Bull Environ Contam Toxicol (2011) 86:679–683
DOI 10.1007/s00128-011-0253-8

# Total and Organic Mercury in Ten Fish Species for Human Consumption from the Mexican Pacific

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Received: 10 November 2010 / Accepted: 16 March 2011 / Published online: 24 April 2011


**Abstract** Total mercury and organic mercury were measured in ten fish species from the Mexican Pacific ocean to have a general view on the ratio of total mercury-organic mercury and potential implications on human health. Highest concentration of total mercury was recorded in muscle tissue of *Carcharhinus leucas* (0.62 μg $g^{-1}$ wet weight). Organic mercury was more concentrated in *Haemulon sexfasciatum* (0.4 μg $g^{-1}$ wet weight). Percentages of organic mercury ranged from 33 to 100%. Hazard indices associated to organic mercury and average fish consumption in Mexico ranged from 0.25 in *Lutjanus colorado* to 1.65 in *Haemulon sexfasciatum.*

**Keywords** Mercury (Hg) · Ichthyofauna · Risk assessment · Mexico

It has been widely recognized (Agah et al. 2007) that fish ingestion is the main pathway for total mercury (Hg) and organic Hg (mainly as methylmercury- MeHg) exposure in humans. A key feature related to variations in Hg content in fish is the feeding habit; in diverse studies (Pellegrini and Barghigiani 1989), it has been mentioned that individuals living in the proximity of surficial sediments and with a diet consisting mainly of fish have more elevated levels of Hg and other metals than ichthyofauna from the pelagic environment that consume other type of food (such as crustaceans or molluscs). Mercury dynamics in fish from the marine environment is related to the ratio of MeHg and total Hg in muscle tissue; some authors have reported that from 85% to 97% of the total Hg is in the form of MeHg, but other researchers have found that MeHg may reach from 64% to 100% of the total amount of Hg (Agah et al. 2007). This variation in Hg accumulation is related to the processes that take part at the base of trophic chains. It was demonstrated that assimilation of inorganic and organic Hg by phytoplankton is not the same; while the organic Hg enters the cytoplasm, inorganic Hg is bound to the cell membrane; when plankton feeders capture their food, they digest the cytoplasmic content but eliminate the membrane of citoplasmic cells where inorganic Hg is bound, this processes accounts for a differential accumulation of organic Hg with respect to the inorganic Hg (Mason et al. 1995).

Organic Hg accumulation is a key feature of the Hg cycle in the marine environment. It is well known that organic mercury, mainly as MeHg, is more toxic to humans than inorganic forms because of their capacity to cross biological membranes, high stability and potential of accumulation in animals and human food chain (Clarkson and Magos 2006). In this sense, it is necessary to know Hg concentrations in the edible portion of fish of human interest; moreover, the ratio of organic to inorganic Hg in fish of commercial value can help to advise population on the health risks associated to fish consumption. Health agencies as well as local and federal governments in some countries are concerned about Hg levels in fish for human consumption; in Mexico, the maximum permissible level for total Hg in fish and mollusks was set as 1.0 μg $g^{-1}$ on a wet weight basis, whereas for MeHg this level is

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0.5 μg $g^{-1}$. Contrastingly, published studies related to the occurrence of total Hg in fish from Mexican waters in the Pacific Ocean are scarce; with respect to the organic form of Hg, no studies have been published in fish from the Mexican Pacific. The purpose of this study was to have a general view on the ratio of total Hg-organic Hg and the potential implications on the health of consumers.

## Materials and Methods

In the present study, levels of total Hg and organic Hg were measured in muscle of nine fish species from the coastal waters of Mexico and one oceanic species from the eastern Pacific Ocean. Fish species considered in the present study are widely consumed by the Mexican population. Fish were collected by local fishermen from different sites in the eastern Pacific Ocean; a tuna specimen was collected and provided by a commercial vessel based in Mazatlán (SE Gulf of California; Fig. 1). Dates of collection, biometric (total weight and total length) data and other ecological information are provided in Table 1. Taxonomic identification of fish was made according to illustrated keys. The tissue of interest for the present study was muscle; dissection of the median dorsal portion was made by using a stainless steel scalpel. In order to avoid contamination of samples from manipulation and storage, glassware and other plastic utensils were previously washed according to Moody and Lindstrom (1977). Muscle samples were placed in plastic bags for transportation at a low temperature (−5°C). Considering the size of the specimens and the amount of tissue required for Hg determinations, a total of 18 individual samples were analyzed. Muscle samples were liophilized for 72 h ($133 \times 10^{-3}$ mBar and −49°C) then manually ground with an agate mortar and pestle. Portions (0.25 g) of powdered and homogenized muscle samples were used for total Hg and organic Hg analysis.

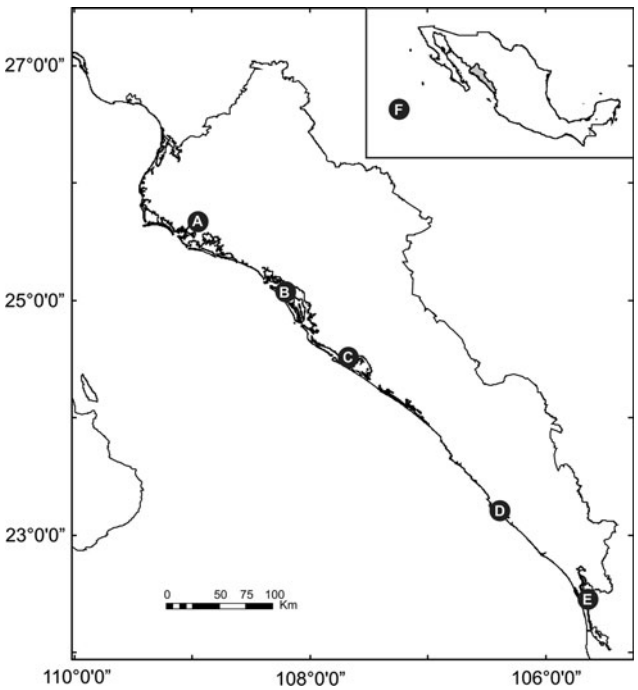


**Fig. 1** Collection sites of fish in the Mexican Pacific: *a* Topolobampo, *b* Santa María, *c* Altata-Ensenada del Pabellón, *d* Urías; *e* Teacapán; *f* Open ocean

For total Hg analysis, samples were pre-digested with concentrated nitric acid (5 mL; trace metal grade) overnight using Teflon vessels (Savillex). Digestion was made by using capped Teflon vessels and a hot plate at 120°C for 3 h. Digested samples were stored in polyethylene containers for further analysis. Analyses were carried out by reducing mercury compounds in solution samples using $SnCl_2$ (Loring and Rantala 1995); measurements were made by cold vapour atomic absorption spectrophotometry (CV-AAS) with a Varian SpectrAA220 equipment. For organic mercury determinations, four steps were followed according to (Barregard et al. 1993): (a) acid extraction with HCl 6 M; (b) separation of inorganic Hg by ionic exchange in glass columns filled with a Dowex resin (Cl-form; 100–200 mesh size); (c) conversion of organic Hg to $Hg^{+2}$ by ultraviolet radiation (100 w lamp) during 48 h; and (d) detection by CV-AAS. In order to minimize matrix interferences with organic Hg (Sanz-Landaluze et al. 2004), the standard addition method was used. Additionally, antifoaming silicon (Merck) was used to avoid the saponification of fatty acids in fish tissues (Gómez-Ariza et al. 2004).

Total Hg and organic Hg concentrations are expressed as μg $g^{-1}$ on a wet weight basis; precision and accuracy of the analytical method were assessed by using certified reference material (NIST-2977); calculated total and organic Hg fell (recoveries 95% and 99%, respectively) within certified values. The variation coefficients were below 10%. Limit of detection and of quantification for total Hg and organic Hg were 0.025 and 0.125 μg $g^{-1}$ (wet weight) respectively. To check for contamination, blanks were run with every batch of samples. Hazard index (HI) for organic Hg was estimated according to (Newman and Unger 2002): HI = E/RfD, where E is the exposure level or intake of organic mercury, and RfD is the reference dose (0.1 μg $kg^{-1}$ $day^{-1}$). The exposure level (E) is calculated as $E = C \times I/W$; where C is the concentration of organic Hg in fish, I is the ingestion rate of fish (25 g $day^{-1}$) and W is the weight of an average adult (70 kg).

## Results and Discussion

From Table 1, it can be seen that fish from the different sites belonged to different species, such situation is

**Table 1** Dates and sites of collection, biological information and levels of Hg (in μg $g^{-1}$ wet weight) in muscle tissue of studied fish

| Scientific name (common name) | N | Site code[a] | Weight (g) | Length (cm) | Date of collection | Habitat | Feeding mode | Total Hg | Organic Hg | %Organic Hg |
|---|---|---|---|---|---|---|---|---|---|---|
| *Caranx caninus* (Pacific crevalle jack) | 3 | A | 45–72 | 14–18 | March/2004 | BP | Ca | 0.20 ± 0.04 | 0.20 ± 0.07 | 100 |
| *Nematistius pectoralis* (Roosterfish) | 4 | A | 139–173 | 23–25 | March/2004 | P | Ca | 0.46 ± 0.02 | 0.32 ± 0.05 | 69 |
| *Roncador stearnsii* (Spotfin croaker) | 1 | A | 88 | 19 | March/2004 | De | Ca | 0.27 ± 0.04 | 0.26 ± 0.09 | 96 |
| *Haemulon sexfasciatum* (Greybar grunt) | 3 | B | 77–134 | 18–22 | November/2003 | De | Ca | 0.60 ± 0.02 | 0.40 ± 0.05 | 66 |
| *Trachinotus paitensis* (Pompano) | 1 | B | 285 | 30 | November/2003 | BP | Ca | 0.27 ± 0.03 | 0.24 ± 0.03 | 89 |
| *Elops affinis* (Pacific ladyfish) | 1 | B | 251 | 38 | November/2003 | P | Ca | 0.34 ± 0.03 | 0.34 ± 0.09 | 100 |
| *Carcharhinus leucas* (Bull shark) | 1 | C | 11,000 | 106 | December/2003 | P | Ca | 0.62 ± 0.20 | 0.27 ± 0.05 | 44 |
| *Lutjanus colorado* (Colorado snapper) | 1 | D | 372 | 29 | June/2003 | De | Ca | 0.18 ± 0.17 | 0.06 ± 0.02 | 33 |
| *Gerres cinereus* (Yellowfin mojarra) | 2 | E | 245–262 | 22–23 | January/2004 | De | O | 0.29 ± 0.08 | 0.23 ± 0.04 | 79 |
| *Thunnus albacares* (Yellowfin tuna) | 1 | F | 10 000 | 87 | July/2005 | P | Ca | 0.20 ± 0.17 | 0.20 ± 0.01 | 100 |

[a] See Fig. 1 for location of collection sites; A, Topolobampo; B, Santa María; C, Altata-Ensenada del Pabellón; D, Urías; E, Teacapán; F, open ocean

*Ca* carnivorous, *O* omnivorous, *De* demersal, *P* pelagic, *BP* benthopelagic, *N* number of individuals

common in tropical and subtropical latitudes where biodiversity is elevated. Fish habitat is important in terms of the prevailing characteristics of the surrounding environment; fish collected here corresponded to pelagic (40%), demersal (40%) and benthopelagic (20%) habitats. In relation to the feeding behavior, with the exception of the yelowfin mojarra *Gerres cinereus*, studied species corresponded to carnivores; since diet is considered as a key factor in relation to Hg uptake in fish, it is important to consider the feeding mode in order to make a more complete interpretation of results.

Highest concentration of total Hg was recorded in muscle tissue of the bull shark *Carcharhinus leucas* (0.62 μg $g^{-1}$) from site C (Table 1); it is probable that the feeding mode (carnivorous), combined with the degree of anthropogenic development in that lagoonal system (intensive agriculture, urban developments, aquacultural ponds and sugar cane facilities) may account for such pattern. Organic Hg was more concentrated in muscle tissue of the carnivorous fish *Haemulon sexfasciatum* (0.4 μg $g^{-1}$) from site B, this area is also impacted (shrimp aquaculture, urban discharges) but in a lesser extent than site C. The percentage of organic Hg with respect to total Hg was highly variable (from 33% to 100%) in our study; in other regions where fish have been analyzed (Magalhães et al. 2007; Carbonell et al. 2009) it has been found that the percentage of organic Hg with respect to total Hg is over 80%. Other researchers (Holsbeek et al. 1997; Agah et al. 2007) have reported lower ratios (from 19% to 64%) of total to organic Hg. In this context, it has been proposed that fish can be grouped into three categories, depending on the patterns of Hg accumulation (Holsbeek et al. 1997): type I, when the concentration of organic Hg increases with the length of fish and inorganic fraction stays at a constant low level; type II with a low and constant organic Hg fraction but the inorganic fraction increases with length of fish; and type III, when both Hg fractions increase with fish length. In the present study, it was not possible to define a pattern of Hg variation with length of specimens due to the small number of samples, but 60% of the ichthyofauna had an elevated percentage of the organic Hg fraction and a low concentration of inorganic Hg as indicative of a type I behavior. In this sense, it has been concluded that this pattern is generally considered as the normal situation.

For comparative purposes, levels of total Hg and organic Hg in muscle tissue of fish from elsewhere are presented in Table 2. Highest levels of total Hg and organic Hg corresponded to the common mora *Mora moro* (3.70 and 2.96 μg $g^{-1}$) and the ghostshark *Chimaera monstrosa* (3.14 and 2.67 μg $g^{-1}$) from the Mediterranean; the reasons for such elevated Hg concentration are related to the characteristics of the deep environments where these species live (Johnson and Stevens 2000), combined with an

**Table 2** Levels of total Hg and organic Hg (in μg $g^{-1}$ wet weight) in muscle tissue of marine fish from diverse sites

| Species | Common name | Total Hg | Organic Hg | Organic Hg (%) | Site | References |
|---|---|---|---|---|---|---|
| *Chimaera monstrosa* | Ghostshark | 3.14 | 2.67 | 83 | Mediterranean Sea | Storelli et al. (2002) |
| *Saurida tumbil* | Greater lizard fish | 0.04 | 0.04 | 100 | Persian Gulf | Agah et al. (2007) |
| *Hilsa kelee* | Shad | 0.021 | 0.004 | 20 | Bangladesh | Holsbeek et al. (1997) |
| *Ilisha indica* | Jewelled shad | 0.015 | 0.004 | 19 | Bangladesh | Holsbeek et al. (1997) |
| *Ilisha filigera* | Jewelled shad | 0.016 | 0.004 | 27 | Bangladesh | Holsbeek et al. (1997) |
| *Ageneiosus caucanus* | Flatnose catfish | 0.51 | 0.49 | 95 | Mojana region, Colombia | Marrugo-Negrete et al. (2008) |
| *Tripotheus magdalenae* | Arenca | 0.34 | 0.31 | 93 | Mojana region, Colombia | Marrugo-Negrete et al. (2008) |
| *Lepidopus caudatus* | Silver scabbard fish | 1.44 | 1.33 | 89 | The Azores, Portugal | Magalhães et al. (2007) |
| *Conger conger* | European conger | 1.86 | 1.69 | 91 | The Azores, Portugal | Magalhães et al. (2007) |
| *Mora moro* | Common mora | 3.70 | 2.96 | 84 | The Azores, Portugal | Magalhães et al. (2007) |
| *Haemulon sexfasciatum* | Greybar grunt | 0.60 | 0.40 | 66 | Santa María, Mexico | This study |
| *Carcharhinus leucas* | Bull shark | 0.62 | 0.27 | 44 | AEP, Mexico | This study |

elevated trophic position of these predators (Kress et al. 1998). The species from the Mexican Pacific showed low total Hg (around 0.6 μg $g^{-1}$) and organic Hg (from 0.27 to 0.4 μg $g^{-1}$) levels, such concentrations are in the same order of magnitude to those reported in fish from the Mojana region (Colombia), an area impacted by gold mining activities. In relation to the percentages of organic Hg, compared data can be grouped into two groups, the ones with levels above 80%, which are considered as normal (Bloom 1992), and a smaller group comprising the cases where organic Hg levels were below 70%. In muscle tissue of fish from the present study, organic Hg values ranged from 100% to 33%, six fish species had organic Hg percentages from 79 to 100, and four fish species were below 70 (Table 1).

Hazard indices (HI) associated to levels of organic Hg and average fish consumption by the Mexican population are presented in Table 3. This index is useful for estimating the level of exposure to a single substance (E); if HI is above unity, there may be potential health effects (i.e. if the reference dose (RfD) is lower than calculated E, the values are above unity). Analyzed ichthyofauna presented HI that ranged from 0.25 in *L. colorado* to 1.65 in *H. sexfasciatum*; in 50% of the studied fish, values were higher than unity, it implies that there is a potential health risk from the consumption of these fish species according to the rate of fish consumption in Mexico. It is worth mentioning that RfD (0.1 μg $kg^{-1}$ $day^{-1}$) developed by the US Environmental Protection Agency (EPA 1989) corresponds to methylmercury (MeHg), but considering that most organic Hg is in the form of MeHg such value was used here for HI calculations. In comparison with other studies, HI values obtained here were below results presented in the Mojana region, Colombia (HI from 1.5 to 5.9) where daily fish consumption is elevated (120 g *per capita*) and gold-mining activities exist (Marrugo-Negrete et al. 2008); but in comparison to a study in Tianjin (China) (daily fish consumption ranges from 38 to 57.5 g *per capita*) where HI were from 0.03 to 0.40 (Wang et al. 2005), values estimated here were more elevated.

**Table 3** Hazard indices (HI) for organic Hg of analyzed ichthyofauna from the Mexican Pacific

| Species | HI |
|---|---|
| *Caranx caninus* | 0.83 |
| *Nematistius pectoralis* | 1.30 |
| *Roncador stearnsii* | 1.13 |
| *Haemulon sexfasciatum* | 1.65 |
| *Trachinotus paitensis* | 0.99 |
| *Elops affinis* | 1.38 |
| *Carcharhinus leucas* | 1.15 |
| *Lutjanus Colorado* | 0.25 |
| *Gerres cinereus* | 0.94 |
| *Thunnus albacores* | 0.84 |

Though Se was not included in this study, Hg toxicity should be considered as a multifactor issue; in this context, Se in marine fish has been shown to confer protective effects when elevated levels of MeHg are added to diets to induce toxicity in vertebrates (Ganther and Sunde 2007). From this statement, health risk posed by Hg exposure through fish consumption should be made considering the concurrent levels of Se since it could influence the Hg bioaccesible fraction (Kaneko and Ralston 2007), i.e., the sole presence of mercury does not imply necessarily a direct toxic effect on humans. More work is necessary on the consumption rates in different sectors of the Mexican population in order to estimate HI for single and several metals as well as more precise information related to consumption patterns since fish consumption is highly variable. On the other hand, in this study the number of

individuals was relatively low (1–4) that a sound conclusion is difficult to establish, therefore more research is needed.

**Acknowledgments** The authors express special thanks to H. Bojórquez for laboratory help, S. Rendón-Rodríguez and A. Núñez-Pasten for the collection of specimens, C. Ramírez-Jáuregui for bibliographic support, G. Ramírez-Reséndiz for his help with map elaboration, F. Amezcua-Martínez for the taxonomic identification of fish.

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