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Total Mercury and Methyl Mercury Concentrations in Fish from the Persian Gulf and the Caspian Sea

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Abstract In order to understand the bioaccumulation of mercury in fish in the Iranian coastal waters of the Caspian Sea and the Persian Gulf, different fish species were sampled from both regions in January 2002. Mullet fishes were sampled from the Caspian Sea and six other species from the Persian Gulf: Largetooth flounder, Spotfin flathead, Japanese threadfin bream, Greater lizardfish, Elongate sole and Giant seacatfish. In the Persian Gulf, total Hg concentrations in fish ranged from 0.0123 to 0.0867 mg kg^{-1} w.w. (0.0614 to 0.433 mg kg^{-1} d.w.). Methylmercury accounts for 64–100% of the total mercury. Highest mercury concentrations were observed in the predatory fish: Giant seacatfish, Threadfin bream and the larger Greater lizardfish caught near Mogham Port. In these species the methylmercury fraction is always higher than 90%. A low methylmercury fraction was only observed in the smallest specimen of flounder and Elongate sole. In the Caspian Sea Hg concentrations in Mullet ranged from 0.0102 to 0.108 mg kg^{-1} w.w. The observed concentrations are comparable to those found in other areas of the Persian Gulf as well as in other marine environments and are much lower then the WHO guideline of 0.5 mg kg^{-1} w.w.

Keywords total mercury · methyl mercury · Persian Gulf · Caspian Sea · fish

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1 Introduction

Mercury (Hg) is one of the most hazardous environmental pollutants, due to its toxicity and its accumulation in aquatic organisms. The relative toxicity of mercury depends on its chemical form, methyl mercury being one of the most toxic substances existing in the environment. The consumption of fish is the main route of exposure of humans to monomethylmercury (MMHg), which represent the main form of mercury in fish due to biomagnification in the marine food chain. (Harada, Akagi, Tsuda, Kizaki, & Ohno, 1999; Oken et al., 2005; Schober et al., 2003).

Mercury exposure leads to numerous symptoms such as: impaired vision and hearing, dizziness, vomiting, headache, muscular weakness, allergies, depressed immune system, brain damage, but finally can lead to death (Risher, 2003).

As most of the anthropogenic Hg enters the aquatic system in its inorganic form – chlor-alkali industry is one of the main mercury pollution sources (Manohar, Krishnan, & Anirudhan, 2002) – MMHg must be formed in situ. It is now known that methylation is mainly occurring in sediments and anoxic aquatic systems (e.g., Compeau & Bartha, 1987; Craig & Moreton, 1985; Hammerschmidt & Fitzgerald, 2006; Ullrich, Tanton, & Abrdashitova, 2001). Sulphate reducing bacteria are often involved in the transformation of inorganic into organomercury compounds, but the methylcobalamine coenzyme seems to play a major role too. Factors favoring the methylation process are higher temperature, lower pH, anoxic conditions, higher organic matter content and appropriate sulphate (200–500 μM) concentrations (Bloom, Watras, Hurley, 1991; Gilmour & Henry, 1991; Hammerschmidt & Fitzgerald, 2004; Muhaya, Leemakers, & Baeyens, 1997), while sulphides appear to limit the production of methylmercury in saline sediments (Benoit, Gilmour, Mason, & Heyes, 1999; Craig & Moreton, 1985; Compeau & Bartha, 1987). Besides methylation, demethylation also occurs, thus the net result observed in a natural system will be the difference between both processes.

The concern about Hg pollution in the marine environment started with the well-known case of Minamata in Japan, where in the 1950s many people were poisoned and part of them even died after consuming fish and shellfish containing relatively high concentrations of methyl mercury. The Persian Gulf and the Caspian Sea, which are the main seafood sources in Iran, are increasingly exposed to various natural, agricultural and industrial pollutants. Hence, understanding the ecotoxicological state of these seas is an important step towards their protection and sustainable development. In order to better understand the mercury accumulation in Iranian seafood, different fish species were sampled from both seas as a preliminary investigation. Total and methyl mercury concentrations were assessed in the samples.

2 Materials and Methods

2.1 Sampling areas

The Persian Gulf The Persian Gulf is a partially closed sea covering a surface of 240,000 km^2 and with an average depth of 35 m (Kardovani, 1995). The average seawater temperature of the Persian Gulf is 28–30°C but it can go up to 35.8°C (ROPME, 1999) and the oxygen content can vary from 4 to 7 mg l^{-1}. High evaporation results into increasing salinities, with values as high as 40. Fresh water is supplied mainly by rivers in the northwest, but this amount is insufficient to compensate for the evaporation. Water circulation is thus essential in maintaining the ecological balance of the Gulf. A surface current from the Indian Ocean moves slowly counter clock wards towards the Iranian coast. This current plays an important role in salinity and likewise pollutant distributions of the Persian Gulf and has also an effect on suspended particles and plankton. Particular characteristics of the Persian Gulf are the presence of coral reefs and mangrove forests. According to estimations made by the FAO, potential fish resources in the Persian Gulf amount to 550,000 tons, about eight times more than the Oman Sea (Kardovani, 1995).

Pollution in the Persian Gulf zone Besides pollution through riverine inputs from adjacent countries (Iran, Iraq, Kuwait, Saudi Arabia, and the Emirates of Bahrain, Qatar and Oman), the Gulf has been exposed to various additional contaminants as a consequence of marine accidents and wars in recent years. Being located in a major area of petroleum resources, extraction of oil and the passage of oil tankers have an additional destructive impact on its marine ecosystem.

Two ports in the Persian Gulf have been selected. Mogham port is a small rustic and low active port – vessel activity is limited to local fishery vessels – with a population of less than 5,000 inhabitants. On the contrary, Lengeh port, which is located 168 km from Mogham port, is an active port with heavy ship traffic.

Very little information is available on the extend of Hg pollution in the Persian Gulf. Al-Majed and Preston (2004) found 0.05±0.03 μg g^{-1} d.w. Hg in sediments of outer Kuwait Bay and up to 36.5 μg g^{-1} d.w. in sediments at a former Salt and Chlorine Plant at Shuwaikh, in Kuwait Bay. Methylmercury levels ranged from <0.3 ng g^{-1} d.w. up to 85 ng g^{-1} d.w. at the former Salt and Chlorine Plant. No data is available for the Iranian coast.

The Caspian Sea Iran is located at the southern border of the Caspian Sea, the largest inland water body in the world, with an average dept of 180 m and a total capacity of 77,000 km^3. It is a landlocked sea with semi-saline water, having a surface of about 436,000 km^2, a length of 1,200 km and a width between 204 and 566 km with an average of 330 km. There are three distinct basins: the central and southern basins are quite deep, with maxima of 788 and 1,025 m, respectively, however, the northern part is shallow with an average depth of about 5 m and a maximum depth of only 20 m. The sea level is presently about 27 m below the level of the world oceans, although there is a marked increase of about 2.5 m since 1977.

The Caspian Sea is economically important, especially regarding fishing activities. About 510,000 tons of fish are captured each year by the different bordering countries with especially Sturgeon fishing representing 90% of the world's catch. The sea hosts about 76 different fish species (such as sturgeon, salmon and kilka), of which 44 species are important from a commercial point of view. The average salinity of the sea is 12.64–12.68 and the dissolved oxygen varies from 2 mg l^{-1} at 300 m depth to 0.3 mg l^{-1} at 700 m depth (Kardovani, 1995).

Pollution in the Caspian Sea The Caspian Sea is surrounded by Turkmenistan, Kazakhstan, Russia, Azerbaijan and Iran and has been the recipient of various polluting substances. The main sources of pollution are generally believed to be the offshore oil production and land based sources, notably the Volga River, which is the main river in the north, and from rivers at the western border coming from the Republic of Azerbajan and Kazhakhstan. (de Mora & Turner, 2004; Kardovani, 1995). Due to excessive pollution in some western Caspian Sea areas, there is no trace of aquatic life, especially in the coastal areas in Baku Harbour (Azerbaijan) and Kazakhstan. The expanded oil spill in coastal areas in Azerbaijan and Kazakhstan hinders the process of photosynthesis. Industrial effluents from over 40 factories in Baku Bay have caused a serious local contamination of the area (de Mora, Shekholeslami, Wyse, Azemard, & Cassi, 2004). On the Iranian coastline there are over 350 small and large rivers flowing into the Caspian Sea. The concentration of metals in sediments was studied by de Mora et al. (2004). With respect to mercury, concentrations were low in the northern Caspian and southeastern Caspian (0.01–0.1 μg g^{-1} d.w.) and notably higher at a number of sites in Azerbaijan, especially at Baku Bay, were concentrations up to 0.45 μg g^{-1} d.w. were found.

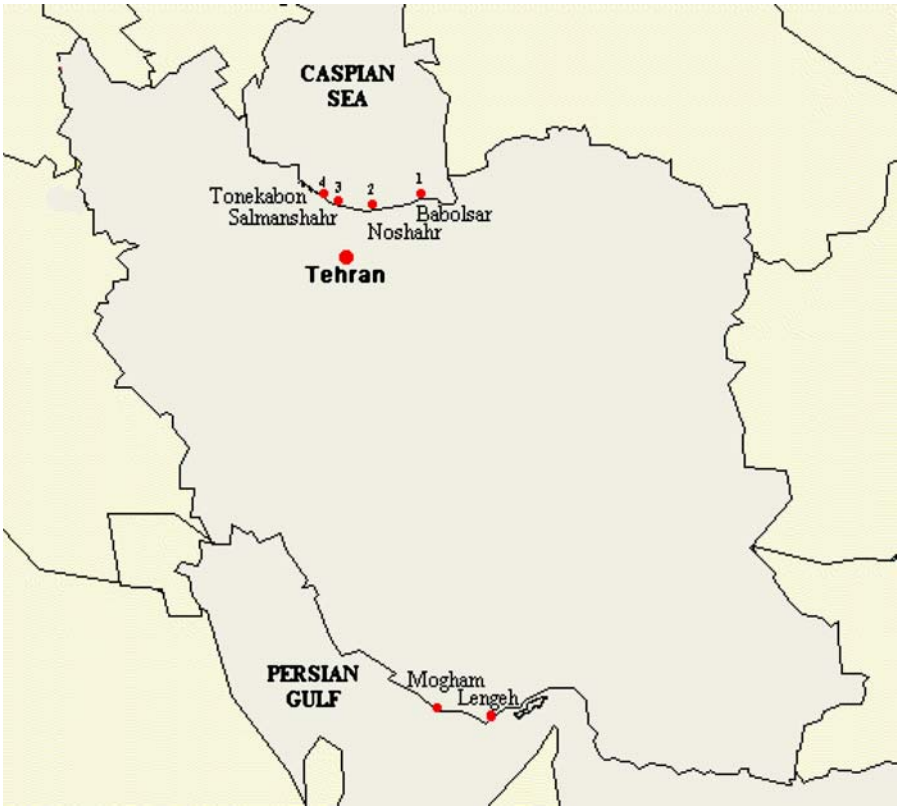

Fig. 1 Map of sampling stations in the Persian Gulf (Mogham and Lengeh Port) and Caspian Sea (*1* – Babolsar; *2* – Noshahr; *3* – Salman Shahr; *4* – Tonekabon)

2.2 Sampling

Sampling was performed in January 2002 (during the wet season) in the Persian Gulf, south of Iran and in the Caspian Sea, north of Iran. In the Persian Gulf 65 fishes, belonging to six different species, were sampled by bottom trawl survey at two stations (Mogham port and Lengeh port) located in the Hormozgan province (Fig. 1). The selected fish species in the Persian Gulf were: (1) Largetooth flounder (*Pseudorhombus arsicus*), (2) Spotfin flathead (*Gramnoplites suppositus*), (3) Japanese threadfin bream (*Nemipterus japonicus*), (4) Greater lizardfish (Saurida tumbil), (5) Giant seacatfish (*Arius thalassinus*) (6) Elongate sole (*solea elongata*). In Mogham port Flounder, spotfin flathead, Japanese threadfin bream and Greater lizardfish were caught. In Lengeh port Spotfin flathead, Greater lizardfish, Elongate sole and Giant seacatfish were caught.

In the Caspian Sea the most popular fish species, Sharpnose Mullet (*Liza saliens*) was obtained from four different local fish markets, (catch of local fishermen) in the Mazandaran Province, including: Babolsar, Noshahr, Salman shahr and Tonekabon (Fig. 1). Babolsar (the most eastern station) is located 93 km from Noshahr, 126 km from Salman shahr and 157 km from Tonekabon (Fig. 1).

Table 1 Overview of fish samples collected in the Persian Gulf and Caspian Sea

Sea	Sampling stations	Fish species	Number	Weight (g)	Length (cm)
Persian Gulf	Mogham port	Largetooth flounder	1	256	27
			1	321	26
			1	323	28
			1	352	30
		Spotfin flathead	2	104±26	24±1
			2	155±19	27
			2	178±17	30±0.4
			2	197±11	31±1
		Japanese threadfin bream	2	104±4	21
			3	117±3	21±0.3
			3	147±4	23±0.3
			1	240	26
		Greater lizardfish	4	137±27	28±1
			3	198±17	31±2
			2	265±9	33
			1	340	36
	Lengeh port	Giant seacatfish	1	173	27
			1	225	29
			4	257±8	30±0.5
			1	293	29
			2	321±25	33±0.7
			1	541	38
		Spotfin flathead	4	94±43	23±4
			3	158±10	27±0.5
		Elongate sole	1	71	18
			3	83±2	20±1
			1	114	19.5
		Greater lizardfish	4	60±21	20±3
			3	89±10	24±1
			5	124±11	26±2
Caspian Sea	Babolsar	Mullet	3	114±7	24±0.8
	Noshahr	Mullet	3	111±7	24±0.8
	Salman shahr	Mullet	3	230±34	31±3
	Tonekabon	Mullet	3	354±45	39±1.6

Prior to analysis, length and weight of the fish was determined and the fish were pooled according to their size in order to obtain four different size classes per species (for the samples of the Persian Gulf). The number of fish in each size class, together with the average weight and length of the fish and the sampling station is shown in Table 1. For the Caspian Sea three fishes were pooled at each station.

For analysis, the muscle tissue was separated, weighed, then deep frozen and lyophilized (Leybold Heraus Lyophilizer) and again weighted to determine the water content. After homogenization by manual grinding in a ceramic mortar, the samples were kept in the deep freezer until analysis.

2.3 Analytical procedures

Total Hg in fish was determined by direct combustion atomic absorption spectrometry using the advanced mercury analyser (AMA 254, Altec, Chech Republic). This method requires no chemical pretreatment of the sample. Ten to fifty milligrams sample were weighed into the analyzing shuttle and introduced in the instrument. All the samples were analyzed according the following cycle: 60 s drying (100°C), 150 s decomposition (550°C) and 45 s cooling. All samples were analyzed in duplicate.

In order to extract methyl mercury from the biological sample, 2 ml tetra methyl ammonium hydroxide (25% TMAH, Acros Organics) was added to 0.1–0.2 g lyophilized and homogenized sample in a 30 ml Teflon bottle. The bottle was capped and placed in an oven at 85°C for 3 h. After cooling, solvent extraction was performed by using 10 ml dichloromethane CH_2Cl_2 and 1.5 ml concentrated HCl (Merck, suprapure), shaking for 15 min and centrifugation (at 4,000 rpm) for 5 min. This procedure was repeated. The organic phases were combined and transferred to 50 ml Milli-Q water in a 125 ml Teflon bottle for back extraction to the water phase. CH_2Cl_2 was evaporated by purging with a constant and gentle N_2 flow at 50°C in a water bath.

Methylmercury was analysed by aqueous phase ethylation, headspace gas chromatographic separation (PERKIN ELMER HS 40) of the ethylated compounds, pyrolitic decomposition and atomic fluorescence detection (TEKRAN 2500). The details of the analysis are described in Leermakers et al. (2003). All analysis were performed in duplicate.

Quality control included the use of blanks and certified reference materials (DOLT-2, DORM-2) in each digestion batch and duplicate sample analysis. Table 2 shows the results obtained on certified reference materials values; the agreement with the certified values was satisfactory.

The detection limits based on three times the standard deviation (3 s.d.) of the procedural blanks (including the whole process) were 0.056 ng g^{-1} w.w. (0.28 ng g^{-1}d.w.) for total mercury and 0.8 ng g^{-1} w.w. (4 ng g^{-1} d.w.) for methyl mercury.

3 Results and Discussion

3.1 Persian Gulf

In the Persian Gulf, total Hg concentrations in fish ranged from 0.012 to 0.087 mg kg^{-1} w.w. (0.061 to 0.433 mg kg^{-1} d.w.) with an average of 0.0368 mg kg^{-1} w.w (Table 3). The fraction of methylmercury accounts for 64–100% of the total mercury. The average concentrations found in the different species are shown in Fig. 2. Highest levels were observed in Threadfin bream (Mogham port), Greater lizardfish (Mogham Port) and the Giant seacatfish (Lengeh). In these species the methylmercury fraction is always higher than 90%. The relationship between the size of the fish and the concentrations of Hg species is shown in Fig. 3 (combining data of Mogham Port and Lengeh Port). Positive correlations between the length of the fish and MMHg levels can be found for Largetooth flounder, Spotfin flathead, Japanese threadfin bream and Greater lizardfish. An exponential increase can be observed for

Table 2 Total and methyl mercury concentrations in certified reference materials (mg kg^{-1} d.w.)

CRMs	Total mercury (n=6)			Methyl mercury (n=4)		
	Certified value	Our result	Recovery (%)	Certified value	Our result	Recovery (%)
DOLT-2	2.140±0.280	2.130±0.108	97	0.693±0.053	0.670 ±0.076	97
DORM-2	4.640±0.260	4.433±0.277	92	4.470±0.320	4.192±0.280	94

Table 3 Total and methylmercury concentrations and the percentage of methyl mercury (mg kg^{-1} w.w.) in Persian Gulf fish

Station	Species	Number	THg range (Mean±Sd)	MMHg range (Mean±Sd)	Percent MMHg
Mogham port	Largetooth flounder	4	0.023–0.034 (0.028±0.005)	0.018–0.039 (0.027±0.010)	64–100
	Spotfin flathead	8	0.014–0.073 (0.039±0.025)	0.011–0.060 (0.034±0.020)	83–100
	Japanese threadfin bream	8	0.030–0.087 (0.049±0.025)	0.025–0.097 (0.048±0.033)	84–100
	Greater lizardfish	9	0.012–0.086 (0.043±0.032)	0.011–0.100 (0.047–0.038)	92–100
Lengeh port	Greater lizardfish	12	0.015–0.020 (0.017±0.003)	0.015–0.017 (0.018±0.003)	100
	Giant seacatfish	10	0.030–0.078 (0.045±0.017)	0.030–0.074 (0.045±0.015)	95–100
	Elongate sole	5	0.018–0.042 (0.028±0.013)	0.017–0.032 (0.023±0.007)	75–99
	Spotfin flathead	7	0.022–0.032 (0.027±0.007)	0.014–0.021 (0.017±0.005)	63–67

Spotfin flathead. The largest individuals of this species have already gained their full grown size (30 cm) whereas this is not the case for the other species. Largetooth flounder can attain a length of 45 cm, Japanese threadfin bream 32 cm, Greater lizardfish 60 cm, Giant seacatfish 185 cm and Elongate sole 30 cm. The small size differences in the samples of Elongate sole and Giant seacatfish (in relation to their maximum length) do not permit us to establish a relationship between size and Hg accumulation. Figure 3 also shows that for a number of species such as Largetooth flounder and Elongate sole the smallest fish have a relatively higher inorganic Hg fraction. This may be linked to changes in feeding behaviour during their growth (from detritus and phytoplankton to small prey) and relatively more direct uptake of inorganic Hg. A lower methylmercury fraction was also observed in Flounder caught in the Scheldt estuary compared to Flounder caught in coastal waters (Baeyens et al., 2003b). Differences in the methylmercury fraction between species can be found. Giant seacatfish, Japanese threadfin bream and Greater lizardfish have the highest Hg levels and also the highest fraction of methylmercury (>90%). For the other species, the methylmercury fraction varies between 62 and 100%. The differences in Hg levels and MMHg fraction may be linked to the diet and hence the trophic level of the fish species. Flounder, Elongate sole and Spotfin flathead are feeding on detritus and phytoplankton at the bottom and are at a lower trophic level than Threadfin bream, Seacatfish and Lizardfish which are feeding on mollusks and small fishes.

No significant differences between the ports can be found. The fish of the same species collected at both

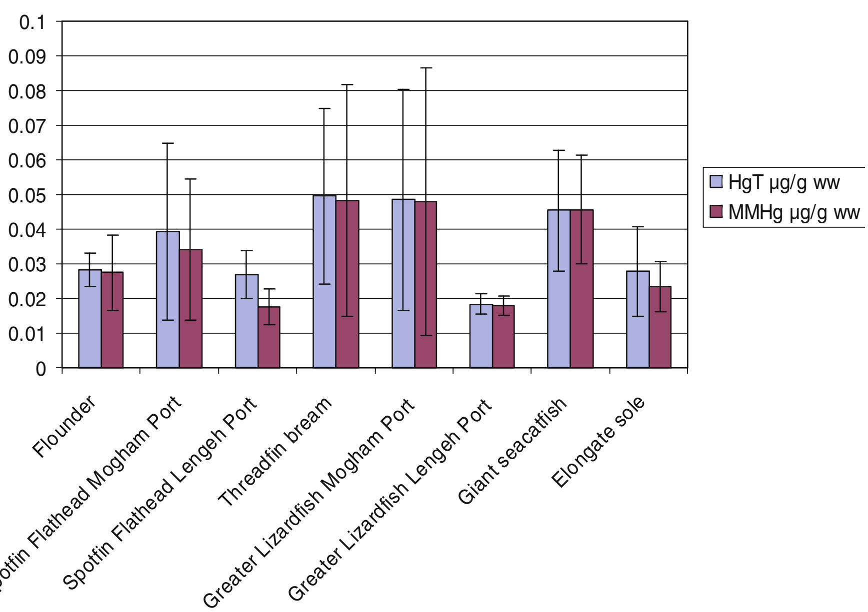

Fig. 2 Average THg (µg g^{-1} w.w.) and MMHg (µg g^{-1} w.w.) concentrations found in different fish species of the Persian Gulf

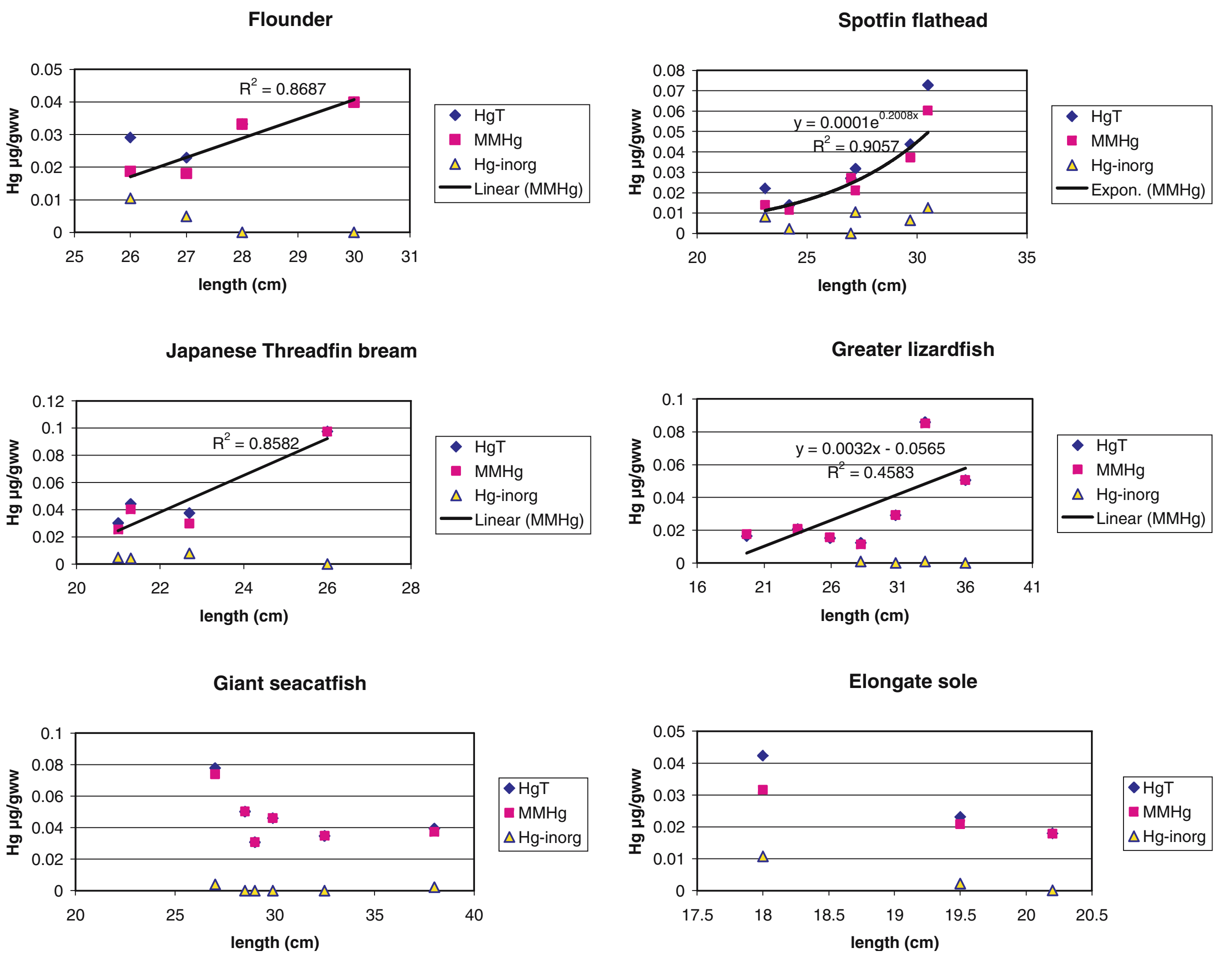

Fig. 3 Relationship between fish size (cm) and THg (µg g^{-1} w.w.), MMHg (µg g^{-1} w.w.) and inorganic Hg (µg g^{-1} w.w.) concentrations in different fish species of the Persian Gulf

ports were generally smaller at Lengeh port and had lower Hg levels.

3.2 Caspian Sea

In the Caspian Sea total Hg concentrations in mullet fish ranged from 0.010 to 0.108 mg kg^{-1} w.w. (0.051 to 0.542 mg kg^{-1} d.w.) with an average of 0.0397 mg kg^{-1} w.w. (Table 4). The methylmercury fraction was always above 95%.

Comparing the mercury levels between the four stations, it is clear that the values at Noshahr station were at least five times more than at Babolsar and Tonekabon stations and 10 times more than at Salman shahr station. It is clear that this observation is based on only a very limited number of samples and can thus not

Table 4 Total and MMHg concentrations in Caspian Sea fish (mg kg^{-1} w.w.)

Stations	Weight (g)	Number	THg	MMHg	Percent MMHg
Babolsar	114±7	3	0.020±0.001	0.020±0.0005	100
Noshahr	111±7	3	0.108±0.006	0.107±0.006	99
Salman shahr	230±34	3	0.0102±0.008	0.010±0.0004	99
Tonekabon	345±45	3	0.020±0.001	0.0195±0.0007	97

Table 5 Total Hg concentrations in various fish species in the marine environment (mg kg^{-1} w.w.)

Sea	Species	Hg mg kg^{-1} w.w.	Reference
Persian Gulf (Iranian coastal area)	Mean (range) of the species	0.0368 (0.012–0.087)	This research
	Largetooth Flounder	0.0229–0.0345	
	Spotfin Flathead	0.0139–0.0728	
	Japanese Threadfin bream	0.0301–0.0778	
	Greater Lizardfih	0.0123–0.0859	
	Giant seacatfish	0.0305–0.0476	
	Tuna fish	0.24–0.3	Parvaneh, 1979
	Different fishes	0.16	
Persian Gulf	Canned tuna fish	0.117	Khansari et al., 2005
Persian Gulf (Bahrain)	Different fish species	0.084	Madany et al., 1996
	shellfish	0.042	
Persian Gulf (United Arab Emitates)	Greasy grouper	0.107	Ahmad and Al-Ghais, 1996
	Dory snapper	0.107	
Persian Gulf (Qatar – coast of Doha)	Flounder	0.13–0.16	Kureishy, 1993
	Threadfin bream	0.02	
	Mussels	0.02–0.46	
Persian Gulf (Kuwait, n=330)	Different fish species	0.014–0.78	Al Majed and Preston, 2000
Persian Gulf	Different fish species		ROPME, 1999
Kuwait (n=5)		0.011–0.28	
Saudi Arabia (n=4)		0.007–0.25	
Qatar (n=4)		0.06–0.208	
Caspian Sea (Iranian coastal area)	Mullet mean (range)	0.0397 (0.010–0.108)	This research
Caspian Sea	Sturgeon (five different species)	0.012–0.28	Agusa, Kunito, Tanabe, Poukazemi, & Aubrey, 2004
Mediterranean Sea (Italy)	Different fishes	0.67–4.53	Storelli, Stuffler & Marcotrigiano, 2002
Greenland and Barents Seas	Pelagic fishes	0.008–0.016	Joiris, Ali, Holsbeek, Kanuya-Kinokti, & Tekele-Michael, 1997
Greenland Sea	Long rough dab	0.12–0.368	
	Greenland halibut	0.146–0.5	
Barents Sea	Long rough dab	0.02–0.368	
	Greenland halibut	0.014–0.17	
	Halibut	0.032–0.226	
	Starry ray	0.04–0.08	
	Atlantic code	0.014–0.038	
North-east Atlantic (French coast)	Plaice	0.028–0.15	Cossa, Thibaud, Romeo, & Gnassia, 1990
	Sole	0.03–0.27	
Southern North Sea	Plaice	0.036–0.104	Joiris et al., 1997
North Sea – Belgian coastal area	Flounder (n=24)	0.134±0.058	Baeyens et al., 2003a
	Plaice (n=13)	0.063±0.017	
Greater North Sea	Ray (n=19)	0.039±0.021	Baeyens et al., 2003a
	Dogfish (n=20)	0.61±0.23	
	Plaice (n=17)	0.045±0.023	
	Sole (n=16)	0.088±0.067	
	The range of the averages of all fish species (15 species, n=197)	0.039–0.61	

be considered as very relevant. It is necessary to repeat these analyses on a much larger number of samples. The Hg levels in mullet from the three other Caspian Sea stations are similar. Regarding Hg contamination in the Iranian coastal waters of the Caspian Sea, the average concentration of Hg in sediments was 0.1 μg/g d.w. and no significant difference was observed between the Hg levels in sediments at these sites (de Mora et al., 2004).

3.3 Comparison with literature data

An overview of Hg concentrations in marine fish in different marine environments is shown in Table 5. In several coastal areas of the Persian Gulf, Iran, United Arab Emirates, Qatar, Kuwait, Hg levels exceeded 0.1 mg kg^{-1} w.w. in one or more fish species. Only in the coastal area of Bahrain, the average Hg concentrations were below 0.1 mg kg^{-1} w.w. (Madany, Wahab, & Alalawi, 1996). The mean mercury level in the different fish species in this research (0.037 mg kg^{-1} w.w.) was two times lower than the mean mercury concentration in the Bahrain fish. In addition, all fish samples in our study contained less Hg than 0.086 mg kg^{-1} w.w. It is difficult to compare actual contamination levels with those in the past because only for tuna some older data exist. Khansari, Ghazi-Kansari, and Abdollahi (2005) reported an average Hg value of 0.117 mg kg^{-1} w.w. for canned tuna fish from the Persian Gulf whereas the older data of Parvaneh (1979) reported concentrations in tuna of 0.2–0.3 mg kg^{-1} w.w. The highest Hg levels in fish (up to 0.78 mg kg^{-1} w.w., with a methylmercury fraction ranging from 40 to 80%) have been reported in Kuwait coastal waters by Al Majed and Preston (2000). These samples were, however, taken in the vicinity of a chlor-alkali plant. In the vicinity of this plant coastal sediments were severely contaminated with Hg, but a redistribution of the contaminated sediment by shipping traffic and bottom currents took place (Al Majed & Preston, 2004). Low methylmercury percentages are characteristic of contaminated hot spots, where direct uptake of Hg from the environment is important in addition to uptake through the food chain. The lower Hg levels and the normal methylmercury to total mercury ratios in our samples indicate that there is no important point source of Hg in the area under investigation.

Mean mercury levels we observed in Persian Gulf (0.012–0.087 mg kg^{-1} w.w.) and Caspian Sea fish (0.010–0.108 mg kg^{-1} w.w.) were higher than Pelagic fish in the Greenland and Barents Seas (0.008–0.016 mg kg^{-1} w.w.), and were similar to the mercury levels in ray (0.018–0.06 mg kg^{-1} w.w.) and plaice (0.02–0.07 mg kg^{-1} w.w.), but much lower than dog fish (0.38–0.84 mg kg^{-1} w.w.) in the Greater North Sea. Mercury levels in Flounder in the Persian Gulf (0.023–0.035 mg kg^{-1} w.w.) were much lower than in the same fish species in the Belgium coastal area of the North Sea (0.076–0.192 mg kg^{-1} w.w.).

3.4 Toxic and health aspects

Because of its high toxicity, most governments established toxicological standards for mercury in food and especially seafood, which is of great concern for (international) trade. The most commonly applied standards are 0.5 μg g^{-1} w.w. except for predatory fish such as shark, swordfish and eel for which a standard of 1 μg g^{-1} w.w. is applied. All the fish samples analyzed in this study were below the 0.5 μg g^{-1} w.w. standard.

It is widely assumed that the principal pathway for mercury exposure in humans is through food consumption, in particular of fish. Exceptions are exposure to Hg in contaminated sites such as the Carson River Drainage Basin in Nevada, USA (Gustin, Tayler, & Leonard, 1994), and the Katun River Drainage Basin in Altai, Siberia (Baeyens et al., 2003a). However, the characterization of risk to human populations focuses more and more on exposure to MMHg over lifetime instead of acute exposure. So a reference dose (RfD) for MeHg has been defined as an estimate of daily exposure that is likely to be without an appreciable risk of deleterious effects during a lifetime (Risher & DeWoskin, 1999). In 1978, the World Health Organization established an allowable daily intake standard of 0.5 μg of methylmercury per kg bodyweight whereas recent recommendations by EPA reduced the safe daily allowance to 0.1 μg methylmercury per kg body weight per day (Moore, 2000). This is equal to 50 μg MeHg per week for a person of 75 kg body weight. Taking the highest observed methylmercury concentrations in this study – about 0.1 μg g^{-1} w.w. were observed in mullet and lizard – a person of 75 kg can consume 500 g fish a week.

4 Conclusions

This preliminary study shows that the levels of Hg in commercial fish species of the Persian Gulf and

Caspian Sea in Iranian coastal waters are low ranging from 0.010 to 0.108 mg kg^{-1} w.w. (0.050 to 0.542 mg kg^{-1} d.w.), far below the WHO guideline of 0.5 mg kg^{-1} w.w. Methylmercury generally accounts for more than 90% of the total Hg which is typical for a marine environment in the absence of important point sources. However, as only a few species were analysed, with a limited size range and at a limited amount of stations, it is clear that further research is required in order to assess the ecological state of the Iranian marine environment regarding Hg pollution.

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