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Level of Polychlorinated Biphenyls (PCBs) in Selected Marine Fish (pelagic) from Straits of Malacca

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ABSTRACT

Fish is a good source of protein, supply important vitamins and other essential nutrients including essential fatty acids (EFA), the EPA and DHA which help to reduce risk of death from coronary heart diseases. However, diet and food of animals' origin are the most predominant sources of polychlorinated biphenyls (PCBs) to human which accounts to over 90%, with fish as one of the major routes of contaminants in human body. PCBs are a group of extremely stable aromatic chlorinated compounds which are relatively resistant to biological degradation and very persistent in the environment. This study has identified the type and level of 12 congeners of PCBs that are most toxic to humans. The maximum permitted level of PCBs in muscles meat of fish and fishery products is 4 pg/g, as recommended by World Health Organization (WHO) using the WHO-TEFs. Meanwhile, the highest amount of PCBs concentration was in *Rastrelliger kanagurta* (Indian mackerel), with the level of PCBs at 1.37 pg/g wet weight. Other species like *Scomberomorus guttatus* (Spanish mackerel), *Pampus argenteus* (Silver pompret), *Megalapsis cordyla* (Hardtail scad), *Eleutheronema tradactylum* (Fourfinger threadfin) and *Chirocentrus dorab* (Dorab wolfherring) showed PCBs levels ranging from 0.35 pg/g to 1.05 pg/g wet weight. Thus, the PCBs in all the samples were below the permitted level. It can be concluded that the studied pelagic fish are safe to consume. Although the levels were not high, it is still important to set limits for the PCBs in fish and shellfish species so as to make a better estimation of the risk of exposure to human through dietary intake of fish, specifically fatty fish to meet nutritional requirement for EPA and DHA.

Keywords: Fish, Polychlorinated biphenyls, PCBs, pelagic

INTRODUCTION

Polychlorinated biphenyls (PCBs) are a group of extremely stable aromatic chlorinated compounds which are relatively resistant to biological degradation and very persistent in the environment. Two important events involving direct overexposure of human to PCBs occurred

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in Japan (Yusho) in 1968 and Taiwan (Yu-Cheng) in 1979. In both cases, rice oil contaminated with PCBs was ingested and caused illnesses to individuals consuming the rice oil (Yu *et al*., 1991) such as various somatic complaints, low birth weights, chloracne and hyperpigmentation, especially of newborn children (Kuratsune *et al*., 1972). There are many reported biological and toxicological effects of these compounds and their impacts on human health had become an extremely controversial issue in environmental toxicology, endocrinology and carcinogenesis. Consequently, the marketing and use of PCBs have been restricted in European Union (EU) through Directive 85/467/EC, while the use of PCBs in some European countries has been banned since as early as 1973 (Boscolo *et al*., 2007). Generally, PCBs accumulate in the environment and food chain (Bocio *et al*., 2007). There are 209 PCB congeners altogether, but only 12 of the non-*ortho* and mono-*ortho* PCBs are identified as dioxin-like by World Health Organization (Van den Berg *et al*., 2006). The principal sources of PCBs encountered in the environment include open burning or incomplete combustion, vaporization of PCBs in open applications, accidental spills or leakages of PCBs in close system applications and disposal into sewage system (Connell, 2005). One of the strongest tendencies to accumulate PCBs from water and food source is aquatic organisms. Diet and food of animal origin are the most predominant sources of PCBs to human, and these account to over 90% (Svensson *et al*., 1991). Although fish and shellfish generally represent only a small percentage (10%) of these contaminants, these foods are some of the major routes of the contaminants in the human body (Harisson *et al*., 1998).

Fish can be classified according to the environment where they live in, i.e. whether from freshwater or marine, pelagic or demersal. Pelagic fish are ones that live in the surface of ocean. Naturally, this variation in habitat leads to a wide variance in the character of the fish. In Malaysia, Indian mackerel, Silver pompret, Fourfinger threadfin, Hardtail scad are some examples of the pelagic fish (Abdul Majid, 2004). In addition, the fat contents in fish are also depending on the habitats. Besides, fish is also commonly classified as white fish and oily fish, depending on the parts of the body they store fat in. The white fish store their fat in the liver, while oily fish store their fat in the liver and throughout their bodies (Brown, 2008).

Fish is a good source of protein. Fish protein is of high-quality, providing 17% of the total animal protein and 6% of all the protein consumed by humans. Fish also supply important vitamins and other essential nutrients (Torpy *et al.,* 2006; Domingo *et al.*, 2007). Nutritionist has suggested intake of 35g or more fish daily (Daviglus *et al.,* 1997) and two fatty fish-meals per week (Siscovick *et al.,* 1995) to reduce relative risk of death from coronary heart diseases. Besides protein, fish is also high in essential fatty acids (EFAs) known as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are important to human diet.

The presence of PCBs in some fish and seafood can be sufficiently high, and this poses a potential health risk to consumers, particularly susceptible adults, foetuses, neonates, and developing infants (Burger & Gochfeld, 2008). Various investigations have been conducted over the past few years to quantitatively compare the risks of exposure to chemical pollutants in fish with omega-3 fatty acids associated health benefits of fish consumption (Sidhu, 2003). For example, Hites *et al*. (2004) determined the concentrations of various organic contaminants including PCBs in salmon. The results of the risk analysis indicated that the consumption of farmed Atlantic salmon might pose health risks that detracted from the beneficial effects of consuming fish. Salmon is one of the fatty fish included in the list of species that contain high omega-3 fatty acids, EPA and DHA. According to World Health Organization (WHO), toxic equivalents using the WHO-TEFs, the maximum level of PCBs is 4 pg/g for muscles meat of fish and fishery products and products thereof with the exception of eel (Van den Berg *et al*., 2006).

Up to this date, varied levels of polychlorinated compounds (PCBs together with dioxins and furans) in various fish and shellfish species have been widely published from different countries, including Tunisia (Masmoudi *et al*., 2006), Spain (Bocio *et al*., 2007), Ireland (Tlustos *et al*., 2006), Scotland, UK (Jacobs *et al*., 2002) and US (Jensen & Bolger, 2001). In Asia, however, reported data on these contaminants are still lacking and sparse. Therefore, this study was carried out to obtain data on the level of PCBs in fish from this region, particularly Malaysia.

As for Malaysia, specifically along the Straits of Malacca, the level of PCBs could be potentially high due to the various industrial activities along the West Region of Peninsular Malaysia, as well as the Straits, being one of the busiest routes in the world. Therefore, this study is important for identifying and quantifying the type and the amount of polychlorinated biphenyls (PCBs) in commonly consumed marine fish caught along the strait. In addition, data of this study are also useful to economically protect local and export markets of fish industry in Malaysia. Moreover, it gives important information on the safety aspect of local fish as consumers nowadays are aware on the beneficial intake of fish, particularly for its high level of EFAs.

MATERIALS AND METHODS

Chemical

The reagents used were pesticide residue grades, such as hexane, dichloromethane, toluene from Fisher Scientific, Leicestershire, UK.

Instrumentation

Accelerated solvent extraction (ASE200, Dionex Corp., Sunnyvale, CA, USA), Fluid Management System (FMS, Inc, Waltham, MA, USA), High-resolution gas chromatography/ high-resolution mass spectrometry (MAT 95 XL, Agilent 6890 Series, USA), Rotary Evaporator (BUCHI Labortechnik, Flawil, Switzerland).

Sample Collection

In this study, a stratified sampling method was used to collect the fish samples. In this sampling method, fish samples were collected from defined strata of the known fish landing areas along the Straits of Malacca. Within each landing site, the samples were taken randomly. Stratified sampling is the most suitable method for a database study (Greenfield & Southgate, 2003). Fresh fish samples were collected from 10 identified fish landing areas, along the Strait of Malacca, which were further divided into 3 regions; namely North region (Kuala Perlis, Kuala Kedah, Teluk Bahang and Batu Maung), South region (Port Dickson, Malacca and Muar) and Middle region (Kuala Selangor, Manjung Utara and Matang) (*Fig. 1*). The collection of the samples at each region was carried out twice in August to November 2008. The fish samples were freshly collected from the landing sites with the help from the Fisheries Development Authority of Malaysia (FDAM/ LKIM). The fresh samples of fish were immediately dipped in a mixture of water and ice to block any digestive and unfavourable changes. From the collection site to the laboratory, the samples were transferred in polystyrene boxes containing ice and transported on the same day at a refrigerated temperature (4^{o}C).

Fish Samples

There were 6 species of fish collected; namely, *Rastrelliger kanagurta* (Indian mackerel), *Scomberomorus guttatus* (Spanish mackerel), *Pampus argenteus* (Silver pompret), *Megalapsis cordyla* (Hardtail scad), *Eleutheronema tradactylum* (Fourfinger threadfin), and *Chirocentrus dorab* (Dorab wolfherring). The selection of the fish samples was based on work by Osman *et al*. (2001), with most of the species were those preferred by the local consumers.

Preparation of the Sample

Upon arrival in the laboratory, the collected samples were individually measured for their

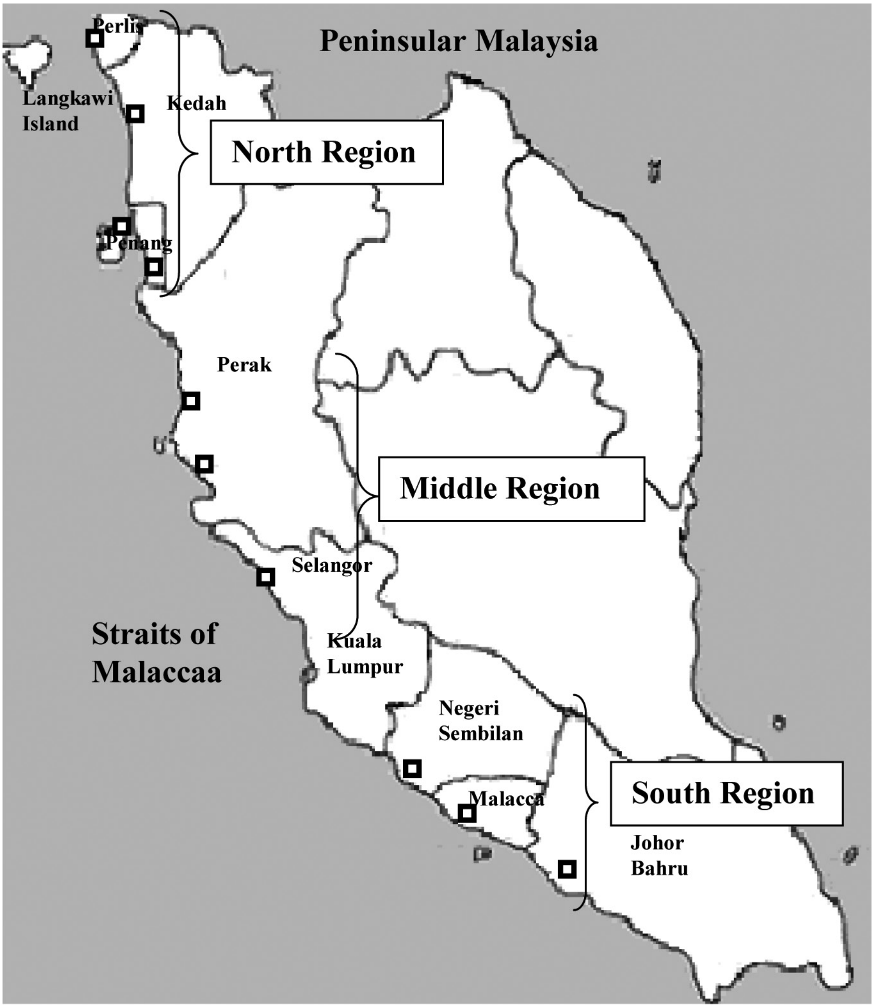

Fig. 1: Location of the sampling sites

length and weight. Fish samples were gutted, viscera removed, beheaded, washed and fillet before frozen. All the samples were kept at -75^{o}C without any prior treatment. Before the analysis, the composite sample of each species in different regions was prepared by homogenously mixing and grinding the prepared samples using a blender (National, Petaling Jaya, Malaysia). All the composite samples were packed into polyethylene (PE) covered cup, stored in a freezer at -20^{o}C and analyzed within a week.

Fat Extraction and Sample Clean-up

Twenty (20µl) of 4937 PCBs internal standard (Cambridge Isotope Laboratories, Inc., Andover, MA, USA) was injected into ten grams of homogenized wet muscle tissue and extracted by Accelerated Solvent Extraction (ASE) 200 (Dionex Corp., Sunnyvale, CA, USA). Meanwhile, about 7g of hydromatrix was added and mixed together with the sample. After that, the sample mixture was put in a microwave oven (Khind, Petaling Jaya, Malaysia) for drying for about 2 minutes. The dried sample was then put into ASE extraction cell (size

TABLE 1
List of the samples with narrow range of weight and length

Regions	Local name	Common name	Scientific name	n	Weight (g) (min-max)	Length (cm) (min-max)
North	Bawal putih	Silver pomfret	*Pampus argentus*	5	131 – 243	15 - 25
	Cencaru	Hardtail scad	*Megalapsis cordyla*	8	154 – 254	17- 22
	Kembung	Indian mackerel	*Rastrelliger kanagurta*	10	42 – 104	16- 19
	Senangin	Fourfinger threadfin	*Eleutheronema tetradactylum*	4	210 - 379	30- 31
South	Cencaru	Hardtail scad	*Megalapsis cordyla*	8	209 - 256	25- 27
	Parang	Dorab wolfherring	*Chirocentrus dorab*	2	200 - 900	40 - 71
	Tenggiri papan	Spanish mackerel	*Scromberomorus guttatus*	2	200 – 450	30 - 42
Middle	Cencaru	Hardtail scad	*Megalapsis cordyla*	9	63 – 230	28- 30
	Kembung	Indian mackerel	*Rastrelliger kanagurta*	12	22 – 54	13- 16
	Senangin	Fourfinger threadfin	*Eleutheronema tetradactylum*	6	158 – 245	28- 30

TABLE 2
Fat contents (g/100g) and total PCBs (WHO-iTEQ pg/p wet weight) in the pelagic fish from different regions along the Strait of Malacca

Regions	Species (common name)	Fat (g/100g)		Mean	Variation (%)	WHO-iTEQ (pg/g)		Mean	Variation (%)
		T1	T2			T1	T2		
North	*Megalapsis cordyla* (Hardtail scad)	0.6	1.0	0.80	35.36	0.73	0.35	0.54	49.76
	Eleutheronema tradactylum (Fourfinger threadfin)	2.0	2.7	2.35	21.06	0.37	0.55	0.46	27.67
	Rastrelliger kanagurta (Indian mackerel)	1.0	3.1	2.05	72.44	1.37	0.35	0.86	83.87
	Pampus argenteus (Silver pompret)	3.6	3.7	3.65	1.94	0.35	0.53	0.44	28.93
South	*Megalapsis cordyla* (Hardtail scad)	0.4	3.1	1.75	109.10	0.35	0.50	0.43	24.96
	Chirocentrus dorab (Dorab wolfherring)	3.8	3.5	3.65	5.81	0.54	0.68	0.61	16.23
	Scomberomorus guttatus (Spanish mackerel)	3.2	5.5	4.35	37.39	0.64	0.72	0.68	8.32
Middle	*Megalapsis cordyla* (Hardtail scad)	2.8	3.5	3.15	15.71	1.05	0.77	0.91	21.76
	Eleutheronema tradactylum (Fourfinger threadfin)	1.8	3.3	2.55	41.59	0.47	0.38	0.43	14.97
	Rastrelliger kanagurta (Indian mackerel)	3.3	6.7	5.00	48.08	0.35	0.35	0.35	0.00

% variation was calculated based on the following formula: (SD/Mean) × 100
TI is Trip 1 (12 August 2008 to 9 September 2008)
T2 is Trip 2 (15 October 2008 to 12 November 2008)

33) and the extraction process was carried out for 20 minutes. After the ASE extraction, the solvents used were removed by means of a rotary evaporator (BUCHI Labortechnik, Flawil, Switzerland) that was at 500 Mbar, at 40-50°C for 20-30 minutes. The fat fraction extracted was determined gravimetrically.

After fat extraction, eluents (fat and hexane) were cleaned up using acid/base modified silica gel, alumina, and graphitized carbon column chromatography for about 1 hour. Later, hexane was removed from the PCBs eluent using a rotary evaporator (BUCHI Labortechnik, Flawil, Switzerland). Then, 20µl of 4798 PCBs external standard (Cambridge Isotope Laboratories, Inc., Andover, MA, USA) was added into the sample in a small vial and mixed well. The process was continued by drying the mixture of the samples on a heating block at 70°C with nitrogen gas until the amount of the samples reached 10µl. After that, the sample was analyzed using high-resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS). Later, the samples were analyzed for 12 dioxin like co-planar PCBs; PCBs 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169 and 189. The sample preparation procedures, analytical techniques, and quality control strategies described are as defined in the US EPA's Method 1613 and by Ferrario *et al*. (1996, 1997).

Calculation of Toxicity Equivalents (iTEQ)

Toxicity equivalent (iTEQ) was calculated using the procedure developed by WHO (2005). The toxicity of PCBs congeners was expressed using toxic equivalence factors (TEFs) representing the relative toxicity of the compound being measured to the most toxic PCBs 126 congener, with TEF value of 0.1. The TEQ of PCBs was calculated by multiplying the analytical determined concentration of each congener by its corresponding TEF.

RESULTS AND DISCUSSION

Table 1 shows details of 6 pelagic species of fish analyzed in this study. Knowledge on each species size is important as previous literature has stated that the occurrence of chemical contaminants and bioaccumulation is related to length, weight and age of fish (De Marco *et al.*, 2006). Furthermore, certain ecological factors, such as season, place of development, nutrient availability, temperature and salinity of the water may also contribute to the inconsistency of contaminants in fish tissue (Tuzen, 2003). Table 2 shows the summary information on the level of fat and PCBs measured in the pelagic species of fish available from the fishing landing areas during the sampling period. The value of the results was expressed as total WHO-iTEQ in pg/g wet weight samples for PCBs and g/100g of the wet weight for the fat content. There were 12 congeners of PCBs detected and reported for each sample. Meanwhile, WHO toxic equivalent factors (WHO-TEFs-2005) were used to calculate the TEQ of each sample. The results consisted of 6 different fish species of 20 samples. The fat content varied from one species to another. In the present study, the highest fat content was observed in *Rastrelliger kanagurta* (Indian mackerel), i.e. in the range of 2.05-5.00 g/100g wet weight sample. This was followed by *Megalapsis cordyla* (Hardtail scad) which contained low fat in the range of 0.80-3.15 g/100g of the wet weight sample. Other species, such as *Eleutheronema tradactylum* (Fourfinger threadfin), *Pampus argenteus* (Silver pompret), *Chirocentrus dorab* (Dorab wolfherring) and *Scomberomorus guttatus* (Spanish mackerel) showed fat contents of 2.35-2.55 g/100g, 3.65 g/100g, 3.65 g/100g and 4.35 g/100g, respectively. Osman *et al.* (2001) reported the fat content of *Rastrelliger kanagurta* (Indian mackerel) was 4.54 g/100g, and this is within the range obtained in this study. As for other species, such as *Pampus argenteus* (Silver pompret), Osman *et al*. (2001) reported that it contained 2.91 g/100g, the amount which is much lower than the value obtained in the present study. On the other hand, Tee *et al.* (1997) reported the fat content of *Pampus argenteus* (Silver pompret) at 4.0 g/100g, and this is much higher than the value stated in this study. The differences in fat content observed could be due to variations in the sub-species, seasons, geographical regions, age and maturity that might influence the fat of fish (Osman *et al*., 2001). For instance, the variations within the species between Trip 1 and Trip 2 vary greatly between 1.94% to less than 50%, except for *Megalapsis cordyla* (Hardtail scad) and *Rastrelliger kanagurta* (Indian mackerel), which clearly indicated that the fat content variation in one species was affected by various factors.

For the North region, the highest value of the total PCBs in Trip 1 was obtained in the *Rastrelliger kanagurta* (Indian mackerel) species, at the concentration of 1.37pg/g in the wet weight of sample. In contrast, the lowest value was obtained in *Pampus argenteus* (Silver pompret) species at 0.35pg/g wet weight. As for *Megalapsis cordyla* (Hardtail scad) and *Eleutheronema tradactylum* (Fourfinger threadfin), the levels obtained in this study were 0.73 pg/g and 0.37 pg/g, respectively. For the South region, the highest value of the total PCBs was obtained at 0.64 pg/g for *Scomberomorus guttatus* (Spanish mackerel), followed by 0.54 pg/g in *Chirocentrus dorab* (Dorab wolfherring) and 0.35 pg/g for *Megalapsis cordyla* (Hardtail scad). In the Middle region, it was shown that the highest level of total PCBs was detected in *Megalapsis cordyla* (Hardtail scad), with the value of 1.05 pg/g wet weight, followed by *Eleutheronema tradactylum* (Fourfinger threadfin) and *Rastrelliger kanagurta* (Indian mackerel), with the values of 0.47pg/g and 0.25pg/g, respectively. In Table 2, different levels of the total PCBs can be present in the same species, depending on the sizes, maturity and total fat of the fish. When comparing the regions in the first trip of sample collection, those from the North region were found to contain the highest level of PCBs. The North region (comprising of Penang, Kedah and Perlis states) is within the vicinity of famous tourism place (i.e. Langkawi Island) which is close to one of the biggest ports in Kuala Perlis and neighbouring with plastics and agricultural industries in the north Peninsular. It has been well established that aquatic organisms situated within human and industrial activities may bio-accumulate chlorinated organic compounds in their bodies (Smeds & Saukko, 2001; Ntow, 2001).

In the second trip of sample collection, the Middle region showed the highest concentrations of PCBs in three pelagic species. In particular, *Megalapsis cordyla* (Hardtail scad) demonstrated the highest level of the total PCBs (0.77 pg/g wet weight), compared to *Eleutheronema tradactylum* (Fourfinger threadfin) and *Rastrelliger kanagurta* (Indian mackerel), which were at 0.38 pg/g and 0.35 pg/g wet weight, respectively. In the South region, on the other hand, *Scomberomorus guttatus* (Spanish mackerel) contained the highest total PCBs at 0.72 pg/g of wet weight, whereas *Chirocentrus dorab* (Dorab wolfherring) and *Megalapsis cordyla*_(Hardtail scad) had about 0.68pg/g and 0.50pg/g of wet weight, respectively. For the samples taken from the North region, *Eleutheronema tradactylum* (Hardtail scad) and *Pampus argenteus* (Silver pompret) showed the highest values of the total PCBs concentration at 0.55 pg/g wet weight and 0.53 pg/g wet weight, respectively. Meanwhile, *Rastrelliger kanagurta* (Indian mackerel) and *Megalapsis cordyla* (Hardtail scad) had lower concentrations of the total PCBs at 0.35 pg/g wet weight in both species. A study by Bocio *et al.* (2007) in Spain showed that the mackerel species contained the PCBs level of 0.89 pg/g of wet weight, which is within the range (0.35-1.37 pg/g of wet weight) of the values obtained in the present study. Different species of mackerel (*Scomber scombrus*) from the Adriatic sea in Italy was reported to contain PCBs at 3015 pg/g wet weight, which is much higher than the value obtained in the present study (Storelli *et al.*, 2003). The findings of this study have clearly shown that the level of PCBs varies greatly between Trip 1 and 2 as variation, i.e. ranging from 0 to 83.87% across the different species and regions. The differences in the level of PCBs in the fish samples are dependent upon the surrounding human activities and industrial waste releases. In all the studied samples, PCBs were found to be generally presence in all the samples at varied concentrations. However, the levels were well below the permitted level of

TABLE 3
Polychlorinated biphenyls (four non-*ortho*-PCBs and eight mono-*ortho*-PCBs congeners) and toxic equivalents (WHO-iTEQ) as pg/g in the fish species

Fish Analytes	Hardtail scad	Fourfinger threadfin	Indian mackerel	Silver pompret	Dorab wolfherring	Spanish mackerel
Non-*ortho* PCBs	1.0	0.44	1.29	0.46	0.62	0.68
Mono-*ortho* PCBs	0.05	0.11	0.08	0.07	0.06	0.04
WHO-iTEQ (pg/g)	1.05	0.55	1.37	0.53	0.68	0.72

Non-*ortho* PCBs include (PCBs 77, 81, 126 and 169)
Mono-*ortho* PCBs include (PCBs 105, 114, 118, 123, 156, 157, 167 and 189)

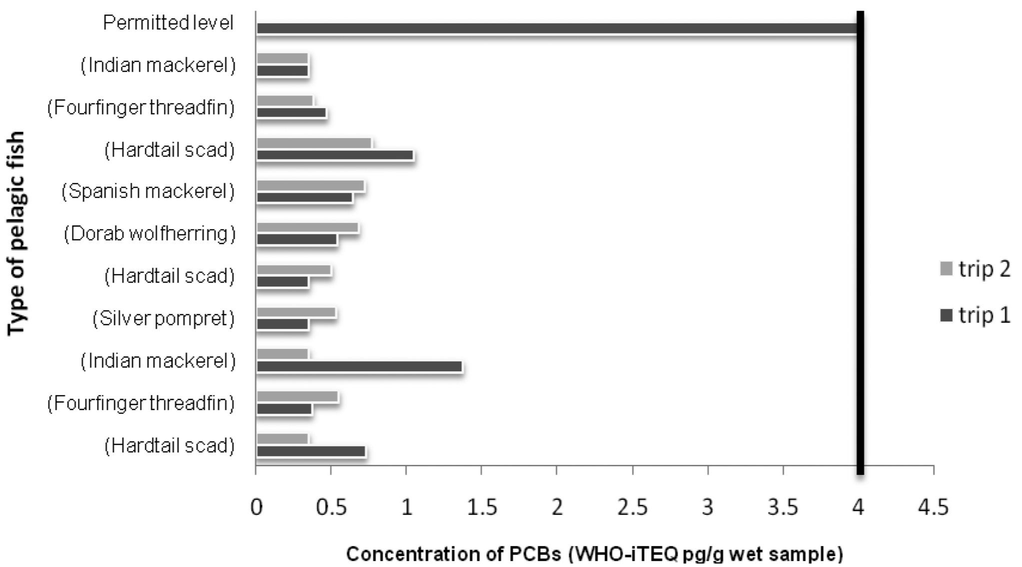

Fig. 2: Total PCBs in the pelagic species (WHO-iTEQ pg/g wet weight)

4 pg/g for muscle fish and fishery products, as shown in Figure 2 (Van den Berg *et al*., 2006).

Table 3 shows congeners of all the samples that were further divided into non-*ortho* (PCBs 77, 81, 126 and 156) and mono-*ortho* (PCBs 105, 114, 118, 123, 156, 157, 167 and 189) families. There were more than 80% of the non-*ortho* PCBs which dominated in the samples compared to the mono-*ortho* congeners. The profile of polychlorinated congeners in the fish samples caught from the Straits of Malacca was distinct from those taken from the southern areas of the Adriatic Sea (Storelli *et al*., 2003), the Mediterranean waters of Tunisia (Masmoudi *et al*., 2007) and farmed Rainbow Trouts in Southern Finland (Kiviranta *et al*., 2001). Based on the findings of the present study, the Indian mackerel attained the highest amount of non-*ortho* (1.29 pg/g) and mono-*ortho* (0.08 pg/g) PCBs. Meanwhile, the lowest amount of non-*ortho* and mono-*ortho* was observed in Silver pompret, at 0.46pg/g and 0.07 pg/g, respectively. A study by Fernandez *et al.* (2004) revealed that Mackerel species (known as *Scomber scombrus*) contained 1.58 pg/g and 1.95 pg/g of non-*ortho* and mono-*ortho* PCBs,

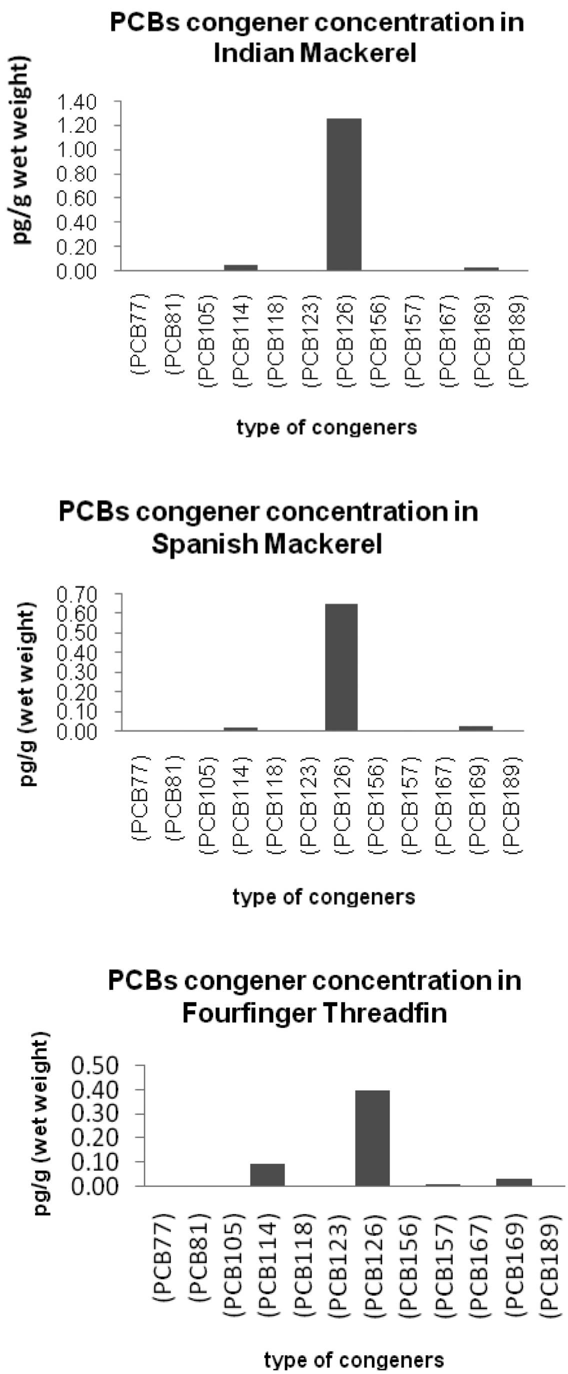

Fig. 3: Type of the pelagic fish with fat contents >2%

respectively. These samples were collected in Spain and the amount was much higher than the levels of non-*ortho* (0.68 pg/g) and mono-*ortho* (0.04 pg/g) of *Scomberomorus guttatus* (Spanish mackerel) obtained in the present study. These discrepancies may due to the differences in the geographical area, size, maturity and species of the fish although they came from the same family.

Besides determining the total PCBs concentration in the fish species, this study was also looking at the amount of each congener of PCBs. All of the species undertaken in this study had their own congener profile. According to Bocio *et al*. (2007), the predominant PCB congeners are PCB 118 and PCB 126, with PCB 126 being the most toxic (WHO-TEF = 0.1) to human, and can be accounted for the largest contribution of PCBs to the TEQs for each species (Fernandez, *et al*., 2004). PCB 126 was present in most of the samples studied in the present study. In fact, PCB 126 was found to be highest in Indian mackerel (1.26 pg/g) but lowest in Silver Pompret (0.30 pg/g). Other congeners like PCB 114 and PCB 169 were also found in most samples, including Hardtail scad, Indian Mackerel, Spanish Mackerel and Fourfinger threadfin (Figure 3), but in low concentrations.

CONCLUSION

This study has identified the total PCBs concentration, including the type and level of 12 congeners of PCBs that are most toxic to humans. The most toxic congener, i.e. PCB 126, was detected in the samples at relatively low concentration in the muscle tissue of fish species collected along the Strait of Malacca. Nonetheless, the values obtained for the total PCBs in this study were generally well below the permitted level recommended by WHO. Therefore, it can be concluded that the pelagic fish taken from the Strait of Malacca are safe to consume, based on their PCBs level. Although the level was not high, it is still important to set limits for the PCB levels in fish species to have a better estimation of the risk of exposure to human through dietary intake of fish, specifically fatty fish, to meet nutritional requirement for long-chain n-3 polyunsaturated fatty acids.

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