Risk-benefit assessment of methyl mercury and fatty acids in imported marine fish in Macao

1. Objective

As a food source, marine fish are rich in high-quality proteins, trace elements, unsaturated fatty acids, and various beneficial nutrients, which make up an important part of a balanced diet of Macao residents. However, marine pollution can lead to contamination of marine fish by various heavy metals. Among these contaminants, methyl mercury can readily accumulate in marine fish and may cause harm to the human nervous system, posing health risks associated with exposure to methyl mercury through consuming marine fish. In this respect, the consumption of marine fish brings benefits as well as potential hazards to the health of the general public.

The main purpose of this study is to detect the levels of total mercury and methyl mercury in different species of fish commonly found in the market of Macao that are intended for human consumption, and to determine the levels of EPA, DHA, and other nutrients in different species of marine fish. Based on the detected levels

in the aforementioned study, an assessment is made on the nutritional benefits and risks to food safety associated with the consumption of the various fish species on consumers, and the effectiveness of existing food safety measures is evaluated to determine whether there is a necessity for further food safety regulation and control. Moreover, dietary recommendations are provided to better safeguard public health.

2. Background

2.1 Mercury and Methyl mercury

Mercury, commonly known as quicksilver, is a naturally occurring element in the Earth's crust. It can enter the environment through natural phenomena such as volcanic eruptions, as well as through human industrial activities, including mining, burning of fossil fuels, industrial emissions, fertiliser application or disposal of solid waste. Mercury in the environment can be absorbed by organisms from the marine environment and can accumulate in the food chain.

Mercury primarily exists in three forms in the Nature, which are elemental mercury, inorganic mercury and organic mercury. The most common form of organic mercury found in the environment and in food is methyl mercury (CH_3Hg), with a relative molecular mass of 215.63. In aquatic organisms, mercury primarily exists in the form of methyl mercury, which can readily bind to the cellular proteins in aquatic organisms and accumulate in other organisms in the food chain. The levels of methyl mercury in fish are significantly higher than those in the water they inhabit, potentially tens of thousands of times higher. Due to the effects of biological magnification in the food chain, predatory fish at higher trophic levels (such as trout, pike, tuna, swordfish, sharks) tend to have relatively high levels of methyl mercury accumulated in their body.

The primary routes of human exposure to mercury is consumption of mercury-contaminated food, contact with dental amalgam, or exposure to mercury during agricultural and manufacturing activities. Among them, food is the main source of mercury exposure among the public.

2.2 Toxicity of mercury

As to whether the intake of mercury affects human health, it depends on the chemical form of mercury, the route of exposure (inhalation, ingestion or skin contact), and the level of exposure. The mercury found in food can be categorised into inorganic and organic forms. Organic mercury has higher toxicity than inorganic mercury, and causes more severe damage to human health, thus raising greater health concerns. Research indicates that fish, shellfish and other aquatic animals are the primary dietary sources of methyl mercury exposure among the general population.

In humans, the nervous system is most sensitive to methyl mercury, which can cause various neurotoxic effects, including neuronal loss, ataxia, vision impairment, hearing loss, paralysis, and even death. It can affect both the central and peripheral nervous systems.

Moreover, methyl mercury is lipophilic, allowing it to cross the blood-brain barrier and placental barrier, causing permanent and irreversible damage to the neurological development of foetuses and newborns. For pregnant women, methyl mercury can enter the placenta into the foetal body, accumulating in the foetal brain and other tissues, thereby affecting development of the brain.

Excessive intake of methyl mercury in adults may lead to behavioural changes, tremors, vision alteration, hearing loss, loss of muscle coordination and somatosensory disturbances, amnesia, and cognitive impairment.

2.3 Health-based Guidance Value for methyl mercury in fish

The Joint FAO/WHO Expert Committee on Food Additives (hereinafter referred to as JECFA) has analysed the health-based guidance value for methyl mercury. In 2003, JECFA recommended establishing the Provisional Tolerable Weekly Intake (PTWI) for dietary exposure to methyl mercury at 1.6μg/kg bw. In 2007, JECFA set the Health-based Guidance Value (HBGV) for dietary exposure to methyl mercury specific to different groups of people, and indicated that women of childbearing age and young children are more sensitive to methyl mercury than others. In general, when the level of dietary methyl mercury intake in adults does not exceed twice the PTWI, it will not pose a risk of neurotoxicity. However, for women of childbearing age, the intake of methyl mercury should not exceed the PTWI in order to protect the neurological development of the foetus. For infants and children, JECFA has not yet established any intake level higher than the PTWI which would not pose a risk of developmental neurotoxicity.

2.4 Limits for methyl mercury in food

The Codex Alimentarius Commission established new maximum levels (MLs) for methyl mercury in fish in 2018 and 2022 respectively, which aimed to prevent risks associated with methyl mercury intake. As predatory fish need longer periods to grow and are at higher trophic levels in the aquatic food chains, they tend to accumulate higher levels of mercury in their body. In view of this, the Codex Alimentarius Commission has established the international reference standard for maximum level (ML) for methyl mercury in certain fish species: tuna (1.2mg/kg), alfonsino (1.5mg/kg), marlin (1.7mg/kg), shark (1.6mg/kg), orange roughy (0.8mg/kg) and pink cusk-eel (1.0mg/kg). Even if the mercury levels in fish do not exceed the established maximum levels (MLs), the intake of methyl mercury in some consumers may surpass the PTWI. Therefore, JECFA considered it is necessary to explore how mercury exposure through fish consumption could be further reduced.

2.5 EPA and DHA, the nutritive substances in fish

Though some marine fish contain small amounts of methyl mercury, fish products are rich in various nutrients essential for the human body, such as Omega-3 fatty acids, DHA (docosahexaenoic acid), and EPA (eicosapentaenoic acid), which are beneficial for brain development. The chemical formula for EPA is $C_{20}H_{30}O_2$ with a molecular mass of 302.451 and that for DHA is $C_{22}H_{32}O_2$ with a molecular mass of 328.448. Both EPA and DHA are in the group of n-3 polyunsaturated fatty acids.

Existing scientific evidence indicates that adequate intake of fatty acids, particularly EPA and DHA, is crucial for maturation of the foetal nervous system. DHA is primarily found in the grey matter of the human brain, mainly in the form of phospholipids. It is a key lipid component of neuronal membranes of the human brain and is the fatty acid preferentially used by the brain cells, and plays a vital role in the development of visual and cognitive functions. DHA is also an essential and indispensable component of the cell membranes of the human brain, contributing significantly to the growth of synapses and formation of neurotransmission networks. Additionally, DHA is abundant in the retinal cells in the form of phospholipids, supporting signal transmission between retinal cells and the brain, thereby maintaining normal visual function.

In human diets, EPA and DHA are primarily sourced through the consumption of fatty fish and fish oil, such as cod liver, black carp, mackerel, salmon, herring, sardines, and a variety of edible marine seaweeds and phytoplankton. These fatty acids are also present in human breast milk.

The Food and Agriculture Organization of the United Nations (FAO)/World Health Organisation (WHO) recommends that adult men, non-pregnant women and non-breastfeeding women should be supplemented with 250mg of DHA + EPA daily, while pregnant and breastfeeding women with 300mg of DHA + EPA daily, and no less than 200mg of DHA in the supplement. The European Food Safety Authority (EFSA) recommends a daily intake of 100mg of DHA for infants and young children in the age range of 7 to 24 months, and a daily intake of 250mg of DHA for children and adolescents in the age range of 2 to 18 years.

3. Research methods

3.1 Testing and collation of data

The Municipal Affairs Bureau collected samples of 20 species of marine fish commonly found in the local market, based on the volume of marine fish imported into Macao (see Table 1). A total of 143 samples were collected and categorised by species. The levels of total mercury, methyl mercury, fats, and fatty acids in the samples were measured by applying the "National Food Safety Standard - Determination of Total Mercury and Organic-mercury in Food" (GB 5009.17-2014) and the "National Food Safety Standard - Determination of Fatty Acids in Foods" (GB 5009.168-2016). Method 2 (Cold Atomic Absorption Spectrometry) mentioned in "National Food Safety Standard - Determination of Total Mercury and Organic-mercury in Food" (GB 5009.17-2014) was employed to determine the levels of total mercury in the samples, with a detection limit of 0.002 mg/kg and a quantification limit of 0.007 mg/kg. The Liquid Chromatography - Atomic Fluorescence Spectrometry (LC-AFS) method was used to determine levels of methyl mercury in the samples, with a detection limit of

0.008 mg/kg and a quantification limit of 0.025 mg/kg. Method 2 mentioned in "National Food Safety Standard - Determination of Fatty Acids in Foods" (GB 5009.168-2016) was applied to determine the content of fats in the samples, while Method 3 in GB 5009.168-2016 was used to determine their levels of unsaturated fatty acids (including EPA and DHA). The collected data includes the name of each sample (scientific name, in Latin), its country of origin, net weight (gram) and photo, the address at which it was purchased, its concentration of unsaturated fatty acids (g/100g of edible portion) and of EPA and DHA (mg/100g of edible portion), the fat percentage in the total weight, and the levels of total mercury (mg/kg) and methyl mercury (mg/kg) in the sample, among others. Subsequently, the Guangdong Provincial Institute of Public Health was commissioned to analyse the collected data derived from the 143 samples, and produced a list of the average levels of methyl mercury, DHA, and of EPA in the different species of marine fish.

Table 1 - Name of 20 marine fish species, in Chinese, English and Latin

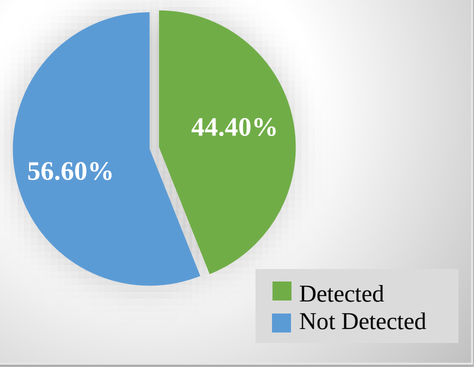
Code number	Name	Name in Latin
1	大西洋鮭 Atlantic salmon	*Salmo salar*
2	大黃魚 Large yellow croaker	*Larimichthys crocea*
3	康氏馬鮫 Narrow-barred Spanish mackerel	*Scomberomorus commerson*
4	日本竹筴魚 Japanese jack mackerel	*Trachurus japonicus*

5	卵形鯧鯵 Derbio	*Trachinotus ovatus*
6	布氏鯧鯵 Golden pomfret	*Trachinotus blochii*
7	銀鯧 Silver pomfret	*Pampus argenteus*
8	金線魚 Golden threadfin bream	*Nemipterus virgatus*
9	棘鯛屬魚類 Fish of the genus Acanthopagrus	*Acanthopagrus*
10	紅金眼鯛 Splendid alfonsino	*Beryx splendens*
11	黑棘鯛 Blackhead seabream	*Acanthopagrus schlegelii*
12	秋刀魚 Pacific saury	*Cololabis saira*
13	吞拿魚 Tuna	*Tuna*
14	鱈魚 Cod	*Gadus*
15	鰈魚 Flatfish	*Pleuronichthys cornutus*
16	沙丁魚 Sardine	*Sardine*
17	鰻鱺 Japanese eel	*Anguilla japonica*
18	劍魚 Swordfish	*Xiphias gladius*
19	鯖魚 Mackerel	*Pneumatophorus japonicus*
20	石斑魚 Groupers	*Epinephelus spp*

3.2 Data analysis

The data of the samples used in the assessment revealed that the methyl mercury levels in 81 samples were below the limit of detection (LOD), resulting in a non-detection rate of 56.6%. In this respect, the principle for handling undetected values specified in the second meeting about "Credible Evaluation of Low-Level Contaminants in Food" of WHO Global Environmental Monitoring System/Food Contamination Monitoring and Assessment Programme (GEMS/FOOD) was adopted. Thus, the levels of methyl mercury in the 81 samples were also assigned a value of "0" when used in calculation, besides using their actual levels, which were below detection limit.

Figure 1 - Detection rate of methyl mercury in the samples



3.3 Risk-Benefit Assessment

The Quantitative Risk-Benefit Assessment model proposed by the Food and Agriculture Organization of the United Nations (FAO)/World Health Organisation (WHO) was adopted. According to this model, the effects of maternal intake of methyl mercury, DHA, and EPA from fish consumption during pregnancy on the child's intelligence quotient (IQ) can be quantified. To measure the effects, different fish species were tested to determine the average levels of methyl mercury, DHA, and of EPA in them. This model can assess the effects of DHA intake and exposure to methyl mercury of pregnant women and wet nurses through marine fish consumption on the neurological development of newborns, infants and young children, using the increase in IQ points as the assessment indicator.

Based on the data of levels of methyl mercury, DHA, and EPA detected in samples of the commonly found species of marine fish imported into Macao, and taking into consideration of the consumption levels of aquatic products recommended by the "Chinese Dietary Guidelines 2016", as well as referring to the data on marine fish consumption among adults aged 18 and older in Hong Kong between 2018 and 2020, the Quantitative Risk-Benefit Assessment model of FAO/WHO was employed to comprehensively assess the risks and benefits behind consuming the commonly found species of marine fish imported into Macao.

Moreover, the quantitative assessment applied the three hypothetical levels of marine fish consumption set by FAO/WHO, which are 100g/week, 200g/week, and 400g/week, in analysing the data on marine fish consumption of pregnant women, wet nurses and women of childbearing age. The assessment evaluated the beneficial effects (i.e. net increase in IQ points) of consuming different species of marine fish, estimated the optimal weekly consumption (g/week) of each species required to achieve a maximum increase in IQ points, and identified the health risks associated with exposure to methyl mercury at the different hypothetical levels of consumption of different species of marine fish.

4. Results

4.1 Detection levels of methyl mercury and fatty acids

Results of analysis indicated that the levels of total mercury and methyl mercury in 143 samples of marine fish ranged from not detected to 2.5mg/kg, and from not detected to 2.3mg/kg respectively, while their median levels were 28μg/kg and 15.5μg/kg respectively, and their average levels were 104.7μg/kg and 122.3μg/kg respectively. Moreover, the level of total mercury in 136 samples was below 0.5mg/kg, accounting for 95.1% of total, while methyl mercury level in 140 samples was below 0.5mg/kg, accounting for 97.9% of total.

Among the 20 imported marine fish species commonly found in Macao covered by the assessment, the average levels of DHA + EPA in them ranged from 0.20mg/kg to 27.93mg/kg, while the average methyl mercury levels in them ranged from not detected to 0.948mg/kg. The fish species with the highest average methyl mercury level was swordfish (0.948mg/kg), followed by cod (0.224mg/kg) and tuna (0.086mg/kg).

4.2 Exposure to methyl mercury through consumption of various marine fish species

Assessment of exposure to methyl mercury through marine fish consumption at various levels (100g/week, 200g/week and 400g/week) was performed. The results showed that, except for a few species, such as swordfish, the levels of methyl mercury in majority of the marine fish species did not exceed the Provisional Tolerable Weekly Intake (PTWI) of 1.6μg/kg bw set by JECFA, indicating a low risk of methyl mercury exposure (see Table 2). In 17 fish species, including groupers, the highest methyl mercury exposure at different consumption levels was only 6.9% of the PTWI, suggesting a low health risk of methyl mercury exposure through consumption of such marine fish.

However, risk of methyl mercury exposure through consumption of certain marine fish species is worthy of attention. Swordfish had the highest methyl mercury level. At consumption levels of 100g/week, 200g/week and 400g/week, the levels of methyl mercury exposure were 1.580μg/kg bw/week, 3.160μg/kg bw/week and 6.320μg/kg bw/week respectively, which accounted for 98.8%, 197.5%, and 395.9% of PTWI respectively, thus approaching or exceeding PTWI, which is set at 1.6μg/kg bw/week. For consumption of cod, the levels of methyl mercury exposure at the different consumption levels accounted for 23.3%, 46.6% and 93.2% of PTWI respectively; for consumption of tuna, the levels of methyl mercury exposure were 5.4%, 18.0% and 36.0% of PTWI respectively (see Table 2). According to JECFA recommendations, when the dietary intake of methyl mercury in adults does not exceed twice the PTWI, there is no neurotoxic risk. For women of childbearing age, their methyl mercury intake should not exceed the PTWI to protect the neurological development of the foetus. JECFA recommended that adults should not consume more than 200g of swordfish per week, while women of childbearing age and wet nurses should limit their dietary intake of swordfish to no more than 100g per week.

Table 2 - Levels of methyl mercury exposure based on consumption levels of different marine fish species (μg/kg bw/week)

Fish species	n	Level of MeHg (μg/g)	Consumption level of marine fish		
			100 g/week	200 g/week	400 g/week
劍魚 Swordfish	5	0.948	1.580	3.160	6.320

鱈魚 Cod	8	0.224	0.373	0.745	1.491
吞拿魚 Tuna	6	0.086	0.144	0.288	0.576
石斑魚 Groupers	8	0.016~0.017	0.026~0.028	0.052~0.055	0.103~0.110
鰻鱺 Japanese eel	8	0.009~0.012	0.015~0.020	0.031~0.041	0.062~0.082
康氏馬鮫 Narrow-barred Spanish mackerel	5	0.007~0.012	0.012~0.020	0.025~0.041	0.049~0.081
金線魚 Golden threadfin bream	8	0.009~0.012	0.015~0.020	0.030~0.040	0.061~0.081
秋刀魚 Pacific saury	5	0.010~0.012	0.017~0.020	0.035~0.040	0.070~0.081
棘鯛屬魚類 Fish of the genus Acanthopagrus	8	0.003~0.010	0.005~0.016	0.009~0.033	0.018~0.065
鰈魚 Flatfish	8	0.006~0.010	0.009~0.016	0.019~0.032	0.038~0.065
紅金眼鯛 Splendid alfonsino	8	0.006~0.010	0.009~0.016	0.018~0.032	0.037~0.063
鯖魚 Mackerel	8	0.007~0.009	0.012~0.015	0.023~0.030	0.046~0.060

黑棘鯛 **Blackhead seabream**	5	0.002~0.009	0.004~0.014	0.007~0.029	0.015~0.057
大黃魚 **Large yellow croaker**	8	0.005~0.009	0.008~0.014	0.015~0.028	0.030~0.057
布氏鯧鰺 **Golden pomfret**	8	0~0.008	0~0.013	0~0.027	0~0.053
卵形鯧鰺 **Derbio**	8	0~0.008	0~0.013	0~0.027	0~0.053
大西洋鮭 **Atlantic salmon**	8	0~0.008	0~0.013	0~0.027	0~0.053
日本竹筴魚 **Japanese jack mackerel**	5	0~0.008	0~0.013	0~0.027	0~0.053
沙丁魚 **Sardine**	8	0~0.008	0~0.013	0~0.027	0~0.053
銀鯧 **Silver pomfret**	8	0~0.008	0~0.013	0~0.027	0~0.053

4.3 Fatty acid intake from consumption of different marine fish species

The intake of DHA + EPA from different marine fish species was calculated at the consumption levels of 100g/week, 200g/week and 400g/week, with daily intake levels indicated in Table 3:

① When the consumption of marine fish is at 100g/week, the daily intake of DHA+EPA from 12 species (accounting for 60%) of marine fish is less than 100 mg/day, the daily intake from 7 species (accounting for 35%) is 100 mg ~ 249 mg/day, and the daily intake from 1 species (5%) is ≥300 mg/day.

② When the consumption of marine fish is at 200g/week, the daily intake of DHA+EPA from 8 species (accounting for 40%) of marine fish is less than 100 mg/day, the daily intake from 8 species (accounting for 40%) is 100 mg ~ 249 mg/day, and the daily intake from 4 species (20%) is ≥300 mg/day.

③ When the consumption of marine fish is at 400g/week, the daily intake of DHA+EPA from 4 species (accounting for 20%) of marine fish is less than 100mg/day, the daily intake of DHA+EPA from 7 species (accounting for 35%) is 100 mg ~ 249 mg/day, and the daily intake of DHA+EPA from 9 species (45%) is ≥300 mg/day.

According to FAO/WHO recommendations, adult men, non-pregnant women and non-breastfeeding women should be supplemented with 250 mg of DHA+EPA daily while pregnant women and breastfeeding women should be supplemented with 300mg of DHA+EPA daily. Consuming sardine, swordfish, mackerel and flatfish is an easy way to reach the recommended level of fatty acid intake.

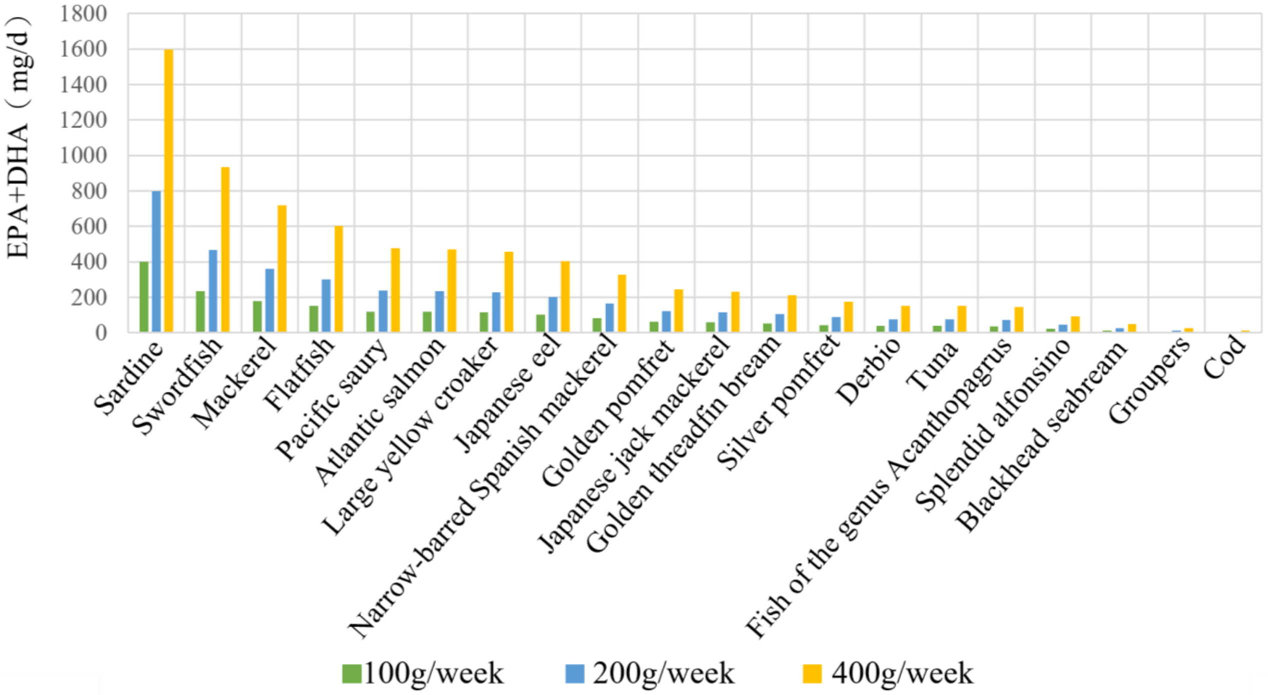
Table 3 - DHA+EPA intake (mg/day) based on consumption levels of different marine fish species

Fish species	n	EPA+DHA (mg/g)	Consumption level of marine fish		
			100 g/week	200 g /week	400 g/week
沙丁魚 Sardine	8	27.93	399.04	798.09	1596.18
劍魚 Swordfish	4	16.33	233.23	466.46	932.92
鯖魚	8	12.58	179.77	359.53	719.06

Mackerel					
鰈魚 Flatfish	8	10.54	150.52	301.05	602.09
秋刀魚 Pacific saury	5	8.36	119.36	238.72	477.45
大西洋鮭 Atlantic salmon	8	8.21	117.32	234.63	469.27
大黃魚 Large yellow croaker	8	8.01	114.48	228.96	457.91
鰻鱺 Japanese eel	8	7.06	100.81	201.62	403.23
康氏馬鮫 Narrow-barred Spanish mackerel	5	5.73	81.93	163.85	327.71
布氏鯧鯵 Golden pomfret	8	4.28	61.12	122.24	244.48
日本竹筴魚 Japanese jack mackerel	5	4.07	58.11	116.21	232.42
金線魚 Golden threadfin bream	8	3.68	52.64	105.27	210.54
銀鯧 Silver pomfret	8	3.06	43.70	87.40	174.80

卵形鯧鯵 Derbio	8	2.63	37.59	75.18	150.36
吞拿魚 Tuna	3	2.63	37.54	75.09	150.18
棘鯛屬魚類 Fish of the genus Acanthopagrus	8	2.56	36.50	73.00	146.00
紅金眼鯛 Splendid alfonsino	8	1.64	23.43	46.87	93.73
黑棘鯛 Blackhead seabream	5	0.87	12.46	24.92	49.85
石斑魚 Groupers	8	0.45	6.44	12.87	25.75
鱈魚 Cod	7	0.20	2.87	5.74	11.48

Figure 2 - DHA+EPA intake based on consumption levels of different marine fish species



4.4 Net increase in IQ points obtainable from consumption of different marine fish species

After calculation, at a consumption level of 100g/week of sardine, the net increase in IQ points approaches or reaches the maximum level (an increase of 5.8 IQ points). At a consumption level of 200g/week of any of the six marine fish species, which are sardine, mackerel, flatfish, Pacific saury, Atlantic salmon and large yellow croaker, the net increase in IQ points may approach or reach the maximum level. At a consumption level of 400g/week of any of the 11 marine fish species, which are sardine, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel and golden threadfin bream, the net increase in IQ points may approach or reach the maximum level (see Table 4). Thus, the above-mentioned marine fish species are beneficial to women of childbearing age, pregnant women and wet nurses.

In the assessment, the level of DHA + EPA detected in cod was relatively low while that of methyl mercury was rather high, resulting in a negative net increase in IQ points across the different consumption levels of cod (-0.270 to -1.079). At a consumption level of 400g/week of swordfish, it also showed a negative net increase in IQ points (-0.078), indicating a potential adverse effect on infant's intelligence. So, it is not advisable for women of childbearing age, pregnant women, and wet nurses to consume swordfish.

Table 4 - Net increase in IQ points obtainable from consumption of different marine fish species

Fish species	100 g/week	200 g/week	400 g/week
沙丁魚 Sardine	5.788~5.800	5.775~5.800	5.750~5.800
鯖魚 Mackerel	4.804~4.807	5.772~5.778	5.745~5.757
劍魚 Swordfish	4.331	2.861	-0.078
鰈魚 Flatfish	4.019~4.025	5.770~5.782	5.740~5.765
秋刀魚 Pacific saury	3.180~3.183	5.763~5.768	5.725~5.735
大西洋鮭 Atlantic salmon	3.132~3.144	5.775~5.800	5.750~5.800
大黃魚	3.055~3.061	5.774~5.786	5.747~5.772

Large yellow croaker			
鰻鱺 Japanese eel	2.683~2.687	5.365~5.375	5.724~5.743
康氏馬鮫 Narrow-barred Spanish mackerel	2.177~2.184	4.353~4.368	5.724~5.754
布氏鯧鰺 Golden pomfret	1.626~1.638	3.251~3.276	5.750~5.800
日本竹筴魚 Japanese jack mackerel	1.545~1.557	3.090~3.114	5.750~5.800
金線魚 Golden threadfin bream	1.392~1.397	2.784~2.793	5.567~5.586
銀鯧 Silver pomfret	1.159~1.171	2.317~2.342	4.635~4.685
卵形鯧鰺 Derbio	0.995~1.007	1.99~2.015	3.980~4.030
棘鯛屬魚類 Fish of the genus Acanthopagrus	0.963~0.974	1.926~1.948	3.852~3.896

吞拿魚 **Tuna**	0.872	1.745	3.489
紅金眼鯛 **Splendid alfonsino**	0.613~0.619	1.226~1.239	2.453~2.478
黑棘鯛 **Blackhead seabream**	0.321~0.331	0.641~0.661	1.283~1.322
石斑魚 **Groupers**	0.147~0.148	0.294~0.297	0.588~0.594
鱈魚 **Cod**	-0.270	-0.539	-1.079

4.5 Optimal weekly consumption level of marine fish

Without considering the health impacts of methyl mercury, calculation of the optimal weekly consumption level (Optimal X) of marine fish is based on the highest increase in IQ points (i.e. 5.8 points) achievable through DHA + EPA intake. The lower is the optimal consumption level, the easier to benefit from the DHA + EPA obtained through consumption of the marine fish species. By taking the daily consumption levels of aquatic products recommended by the “Chinese Dietary Guidelines 2016” as reference, which is 40g-75g/day (equivalent to 280g-525g/week), when the optimal consumption level of a certain marine fish species does not exceed the maximum recommended level, that marine fish species can be considered to have a beneficial dietary value towards an increase in IQ points.

Among the 20 marine fish species, the optimal weekly consumption levels for sardine, swordfish, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel, golden threadfin bream and silver pomfret, range from 54.2g to 495.2g per week, which are within the consumption levels of aquatic products recommended by the "Chinese Dietary Guidelines 2016".

In contrast, the optimal weekly consumption levels for 7 marine fish species, namely derbio, tuna, fish of the genus Acanthopagrus, splendid alfonsino, blackhead seabream, groupers and cod, range from 575.7g to 7542.2g per week, exceeding the maximum level of 525g/week recommended by the "Chinese Dietary Guidelines 2016", particularly high in blackhead seabream (1736.6g/week), groupers (3362.1g/week) and cod (7542.2g/week). Refer to Table 5 for details.

Table 5 - Optimal weekly consumption level and maximum acceptable weekly intake of marine fish (g/week)

魚種	Optimal X	AWI
沙丁魚 Sardine	54.2	12000~
劍魚 Swordfish	92.8	101.3
鯖魚 Mackerel	120.4	10741.3~13837.8
蝶魚 Flatfish	143.8	9922.5~16916.3

秋刀魚 Pacific saury	181.3	7947~9160.3
大西洋鮭 Atlantic salmon	184.5	12000~
大黃魚 Large yellow croaker	189.0	11294.1~21333.3
鰻鱺 Japanese eel	214.7	7836.7~10378.4
康氏馬鮫 Narrow-barred Spanish mackerel	264.2	7868.9~12973
布氏鯧鰺 Golden pomfret	354.1	12000~
日本竹筴魚 Japanese jack mackerel	372.5	12000~
金線魚 Golden threadfin bream	411.2	7917.5~10520.5
銀鯧 Silver pomfret	495.2	12000~
卵形鯧鰺	575.7	12000~

Derbio		
吞拿魚 Tuna	576.4	1112.0
棘鯛屬魚類 Fish of the genus Acanthopagrus	592.9	9846.2~34909.1
紅金眼鯛 Splendid alfonsino	923.6	10092~17415
黑棘鯛 Blackhead seabream	1736.6	11162.8~43636.4
石斑魚 Groupers	3362.1	5818.2~6193.5
鱈魚 Cod	7542.2	429.3

Note: Optimal X refers to the optimal weekly consumption level and AWI refers to the maximum acceptable weekly intake.

4.6 Risk-Benefit Characterisation

The assessment covered 20 imported marine fish species commonly found in Macao. The average levels of DHA + EPA in them ranged from 0.20mg/g to 27.93mg/g, while that of methyl mercury ranged from not-detected to 948.0μg/kg. The evaluation of risk of methyl mercury exposure and benefits of DHA + EPA intake was based on three hypothetical consumption levels of marine fish (100g/week, 200g/week, and 400g/week). At these three consumption levels, except swordfish, the levels of methyl mercury of all other 19 marine fish species did not exceed the PTWI (1.6μg/kg bw) set by JECFA. The weekly exposure to methyl mercury through swordfish at these three consumption levels was 1.580μg/kg bw, 3.160μg/kg bw and 6.320μg/kg bw respectively, which accounted for 98.8%, 197.5% and 395.9% of PTWI respectively and was worthy of attention. The methyl mercury exposure through cod accounted for 23.3%, 46.6% and 93.2% of the PTWI respectively, while that through tuna accounted for 5.4%, 18.0% and 36.0% respectively. The levels of methyl mercury detected in the rest 17 species of marine fish were low, so consumption of these fish species posing a low health risk.

The Quantitative Risk-Benefit Assessment model proposed by FAO/WHO was adopted to comprehensively analyse the net health effects caused by risk of methyl mercury exposure and benefits from DHA + EPA intake through consumption of marine fish. The results showed at consumption levels of 100g/week, 200g/week and 400g/week of different marine fish species, the respective net increase in IQ points in newborns, infants and young children ranged from -0.270 to 5.800, -0.539 to 5.800, and -1.079 to 5.800. Moreover, consumption of cod and swordfish by pregnant women and wet nurses could lead to a negative net increase in IQ points of newborns, infants and young children, while consumption of the other 18 marine fish species would provide considerable benefits to the neurodevelopment of newborns, infants and young children. Additionally, net increase in IQ points through consumption of marine fish varied significantly across different species.

When consumption level of the 11 species of marine fish, including sardine, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel and golden threadfin bream, is at 400g/week, it can promote a higher net increase in IQ points of newborns, infants and young children, while risk of methyl mercury exposure is low. The consumption level of 400g/week of marine fish is within the range (280g-525g/week) [22] of consumption of aquatic products recommended by "Chinese Dietary Guidelines 2016", so this is a reasonable and achievable consumption level. The general population can obtain higher health benefits by consuming an amount of the above-mentioned 11 marine fish species within the recommended consumption level, so it is advisable to consume these marine fish species.

This assessment explores a method of classifying the consumption value of commonly found species of marine fish imported into Macao based on a balanced diet, taking into account the health effects of DHA + EPA and the health hazards of methyl mercury, and makes recommendations, as follows:

Classification	Fish species	Recommendations on marine fish consumption
Class Ⅰ (12 species)	Sardine, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel, golden threadfin bream, silver pomfret	**Priority recommendation** Reason: When the balanced diet of pregnant women and wet nurses contains these marine fish species, it will offer greater benefits to IQ growth of newborns, infants and young children, while the risk of methyl mercury exposure is relatively low.

Class Ⅱ (6 species)	Derbio, fish of the genus Acanthopagrus, splendid alfonsino, blackhead seabream, groupers, tuna	**General Recommendations** **Reason:** 1. Maximum IQ growth can be achieved only by a consumption level exceeding the level of consumption recommended by "Chinese Dietary Guidelines 2016". Moderate consumption can obtain high-quality proteins, various vitamins and minerals; 2. There is considerable health risk associated with exposure to methyl mercury. It is advisable to avoid consumption of large quantities over extended time periods to minimise health risk of methyl mercury.
Class III (2 species)	Swordfish, cod	**Not Recommended** **Reason:** When the balanced diet of pregnant women and wet nurses contains any of these marine fish species, it offers lower benefits to IQ growth of newborns, infants and young children, and risk of methyl mercury exposure is relatively high.

5. Conclusion and Recommendations

① The amount of mercury ingested by humans depends on the mercury levels in food and the quantity consumed. Based on the detected levels of mercury in samples of marine fish, and on data about local consumption, the risk of Macao residents' exposure to methyl mercury due to marine fish consumption is generally low. The 20 marine fish species with the largest import volume into Macao are fairly safe for consumption.

② Of the 20 marine fish species subject to assessment, 17 species, including sardine, pose a low risk of methyl mercury exposure, since their methyl mercury levels did not exceed the PTWI set by JECFA. They are rich in nutrients and are recommended for consumption. Swordfish, cod and tuna have relatively high methyl mercury levels, which may pose higher risk of methyl mercury exposure for individuals with a dietary preference for these fish species and for those who tend to consume them in large quantities over extended periods of time. It is recommended to increase the quantity of fish of these three species subject to testing for methyl mercury, or conduct routine monitoring of them, and issue consumption warnings if necessary to ensure food safety.

③ The nutritional benefits from consuming different marine fish species vary in accordance to the amount consumed. When consumption of marine fish is at a low level, sardine provides the highest nutritional benefits; when at a moderate level, six marine fish species, including sardine and mackerel, yield higher nutritional benefits; when at a higher consumption level, the nutritional benefits derived from 11 species, including sardine, mackerel, flatfish and Pacific saury, reach the maximum level.

④ Data analysis indicated that when the balanced diet of pregnant women and wet nurses contains any of these 12 marine fish species, namely sardine, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel, golden threadfin bream, and silver pomfret, it helps to achieve a higher net increase in IQ points of newborns, infants and young children, while risk of methyl mercury exposure is relatively low. Overall, these fish species provide comprehensive health benefits and are high in dietary value, making them recommendable for the public's consumption.

⑤ Recommendations for consumers:

- Maintain a balanced and diverse diet to avoid excessive intake of metal contaminants due to selective eating.
- As fish contain various essential nutrients for human body, such as omega-3 fatty acids and high-quality proteins, it is advisable to eat a variety of fish species in moderation.
- Pregnant women, women planning to get pregnant and young children are more susceptible to effects of mercury. They should avoid large predatory fish and other fish species with a higher mercury level, including swordfish, cod and tuna. Instead, they may opt for sardine, mackerel, flatfish, Pacific saury, Atlantic salmon, large yellow croaker, Japanese eel, narrow-barred Spanish mackerel, golden pomfret, Japanese jack mackerel, golden threadfin bream and silver pomfret, etc.
- Upon purchase of fish products, pay attention to the food label and the fish species used in making the products.

⑥ Recommendations for the sector:

- Purchase food from reliable suppliers.
- Keep the information on origin or source of food properly to facilitate traceability of food as necessary.

- Provide customers with information on the species of fish for sale and used in making fish products.

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