae). Penaeidae and Loliginidae constitutes the crustacean and cephalopod families. The selection of fish and seafood were based on the results of food dietary survey conducted among 3536 subjects in Peninsular Malaysia [14].

2.2. Sample preparation

All samples were transported to the laboratory on ice. Only edible portions were used for analysis. For fish, scales were removed, samples filleted, homogenized and wrapped in aluminium foil before being inserted into labeled plastic bags. For prawns and shrimps, the outer shells were removed. Samples which have been wrapped and labeled were kept in freezer at −20 °C until further analysis. All samples were freeze dried for approximately 48 h and ground into fine powder using a mill before being put into 50 ml polypropylene tubes and sent to Australia by courier service.

2.3. Measurement of total Hg concentrations

Approximately 0.07 g of freeze-dried sample was weighed into 7 ml polytetrafluroacetate digestion vessels (A.I. Scientific Australia) and 1 ml of concentrated nitric acid (Aristar, BDH, Australia) added. Samples were digested at 600 W for 2 min, 0 W for 2 min and 450 W for 45 min [15]. After cooling, digests were diluted to 10 ml with deionised water (Milli-Q, Millipore, Australia) in 10 ml polyethylene vials (Sarstedt, Australia). Hg in digests were measured by ICP-MS [16]. External calibration standards used for quantitation were made up from a 10 mg/L Reference Standard, ICP-MS Calibration Multi Element Standard 2 (AccuTrace ™) in 1% (v/v) HNO_3 acid as 0.1, 1, 10 and 100 mg/L solutions.

The calibration curves generated for total Hg determination were highly linear ($r^2 > 0.999$). The limit of detection (3 times the standard deviation of procedural blank values) for total Hg measurements was 0.05 μg/L (equivalent to approximately 70 μg/kg dry mass in tissue). Measurement of total Hg concentrations in National Research Council Canada DORM-2 (Dogfish muscle) 4.87 ± 0.51 μg/g ($n = 21$) was in agreement with the certified values (4.64 ± 0.26 μg/g). As the recommended mercury limits were expressed in wet mass, for comparative purposes, dry mass was converted into wet mass using this formula: Dry weight concentration = Wet weight concentration × (100/100-moisture percentage). Moisture content was calculated based on the works of [6,17]. The results were then grouped into five categories following [18] as cited by [19]. They described mercury in wet weight of fish from 0.05 to 0.15 μg/g as very low, 0.15–0.25 μg/g as low, 0.25–0.35 μg/g as medium, 0.35–0.45 μg/g as high and above 0.45 μg/g as very high.

2.4. Measurement of MeHg concentrations

All fish samples were tested initially for total Hg concentration and MeHg determination was conducted for samples that contained at least 0.5 μg/g total Hg. MeHg was measured in crustaceans, cephalopods and fish according to method of [20]. Freeze-dried samples (0.2 g) were weighed into 5 ml glass culture tubes with 20 mg of protease type XIV (Sigma, Australia) and 8 ml of phosphate buffer (pH 7.5) containing 0.05% cysteine. The tubes were incubated for 2 h in a hybridisation oven (XTRON HI 2002, Bartlett Instruments) at 37°C with rotation of samples at 20 rpm. Extracts were transferred to acid washed 10 ml polypropylene centrifuge tubes (Sarstedt, Australia), made up to a final volume of 10 ml with buffer and centrifuged for 20 min at 3000 rpm. Supernatants were filtered through Acrodisc LC 13-mm Syringe filter with 0.2 mm PVDF membrane (Gelman, USA) before analysis. A portion of the enzyme extract (1 mL) was acidified to 1% (v/v) with nitric acid (Aristar, BDH, Australia) and total Hg measured by ICP-MS [16].

Aliquots of the enzyme extracts (100 μl) were injected onto a HPLC system consisting of a PerkinElmer Series 200 mobile phase delivery and auto sampler system (PerkinElmer, Australia). A Sphericlone 5 μm ODS2 80A PEEK chromatography column was used for the separation of Hg species. The eluent from the HPLC column was directed by PEEK (polyether ether ketone) capillary tubing into the cross-flow nebulizer of a PerkinElmer Elan 6000 inductively coupled plasma mass spectrometer (PerkinElmer SCIEX, Australia). The mobile phase contained 5% v/v methanol, 0.06 M ammonium acetate and 0.1% w/v cysteine, pH 6.8 (flow rate 1.0 ml/min, temperature, 25°C). External calibration standards were used. The chromatography package Turbochrom (PerkinElmer, Australia) was used to quantify Hg species by peak area.

Measurement of MeHg concentrations in National Research Council Canada DORM-2 (Dogfish muscle) 4.78 ± 0.04 ($n = 6$) were in agreement with the certified value (4.47 ± 0.32 μg/g).The limit of detection for MeHg concentrations was 0.1 μg/g wet mass (equivalent to approximately 50 μg/kg dry mass in tissue).

2.5. Estimation of potential human health risk

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a Provisional Tolerable Weekly Intake (PTWI) for inorganic Hg and MeHg of 4 μg/kg body weight/week and 1.6 μg/kg body weight/week respectively [21]. The daily fish consumption by the Malaysian population is 160 g/person/day [22] with an average weight of an individual of 64 kg [23]. PTWI values for Hg and MeHg by an adult (μg/kg^{-1} body weight/week) for each species were calculated using the formula below:

$$\text{PTWI } (\mu g/kg) = \frac{\text{Mean Hg in fish } (\mu g/g \text{ wet weight}) \times \text{Weekly fish consumption (g)}}{\text{Body weight (kg)}}$$

In this study, Maximum Safe Weekly Consumption (MSWC) for a 64 kg adult to reach the PTWI was also estimated. The PTWI (μg/kg body weight/week) was first multiplied by body weight (64 kg) and divided by the Hg concentrations to obtain the MSWC.

2.6. Statistical analysis

Neither total Hg nor MeHg concentrations in fish were normally distributed based on Kolmogorov–Smirnov normality test ($p < 0.05$) hence non-parametric tests were used. All statistical analyses were conducted with SPSS, version 17.0 for Windows. Differences between groups were tested using Kruskal-Wallis followed by Mann-Whitney U test. A p value of < 0.05 was considered to indicate statistical significance in this study. The correlation coefficient was studied using Spearman correlation analysis. For data points that are statistically inconsistent with the rest of the data, the modified Thompson Tau technique is used to determine whether to keep or discard outliers at 95% confidence level.

3. Results

3.1. Hg concentrations

The trophic level (TL) for fish in this study ranged from 2.7 to 4.5 (Table 1). No information was obtained from the database for crustaceans and cephalopods hence only TL of fish are reported. More than half of the samples (68%) had TL between 3.7 and 4.5; an indication of carnivores or predatory fish. About 29% of samples were omnivores that feed on a variety of prey (TL between 2.9 and 3.7). Only 3% of samples fed on vegetable materials (herbivores).

Total mercury concentrations of fish from this study are summarized in Table 2. Mercury concentrations in fish ranged from 0.021 to 0.645 μg/g wet weight. Significant variations of mercury concentrations exist in different species ($\chi^2_{KW} = 64.458$; $p = 0.011$). Among pelagic fish, median mercury concentrations were highest in dogtooth tuna (*Gymnosarda unicolor*) and oxeye scad (*Selar boops*). For demersal fish, the highest mercury concentrations were shown in doublewhip threadfin bream (*Nemipterus nematophorus*), John's snapper (*Lutjanus rusellii*) and mangrove red snapper (*Lutjanus argentimaculatus*). Demersal fish showed significantly higher ($\chi^2_{KW} = 11.727$; $p = 0.001$) mercury concentrations (0.144 ± 0.150 μg/g wet weight) compared to pelagic fish (0.073 ± 0.082 μg/g wet weight). Significantly elevated mercury concentrations were observed in fish of higher trophic level ($\chi^2_{KW} = 9.288$; $p = 0.010$) by which mercury concentrations were highest in carnivores as opposed to omnivores and herbivores. Among the family groups, median mercury concentrations were observed to be highest in Latidae, followed by Nemipteridae, Sciaenidae and Lutjanidae. No significant differences were found between mercury concentrations and sampling locations ($\chi^2_{KW} = 0.093$; $p = 0.954$) as well as sampling points ($\chi^2_{KW} = 0.080$ $p = 0.777$). Larger fish (length of > 20 cm) showed significantly higher mercury concentrations in comparison to smaller fish ($\chi^2_{KW} = 5.512$; $p = 0.019$).

Mercury concentrations ranged from 0.012 to 0.119 μg/g wet weight in crustaceans and 0.015 to 0.218 μg/g wet weight in cephalopods respectively. For crustaceans, mercury concentrations were observed highest in pink shrimp, followed by banana prawn and spear shrimp whereas for cephalopods, mercury concentrations were found to be highest in little squid, sibogae squid and mitre squid. Mercury concentrations, however, did not show any difference among species in crustaceans and cephalopods.

3.2. MeHg concentrations

The methyl mercury concentrations for fish, crustaceans and cephalopods are summarized in Table 3. Methyl mercury concentrations ranged from 0.059 to 0.637 μg/g wet weight. The proportion of methyl mercury in fish was 81–99% with a mean of 93 ± 5% ($n = 15$). Lower proportions of methyl mercury were observed in crustaceans (49%) and cephalopods (81%). (Please note that only one sample each was analyzed for both crustaceans and cephalopods). A significant positive correlation was found between Hg and MeHg concentrations (ρ = 0.996; $p < 0.000$).

3.3. Estimation of potential health risk

The distribution of total mercury in seafood based by categories [18] is shown in Fig. 1. Majority of the samples (74%) had very low concentrations of mercury followed by 15% of samples with low mercury concentrations. Another 7% of samples had medium mercury concentrations. One fish sample had high mercury concentrations (1%) whereas another three fish samples had very high mercury concentrations (3%).

In comparison with the Fourteenth Schedule of Regulation 38, Malaysian Food Regulation 195 (Food Act 1983, (Act 281) and Regulations 2006) and JECFA (2006) of 0.5 μg/g wet weight mercury permitted for fish and fishery products and 1.0 μg/g wet weight for predatory fish (both as methyl mercury), none of the samples exceeded the stipulated guidelines. Although 4% of the samples had high mercury concentrations (> 0.451 μg/g wet weight), these samples are predatory fish (doublewhip threadfin bream, dogtooth tuna, John's snapper) which did not exceed the 1.0 μg/g wet weight of mercury.

In order to evaluate the potential health risk of population through consumption of seafood, the weekly intake rates for all species were estimated and compared with the PTWI and MSWC (Table 4). PTWI for inorganic Hg is 4 μg/kg body weight whereas for MeHg is 1.6 μg/kg body weight [21].

The estimated weekly intake was higher than the recommended PTWI for bream, snapper, croaker, barramundi and tuna. PTWI for bream and barramundi was 2 and 2.5 times higher than the recommended PTWI whereas PTWI for other seafood was between 0.228 and 1.582 μg/kg body weight/week. A 64 kg person is allowed to consume 3.75 kg of prawns a week (equivalent to 23 servings per week) to exceed the PTWI whereas the same person can only consume 412 g of barramundi (equivalent to 2.6 servings per week) to reach the PTWI of 1.6 μg/kg/body weight.

4. Discussion

4.1. Hg concentrations

The present study provides data on total mercury as well as methyl mercury concentrations in crustaceans, cephalopods and fish both from fish landing ports and wholesale markets in West Peninsular Malaysia. Mercury concentrations differed significantly among fish of different families and species. The concentrations of mercury among the different organisms were in the order fish > cephalopods > crustaceans.

Comparable mercury concentrations in fish measured in this study were reported by [8] for *Parastromasus niger* (0.04 ± 0.08 μg/g wet weight), *Thunnus tonggol* (0.12 ± 0.38 μg/g wet weight) and *Selaroides leptolepis* (0.03 ± 0.04 μg/g wet weight). Lower mercury concentrations for *Euthynnus affinis* (0.09 μg/g dry weight), *Megalaspis cordyla* (0.21 μg/g dry weight) and *Rastrelliger kanagurta* (< 0.05 μg/g dry weight) were reported by [12] in comparison with similar fish species from this study. A study by [14] portrayed comparable mercury concentrations to fish in this study particularly for *Himantura gerrardi* (0.384 ± 0.741 μg/g dry weight), *Otolithoides ruber* (0.421 ± 0.423 μg/g dry weight) and *Selaroides leptolepis* (0.252 ± 0.125 μg/g dry weight).

Comparison with studies from other areas indicates that total Hg concentrations (on a wet weight basis) reported in similar organisms were generally lower than the median values obtained from this study. A study by [25] conducted in New Caledonia reported total Hg concentrations in *Lutjanus argentimaculatus* to be between 0.403 and 0.994 μg/g dry weight. Hg concentrations in pink shrimp, *Metapenaeus affinis* reported by [26] from Italy was 0.09–0.69 μg/g dry weight and

Table 1
Characteristics of seafood collected from fish landing complex and wholesale market in Peninsular Malaysia.

Groups/family/common name	Scientific name	No of samples	Length (cm)	Main food	Feeding habit	Trophic level
Pelagic fish						
Carangidae						
Yellowstripe scad	*Selaroides leptolepis*	3	14–15	Nekton, zooplankton, zoobenthos	Predator	3.5
Oxeye scad	*Selar boops*	1	25	Zooplankton, zoobenthos	Variables	3.5
Greater amberjack	*Seriola dumerili*	1	20	Nekton, zooplankton, zoobenthos	Predator	4.5
Slander scad	*Decapterus russelli*	1	30	Nekton, zooplankton, plants zoobenthos	Variables	3.7
Torpedo scad	*Megalaspis cordyla*	4	22–30	Nekton, zooplankton, zoobenthos, plants detritus	Predator	4.4
Black pomfret	*Parastromateus niger*	5	22–33	Plants, zooplankton, zoobenthos	Variables	2.9
Scrombidae						
Indian mackerel	*Rastrelliger kanagurta*	2	13–24	Nekton, zooplankton, zoobenthos, plants detritus	Predator	3.2
Indo-Pacific mackerel	*Rastrelliger brachysoma*	2	17–18	Zooplankton, plants	Plankton feeder	2.7
Indo-Pacific king mackerel	*Scomberomorus guttatus*	6	38–56	Nekton, zoobenthos	Predator	4.3
Narrowbarred spanish mackerel	*Scomberomorus commerson*	4	40–66	Nekton, zooplankton, zoobenthos	Predator	4.5
Faughni mackerel	*Rastreliger faughni*	3	18–22	Zooplankton	Plankton feeder	3.4
Slimy mackerel	*Scomber australasicus*	3	16–18	Nekton, zooplankton, zoobenthos	Predator	4.2
Dogtooth tuna	*Gymnosarda unicolor*	2	28–40	Nekton	Predator	4.5
Longtail tuna	*Thunnus tonggol*	1	17	Nekton, zoobenthos/predator	Predator	4.5
Kawakawa	*Euthynnus affinis*	2	36–69	Nekton, zoobenthos/predator	Predator	4.5
Demersal fish						
Lutjanidae						
Mangrove red snapper	*Lutjanus argentimaculatus*	3	38–39	Nekton, zooplankton, zoobenthos	Predator	3.6
Emperor red snapper	*Lutjanus sebae*	3	32–46	Nekton, zooplankton, zoobenthos	Predator	4.3
Malabar blood snapper	*Lutjanus malabaricus*	5	28–50	Nekton, zoobenthos	Predator	4.5
John's snapper	*Lutjanus johnii*	1	66	Detritus, nekton, zoobenthos	Predator	4.3
Latidae						
Barramundi	*Lates calcarifer*	4	50–72	Nekton, zooplankton, zoobenthos	Predator	4.4
Dasyatidae						
Sharpnose stingray	*Himantura gerrardi*	2	21–32	Zoobenthos	Predator	3.7
Honeycomb stingray	*Himantura uarnak*	1	142	Nekton, zoobenthos/predator	Predator	3.6
Bluespotted stingray	*Dasyatis kuhlii*	4	49–114	Nekton, zoobenthos/predator	Predator	3.2
Sciaenidae						
Soldier croaker	*Nibea soldado*	6	15–22	Zoobenthos, nekton/predator	Predator	4.0
Tigertooth croaker	*Otolithes ruber*	1	13	Zoobenthos/predator	Predator	3.6
Bronze croaker	*Otolithoides biauritus*	1	21	Zoobenthos, nekton/predator	Predator	4.1
Nemipteridae						
Yellowbelly threadfin bream	*Nemipterus bathybius*	1	34	Zoobenthos, nekton/predator	Predator	4.0
Japanese threadfin bream	*Nemipterus japonicus*	5	17–29	Zoobenthos, nekton/predator	Predator	3.8
Doublewhip threadfin bream	*Nemipterus nematophorus*	1	26	N/a	N/a	3.7
Penaeidae						
Sand velvet shrimp	*Metapenaeopsis barbata*	1	14			
Pink shrimp	*Metapenaeus affinis*	2	10–13			
Yellow shrimp	*Metapenaeus brevicornis*	3	10–39			
Rainbow shrimp	*Parapenaeopsis sculptilis*	3	12	Information not available		
Spear shrimp	*Parapenaeopsis hardwickii*	1	13			
Indian white prawn	*Penaeus indicus*	2	14–22			
Banana prawn	*Penaeus merguiensis*	2	10–20			
Giant Tiger Prawn	*Penaeus monodon*	1	29			
Loliginidae						
Indian squid	*Loligo duvaucelli*	6	16–45			
Sibogae squid	*Loligo sibogae*	1	33			
Little squid	*Loligo uyii*	1	24			
Mitre squid	*Loligo chinensis*	1	39			
Sword tip squid	*Loligo edulis*	3	18–24			

Source: http://www.fishbase.usNekton – aquatic organisms swimming actively in body of water, capable of traveling over long distances. Fish, squids, cetaceans, pinnipeds, sea snakes, turtles and penguins constitute the nekton group. Zooplankton - animal constituent of plankton; mainly small crustaceans and fish larvae. Zoobenthos – the invertebrate that live in or on the seabed, including the intertidal zone. Plants – phytoplankton and other plants. Detritus – non-living particulate organic material including fragment of dead animals and fecal material (n/a denotes information not available).

Trophic Levels (TL):

$2.0 < TL < 2.1$ (mean 2.02) - pure herbivores.

$2.1 < TL < 2.9$ (mean 2.50) - omnivores with a preference for vegetable material.

$2.9 < TL < 3.7$ (mean 3.40) - omnivores with a preference for animal material (feeding on a variety of prey).

$3.7 < TL < 4.0$ (mean 3.85 - carnivores with a preference for decapods and fish.

$4.0 < TL < 4.5$ (mean 4.32) - carnivores with a preference for fish cephalopods.

Reference: [24].

Table 2
Total mercury concentrations (μg/g wet weight) in seafood from fish complex and wholesale market in West Peninsular Malaysia.

Groups/family/species	Common name	No. of samples	Median	IQR[a]	Min	Max	Range
Pelagic							
Carangidae							
Selaroides leptolepis	Yellowstripe scad	3	0.053	0.042	0.037	0.121	0.084
Selar boops	Oxeye scad	1	0.195	–	–	–	–
Seriola dumerili	Greater amberjack	1	0.073	–	–	–	–
Decapterus russelli	Slender scad	1	0.073	–	–	–	–
Megalaspis cordyla	Torpedo scad	4	0.184	0.108	0.043	0.340	0.297
Parastromateus niger	Black pomfret	5	0.054	0.012	0.035	0.096	0.061
	Total	15	0.073	0.012	0.035	0.340	0.305
Scrombidae							
Rastrelliger kanagurta	Indian mackerel	2	0.059	0.012	0.047	0.070	0.023
Rastrelliger brachysoma	Indo-Pacific mackerel	2	0.025	0.004	0.021	0.030	0.009
Scomberomorus guttatus	Indo-Pacific king mackerel	6	0.051	0.089	0.029	0.195	0.166
Scomberomorus commerson	Narrowbarred Spanish mackerel	4	0.108	0.021	0.061	0.132	0.071
Rastreliger faughni	Faughni mackerel	3	0.058	0.015	0.042	0.073	0.031
Scomber australasicus	Slimy mackerel	3	0.098	0.036	0.051	0.123	0.072
Gymnosarda unicolor	Dogtooth tuna	2	0.360	0.253	0.107	0.612	0.505
Thunnus tonggol	Longtail tuna	1	0.160	–	–	–	–
Euthynnus affinis	Kawakawa	2	0.108	0.024	0.084	0.132	0.048
	Total	25	0.073	0.081	0.021	0.612	0.591
Demersal							
Lutjanidae							
Lutjanus argentimaculatus	Mangrove red snapper	3	0.275	0.052	0.235	0.339	0.104
Lutjanus sebae	Emperor red snapper	3	0.118	0.040	0.056	0.135	0.079
Lutjanus malabaricus	Malabar blood snapper	5	0.132	0.067	0.032	0.160	0.128
Lutjanus russellii	John's snapper	1	0.522	–	–	–	–
	Total	12	0.203	0.209	0.032	0.160	0.128
Latidae							
Lates calcarifer	Barramundi	4	0.134	0.185	0.032	0.339	0.307
Dasyatidae							
Himantura gerrardi	Sharpnose stingray	2	0.076	0.028	0.048	0.105	0.057
Himantura uarnak	Honeycomb stingray	1	0.095	–	–	–	–
Dasyatis kuhlii	Bluespotted stingray	4	0.123	0.173	0.032	0.351	0.319
	Total	7	0.095	0.138	0.032	0.351	0.319
Sciaenidae							
Nibea soldado	Soldier croaker	6	0.144	0.056	0.049	0.200	0.151
Otolithes ruber	Tigertooth croaker	1	0.097	–	–	–	–
Otolithoides biauritus	Bronze croaker	1	0.187	–	–	–	–
	Total	8	0.144	0.086	0.049	0.200	0.151
Nemipteridae							
Nemipterus bathybius	Yellowbelly threadfin bream	1	0.322	–	–	–	–
Nemipterus japonicus	Japanese threadfin bream	5	0.132	0.103	0.085	0.286	0.201
Nemipterus nematophorus	Doublewhip threadfin bream	1	0.645	–	–	–	–
	Total	7	0.198	0.227	0.085	0.286	0.201
Penaeidae							
Metapenaeopsis barbata	Sand velvet shrimp	1	0.025	–	–	–	–
Metapenaeus affinis	Pink shrimp	2	0.076	0.043	0.033	0.119	0.086
Metapenaeus brevicornis	Yellow shrimp	3	0.021	0.005	0.021	0.031	0.010
Parapenaeopsis sculptilis	Rainbow shrimp	3	0.053	0.014	0.053	0.080	0.027
Parapenaeopsis hardwickii	Spear shrimp	1	0.060	–	–	–	–
Penaeus indicus	Indian white prawn	2	0.024	0.003	0.021	0.027	0.006
Penaeus merguiensis	Banana prawn	2	0.064	0.053	0.012	0.117	0.105
Penaeus monodon	Giant Tiger Prawn	1	0.043	–	–	–	–
	Total	15	0.033	0.039	0.012	0.119	0.107
Loliginidae							
Loligo duvaucelli	Indian squid	6	0.036	0.021	0.015	0.218	0.203
Loligo sibogae	Sibogae squid	1	0.056	–	–	–	–
Loligo uyii	Little squid	1	0.063	–	–	–	–
Loligo chinensis	Mitre squid	1	0.024	–	–	–	–
Loligo edulis	Sword tip squid	3	0.041	0.020	0.039	0.080	0.041
	Total	12	0.040	0.031	0.015	0.218	0.203

[a] IQ IQR = interquartile range.

was lower than the ones observed in this study. Similarly, Hg concentrations in *Thunnus tonggol* in a study conducted by [27] in Iran also were lower than Hg concentrations reported in this study (0.083 μg/g dry weight).

Demersal fish in this study exhibited mercury concentrations nearly twice higher than pelagic fish which is in agreement with [14] who reported similar findings for commonly consumed marine fish in Peninsular Malaysia. A study by [28] also found that striped mullet, a benthic species of the Mediterranean Sea, showed higher mercury concentrations than hake, a pelagic fish. In general, demersal fish exhibited higher concentrations of metal contaminants as opposed to fish inhabiting the upper water column as they are in direct contact with the

Table 3
The mercury and methyl mercury concentrations (median ± interquartile range; μg/g wet weight) in seafood of West Peninsular Malaysia.

Scientific name	Common name	Number of samples	Total Hg	MeHg	Percentage MeHg (%)
Selar boops	Oxeye scad	1	0.195	0.177	91
Megalaspis cordyla	Torpedo scad	3	0.207 ± 0.089	0.167 ± 0.098	81
Scomberomorus guttatus	Indo-Pacific king mackerel	2	0.175 ± 0.020	0.170 ± 0.022	97
Gymnosarda unicolor	Dogtooth tuna	1	0.612	0.601	98
Lutjanus argentimaculatus	Mangrove red snapper	3	0.275 ± 0.052	0.252 ± 0.057	92
Lutjanus malabaricus	Malabar blood snapper	3	0.133 ± 0.014	0.119 ± 0.022	89
Lutjanus russellii	John's snapper	1	0.522	0.510	98
Lutjanus sebae	Emperor red snapper	1	0.135	0.116	86
Lates calcarifer	Barramundi	4	0.248 ± 0.120	0.231 ± 0.127	93
Dasyatis kuhlii	Bluespotted stingray	2	0.268 ± 0.083	0.259 ± 0.084	96
Nibea soldado	Soldier croaker	4	0.161 ± 0.040	0.147 ± 0.049	91
Otolithoides biauritus	Bronze croaker	1	0.187	0.184	98
Nemipterus bathybius	Yellowbelly threadfin bream	1	0.322	0.300	93
Nemipterus japonicus	Japanese threadfin bream	2	0.242 ± 0.044	0.225 ± 0.048	93
Nemipterus nematophorus	Doublewhip threadfin bream	1	0.645	0.637	99
Metapanaeus affinis	Pink shrimp	1	0.119	0.059	49
Loligo duvaucelli	Indian squid	1	0.218	0.177	81

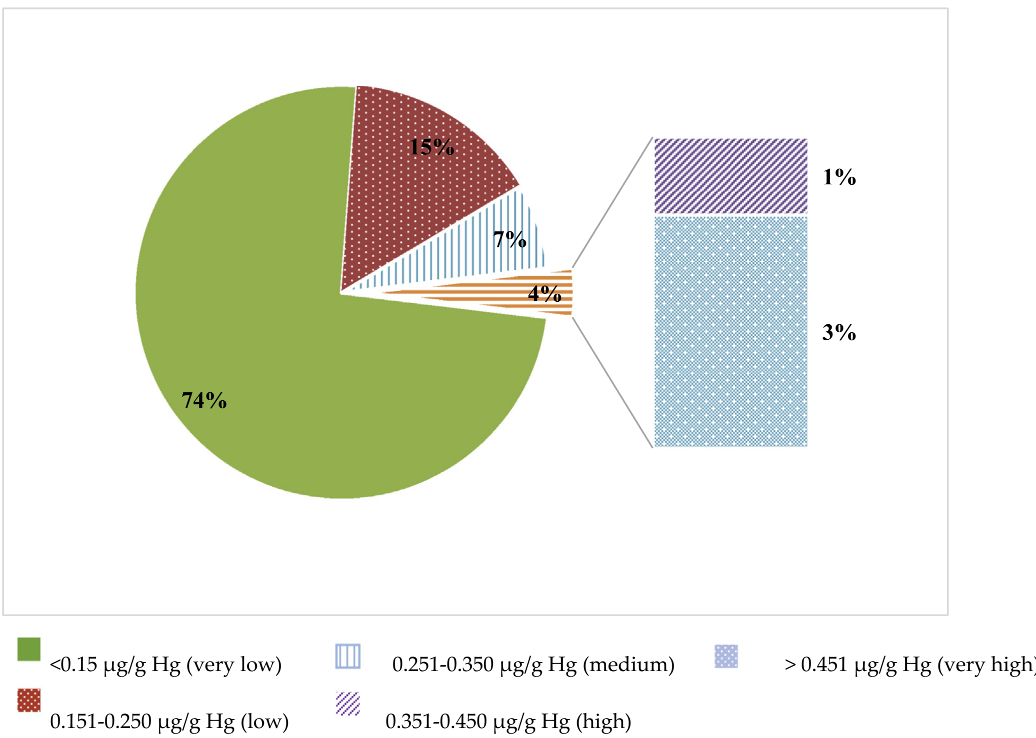

Fig. 1. The distribution of total mercury concentrations (μg/g wet weight) in crustaceans, cephalopods and fish from West Peninsular Malaysia.

sediments [29].

The median Hg concentrations were found to increase significantly across trophic levels in the order: herbivores < omnivores < carnivores which agree with findings from [14]. Carnivorous species live and feed in the open sea, associated with surface or middle depths of a body of water and are placed at higher trophic level than non-carnivorous species in a food chain [24]. Bioaccumulation of mercury is influenced by both environmental (water chemistry, pH, season) and biological factors (species, sex, trophic level, habitat, body size, age) [30]. Predatory fish accumulates higher mercury concentrations than non-predatory fish because of bioaccumulation and biomagnification of MeHg [13]. Hg concentrations of carnivorous fish in this study were 5.1 times higher than herbivorous fish. A study by [31] also found that mercury concentrations in carnivorous fish (197 μg/kg) of South China Sea were five times higher than herbivorous fish (39.6 μg/kg).

An important factor in determining the rate of uptake, distribution as well as elimination of contaminants is fish size [9]. Due to longer exposure time, it is common that older individuals show higher mercury concentrations than younger ones. It is often difficult to determine the age of fish and size is normally used as surrogate for age [30]. This study showed that mercury concentrations in fish with body length above 20 cm were 1.5 times higher than fish with body length < 20 cm suggesting that consumers who eat larger fish would be exposed to higher concentrations of mercury than those who eat smaller fish. Hence, by eating smaller fish, exposure to mercury could be greatly reduced.

4.2. MeHg concentrations

The mean percentage of methyl mercury to total mercury in all species was 93 ± 5% indicating that this is the predominant form of mercury present in most organisms. This is in agreement with findings from other studies [13,32] in which the majority of mercury present in fish was as MeHg (> 70%). MeHg percentage close to 100% in marine

Table 4
Estimation of allowable intake of seafood based on PTWI and MSWC.

	n	Median Hg (μg/g ww)	Median MeHg (μg/g ww)	PTWI[a] (μg/kg bw)	MSWC[b] (g)	Serves[c]/week
Prawn	5	0.027	0.013	0.228	3751	23.4
Shrimp	10	0.043	0.021	0.368	2387	14.9
Squid	12	0.040	0.032	0.560	2561	16.0
Scad	10	0.097	0.090	1.582	1053	6.6
Mackerel	20	0.059	0.055	0.967	1724	10.8
Bream	7	0.198	0.184	3.220	518	3.2
Stingray	7	0.095	0.089	1.554	1072	6.7
Snapper	12	0.134	0.125	2.185	763	4.8
Croaker	8	0.144	0.134	2.341	712	4.4
Barramundi	4	0.248	0.231	4.041	412	2.6
Pomfret	5	0.054	0.050	0.880	1895	11.8
Tuna	5	0.132	0.122	2.141	778	4.9

[a] Provisional Tolerable Weekly Intake (PTWI) for MeHg is 1.6 μg/kg body weight and average weight of individual is 64 kg.
[b] Maximum Safe Weekly Consumption (MSWC) was calculated as PTWI multiplied by body weight and divided by MeHg concentrations.
[c] Daily fish consumption by the Malaysian population is 160 g/person/day which is equivalent to one serve.

organisms from New Caledonia were observed by [25] which increases the bioavailability to predator and humans.

4.3. Estimation of potential health risk

Results from this study showed that none of the samples exceeded the national and international health limits. Study by [14] reported that 2% of the fish samples from marine fish in Peninsular Malaysia exceeded the guidelines of 0.5 μg/g wet weight of mercury. Studies by [33] in fish from Langat River and Engineering Lake in Malaysia reported that heavy metals concentrations in all fish species studied were safe for human consumption. Likewise, mercury concentrations in fish from studies conducted in Malaysia were all within the stipulated value and fit for human consumption [8,12,13]. Total mercury concentrations for seafood measured in this study are relatively low when compared to some other areas in Asia. Higher concentrations of total mercury (3.51 ± 0.72 μg/g wet weight) in different species of tuna was reported by [32] in Japan while [31] observed that fish from Hainan Island and Yongxing Island of the South China Sea had 0.152 μg/g wet weight of mercury.

The main driving factors for seafood choices by an individual differ considerably from one another depending on personal preference. The daily intake of an element from food consumption relies on the element concentration in food and the amount of food consumed. To estimate the "degree" of mercury and methylmercury intake through seafood, our results were interpreted in terms of the PTWI and MSWC. The PTWI for total mercury is 4 μg/kg body weight and methyl mercury 1.6 μg/kg body weight [34]. These values represent "permissible human weekly exposure, protecting the most susceptible part of the population, to those contaminants unavoidably associated with the consumption of otherwise wholesome and nutritious foods" [34]. The results in this study showed that the lower the concentration of mercury contained in a fish, the higher amount of fish can be consumed. For example, a person can consume up to 12 serves of pomfret a week whereas only about two and a half servings of barramundi can be consumed per week to ensure that the PTWI limit of 1.6 μg/kg body weight/week of methyl mercury is not exceeded.

Fish advisory notices are intended to inform consumers of the positive and negative attributes of their potential choices which should lead to appropriate behavioral changes when choosing types of fish to consume. Nevertheless, [35] indicate that many advisories emphasize more on the risk information rather than the benefits of fish consumption. Fish advisories should not reduce fish consumption [36] even among women of high risk groups [37] but encourage a shift from consuming highly contaminated fish to those fish which are less contaminated and safer to eat [38]. Therefore, a person equipped with knowledge on mercury concentrations in fish may generally make sounder choices which will then assist in managing risk better than a person with zero knowledge in this matter.

5. Conclusions

This study measured total mercury and methyl mercury concentrations in 42 species of commonly consumed crustaceans, cephalopods and fish in West Peninsular Malaysia. Findings from this study improves the baseline data and information on mercury concentration in fish and seafood commonly consumed in Malaysia. In general, all fish and seafood had low mercury concentrations and were below permissible national and international mercury consumption guidelines (0.5 μg/g for fish and fishery products; 1.0 μg/g for predatory fish). The results from this study showed that total mercury concentrations in fish were influenced by habitat, feeding habits, family groups and body length. Although some fish had higher mercury concentrations than others, the benefit of consuming fish should outweigh the risk and do not deter consumers to eat fish. The consumption of some fish species, however, should be limited to ensure that the PTWI of MeHg is not exceeded.

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Conflicts of interest

The authors declare no conflict of interest.

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