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Total and Organic Hg in Fish from the Reservoir of a Chlor-alkali Plant in Tainan, Taiwan

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ABSTRACT

Total mercury (THg) and organic mercury (OHg) concentrations were determined by cold-vapor AAS in ten species of fish, which were caught in the reservoir of a chlor-alkali plant in Tainan, Taiwan that had been abandoned for 22 years. The fishes, including *Elops machnata*, *Pelates quadrilineatus*, *Gerres filamentosus*, *Leiognathus equulus*, *Thryssa hamiltonii*, *Orechromis* spp., *Nematalosa come*, *Liza macrolepis*, *Mugil cephalus* and *Chanos chanos*, were sampled from September to October 2003. THg and OHg concentrations (μg/g flesh wt.) in fish muscles were 0.43 ± 0.36 and 0.31 ± 0.21, respectively, similar to values reported from various chlor-alkali plants worldwide. Of the OHg values, 37% exceeded the food safety limit of 0.3 μg/g set by the World Health Organization. Moreover, 77% of the tested OHg values were over 0.17 μg/g, which had been suggested for seafood safety limit in Taiwan. Finally, 100 g of fish muscle is the maximum allowable weekly consumption amount for the adult residents to avoid health treat that arise from ingesting toxic OHg.

Key words: heavy metal, estuarine fishes, fish muscles, safety seafood consumption, health threat

INTRODUCTION

Elemental mercury (Hg) is emitted naturally into the environments through volcanic eruptions, forest fires, and biological emissions[(1)]. Various human activities, such as mining, metallurgy, waste handling, chlor-alkali production, and coal burning, have caused severe Hg pollution[(2-5)], e.g. the "Minamata disease" from production of chlor-alkali. In 1953, Minamata disease was discovered in Japan and resulted in 121 severe poisoning cases[(6)]. Moreover, the toxic effects on residents have persisted for three generations up to the present. For this reason, careful monitoring of the point sources of Hg from chlor-alkali waste is essential.

Traditional chlor-alkali industry introduced sea water as a raw material, and used the Hg-electrolysis method to produce chlorine. During production, the used Hg is released through drainage into the aquatic environment and then stored in the sediment. Therefore, the impacts on environment from chlor-alkali industry have been driven attentions by scientist worldwide[(7-10)]. Previous studies showed that Hg levels in the air, water, and sediment have potential toxic effects on aquatic organisms. In fact, seafood is the main source of Hg for humans[(11)], and consumption of polluted fishes may result in irreversible damage to health.

Eight chlor-alkali plants existed in Taiwan from 1940 to 1988 before the ban on chlorine production by Hg-electrolysis. For every 900 kg of chlorine produced, one kg of Hg was discharged into the environment. About 1.26×10^5 tons of Hg-containing wastes were produced[(12)] during 48 years of operation, but research on chlor-alkali pollution has seldom been reported in Taiwan. Therefore, we investigated the total mercury (THg) and organic mercury (OHg) concentrations in fishes from a reservoir next to a chlor-alkali plant to determine its pollution status, in addition to giving recommendations for the amount of fish from the reservoir that can safely be consumed.

MATERIALS AND METHODS

I. *Samples*

From September to October 2003, sampling was

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conducted four times in the reservoir adjacent to a chlor-alkali factory which operated from 1938 to 1971 in Tainan City, Taiwan. The factory covered an area of 13.5 hectares. A total of 236 specimens of ten species of fish that commonly occur in estuaries were collected, including tenpounder (*Elops machnata*, Ema), fourlined terapon (*Pelates quadrilineatus*. Pq), whipfin silverbiddy (*Gerres filamentosus*, Gf), common ponyfish (*Leiognathus equulus*, Leq), Hamilton's thryssa (*Thryssa hamiltonii*, Th), tilapia (*Orechromis* spp., On), western Pacific gizzard shad (*Nematalosa come*, Nc), large-scaled mullet (*Liza macrolepis*, Lm), flathead mullet (*Mugil cephalus*, Mc), and milkfish (*Chanos chanos*, Cc)(Table 1). All fishes were sealed in polyethylene bags and kept on ice during transport to the laboratory, where they were stored at -20°C till further examination.

Before dissection, each fish was identified to species, and the fork length (cm) and body weight (g) measured. Then a piece of dorsal muscle was removed for analysis. For smaller species such as Ema, Gf, Leq, Th, On, Nc, and Cc, samples from 3 to 7 fish of similar size were combined to make a pooled sample. Fish of other species were analyzed individually. In total, 99 samples were analyzed (Table 1).

II. *THg and OHg Digestion*

Measurement of THg was based on the method established in previous studies[13-15]. Briefly, for each sample, 0.3 g of the homogenized muscle was weighed and placed into a 75-mL glass test tube (Pyrex). One milliliter of HNO_3 and 4 mL of H_2SO_4 were added to digest the sample with heat up to 75°C. Then, 15 mL of 5% $KMnO_4$ was added sequentially to complete the digestion. A final volume of 25 mL was made up by double distilled water.

For OHg analysis, the same method was used as

Table 1. Fish species, code, food items, fork length (FL), and body weight (mean ± S.D. and range) of fish used to determine mercury contents of muscle found in fishes caught in the reservoir adjacent to a chlor-alkali plant in Tainan City, Taiwan

Scientific name	Common name	Code	Food items	Total fish number	Sample number	FL (cm)	BW (g)
Elops machnata	Tenpounder	Ema	small fishes, crustaceans	20	10	23.7 ± 4.8 (15.1~31.3)	116.6 ± 72.5 (26.9~263.1)
Pelates quadrilineatus	Fourlined terapon	Pq	small fishes, invertebrates	2	2	11.8 ± 0.3* (11.6~12.0)	42.4 ± 5.2 (38.7~46.0)
Gerres filamentosus	Whipfin silverbiddy	Gf	detritus, small crustaceans, polychaetes, forams	5	3	10.6 ± 1.4 (9.3~12.9)	33.0 ± 14.7 (22.2~58.8)
Leiognathus equulus	Common ponyfish	Leq	detritus, polychaetes, small crustaceans, small fishes	24	3	9.6 ± 0.8 (8.3~11.9)	27.4 ± 7.4 (17.2~51.7)
Thryssa hamiltonii	Hamilton's thryssa	Th	prawns, zoobenthos, zooplanktons	3	1	9.5 ± 0.5 (9.0~9.5)	8.3 ± 1.5 (6.8~9.7)
Orechromis sp.	Tilapia	On	detritus, zoobenthos, zooplanktons, plants	76	38	15.2 ± 3.4* (8.7~22.6)	81.2 ± 50.9 (12.1~229.1)
Nematalosa come	Western Pacific gizzard shad	Nc	detritus, zoobenthos, zooplanktons, plants	74	20	10.5 ± 3.5 (6.2~18.7)	30.6 ± 29.7 (4.4~142.2)
Liza macrolepis	Large-scaled mullet	Lm	detritus, zoobenthos, plants	7	7	19.4 ± 1.2 (18.2~21.3)	118.5 ± 25.3 (899.7~164.4)
Mugil cephalus	Flathead mullet	Mc	detritus, zooplanktons, plants	5	5	32.6 ± 7.6 (23.5~40.7)	549.4 ± 330.3 (176.1~930.0)
Chanos chanos	Milkfish	Cc	plants, detritus, zoobenthos, zooplanktons	20	10	24.1 ± 3.1 (19.7~27.2)	228.9 ± 84.5 (114.1~326.3)
		Sum		**236**	**99**		

*Total length.

Chen *et al*. (2002)[15] adopted from Shum *et al*. (1979)[16]. First, acetone was added to 0.3 g of muscle in a 50-mL centrifuge tube to remove lipid, then 5 mL of 3 M KBr and 10 mL of 0.1 M $CuSO_4$ were added to extract the organic phase. The extract was transferred into another 50-mL centrifuge tube for further extraction by 5 mL of toluene twice. The upper layer was placed in a 10-mL centrifuge tube and extracted with 1 mL of 0.01 M $Na_2S_2O_3$ solution. Afterwards, 1 mL of 0.01 M $Na_2S_2O_3$ was placed in a 75-mL test tube and once again taken through the THg digestion procedure as previously described. All chemicals were from Merck, GR degree.

III. *Analysis*

Determinations of Hg were conducted by use of cold vapour atomic absorption spectrophotometer (AAS, HITACHI Zeeman-8200, Tokyo, Japan) connected to a hydride formation system (HFS-2, HITACHI, Tokyo, Japan) with a T-type joint sampling device installed at the inlet[13] to improve the reaction efficiency of the sample and the reductant.

IV. *QA and QC*

In every batch of 32 samples measured, two sample blanks were inserted to detect alien contaminant. Certified reference materials (DORM-2, muscle of dogfish and DOLT-2, liver of dogfish), bought from the Research Council of Canada, were analyzed in duplicate to ensure reliability and consistency. Comparison of our results for DORM-2 [THg = 4.49 ± 0.25 (n = 10) and OHg = 3.86 ± 0.27 (n = 10) μg/g dry wt.], and DOLT-2 [THg = 2.14 ± 0.12 (n = 10) and OHg = 0.741 ± 0.050 (n = 10) μg/g dry wt.] with the certified values of DORM-2 (THg = 4.64 ± 0.26 and OHg = 4.47 ± 0.32 μg/g dry wt.) and DOLT-2 (THg = 2.14 ± 0.10 and OHg = 0.693 ± 0.053 μg/g dry wt.) showed that the recovery percentage was within 100 ± 10% except for OHg of DORM-2, for which recovery was 86%.

V. *Detection Limit*

Reagent blanks were inserted into every 10th sample measurement. Detection limits (DL) were calculated as the mean added 3-fold of the standard deviation of the blanks. The DLs of the equipment and method were 0.5 μg/L and 0.042 μg/g flesh wt., respectively. THg and OHg concentrations in fish muscles were all expressed as μg/g flesh wt.

VI. *Statistics*

Since the THg and OHg concentrations in the muscles of each species did not exhibit significant size difference[17], the difference of muscle THg and OHg among species was tested by one-way ANOVA (One-way Analysis of Variance) followed by Duncan's multiple range test ($p < 0.05$)[18].

RESULTS AND DISCUSSION

I. *THg and OHg in Fish Muscles*

The THg concentrations in the fish muscles ranged from 0.08 to 2.10 μg/g flesh wt., with the lowest in *M. cephalus* and the highest in *E. machnata*. THg concentrations showed significant species differences ($p < 0.05$), where *E. machnata* (1.20 ± 0.61) = *P. quadrilineatus* (1.05 ± 0.03) > *G. filamentosus* (0.45 ± 0.18) ≧ *L. equulus* (0.39 ± 0.07) = *Orechromis* spp. (0.38 ± 0.15) = *N. come* (0.32 ± 0.10) = *C. chanos* (0.26 ± 0.10) = *L. macrolepis* (0.21 ± 0.03) ≧ *M. cephalus* (0.11 ± 0.02) ($p < 0.05$). Muscle concentration of THg in *T. hamiltonii* was 0.61 (Figure 1).

The OHg concentrations ranged from 0.05-1.10 μg/g flesh wt., with the lowest in *M. cephalus* and the highest in *P. quadrilineatus*. Muscle OHg concentrations were significantly different among species ($p < 0.05$), showing a similar trend to that of THg, with *P. quadrilineatus* (0.74 ± 0.07) = *E. machnata* (0.61 ± 0.29) > *G. filamentosus* (0.36 ± 0.15) = *Orechromis* spp. (0.31 ± 0.18) ≧ *L. equulus* (0.28 ± 0.04) = *N. come* (0.25 ± 0.08) = *C. chanos*

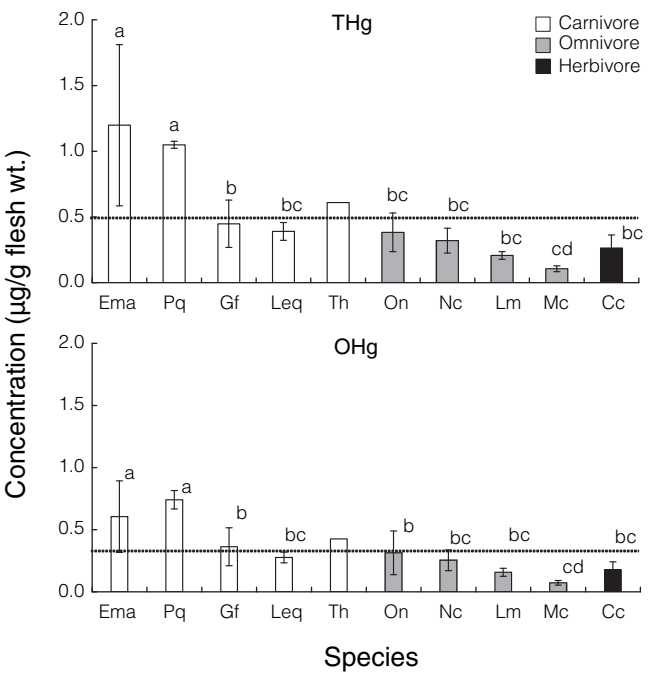

Figure 1. Total Hg (THg) and organic mercury (OHg) concentrations in muscles of 10 fish species from the reservoir adjacent to a chlor-alkali plant in Tainan City, Taiwan. The food habits (as in Table 1) of the different species are indicated by shading. The dotted line indicates seafood THg < 0.5 and OHg < 0.3 μg/g flesh wt. set by WHO. Abbreviations of species are in Table 1. No significant difference was observed between species if the same letter (a, b, or c) is marked above the histogram bars.

(0.18 ± 0.06) = *L. macrolepis* (0.16 ± 0.03) ≧ *M. cephalus* (0.07 ± 0.02) ($p < 0.05$). The only OHg data for *T. hamiltonii* was 0.43 (Figure 1).

The carnivorous fishes (*E. machnata* and *P. quadrilineatus*) were higher in Hg concentrations than those of omnivorous (*Orechromis* spp., *N. come*, *L. macrolepis* and *M. cephalus*), and herbivorous fishes (*C. chanos*), which were similar to various previous studies[19,20], representing a biomagnification effect. However, carnivorous *G. filamentosus* and *L. equulus* accumulated similar muscle THg and OHg to the omnivorous fishes, possibly due to their smaller sizes with shorter exposure times, and diets including small crustaceans and polychaetes[21] from a lower trophic than the prey of other carnivorous species.

Overall, 22% of the THg and 37% of the OHg measurements in fish from the reservoir exceeded the WHO safety levels of 0.5 and 0.3 μg/g, respectively[22].

II. *Comparison with Common Fishes from an Unpolluted Lagoon in Taiwan*

The THg levels of the fishes in the reservoir were extremely high in comparison with the baseline found in Chi-ku Lagoon of Taiwan[14]. The THg levels of *E. machnata*, *P. quadrilineatus*, *G. filamentosus*, *L. equulus*, *N. come*, *L. macrolepis*, *M. cephalus*, and *C. chanos* (THg = 0.11-1.05 μg/g flesh wt.) were 5-81 times higher than that of the same species from Chi-ku Lagoon (THg = <0.025-0.068 μg/g flesh wt.). Moreover, because the sizes of fish in the two waters were similar, the high Hg concentrations measured in this study were much more likely to be caused by Hg pollution from the chlor-akali plant, rather than being caused by longer mercury accumulation times for larger fish[23,24].

III. *Comparison with Chlor-alkali Plants Worldwide*

High THg levels in fish muscles found in this reservoir were similar to those found around chlor-alkali plants worldwide. The highest THg we measured (2.10 μg/g flesh wt. in *E. machnata*) was lower than that measured for *Bagre marinus* in south Florida estuaries (2.22)[25], *Aspius anguilla* in Skalka Reservoir of Czech Republic (3.40)[26], and various fish species (15.00) in Minamata Bay of Japan in 1959[26]. However, the THg values in our study were still higher than value of 1.74 found in unidentified species in Minamata Bay after clean up in 1989[27], *Diplodus sargus* (1.66) in Haifa Bay of Israel[28], *Stizostedion vitreum* (1.41) in the Great Lakes of Canada[29], *Anguilla anguilla* (1.23) in the Cecina river basin of Italy[30], *Dicentrarchus labrax* (1.1) in Ria de Aveiro Lagoon of Portugal[31], *Epinephelus coiodes* (0.98) in Kuwait Bay[32] and *Odontesthes microlepidotus* (0.38) in the upper Negro River of Argentina[33]. As noted above, such high levels of Hg in fishes showed typical chlor-alkali pollution that contained markedly elevated Hg concentrations.

IV. *Consumption Risk*

Based on the provisional tolerable weekly intake (PTWI) of methylmercury (MeHg) of 1.6 μg/kg/week as set by WHO[34], Taiwanese males and females weighing 65 and 55 kg, would have a PTWI of 104 and 88 μg/week, respectively. The weekly amount of fish products consumed by Taiwanese were estimated to be 482 g for male and 319 g for female adults[35]. We assumed that the OHg contents were all MeHg, therefore, the MeHg limit of the fish meats should be below 0.24 μg/g in order to meet the safety requirement under the general diet habits of Taiwanese. Accordingly, seven species (*E. machnata*, *P. quadrilineatus*, *G. filamentosus*, *T. hamiltonii*, *L. equulus*, *Orechromis* spp. and *N. come*) and 45% of the examined data exceeded this limit (Figure 1). Furthermore, if all seafood were major Hg source to humans[36] and the weekly consumption of seafood was 678 g for males and 519 g for females in Taiwan[35], Hg concentration in the seafood should be reduced to 0.17 μg/g to avoid the risk of Hg poison from seafood[36]. Seventy-seven percent of our measured values exceeded this requirement. In this study, we chose the minimum Hg concentration (0.07 in *M. cephalus*), the mean of all fish species sampled (0.31), and the maximum (0.74 in *E. machnata*) as values of OHg to evaluate the risk arising from the amount of fish consumed weekly (Figure 2). The meats from fish such as *C. chanos* and *M. cephalus* with the lowest mean OHg would allow consumption of more than 1200 g/week. However, if the likelihood of consuming each fish species was equal, their total mean Hg concentration, which was similar to the mean value of *Orechromis* spp. meat, would allow consumption of 300 g of fish per week. Finally, if fish containing the highest mean Hg value was eaten, the

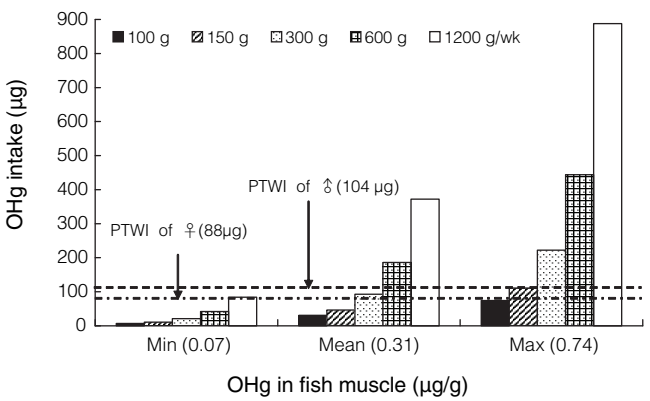

Figure 2. Assesment of human intake of OHg according to the amount of fish muscle consumed (g/week) that contained minimum, mean, and maximum OHg levels found in fishes caught in the reservoir next to a chlor-alkali plant in Tainan City, Taiwan. PTWI = provisional tolerable weekly intake.

allowable amount would be only 100 g per week, which was far less than the average consumption of fish products by Taiwanese (319-482 g fish/week). Conclusively, in order to avoid a health threat from excess Hg intake from eating fish caught in the reservoir, less than 100 g of fish meat can be consumed weekly.

CONCLUSIONS

Although the Tainan chlor-alkali plant has been closed for 22 years, fishes living in the adjacent reservoir still have accumulated Hg concentrations as much as 81 times higher than the baseline of Taiwan. The high Hg concentrations in the fish meats were likely to be harmful to human. Therefore, government organizations should purge the waste as soon as possible and educate the local inhabitants to avoid eating fishes caught in the reservoir.

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REFERENCES

1. Rasmussen, P. E. 1994. Current methods of estimating atmospheric mercury fluxes in remote areas. Environ. Sci. Tech. 28: 2233-2241.
2. Gosar, M., Šajn, R. and Biester, H. 2006. Binding of mercury in soils and attic dust in the Idrija mercury mine area (Slovenia). Sci. Total Environ. 369: 150-162.
3. Pinheiro, M. C., Crespo-Lopez, M. E., Vieira, J. L., Oikawa, T., Guimaraes, G. A., Araujo, C. C., Amoras, W. W., Ribeiro, D. R., Herculano, A. M., do Nascimento, J. L. and Silveira, L. C. 2007. Mercury pollution and childhood in Amazon riverside villages. Environ. Intl. 33: 56-61.
4. Zwerman, P. J. and De Haan, F. A. M. 1973. Significance of the soil in environmental quality improvement-a review. Sci. Total Environ. 2: 121-155.
5. Jarosinska, D., Barregård, L., Biesiada, M., Muszynska-Graca, M., Dabkowska, B., Denby, B., Pacyna, J., Fudala, J. and Zielonka, U. 2006. Urinary mercury in adults in Poland living near a chloralkali plant. Sci. Total Environ. 368: 335-343.
6. Irukayama, K. 1977. Case history of Minamata. In "Minamata Disease". pp. 1-56. Tsubaki, T. and Irukayama, K. eds. Kodansha-Elsevier. Tokyo-Amsterdam.
7. Degetto, S., Schintu, M., Contu, A. and Sbrignadello, G. 1997. Santa Gilla lagoon (Italy): a mercury sediment pollution case study-contamination assessment and restoration of the site. Sci. Total Environ. 204: 49-56.
8. Gagnon, C., Pelletier, E. and Mucci, A. 1997. Behaviour of anthropogenic mercury in coastal marine sediments. Mar. Chem. 59: 159-176.
9. Biester, H., Müller, G. and Schöler, H. F. 2002. Estimating distribution and retention of mercury in three different soils contaminated by emissions from chlor-alkali plants. Sci. Total Environ. 284: 177-189.
10. Landis, M. S., Keeler, G. J., Al-Wali, K. I. and Stevens, R. K. 2004. Divalent inorganic reactive gaseous mercury emissions from a mercury cell chlor-alkali plant and its impact on near-field atmospheric dry deposition. Atmos. Environ. 38: 613-622.
11. Clarkson, T. W. 1992. Mercury: major issues in environmental health. Environ. Health Persp. 100: 31-38.
12. Environmental Protection Administration, Taiwan (R.O.C.). 1988. Report on the regulation and control of industrial wastes. p. 203.
13. Chen, M. H. and Chou, C. L. 2000. An instrumental correction for the determination of mercury in biological and sediment samples using cold vapor atomic absorption spectrophotometry. J. Chin. Chem. Soc. 47: 1145-1153.
14. Chen, M. H. 2002. Baseline metal concentrations in sediments and fish, and the determination of bioindicators in the subtropical Chi-ku Lagoon, S.W. Taiwan. Mar. Pollut. Bull. 44: 703-714.
15. Chen, M. H., Shih, C. C., Chou, C. L. and Chou, L. S. 2002. Mercury, organic-mercury and selenium in small cetaceans in Taiwanese waters. Mar. Pollut. Bull. 45: 237-245.
16. Shum, G. T. C., Freeman, H. C. and Uthe, J. F., 1979. Determination of organic (methyl) mercury in fish by graphite furnace atomic absorption spectrophorometry. Anal. Chem. 51: 414-416.
17. Huang, S. W. 2006. Mercury and selenium concentrations in fishes from the water reservoir of a chlor-alkali plant in Tainan. Master thesis, Department of Marine Biotechnology and Resources, National Sun Yat-sen University. p. 116. Kaohsiung, Taiwan.
18. SAS 8.02. 1999-2001. SAS Institute Inc. NC, U. S. A.
19. Burger, J., Gaines, K. F., Boring, C. S., Stephens, Jr. W. L., Snodgrass, J. and Gochfeld, M. 2001. Mercury and selenium in fish from Savannah River: species, trophic level, and locational differences. Environ. Res. 87A: 108-118.
20. Cizdziel, J., Hinners, T., Cross, C. and Pollard, J. 2003. Distribution of mercury in the tissues of five species

of freshwater fish from Lake Mead, USA. J. Environ. Mon. 5: 802-807.
21. Fishbase web site. http://www.fishbase.org/home.htm (Cited in 4/28/2006)
22. World Health Organization. 1989. Evaluation of certain food additives and contaminants. WHO Technical Report Series 776, World Health Organization, Geneva.
23. Joiris, C. R., Das, H. K. and Holsbeek, L. 2000. Mercury accumulation and speciation in marine fish from Bangladesh. Mar. Pollut. Bull. 40: 454-457.
24. Joiris, C. R., Holsbeek, L. and Moatemri, N. L. 1999. Total and methylmercury in sardines, *Sardinella aurita* and *Sardina pilchardue* from Tunisia. Mar. Pollut. Bull. 38: 188-192.
25. Kannan, K., Smith, R. G., Lee, R. F., Windom, H. L., Heitmuller, P. T., Macauley, J. M. and Summers, J. K. 1998. Distribution of total mercury and methyl mercury in water, sediment, and fish from south Florida estuaries. Arch. Environ. Contam. Toxicol. 34: 109-118.
26. Maršálek, P., Svobodová, Z., Randák, T. and Švehla, J. 2005. Mercury and methylmercury contamination of fish from the Skalka Reservoir: a case study. Acta Veter. Brno 74: 427-434.
27. Fujiki, M. and Tajima, S. 1992. The pollution of Minamata Bay by mercury. Wat. Sci. Tech. 25: 133-140.
28. Hornung, H., Krumgalz, B. S. and Cohen, Y. 1984. Mercury pollution in sediments, benthic organisms and inshore fishes of Haifa Bay, Israel. Mar. Environ. Res. 12: 191-208.
29. Weis, I. M. 2004. Mercury concentrations in fish from Canadian Great Lakes areas of concern: an analysis of data from the Canadian Department of Environment database. Environ. Res. 95: 341-350.
30. Scerbo, R., Ristori, T., Stefanini, B., De Ranieri, S. and Barghigiani, C. 2005. Mercury assessment and evaluation of its impact on fish in the Cecina river basin (Tuscany, Italy). Environ. Pollut. 135: 179-186.
31. Abreu, S. N., Pereira, E. and Duarte, A. C. 2000. Accumulation of mercury in sea bass from a contaminated lagoon (Ria de Aveiro, Portugal). Mar. Polutl. Bull. 40: 293-297.
32. Al-Majed, N. B and Preston, M. R. 2000. An assessment of the total and methylmercury content of zooplankton and fish tissue collected from Kuwait territorial waters. Mar. Pollut. Bull. 40: 298-307.
33. Arribére, M. A., Ribeiro Guevara, S., Sánchez, R. S., Gil, M. I., Román Ross, G., Daurade, L. E., Fajon, V., Horvat, M., Alcalde, R. and Kestelman, A. J. 2003. Heavy metals in the vicinity of a chlor-alkali factory in the upper Negro River ecosystem, Northern Patagonia, Argentina. Sci. Total Environ. 301: 187-203.
34. World Health Organization. 2003. Summary and Conclusions of the Sixty-first Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), JECFA/61/SC. pp. 18-22. Rome, Italy. 10-19 June 2003.
35. Wu, S. J., Chang, Y. H., Fang, C. W. and Pan, W. H. 1999. Food sources of weight, calories, and three macro-nutrients-NAHSIT 1993-1996. Nutr. Sci. J. 100: 41-58.
36. Chen, Y. C. and Chen, M. H. 2006. Mercury levels of seafood commonly consumed in Taiwan. J. Food Drug Anal. 14: 373-378.