Environ Monit Assess (2015) 187: 233
DOI 10.1007/s10661-015-4439-0

Mercury in the blue tilapia *Oreochromis aureus* from a dam located in a mining region of NW Mexico: seasonal variation and percentage weekly intake (PWI)

J. Ruelas-Inzunza · E. Rojas-Ruiz · M. Spanopoulos-Hernández · G. Barba-Quintero

Received: 16 October 2014 / Accepted: 12 March 2015 / Published online: 8 April 2015

Abstract Uptake of mercury (Hg) through fish consumption is one of the key aspects of the Hg cycle in the aquatic ecosystems. In tropical latitudes, biomonitoring of Hg in freshwater reservoirs is scarce. The objectives of the study were to determine Hg distribution in muscle, liver, and kidney of blue tilapia *Oreochromis aureus* from a dam located in a mining region of northwest Mexico, to define temporal variations of Hg concentrations in fish collected during the dry and rainy seasons, and to estimate the percentage weekly intake (PWI) of Hg through fish consumption considering the individual weekly intake of fish in Mexico and the provisional tolerable weekly intake of Hg (5 μg kg^{-1} body weight). The sequence of Hg concentrations was liver>kidney>muscle during the rainy season and kidney>liver>muscle during the dry season. Levels of Hg were significantly higher ($p<0.001$) in muscle (0.36 μg g^{-1}) and kidney (0.65 μg g^{-1}) of specimens collected during the dry season in comparison to individuals collected during the rainy season; accordingly, average PWI in the dry season (5.41) was higher than in the rainy season (1.80). Though collected fish were adults, Hg levels in the edible portion are not harmful to consumers, even during the dry season that Hg levels were higher.

Keywords Cichlidae · Mercury · Tissue distribution · Dry season · Rainy season · NW Mexico

Introduction

Mercury (Hg) mobilization in the environment involves diverse compartments like water, air, land, and biota; the cycle is complex due to physicochemical and biochemical transformations and also because of its global transportation. In the context of Hg dynamics, coastal waters are considered as important boundaries between the oceans and land (Mason et al. 1994). Despite the relevance of Hg in the aquatic environment, research has mainly focused on terrestrial ecosystems (Fitzgerald and Mason 1996). Picachos Dam (23° 30′ N; 106° 13′ W) was built in 2009; it is located 40 km away from Mazatlán harbor in the southern portion of Sinaloa state (NW Mexico) and has an approximate surface of 2975 ha. The area where the dam is located was subjected to mining exploitation and belongs to the western branch of the north-northwest belt of polymetallic deposits (Clark et al. 1982). Wastes from past mining activities have the potential to impact soils with metals and metalloids (Thornton 1996) because of the allocation of pollutants through atmospheric transportation and mine drainage (Chopin and Alloway 2007; López et al. 2008). The Basin of Presidio River drains into this water body where depth can reach 50 m and surficial

J. Ruelas-Inzunza (✉) · E. Rojas-Ruiz · M. Spanopoulos-Hernández · G. Barba-Quintero
Instituto Tecnológico de Mazatlán, Corsario 1 No. 203, Colonia Urías, 82070 Mazatlán, Sinaloa, Mexico
e-mail: ruelas@ola.icmyl.unam.mx

water temperature ranges from 23.5 °C in January to 30.8 °C in October (Beltrán-Álvarez et al. 2012). The weather of the region is catalogued as dry with rains during the summer and a mean annual temperature of 25 °C (García 1973). Volume of the dam ranges from 370 to 535 Mm^3, i.e., water availability is permanent; the rainy season starting in June causes an increase of water level that gets a maximum between August and October. After the rainy season (November), water levels decrease. Among the main fish species inhabiting this dam, the blue tilapia *Oreochromis aureus* is one of the best represented (Fig. 1). The blue tilapia was first introduced (1,600,000 fry) in November 2011; the next year, 5,000,000 fry were introduced. In the context of environmental toxicology, the occurrence of Hg in biota is one of the most important features of Hg cycle in the marine compartment (Fitzgerald et al. 2007); for instance, fish consumption has been recognized as the main pathway of Hg uptake in humans (Agah et al. 2007).

It has been widely accepted that Hg distribution in aquatic organisms results in a differential bioaccumulation; i.e., the diverse tissues and organs accumulate Hg in different amounts. Liver is known to concentrate elevated amounts of Hg because of its metabolizing and detoxifying role in fish (Olsson and Hogstrand 1987; Kojadinovic et al. 2007); in the case of kidney, its filtrating and metabolic functions enhance the accumulation of metals including Hg (Elia et al. 2003). Muscle tissue is less capable of accumulating Hg (Al-Saleh and Shinwari 2002; Gewurtz et al. 2011); however, this tissue is of ecotoxicological relevance because it comprises the highest percentage of the body composition, and it is the tissue that is consumed by humans and also because of the elevated proportion of methylHg. Given the relevance of Hg occurrence in fish and other dietary items for human consumption, the maximum permissible limit of this element in Mexico (NOM-027-SSA1-1993) is 1.0 μg g^{-1} (wet weight). The objectives of the study were (a) to measure Hg levels in muscle, liver, and kidney of blue tilapia *O. aureus* from a dam located in NW Mexico; (b) to monitor seasonal variations of Hg concentrations in the water reservoir through *O. aureus* collected during the dry and rainy seasons; and (c) to determine the percentage weekly intake (PWI) of Hg through fish consumption.

Fig. 1 Photograph of the blue tilapia *Oreochromis aureus* from Picachos Dam (NW Mexico)

Materials and methods

Fish were collected by local fishermen using cast nets in October 17, 2013 (rainy season; 40 individuals) and in February 13, 2014 (dry season; 40 individuals) in the western side (23° 31′ N; 106° 14′ W) of the dam (Fig. 2). After taxonomic identification of fish, total length and total fresh weight were determined in the laboratory. Samples were kept frozen (−19 °C) until laboratory processing and Hg analysis. Plastic utensils and glassware were acid washed according to Moody and Lindstrom (1997). Liver, kidney, and muscle tissue from the median dorsal portion were extracted from every specimen. Samples were freeze-dried in a Labconco (Kansas city, MO, USA) Freeze-dry-System-FreeZone 6 (−52 °C and 60×10^{-3} mbar for 72 h); dried samples were ground and homogenized in an agate mortar (Fisher-Scientific; Loughborough, UK) with pestle. Digestion of duplicate powdered samples was made with concentrated nitric acid (JT Baker, trace metal grade) in capped vessels (Savillex™) on a hot plate (Barnstead Thermolyne; Saint Louis, MO, USA) at 120 °C for 3 h. Analysis were performed in a Hg analyzer (Buck Scientific 410; Norwalk, CT, USA) by cold vapor atomic absorption spectrophotometry (UNEP 1993). Since legal limits of Hg are given on a fresh weight basis, conversion of Hg concentration from dry weight (Hg_{dw}) to fresh weight (Hg_{fw}) was made according to the equation $Hg_{fw}=Hg_{dw}\times(100-\%\ \text{humidity})/100$ (Magalhães et al. 2007); the mean percentage of humidity in the edible portion (muscle) was 73 %. The PWI of Hg was estimated as PWI=167×Cmc/provisional tolerable weekly intake (PTWI); 167 is the individual weekly intake of fish in Mexico (considering an average fish consumption in Mexico of 9.01 kg per capita per year), Cmc is the maximum Hg concentration in fish muscle (mg kg^{-1}), and PTWI (Jinadasa et al. 2014) is the

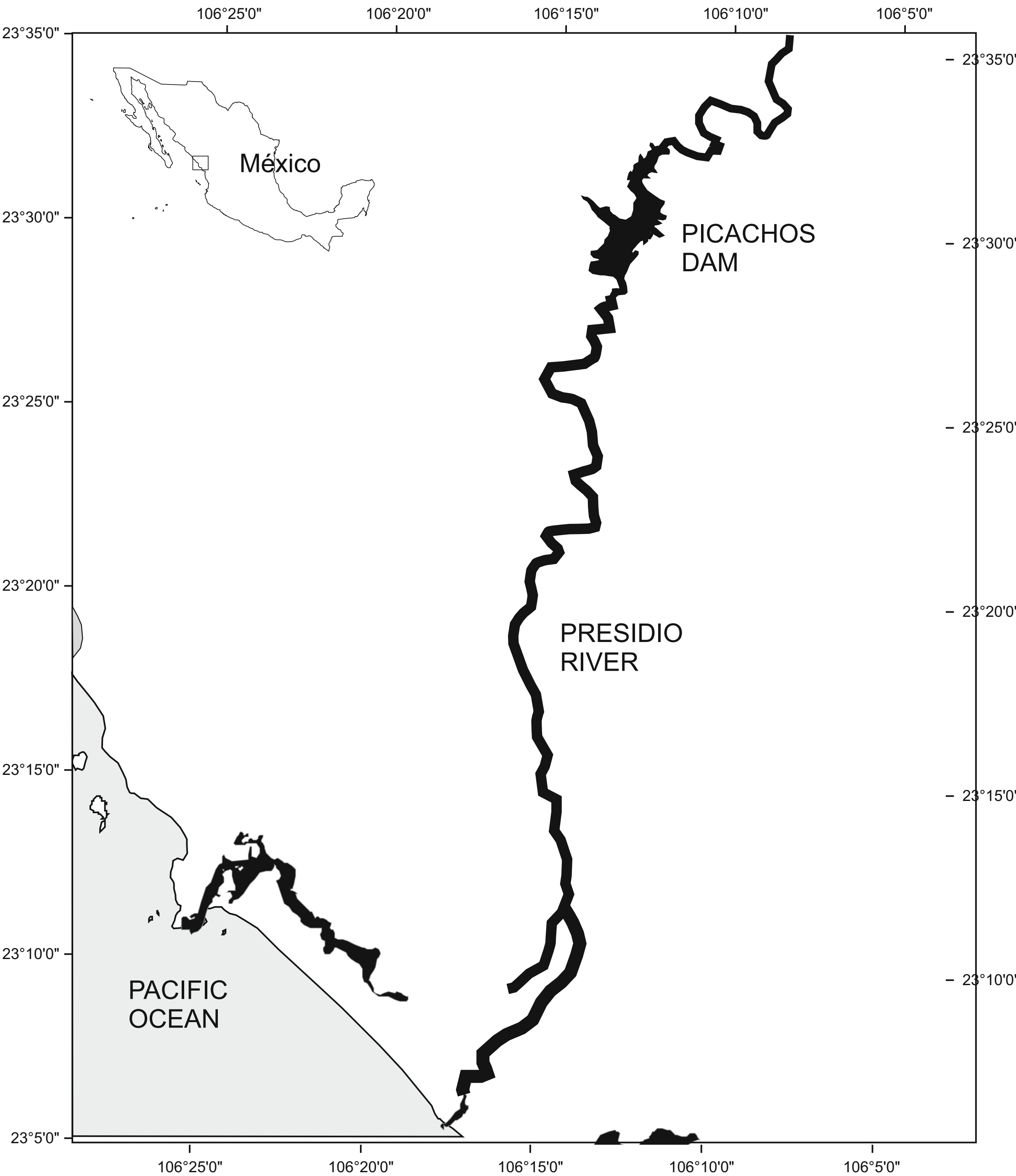

Fig. 2 Location of Picachos Dam (NW Mexico) where fish were collected

provisional tolerable weekly intake of Hg (5 μg kg^{-1} body weight). The accuracy and precision of the method was assessed by analyzing reference materials consistent of fish muscle tissue (DORM-3, NRC-Canada, certified value of Hg=0.382±0.060 μg g^{-1}) and liver (DOLT-4, NRC-Canada, certified value of Hg=2.58±0.22 μg g^{-1}). The limit of detection was 0.013 μg g^{-1} dry weight. Blanks and reference materials were run with every batch of 16–20 samples. Measured concentrations of Hg (DORM-3, Hg=0.351±0.049 μg g^{-1};

Table 1 Mean (±standard deviation) length and weight of collected fish and mean Hg concentrations (±standard deviation) in analyzed tissues during the rainy and dry seasons

Tissue	Number	Length (cm)	Weight (g)	Hg (μg g^{-1} dry weight)
Rainy season				
Muscle	40	30.9±2.4	506.8±100.5	0.12±0.10a
Liver	35			0.57±0.22
Kidney	24			0.31±0.43b
Dry season				
Muscle	40	31.0±2.8	563.4±93.9	0.36±0.18a
Liver	39			0.57±0.23
Kidney	15			0.65±0.38b

Same superscript letters in a given tissue indicate significant differences of Hg concentrations

DOLT-4, Hg=2.60±0.23 μg g^{-1}) were within certified intervals. Recoveries of DORM-3 (n=8) and DOLT-4 (n=7) reference materials (92 and 101 %, respectively) were acceptable. Results are expressed as micrograms per gram on a dry weight basis. Seasonal variations of Hg concentrations in analyzed tissues were determined by a non-parametric Mann-Whitney U test. Statistical analyses were performed with specialized software (GraphPad Prism 4.0; Graph Pad Software, San Diego, CA, USA) at a significance level $p<0.05$.

Results

Total length and weight of fish collected in both seasons were similar. During the rainy season, average length and weight were 30.9 cm and 506.8 g, respectively, and in the dry season, average length and weight were 31.0 cm and 563.4 g, respectively (Table 1). With respect to average Hg concentrations in the analyzed tissues according to sampling period, metal levels were significantly higher ($p<0.001$) in muscle and kidney of specimens collected during the dry season. Regarding tissue distribution of Hg during every season, no significant differences ($p>0.05$) were found; however, the sequence was liver>kidney>muscle (rainy season) and kidney>liver>muscle (dry season).

Results of Hg levels in similar fish species (family Cichlidae) from Mexico are presented in Table 2. Average PWI of Hg in *O. aureus* are presented in Table 3. Results were separated according to the sampling season; overall percentages were also calculated. In the rainy season, average PWI (1.80) was lower than in the dry season (5.41); considering the whole study, PWI values ranged from 0.15 (rainy season) to 12.92 (dry season).

Discussion

From biometric information of studied fish, we estimated that collected individuals were in the adult stage; the length at first maturity of this species ranges from 13 to 20 cm, with a maximum total length of 45.7 cm. With

Table 2 Mercury concentrations in selected tissues of Cichlidae fish from diverse sites in Mexico

Species	Tissue	Site	Hg (μg g^{-1} dry weight)	Remarks	Reference
Oreochromis sp.	Muscle	Baluarte River Basin	0.459	Past mining activities	Ruelas-Inzunza et al. (2011)
Oreochromis urolepis	Muscle	Baluarte River Basin	0.396	Past mining activities	Ruelas-Inzunza et al. (2011)
Tilapia mossambica	Muscle	Cerro Prieto	0.050	Geothermal field	Gutiérrez-Galindo et al. (1988)
Oreochromis sp.	Muscle Liver	Coatzacoalcos estuary	0.054 0.355	Petrochemical activity	Ruelas-Inzunza et al. (2009)
Oreochromis aureus	Muscle Liver	Picachos Dam	0.240 0.570	Artisanal gold extraction in the surroundings	This study

Table 3 Percentage weekly intake (PWI) of Hg through muscle tissue of *O. aureus* from Picachos Dam

Season	Number	PWI (average and range)
Rainy	40	1.80 (0.15–5.56)
Dry	40	5.41 (0.90–12.92)
All	80	3.61 (0.15–12.92)

respect to weight of specimens, a maximum weight of 2.0 kg has been reported (Trewavas 1983). Regarding the seasonal variation of Hg concentrations in *O. aureus* from Picachos Dam, the higher levels reported during the dry season seem to be related to water fluctuation in the reservoir. In tropical latitudes, reservoirs generally receive water from large drainage areas and may be vulnerable depending on the quality of incoming water (Lewis 2000). It is known that from August to October, the water level at Picachos Dam reaches the maximum; on the contrary, from November to January, the volume is minimal. These fluctuations cause a diluting or concentrating effect on Hg concentrations in water and eventually in fish. Moreover, during the cold months (dry season) in the region (January and February), the dam gets thermally stratified, and this process also exerts a concentrating effect. In other studies in Mexico with fish of the genus *Oreochromis* (Ruelas-Inzunza et al. 2009, 2011), it was found that Hg had higher levels of Hg during the dry season in comparison to the rainy season. Other factors that may also contribute to Hg variations in fish tissues are the bioavailability of the element in water, age of individuals, and habitat preferences. With respect to tissue distribution of Hg, it can be seen that muscle was the tissue with the lowest concentrations in both seasons. A similar pattern was found in a laboratory study where *O. aureus* specimens were exposed to Hg; the greatest accumulation was found in the liver while the lowest concentration was detected in the muscle (Sweilum 2006). It appears that the elevated concentrations of Hg in fish liver are related to the transfer of the element from diverse tissues to the liver for detoxifying purposes (Salah El-Deen et al. 1996).

Considering the compared studies in Table 2, the lowest Hg concentration corresponded to the muscle tissue of *Tilapia mossambica* (0.050 $\mu g\ g^{-1}$) from a geothermal field in NW Mexico. The highest Hg level was reported in liver of *O. aureus* (0.570 $\mu g\ g^{-1}$) from Picachos Dam (this study). The sequence of Hg accumulation according to the tissue was liver>muscle; considering the main activities around the areas considered in every study, the fish from places with past or present mining activity accumulated more Hg than individuals from a geothermal field and from sites with petrochemical activity. High concentrations of Hg in the hepatic tissue of fish have been explained by the presence of metallothioneins that participate in detoxification processes (Hidalgo et al. 1985; Kojadinovic et al. 2007). Another factor related to Hg distribution in fish is the time of exposure; muscle indicates a recent exposure, but liver is associated to past exposure to Hg (Palace et al. 2007); nevertheless, metabolic transformation and depuration rates may affect the suggested pattern.

Among metals, Hg is one of the most dangerous because of its elevated toxicity, its ubiquity, and its capacity to transform in the environment to more dangerous chemical species. Additionally, biomagnification of Hg implies high levels along food chains where humans are considered as predators. In this context, the PWI is estimated as a function of the provisional tolerable weekly intake (PTWI); it is on a weekly basis to highlight the relevance of controlling Hg intake over time. The results of PWI of Hg in *O. aureus* imply that there is no human health risk from consumption of blue tilapia at the reported consumption rates during the dry and rainy seasons. In tunas *Thunnus albacares* and *Katsuwonus pelamis* from the Eastern Pacific Ocean (Ruelas-Inzunza et al. 2012), average PWI of Hg (0.855 and 1.138 %) were lower than mean values (3.61 %) reported here for the entire study. Considering the main findings of the study, we can highlight the following: (a) though collected specimens were in an adult stage, Hg concentrations in the edible portion do not pose a health risk to the consumer; (b) the mean Hg levels were higher during the dry season; it implies that it is better to consume fish from this dam during the rainy season; and (c) even though people do not consume the liver of this fish species, the Hg concentrations were more elevated in the liver than in the muscle.

Acknowledgments Financial support was partially provided by the Ministry of Public Education (Project REDES PROMEP/103.5/13/9335), Dirección General de Educación Superior Tecnológica (Project 5098.13-P), and Consejo Nacional de Ciencia y Tecnología (project CONACYT-UNAM 204818). Thanks are due to RED DELFÍN and K. Sánchez-Osuna for the laboratory work and G. Ramírez-Reséndiz for the computing works.

References

Agah, H., Leermakers, M., Elskens, M., Fatemi, S. M. R., & Baeyens, W. (2007). Total mercury and methyl mercury concentrations in fish from the Persian Gulf and the Caspian Sea. *Water, Air, and Soil Pollution, 181*, 95–105.

Al-Saleh, I., & Shinwari, N. (2002). Preliminary report on the levels of elements in four fish species from the Arabian Gulf of Saudi Arabia. *Chemosphere, 48*, 749–755.

Beltrán-Álvarez, R., Ramírez-Lozano, J. P., & Sánchez-Palacios, J. (2012). Temperature and dissolved oxygen of the Picachos reservoir, Sinaloa, Mexico. *Hidrobiológica, 22*(1), 94–98.

Chopin, E. I. B., & Alloway, B. J. (2007). Distribution and mobility of trace elements in soils and vegetation around the mining and smelting areas of Tharsis, Riotinto and Huelva, Iberian pyrite belt, SW Spain. *Water, Air, and Soil Pollution, 182*, 245–261.

Clark, K. F., Foster, C. T., & Damon, P. E. (1982). Cenozoic mineral deposits and subduction-related magmatic arcs in Mexico. *Geological Society American Bulletin, 93*, 533–544.

Elia, A. C., Galarini, R., Taticchi, M. I., Dorr, A. J. M., & Mantilacci, L. (2003). Antioxidant responses and bioaccumulation in *Ictalurus melas* under mercury exposure. *Ecotoxicology and Environmental Safety, 55*, 162–167.

Fitzgerald, W. F., & Mason, R. P. (1996). The global mercury cycle: oceanic and anthropogenic aspects. In W. Baeyens, R. Ebinghaus, & O. Vasiliev (Eds.), *Global and regional mercury cycles: sources, fluxes and mass balances* (pp. 85–108). Dordrecht: Kluwer Academic Publishers.

Fitzgerald, W. F., Lamborg, C. H., & Hammerschmidt, C. R. (2007). Marine biogeochemical cycling of mercury. *Chemical Reviews, 107*, 641–662.

García, E. (1973). *Modificaciones al sistema de clasificación climática de Köppen*. México: Universidad Nacional Autónoma de México.

Gewurtz, S. B., Bhavsar, S. P., & Fletcher, R. (2011). Influence of fish size and sex on mercury/PCB concentration: importance for fish consumption advisories. *Environment International, 37*, 425–434.

Gutiérrez-Galindo, E. A., Flores-Muñoz, G., & Aguilar-Flores, A. (1988). Mercury in freshwater fish and clams from the Cerro Prieto geothermal field of Baja California, Mexico. *Bulletin of Environmental Contamination and Toxicology, 41*, 201–207.

Hidalgo, J., Tort, L., & Flos, R. (1985). Cd-, Zn- and Cu-binding protein in elasmobranch *Scyliorhinus canicula. Comparative Biochemistry and Physiology, 81C*, 159–165.

Jinadasa, B. K. K. K., Ahmad, S. B. N., Edirisinghe, E. M. R. K. B., & Wicramasinghe, I. (2014). Mercury content in yellowfin tuna (*Thunnus albacares*) and swordfish (*Xiphias gladius*) and estimation of mercury intake. *Journal of Food Security, 2*, 23–26.

Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R. P., & Bustamante, P. (2007). Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. *Environmental Pollution, 146*, 548–566.

Lewis, W. M. (2000). Basis for the protection and management of tropical lakes. *Lakes and Reservoirs: Research and Management, 5*, 35–48.

López, M., González, I., & Romero, A. (2008). Trace element contamination of agricultural soils affected by sulphide exploitation (Iberian pyrite belt, SW Spain). *Environmental Geology, 54*, 805–818.

Magalhães, M. C., Costa, V., Menezes, G. M., Pinho, M. R., Santos, R. S., et al. (2007). Intra- and inter-specific variability in total and methylmercury bioaccumulation by eight marine fish species from the Azores. *Marine Pollution Bulletin, 54*, 1654–1662.

Mason, R. P., Fitzgerald, W. F., & Morel, F. M. M. (1994). The biogeochemical cycling of elemental mercury: anthropogenic influences. *Geochimica et Cosmochimica Acta, 58*, 3191–3198.

Moody, J. R., & Lindstrom, R. N. (1997). Selection and cleaning of plastic containers for storage of trace element samples. *Analytical Chemistry, 49*, 2264–2267.

NOM-027-SSA1-1993. Norma Oficial Mexicana (1993). Bienes y Servicios. Productos de la Pesca. Pescados frescos-refrigerados y congelados. Especificaciones sanitarias.

Olsson, P.-E., & Hogstrand, C. (1987). Subcellular distribution and binding of cadmium to metallothionein in tissues of rainbow trout after exposure to 109Cd in water. *Environmental Toxicology and Chemistry, 6*, 867–874.

Palace, V. P., Halden, N. M., Yang, P., Enas, R. E., & Sterling, G. (2007). Determining residence patterns of rainbow trout using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis of selenium in otoliths. *Environmental Science and Technology, 41*, 3679–3683.

Ruelas-Inzunza, J., Páez-Osuna, F., Zamora-Arellano, N., Amezcua-Martínez, F., & Bojórquez-Leyva, H. (2009). Mercury in biota and surficial sediments from Coatzacoalcos estuary, Gulf of Mexico: distribution and seasonal variation. *Water, Air, and Soil Pollution, 197*, 165–174.

Ruelas-Inzunza, J., Green-Ruiz, C., Zavala-Nevárez, M., & Soto-Jiménez, M. (2011). Biomonitoring of Cd, Cr, Hg and Pb in the Baluarte River basin associated to a mining area (NW Mexico). *Science of the Total Environment, 409*, 3527–3536.

Ruelas-Inzunza, J., Soto-Jiménez, M. F., Ruiz-Fernández, A. C., Bojórquez-Leyva, H., Pérez-Bernal, H., et al. (2012). ^{210}Po activity and concentrations of selected trace elements (As, Cd, Cu, Hg, Pb, Zn) in the muscle tissue of tunas *Thunnus albacares* and *Katsuwonus pelamis* from the Eastern Pacific Ocean. *Biological Trace Element Research, 149*, 371–376.

Salah El-Deen, M. A., Sharada, K. M., & Abdu El-Ella, S. M. (1996). Some metabolic alternation in grass carp (*Ctenopharyngodon idella)* induced by exposure to cadmium. *Journal of the Egyptian German Society of Zoology, 21*, 441–457.

Sweilum, M. A. (2006). Effect of chronic exposure to sublethal levels of mercury on total production, physiological functions and economical efficiency of tilapia fish, with regard to properties of ponds water. *Egyptian Journal of Aquatic Biology and Fisheries, 10*(3), 165–183.

Thornton, I. (1996). Impacts of mining on the environment: some local, regional and global issues. *Applied Geochemistry, 11*, 355–361.

Trewavas, E. (1983). *Tilapiine fishes of the genera Sarotherodon, Oreochromis and Danakilia*. London: British Museum of Natural History.

UNEP/FAO/IOC/IAEA. (1993). *Guidelines for monitoring chemical contaminants in the sea using marine organisms*. Reference methods for marine pollution studies No. 6, UNEP 1993.