Mercury Exposure Through Fish and Seafood Consumption in the Rural and Urban Coastal Communities of Peninsular Malaysia

P. Hajeb and S. Jinap

Centre of Excellence for Food Safety Research (CEFSR), Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Malaysia

Abstract: This work addressed the mercury exposure scenarios through the consumption of fish and fish products in the rural and urban communities in four coastal states in Peninsular Malaysia. The concentration of mercury was assessed in frequently consumed processed fish, fish dishes and fish snacks purchased from these coastal communities. Highest fish and seafood consumption, 657.7 and 401.7 g/person/day, was recorded for Tanjung Dawai and Marang, the rural areas in the states of Kedah and Terengganu, respectively. Mercury level in fish and seafood products ranged from 0.006-1.857 µg/g. The food items collected from the two states at the east coast of Peninsular Malaysia, Terengganu and Johor, showed significantly higher levels of mercury. The general adult urban population is exposed to low-level mercury concentration via fish consumption while, the fishermen families at the rural areas presented higher mercury intake. The highest mercury exposure, 2.332 µg/person/day, was for residents of Marang in the state of Terengganu located at the east coast of Peninsular Malaysia.

Key words: Fish · Seafood · Mercury · Exposure assessment

INTRODUCTION

Methylmercury is the mercury organic form, basically originated through biomethylation processes carried out by some marine microorganisms (bacteria, fungi and phytoplankton). Due to their physico-chemical properties and bioaccumulation capacity in the living organisms, mono mercurial organic compounds are the most toxic, causing very harmful effects in exposed populations [1]. Unfortunately, important precedent episodes regarding mercury pollution trough diet exist. The most important example occurred in Minamata (Japan) in 1950 and 60 decades, which happened due to discharge of waste effluents containing mercury to the sea [2]. Fishermen and their families, whose diet was based on fish, were highly exposed to mercury. Death as well as development of very toxic effects in fishermen and their descendents was the consequences of that poisoning by organic mercury [3].

Toxicity and absorption of mercury largely depend on its chemical form, as well as the entrance pathway to the body [4]. Through ingestion, inorganic salts of mercury are more toxic than the elemental form and it is frequently found in drinking waters and soils, rather than in plants and animals. Exposure to methylmercury is oral, basically through fish consumption. It is easily absorbed in the digestive tract and being eliminated hardly. Therefore, it can accumulate in brain, liver and kidney [5]. The way people are exposed to mercury depends on several other factors such as the levels of contamination in the environmental compartments, the existence of potential pathways for human exposure, the size, nature and habits of the community and frequency and duration of the exposure. Risk management of mercury focuses on two schemes: one to reduce the human intake of mercury from environment sources and the second to reduce the mobilization and concentration of mercury from industrial activities. Intake is reduced by limiting the allowable mercury concentration in foods. The Joint FAO/WHO expert committee on food additives in provisional tolerable weekly intake recommend that a maximum weekly intake of 5 µg/kg of total mercury and 1.5 µg/kg of methylmercury should not be exceeded in the diet of an adult with a body weight of 60 kg [6]. However, the purpose of an exposure assessment is to estimate the level of mercury in the environment that different groups of people are exposed.

Corresponding Author: Jinap Selamat, Centre of Excellence for Food Safety Research (CEFSR),
Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM,
Serdang, Malaysia, Telephone: 603- 89468393, Fax: 603-89423552

Fish and other seafood form an important item in Malaysian diet, making up 21% of the per capita consumption of protein intake from all other meats (poultry, pork, beef and mutton] [7]. National per capita fish consumption has reported to increase from 39.1 kg in year 1995 to 49.0 kg in 2000, 60.0 kg in 2005 and it is predicted to rise up to 65.0 kg in year 2010 [8]. Based on FAO report (2006), Malaysian's fish consumption is almost 3 times more compared to the world fish consumption. Research on mercury concentration in different species of fish and seafood from Malaysia has been reported by other studies[9-16]. One of the recent researches have been done by Agusa *et al.*[14] and Agusa *et al.* [15]who reported that some fishes in Malaysia contained high mercury concentration. They have collected the fish samples from east and west coast of Peninsular Malaysia. Fish samples from west coast showed higher mercury levels. This paper was the first detail study on mercury exposure in the Malaysian population. Hence, these findings are significant, considering the risk to human health related to the daily consumption of fish by Malaysian people.

MATERIALS AND METHODS

Chemicals and Materials: All reagents were of analytical reagent grade. Total mercury standard was purchased from Fluka (Tokyo, Japan), BCR-463 (total and methylmercury in tuna fish) from Unit for Reference Materials (EC-JRC-IRMM, Geel, Belgium), hydrochloric acid 37% and nitric acid 65% from Merck (Darmstadt, Germany). All standards and solutions were prepared using deionized water (ELGA LabWater, Marlow, UK). Mercury stock standard solution (1000 mg/L) was prepared by dissolving 0.0677 g of $HgCl_2$ in the 3% HCl in a 100 mL digestion flask. The working solutions were freshly prepared by diluting an appropriate aliquot of the stock solution through intermediate solutions using 3% HCl.

Study Design and Population: The survey on fish consumption was conducted among eight coastal communities situated at four different coastal states of Malaysia: Johor; Terengganu; Kedah; and Selangor as described by Hajeb *et al.* 17]. Sampling locations in each state were divided into two: urban and rural area. The respondents covered were the three main races (Malay, Chinese and Indian) living in Malaysia. A total of 800 adults (387 men, 413 women) aged from 18 to 80 years were interviewed to answer the fish consumption questionnaire. Socio-demographic information was collected using a self administered questionnaire, which included items on age, education and family income.

Selection of the Foods: Dietary intake was assessed using a food frequency questionnaire (FFQ) with 1-month recall. The questionnaires were developed based on a review of the literature and other related studies [18,19]. The questionnaires were pilot-tested on community representatives and were found to be culturally acceptable. A list was prepared which included most of the fish and seafood cuisines present in the region. The FFQ consisted of 97 food items was divided into the three food categories (processed fish and seafood, local fish and seafood dishes and fish and seafood snacks). The participants were first asked to identify whether the item was consumed, whether it was cooked at home or eaten outside and determine the frequency and portion size. To facilitate the recall, a booklet of fish and food picture with serving sizes and local and English names were shown to the respondents.

From the food consumption data of each area, the percentages of total consumption in each food item are calculated. After ranking food consumption data from the highest to the lowest percentage of total consumption, a cut-off 0.5% of total consumption in each area is selected for sample collection[20]. Therefore, the food items to be collected form each area differs from each other. Food samples were collected from the restaurant and food courts nearest to the respondent's resident area. Food samples were kept in ice box during the transportation and stored in the freezer (-20 °C) until analysis.

Analytical Procedures and Determination of Mercury: Sample preparation and determination of mercury were carried out using the method by Hajeb *et al.* [16] Food samples were homogenized by repeated chopping and mixing of the frozen samples followed by blending using a commercial blender (Autovortex type, Stuart, England) that had been cleaned and rinsed with dilute nitric acid and deionized water prior to use. Weigh of 0.5 g of the homogenized samples were placed in the digestion tubes, added with 5 mL HNO3 (65%) and digested in a water bath (Memmert-Schwaback; city, Germany) at 40-90 °C for 3 h. Digested samples were then cooled and subsequently diluted to 40 mL volume with deionized water. Total mercury was determined in all the digested samples using cold vapor atomic absorption spectrophotometry flow injection mercury/hydride analyzer (FIAS 100, Perkin Elmer, Massachusetts, USA), equipped with hollow cathode mercury lamp operated at a wavelength of 253.7 nm and a quartz absorption cell.

Quality assurance, LOD and LOQ: Recovery studies were done in order to detect mercury losses or contamination during sample treatment and matrix interferences during the measurement step. Recovery of total mercury at lower levels was determined by spiking 5, 10 and 15 ng of mercury to digested samples of two different food items (Indian mackerel curry and fried dart). The resulting solutions were analyzed for mercury concentration using the method described in 2.3. The reliability of the analytical method and recovery of total mercury at higher levels were tested by measuring the element in reference material (CRM 463; total mercury and methylmercury in tuna fish) in seven replications. The average concentration of total mercury in the reference material was reported to be 2.85 ± 0.16 µg/g. The limit of detection (LOD) and limit of quantification (LOQ) for total mercury was determined by serial dilutions of the lowest calibrator concentration and established at a ratio of signal/noise (S/N)>3 and signal/noise (S/N)>10, respectively.

The recovery for total mercury by spiking was found to be between 89-113 %. Good recoveries of spiked samples demonstrate the accuracy of the methods used. The reliability of the analytical methods tested by measuring the total mercury in reference material was 2.75 ± 0.19 µg/g. The LOD and LOQ were 1.1 and 3 ng/g, respectively.

Exposure Assessment: Mercury intake (ig/kg bw/day) over the past month was estimated for each of the food items, based on mercury concentration (ig/g) in the food and food consumption (g/day). Mean consumption for each of the food items were multiplied by mean mercury levels to derive mercury intake levels.

RESULTS AND DISCUSSIONS

Table 1 presents the socio-demographic characteristics of the participants. Men and women made up 51.5 and 49.5% (n=47) of the participants in each location, respectively. Equal number of participants (400 adults) was chosen from rural and urban areas. The number of participants from each race was based on the ratio of in the total population of Malaysia, which is 63% Malay, 29.8% Chinese and 10.2% Indian. The highest educational level among the respondents was secondary school level, which contributed to 52.5%. Most of the respondents (80%) had monthly income of less than 500 Malaysian Ringgit.

Estimates of Fish and Seafood Intake for Populations: Figure 1 shows total fish consumption for each location of rural and urban areas in the four states of Peninsular Malaysia. The highest fish and seafood consumption was recorded for Tanjung Dawai and Marang, the rural areas

Table 1: Demographic characteristics of respondents.

Characteristics	Men	Women	Overall
Age	32.15±4.01	26.18±5.44	30.21±3.09
State			
Johor	101	99	200
Terengganu	101	99	200
Kedah	101	99	200
Selangor	101	99	200
Geographical location			
Rural	202	198	400
Urban	202	198	400
Race			
Malay	242	237	479
Chinese	121	119	240
Indian	41	40	81
Education			
None	8	28	36
Primary School	97	63	160
Secondary School	214	206	420
Vocational School	25	8	33
College/university	60	91	151
Income			
<500	315	325	640
500-1000	45	63	108
>1000	44	8	52

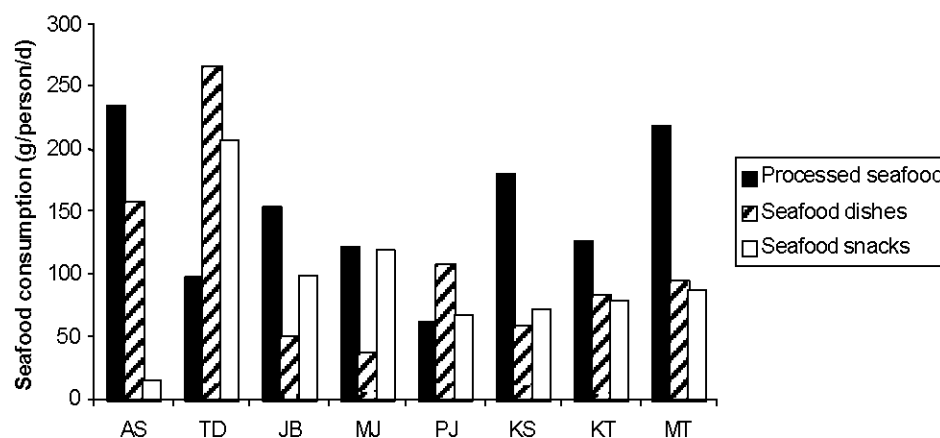All values except age are expressed in Frequency.

Fig. 1: Seafood consumption (g/person/d) in eight coastal areas in Peninsular Malaysia.
AS: Alor Star; TD: Tanjung Dawai; JB: Johor Bahru; MJ: Mersing; PJ: Petaling Jaya; KS: Kuala Selangor; KT: Kuala Terengganu; MT: Marang.

Table 2: Average seafood consumption data (g/person/day), mercury level in seafood items (µg/g) and mercury intake (µg/person/day) in different locations

State/Location/ Food Items	Number of samples	Mercury level (µg/g)		Food consumption (g/day)	Mercury intake (µg/Kg body weight/day)
		Mean	Range		
Selangor *Kuala Selangor (R)*					
African bream in coconut milk	12	0.457	0.098-0.633	5.9	0.054
African bream in chili	15	0.501	0.088-0.804	5.4	0.054
Hairtail scad in vinegar	12	0.404	0.035-0.711	12.5	0.101
Indian mackerel curry	15	0.837	0.145-1.309	12.2	0.204
Fried Spanish mackerel	15	0.655	0.300-0.981	4.7	0.062
Barbequed Indian mackerel	12	0.926	0.331-1.401	4.4	0.082
Fried long tail scad	15	0.592	0.088-0.790	5.4	0.064
Mackerel in chili (canned)	15	0.515	0.093-0.822	16.4	0.168
Seewt swear black pomfret	12	0.389	0.078-0.611	9.9	0.077
Fried catfish eel	15	0.566	0.113-0.885	4.4	0.049
Fried Indian halibut	15	0.309	0.056-0.512	5.2	0.032
Fried stingray	12	1.056	0.409-1.552	7.7	0.162
Tuna curry	12	0.771	0.356-0.928	3.7	0.057
Prawn in chili	15	0.557	0.087-0.811	25	0.278
Hairtail scad in chili	15	0.430	0.099-0.903	13.6	0.117
Sardine in tomsto sauce (canned)	15	0.127	0.024-0.304	35.4	0.090
Anchovies sambal (canned)	15	0.098	0.016-0.211	116.7	0.229
Stingray curry	12	0.983	0.505-1.201	11.9	0.235
Keopok ikan	15	0.165	0.036-0.402	8.5	0.028
Keropok lekor	15	0.103	0.026-0.225	8.1	0.017
Fish nugget	15	0.047	0.009-0.060	18.2	0.026
Nasi lemak	15	0.022	0.007-0.056	5.0	0.002
Sardine sandwich	15	0.036	0.010-0.054	13.3	0.010
Fish balls	15	0.021	0.011-0.049	17.1	0.007
Fried fish cake	15	0.033	0.015-0.047	14.8	0.010
Total		10.600	-	395.2	2.214
Petaling Jaya (U)					
Fried wolf herring	12	0.401	0.091-0.633	3.0	0.024
Sweet swear Indian mackerel	12	0.810	0.316-1.449	2.6	0.043
Fish laksa	12	0.477	0.088-0.527	1.9	0.018
Fried Spanish mackerel	15	0.962	0.510-1.477	1.6	0.030
African bream in chili	15	0.532	0.330-0.948	1.2	0.013
Wolf herring in tamarind	12	0.477	0.227-0.615	11.4	0.108
Treadfish bream in soy sauce	15	0.589	0.249-0.881	2.1	0.025
Nasi kerabu	15	0.054	0.007-0.092	1.4	0.002
Nasi lemak	15	0.047	0.009-0.089	4.2	0.004
Fried catfish eel	15	0.290	0.096-0.466	2.5	0.014
Malaysian river catfish curry	9	0.443	0.098-0.791	1.5	0.013
Mackerel in chili (canned)	15	0.717	0.425-0.991	2.6	0.037

Table 2: Continued

State/Location/ Food Items	Number of samples	Mercury level (µg/g)		Food consumption (g/day)	Mercury intake (µg/Kg body weight/day)
		Mean	Range		
Tuna in mayonnaise (canned)	15	0.880	0.390-1.005	1.8	0.032
Grouper in tamarind	15	0.451	0.115-0.722	4.3	0.039
Fried anchovies in chili	15	0.229	0.017-0.341	1.3	0.006
Indian mackerel in chili	15	0.611	0.309-0.951	1.2	0.015
Sardine in tomato sauce (canned)	15	0.108	0.030-0.282	13.0	0.028
Barbequed Indian mackerel	15	0.779	0.401-1.023	1.2	0.019
Treadfish bream in chili sauce	15	0.449	0.112-0.534	2.2	0.020
Fried dart	12	0.635	0.232-0.801	2.1	0.026
Fried Indian mackerel	15	0.797	0.501-1.008	1.7	0.027
Total		10.738	-	64.7	0.543
Kedah					
Tanjung Dawai (R)					
Fried wolf herring	15	0.602	0.349-0.835	7.9	0.095
Anchovies in chili	15	0.226	0.094-0.560	3.2	0.015
Blach pomfret in chili	15	0.443	0.294-0.726	3.8	0.034
Fried Spanish mackerel	15	0.761	0.450-0.992	5.1	0.077
Sweet swear black pomfret	12	0.449	0.208-0.572	3.4	0.031
Sweet swear Indian mackerel	12	0.686	0.341-0.834	8.5	0.117
Indian mackerel in soy sauce	15	0.635	0.500-0.914	24.9	0.316
Fried dart	9	0.481	0.217-0.530	7.1	0.068
Wolf herring in tamarind	12	0.337	0.126-0.581	5.9	0.040
Fried white pomfret	12	0.394	0.221-0.488	4.1	0.033
Nasi lemak	15	0.036	0.014-0.069	5.2	0.004
Barbequed Indian mackerel	15	0.889	0.437-1.006	14.5	0.257
Boiled wolf herring	15	0.347	0.201-0.607	11.9	0.082
Fried anchovies	15	0.146	0.008-0.089	7.3	0.021
Fried Indian mackerel	15	0.772	0.406-0.991	64.3	0.993
Sardine in tomato sauce (canned)	15	0.204	0.074-0.366	1.6	0.068
Fish laksa	15	0.041	0.019-0.078	5.2	0.004
Total		7.449	-	198.9	2.254
Alor Star (U)					
Treadfish bream in chili	15	0.336	0.115-0.568	4.0	0.027
Nasi lemak	15	0.027	0.009-0.064	4.0	0.002
Tuna in mayonnaise (canned)	15	0.662	0.407-0.801	4.1	0.054
Mackerel in chili (canned)	15	0.636	0.226-0.811	3.5	0.045
Sweet swear Indian mackerel	12	0.771	0.404-0.927	5.3	0.082
Sardine in tomato sauce (canned)	15	0.220	0.046-0.466	14.2	0.062
Grouper in tamarind	12	0.419	0.211-0.605	2.3	0.020
Tuna flakes in water (canned)	15	0.713	0.562-0.989	3.2	0.045
Fried dart	9	0.927	0.498-1.857	7.8	0.144
Indian mackerel curry	15	0.656	0.369-0.881	16.1	0.211
Dart curry	9	0.838	0.598-1.524	11.0	0.185
Fried Indian mackerel	15	0.884	0.641-1.358	26.1	0.461
Barbequed wolf herring	15	0.466	0.231-0.670	4.6	0.043
Boiled wolf herring	15	0.336	0.153-0.468	2.1	0.014
Tuna curry (canned)	12	0.771	0.561-0.994	3.9	0.061
Wolf herring in tamarind	12	0.468	0.247-0.769	5.8	0.054
Indian mackerel in chili	15	0.584	0.498-0.891	11.2	0.131
Fried anchovies	15	0.224	0.067-0.369	2.8	0.012
Fried wolf herring	15	0.438	0.340-0.773	6.9	0.060
Tuna curry	12	0.819	0.503-1.388	3.9	0.064
Anchovies in chili	15	0.155	0.76-0.302	2.7	0.008
Fish laksa	15	0.094	0.011-0.228	4.9	0.009
Total		11.444	-	150.3	1.794
Terengganu					
Kuala Terengganu (U)					
Treadfish bream in chili	15	0.553	0.189-0.737	3.0	0.033
Indian mackerel in soy sauce	15	0.718	0.493-0.991	3.6	0.052
Fried hairtail scad	15	0.398	0.271-0.667	3.3	0.026
Mackerel in chili (canned)	15	0.809	0.511-1.116	3.3	0.054
Tuna curry	12	0.788	0.588-0.991	2.7	0.043
Hairtail scad in chili	15	0.437	0.246-0.711	3.2	0.028
Prawn in chili	15	0.347	0.167-0.540	1.7	0.012

Table 2: Continued

State/Location/ Food Items	Number of samples	Mercury level (µg/g)		Food consumption (g/day)	Mercury intake (µg/Kg body weight/day)
		Mean	Range		
Barbequed Indian mackerel	15	0.886	0.534-1.582	2.6	0.046
Fish balls	15	0.230	0.053-0.402	4.0	0.019
Fish mousse in banana leaf	12	0.136	0.006-0.259	3.2	0.009
Fish nugget	15	0.204	0.078-0.320	5.9	0.024
Fried fish cake	15	0.105	0.008-0.266	2.5	0.005
Sardine sandwich	15	0.201	0.039-0.321	2.7	0.011
Indian mackerel curry	15	0.760	0.349-0.922	2.7	0.042
Nasi kerabu	15	0.058	0.009-0.104	7.5	0.009
Indian mackerel in chili	15	0.731	0.319-0.968	7.3	0.106
Fried anchovies	15	0.203	0.069-0.308	3.0	0.012
Nasi lemak	15	0.105	0.040-0.213	5.1	0.011
Keropok ikan	15	0.111	0.062-0.238	26.2	0.058
Fried Indian mackerel	15	0.782	0.601-1.006	11.0	0.172
Tuna in coconut milk	12	0.689	0.439-0.991	3.9	0.053
Keropok lekor	15	0.125	0.057-0.277	26.1	0.065
Fish laksa	15	0.309	0.230-0.492	5.5	0.034
Total		9.685	-	140.1	0.924
Marang (R)					
Indian mackerel in soy sauce	15	0.798	0.662-0.940	9.8	0.156
Spanish mackerel in chili	15	0.772	0.540-0.922	4.7	0.073
Tuna in chili	12	0.891	0.666-1.099	8.8	0.157
Fried yellow banded travelly	12	0.451	0.309-0.614	11.9	0.108
Barbequed Indian mackerel	15	0.885	0.602-0.997	4.4	0.079
Sweet swear Indian mackerel	12	0.753	0.502-0.933	7.6	0.114
Tuna sour soup	12	0.785	0.611-0.987	8.2	0.129
Indian mackerel in chili	15	0.711	0.548-0.923	12.9	0.184
Yellow banded travelly in chili	12	0.435	0.211-0.659	8.8	0.076
Treadfish bream in chili	12	0.357	0.209-0.518	10.3	0.074
Fried Indian halibut	12	0.437	0.217-0.699	5.0	0.044
Fried Indian mackerel	15	0.868	0.630-1.202	14.2	0.247
Tuna curry	15	0.709	0.633-0.993	8.5	0.120
Dart curry	9	0.502	0.344-0.731	3.5	0.035
Tuna in coconut milk	12	0.717	0.508-0.947	7.3	0.104
Nasi lemak	15	0.109	0.061-0.193	8.3	0.018
Hairtail scad in chili	12	0.323	0.219-0.502	19.9	0.129
Keropok lekor	15	0.096	0.016-0.175	12.2	0.023
Fried tuna	15	0.881	0.503-1.237	10.6	0.187
Anchovies sambal (canned)	15	0.158	0.063-0.218	45.9	0.145
Keropok ikan	15	0.183	0.037-0.244	18.1	0.066
Fried anchovies	15	0.194	0.101-0.305	5.4	0.021
Fish laksa	15	0.277	0.105-0.437	7.9	0.044
Total		12.292	-	254.2	2.332
Johor					
Johor Bahru (U)					
Fried anchovies	15	0.194	0.069-0.246	2.6	0.010
Grouper in tamarind	12	0.467	0.306-0.688	5.4	0.050
Keropok ikan	15	0.148	0.110-0.327	2.7	0.008
Tuna flakes in water (canned)	15	0.699	0.515-0.983	6.0	0.084
Black pomfret chili	15	0.492	0.312-0.725	3.6	0.036
Indian mackerel in chili	15	0.714	0.556-1.008	4.8	0.069
Indian mackerel in soy sauce	15	0.693	0.437-0.882	5.5	0.076
Fried mackerel	15	0.706	0.533-0.917	15.2	0.214
Spanish mackerel in chili	15	0.618	0.498-0.792	1.7	0.021
Sweet swear Indian mackerel	12	0.662	0.510-0.932	5.9	0.078
Keropok lekor	15	0.098	0.042-0.138	3.9	0.008
Fried black pomfret	15	0.389	0.269-0.368	4.0	0.031
Fried Spanish mackerel	15	0.693	0.460-0.915	2.3	0.031
Sardine in chili	15	0.136	0.101-0.248	2.6	0.007
Tuna in chili	15	0.716	0.479-0.993	1.6	0.022
Treadfish bream in soy sauce	12	0.413	0.259-0.593	4.1	0.034
Hairtail scad in chili	12	0.387	0.212-0.538	3.8	0.029
Nasi lemak	15	0.095	0.014-0.127	3.4	0.006
Treadfish bream in chili	12	0.341	0.120-0.407	3.6	0.024

Table 2: Continued

State/Location/ Food Items	Number of samples	Mercury level (µg/g)		Food consumption (g/day)	Mercury intake (µg/Kg body weight/day)
		Mean	Range		
Indian mackerel curry	15	0.698	0.346-0.982	4.1	0.057
Fried catfish eel	15	0.401	0.289-0.519	1.5	0.012
Fried Indian mackerel	15	0.726	0.529-0.895	10.6	0.153
Fried tuna	15	0.931	0.711-1.360	1.5	0.029
Stingray in tamarind	12	0.982	0.690-1.327	2.8	0.055
Sardine in tomato sauce (canned)	15	0.137	0.086-0.248	19.6	0.054
Catfish eel sour soup	15	0.236	0.127-0.450	1.7	0.008
Prawn in chili	15	0.468	0.394-0.611	4.5	0.042
Tuna in mayonnaise (canned)	15	0.762	0.564-0.910	1.8	0.028
Fish laksa	15	0.095	0.038-0.163	7.3	0.014
Total		14.097	-	137.9	1.291
Mersing (R)					
Indian mackerel in chili	15	0.739	0.589-0.942	1.3	0.019
Sweet swear black pomfret	12	0.464	0.261-0.701	1.9	0.018
Black pomfret in chili	15	0.398	0.302-0.691	1.7	0.014
Fried anchovies	15	0.164	0.089-0.236	9.7	0.032
Indian mackerel curry	15	0.794	0.504-0.917	1.5	0.023
Prawn in chili	15	0.502	0.398-0.619	2.1	0.021
Keropok lekor	15	0.132	0.078-0.245	10.5	0.028
Nasi lemak	15	0.079	0.052-0.114	8.5	0.013
Tuna in chili (canned)	15	0.683	0.598-0.711	2.8	0.038
Mackerel in chili (canned)	15	0.718	0.638-0.917	14.7	0.211
Tuna curry (canned)	15	0.828	0.649-0.997	4.1	0.067
Tuna sour soup	12	0.698	0.517-0.800	1.4	0.020
Fried hairtail scad	15	0.426	0.258-0.713	2.0	0.017
Indian mackerel in soy sauce	15	0.780	0.537-0.943	2.3	0.036
Sardine in tomato sauce (canned)	15	0.239	0.094-0.317	3.0	0.014
Fish ball	15	0.078	0.049-0.136	5.7	0.009
Tuna in mayonnaise (canned)	15	0.651	0.571-0.847	4.3	0.056
Anchovy sambal (canned)	15	0.978	0.047-0.179	20.1	0.393
Keropok ikan	15	0.079	0.053-0.148	9.6	0.015
Tuna in chili	15	0.742	0.617-0.901	2.8	0.041
Prawn in chili	15	0.438	0.199-0.567	10.6	0.093
Fish laksa	15	0.294	0.165-0.416	1.7	0.010
Fried Indian mackerel	15	0.892	0.658-1.300	2.5	0.045
Fish sauce	15	0.259	0.147-0.396	3.2	0.016
Total		12.055	-	127.9	1.249

R: rural; U: urban

in the states of Kedah and Terengganu, respectively (Figure 1). In every location, processed fish and seafood comprised the most part (43.5-57.9 %) of seafood consumption, except for Tanjung Dawai and Petaling Jaya. Out of 97 surveyed food items, those being consumed of more than 0.5% of total consumption in each area were sampled and analyzed for mercury content (Table 2).

Mercury Levels in Fish and Seafood: Table 2 shows the most consumed (more than 0.5% being consumed) fish and seafood items, their average consumption (g/day), mercury levels (µg/g) in these food items and mercury exposure to the respondents (µg/Kg body weight/day) from each location. The results of the one-way analysis of variance (ANOVA) suggested that significant variations (P<0.05) existed in mercury concentrations across the various food items and studied areas. Mercury level in

fish and seafood items collected during this study ranged from 0.006-1.857 µg/g. Mercury level in food items prepared from carnivorous fish such as stingray, tuna, dart and mackerel was significantly higher than other food items. Results also revealed that the method of food preparation has an effect on mercury concentration in fish and seafood. It was higher, for instance, in fried and barbequed fish than cooked, boiled and steamed fishes. Indian mackerel, one the most frequent fish consumed in all the location, showed higher concentration of mercury (0.401-1.582 µg/g) in barbequed and fried products compared to the same fish processed differently (curry and cooked, 0.341-0.927 µg/g). This supports the fact that fish losses moisture during frying or grilling. Based on Burger [21[, deep-frying of raw fish resulted in moisture losses. The fillets of deep-fried fish with breading weighed more than those without breading due to the weight of the breading. When fish is deep-fried, it loses

moisture, but gains weight from the breading and from the uptake of oil. There was an apparent increase in mercury concentration in the deep-fried fish (largely because when calculated on the basis of the weight of the sample, the fried fish had lost moisture but retained the same amount of mercury). The end result of the moisture loss in fish on contaminant levels is that levels are higher in cooked fish than fresh fish (on a wet weight basis of the portion itself). Other studies showed that the common cooking methods (frying, microwaving, breading) do not remove mercury in fish fillet [22-24]. Mercury level was also high in canned tuna and mackerel consumed by Malaysians. Canned tuna, for instance, showed higher levels of total mercury (0.515-1.009 compared to cooked tuna in chili or coconut milk (0.356-0.991 μg/g). However, it is still lower than fried tuna (0.711-1.360 μg/g). Canning also was shown to significantly increase the mercury levels in fish [23]. There were no significant differences in mercury level in food samples from rural and urban area. This indicates that most probably the fish and seafood consumed by urban and rural residents of each state were caught from same fish landings. Hence, the food items collected from the two states at the east coast of Peninsular Malaysia (Terengganu and Johor) showed higher levels of mercury (Table 2). Some of the previous studies on mercury concentration in marine fishes from Malaysia also reported higher mercury levels in samples from the east coast [14,15,25]. Mercury concentration in the other fish product such as keropok ikan, keropok lekor, fish nugget, nasi lemak, sardine sandwich, fish balls and fish cake was as low as 0.007 μg/g, because in such products, the fish fillet is mixed with flour, starch, etc. which dilute mercury concentration.

Assessment of Mercury Exposure from Seafood Intake:
The highest mercury exposure, 2.332 μg/person/day, was for residents of Marang in the state of Terengganu located at the east coast of Peninsular Malaysia. The lowest mercury intake, 0.543 μg/person/day, was calculated for Petaling Jaya residents in the state of Selangor located at the west coast of Peninsular Malaysia. Mercury intakes through fish and seafood consumption ware found to be higher in rural population of the four states. This originates from the fact that people at coastal areas, who are mostly fishermen, consume fish more frequently. Food items such as Indian mackerel in chili, fried Indian mackerel, mackerel in chili, fried yellow banded travelly, anchovy sambal, sardine in tomato sauce, keropok lekor and keropok ikan was among highest consumed foods in the rural area. People will be exposed

to higher levels of mercury by consuming more frequent of food items, such as mackerel, with elevated levels of mercury. However, the fish and seafood preferences and rate of consumption of the population depend on the habits, the income level and the cultural characteristics of the population. For instance, residents of Petaling Jaya, who are urban general population, consumed the lowest amount of fish and seafood. Consequently, this population has the lowest intake of mercury (0.543 μg/person/day). While, the fisherman community at the coastal area of the same state, Selangor, is the group with the highest fish ingestion rates (395.2 g/day) and mercury exposure (2.214-2.332 μg/person/day).

The previous study by the current authors found marine, showed high positive correlation between mercury and the methylmercury to total mercury in fishes from Malaysian waters, with the ratio range of 49.1% to 87.5%, with the highest ratio in predatory fishes [26]. Considering those findings, one may assume quite high exposure of methylmercury to the local population through fish and seafood consumption. Mercury level in the hair samples of the current studied population ranged from 0.01 to 21.00 μg/g [17]. The average mercury levels were 13.69, 10.85, 9.94 and 6.78 μg/g for communities in Kedah, Terengganu, Johor and Selangor, respectively. The observed significant positive correlation between hair mercury level and fish consumption, gives an insight that fish consumption is a significant route of mercury exposure for the coastal communities in Peninsular Malaysia.

Compared to other countries in the world, Malaysia was ranked the top second country consuming fish and seafood after Japan and Malysians consumed almost 3 times more compared to the world fish consumption [8]. Therefore, exposure to higher mercury level could be expected, although mercury level is not so high in the fish consumed by local population. Mercury exposure in the population of Cambodia with fish ingestion rate of 32.6 g/day, was reported to be 1.07 μg/day[15].Mercury exposure of people from gold mining areas in Indonesia with fish intake of 50 g/day was reported to be 69.5 μg/day[27].The daily mercury intake from seafood was 15.3 μg/day for Japanese women. [28] For Thai people, the fish consumption rate is approximately 13.1-18.8 kg per capita per year. The maximum weekly mercury intake through fish consumption for this population was estimated to be 0.2 mg per capita. [29] Singaporeans on average, eat fish at about 10 meals a week and fish is still the most common form of protein consumed in this

country. [30] While this country shares coastlines with Peninsular Malaysia, it is expected that the same sources of local fish and seafood is consumed by residents of this country. However, so far there was no report on weekly mercury intake for Singaporean.

REFERENCES

1. Booth, S. And D. Zeller, 2005. Mercury, food webs and marine mammals: Implications of diet and climate change for human health. Environ Health Perspect., 113: 521-526.

2. Gochfeld, M., 2003. Cases of mercury exposure, bioavailability and absorption. Ecotoxicol. Environ. Saf., 56: 174-179.

3. Eto, K., 2000. Minamata disease. Neuropathol., 20: S14-S19.

4. Richardson, G.M., 2003. Inhalation of Mercury-Contaminated Particulate Matter by Dentists: An Overlooked Occupational Risk. Human Ecol Risk Assess., 9: 1519-1531.

5. Lindqvist, O., K. Johansson, M. Aastrup, A. Andersson, L. Bringmark, G. Hovsenius, L. Hakanson, A. Iverfeldt, M. Meili and B. Timm, 1991. Mercury in the Swedish environment-recent research on causes, consequences and corrective methods. Water Air Soil Poll., 55: 1-264.

6. WHO, 2004. Safety evaluation of certain food additives and contaminants, WHO Food Additive Series: 52, International Programme on Chemical Safety, Geneva.

7. Earth trend, Earth trend environmental information. 2004; http://earthtrends.wri.org. Accessed on 07-14-2006.

8. FAO., 2006. Country Profiles of the Food and Agriculture Organization of the United Nations' Fishery Sector. http://www.fao.org/fi/fcp/en/MYS/profile. Accessed on 21-05-2007.

9. Babji, A.S., M.S. Embong and W.W. Woon, 1979. Heavy metal content in coastal water fishes of West Malaysia. Bull. Environ. Contam Toxicol., 23: 830-836.

10. Suan, C.J. and T.S. Loong, 1981. Mercury content of fish from the river mouth of Sungei Kelang. Mardi Res. Bull., 9: 72-77.

11. Noramly, M. And I. Marof, 1973. Mercury content of Malaysian marine fish, cuttlefish and edible shellfish. Science Faculty, Universiti Kebangsaan Malaysia, Kuala Lumpur. Malaysia.

12. Rahman, S.A., A.K. Wood, S. Sarmani and A.A. Majid, 1997. Determination of mercury and organic mercury contents in Malaysian seafood. J Radioanal. Nucl. Chem., 217(1): 53-56.

13. Yap, C.K., A. Ismail and S.G. Tan, 2003. Mercury levels in the green-lipped mussel Perna viridis (Linnaeus) from the West Coast of Peninsular Malaysia. Bull. Environ. Contam. Toxicol., 71: 570-576.

14. Agusa, T., T. Kunito, A. Sudaryanto, I. Monirith, S.K. Atireklap, H. Iwata, A. Ismail, J. Sanguansin, M. Muchtar, S.T. Tana and Sh. Tanabe, 2007. Exposure assessment for trace elements from consumption of marine fish in Southeast Asia. Environ. Pollut., 145: 766-777.

15. Agusa, T., T. Kunito, G. Yasunga, H. Iwata, A. Subramanian, A. Ismail and Sh Tanabe, 2005. Concentration of trace elements in marine fish and its risk assessment in Malaysia. Mar. Pollut. Bull., 51: 896-911.

16. Hajeb, P., S. Jinap, A. Ismail, A.B. Fatimah, B. Jamilah and M. Abdul Rahim, 2009a. Assessment of mercury level in commonly consumed marine fishes in Malaysia. Food Control, 20: 79-84.

17. Hajeb, P., S. Jinap, A. Ismail, A.B. Fatimah, B. Jamilah and H. Nuryani lioe, 2008. Hair Mercury Level of Coastal Communities in Malaysia: A Linkage with Fish Consumption. Euro Food Res. Tech., 227: 1349-1355.

18. McNutt, S., T.P. Zimmerman and S. Hull, 2008. Development of food composition databases for food frequency questionnaires (FFQ). J. Food Compost Anal., 21(1): S20-S26.

19. Tran, N.I., L. Barraj, K. Smith, A. Javier and T.A. Burke, 2004. Combining food frequency and survey data to quantify long-term dietary exposure: a methylmercury case study. Risk Anal., 24(1): 19-30.

20. Institute of Nutrition, 2007. Exposure assessment of free glutamate from food consumption in the central provinces of Thailand, Nahidol University, Thailand. pp: 18.

21. Burger, J., C. Dixon, C.S. Boring and M. Gochfeld, 2003a. Effect of deep-frying fish on risk from mercury. J. Toxicol. Environ. Health, 66(9): 817-828.

22. Morgan, J.N., M.R. Berry and R.L. Graves, 1997. Effects of commonly used cooking practices on total mercury concentration in fish and their impact on exposure assessments. J. Exposure Anal Environ. Epidemiol., 7(1): 119-133.

23. Rasmussen, R.S. and M.T. Morrissey, 2007. Effects of canning on total mercury, protein, lipid and moisture content in troll-caught albacore tuna (Thunnus alalunga). Food Chem., 101(3): 1130-1135.

24. Perelló, G., R. Martí-Cid, J.M. Llobet and J.L. Domingo, 2008. Effects of various cooking processes on the concentrations of arsenic, cadmium, mercury and lead in foods. J. Agri. Food Chem., 56(23): 11262-11269.

25. Hajeb, P., S. Jinap and A. Ismail, 2009b. Biomagnifications of mercury and methylmercury in tuna and mackerel. Environ Monit Assess. In press.

26. Hajeb, P., S. Jinap, A.B Fatimah and B. Jamilah, 2009c. Methylmercury in marine fishes from Malaysian waters and its relationship to total mercury content. Int J Environ Anal Chem. In press.

27. Castilhos, Z.C., S. Rodrigues-Filho, A.P.C. Rodrigues, R.C. Villas-Bôas, Sh. Siegel, M.M .Veiga and Ch Beinhoff, 2006. Mercury contamination in fish from gold mining areas in Indonesia and human health risk assessment. Sci. Total Environ., 368: 320-325.

28. Iwasaki, Y., M. Sakamoto, K. Nakai, T. Oka, M. Dakeishi, T. Iwata, H. Satoh and K. Murata, 2003. Estimation of daily mercury intake from Seafood in Japanese women: Akita cross-sectional study. Tohoku J. Exp. Med., 200: 67-73.

29. Thongra-ara, W. And P. Parkpian, 2002. Total Mercury Concentrations in Coastal Areas of Thailand: A Review. Sci. Asia., 28: 301-312

30. Burger, J., J. Fleischer and M. Gochfeld, 2003b. Fish, shellfish and meat meals of the public in Singapore. Environ Res., 92: 254-261.