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Mercury content and their risk assessment in farmed shrimp *Litopenaeus vannamei* from NW Mexico

C.G. Delgado-Alvarez [a], J. Ruelas-Inzunza [b], J.I. Osuna-López [c], D. Voltolina [d], M.G. Frías-Espericueta [c,*]

[a] Aquatic Resources Postgraduate Program, Faculty of Marine Sciences, Autonomous University of Sinaloa, Mazatlán, Sinaloa 82000, Mexico
[b] Technological Institute of Mazatlán, Mazatlán, Sinaloa 82000, Mexico
[c] Faculty of Marine Sciences, Autonomous University of Sinaloa, Paseo Claussen s/n, Mazatlán, Sinaloa 82000, Mexico
[d] Center of Biological Studies of the NW, UAS-CIBNOR Environmental Studies Laboratory, Mazatlán, Sinaloa 82000, Mexico

HIGHLIGHTS

- The concentration of mercury in muscle is higher than hepatopancreas.
- The consumption of shrimp farmed in Northwest Mexico no represents health risk.
- Mercury levels in farmed shrimp do not exceed the official Mexican standards.

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ABSTRACT

The main objective of this study was to evaluate the total mercury content in hepatopancreas and edible muscle of the whiteleg shrimp *Litopenaeus vannamei* cultured along the NW coast of Mexico, and to evaluate the potential human health risk due to their consumption. Samples were obtained between May and June 2010 in 26 shrimp farms from the three most important shrimp-producing states of NW Mexico, and total Hg was analyzed after reduction with $SnCl_2$ in a mercury analyzer. The ranges of Hg concentrations of the hepatopancreas were 0.101 ± 0.03–0.184 ± 0.13 $\mu g\ g^{-1}$ in Sonora, 0.077 ± 0.055–0.813 ± 0.363 $\mu g\ g^{-1}$ in Sinaloa and 0.139 ± 0.037–0.791 ± 0.33 $\mu g\ g^{-1}$ in Nayarit. In the muscle, values were from 0.078 ± 0.02 to 0.539 ± 0.09 $\mu g\ g^{-1}$ in Sonora, 0.154 ± 0.03–0.861 ± 0.423 $\mu g\ g^{-1}$ in Sinaloa and 0.121 ± 0.041–1.48 ± 0.44 $\mu g\ g^{-1}$ in Nayarit. Considering the concentrations of Hg in the muscle and the national consumption rate, shrimp farmed in NW Mexico does not represent a risk for human health (HQ < 1).

1. Introduction

Due to its high toxicity and persistence, and because it is accumulated by organisms, mercury (Hg) is considered a hazardous metal. Its presence in the environment is due to natural and anthropogenic emissions, and to remobilization of settled Hg (Wang et al., 2004). Natural emissions of Hg include volcanic eruptions, weathering of the crust and possibly oceanic evaporation (Boening, 2000). Anthropogenic activities release more mercury than natural processes (Wang et al., 2004; Ruelas-Inzunza et al., 2013), and include paint, chlor-alkali and metallurgical industry, battery production, fossil fuel burning, agriculture, wood pulping and mining.

Since the central nervous system is the critical target organ of mercury, and because its effects have been associated with cognitive and motor functions (Echeverria et al., 2005), several studies have been carried out to assess the risk to human health caused by marine food consumption. Ruelas-Inzunza et al. (2011) evaluated the hazard quotients (HQ) associated to dietary intake of mercury through consumption of elasmobranchs, other fishes and wild shrimp caught in NW Mexican coastal areas, and reported a high HQ value associated with the shark *Sphyrna lewini* and the fish *Caranx caninus*, while that associated with shrimp was low.

In 2011, the semi-intensive farms of the states of Sinaloa, Sonora and Nayarit (NW Mexico) yielded almost 91% of the 109 815 metric tons of cultured *Litopenaeus vannamei* produced by Mexican shrimp aquaculture (46.2%, 37.2% and 7.5%, respectively: CONAPESCA, 2011). However, studies concerning the concentration of metals in shrimp farmed in Mexico are few and in particular there is no information on the Hg content in cultured shrimp. Shrimp farms are located in the coastal zone, which receives Hg from terrestrial environments. This is retained in estuaries and coastal water bodies,

* Corresponding author. Tel./fax: +52 669 9828656.
E-mail address: friasm@ola.icmyl.unam.mx (M.G. Frías-Espericueta).

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which are the main sources for pond filling and water exchanges. Food and chemicals used during production processes are additional sources of Hg (Lacerda et al., 2011).

The main objective of this study is to evaluate the total mercury content in hepatopancreas and edible muscle of the whiteleg shrimp *L. vannamei* cultured along the NW coast of Mexico, and to evaluate their potential human health risk due to their consumption.

2. Materials and methods

2.1. Sampling

Samples of *L. vannamei* of approximately similar size were obtained from May to June 2010 in five farms in Sonora (mean size 12.5 ± 1.0 cm), 13 in Sinaloa (mean size 12.8 ± 1.5 cm) and eight in Nayarit (mean size 12.0 ± 0.7 cm) (Fig. 1). In each farm, samples (30 shrimp for each pond) were obtained from three ponds (≈5 ha), chosen as representative of each farm because of their historic yield records (highest, average and lowest). Organisms were transported to the laboratory in coolers (4 °C).

2.2. Metal analysis

In the laboratory, organisms were washed and dissected to obtain muscle and hepatopancreas. The two tissues obtained from the 30 shrimp of each pond were pooled, freeze-dried for 72 h, ground and homogenized in a Teflon mortar (three pooled samples tissue^{-1} for each farm), digested in a mod-block system (ModBlock™ Digestion System, Evisa, Netherlands) at 130 °C in 30 mL Teflon vessels with 5 mL of trace metal grade HNO_3:HCl mixture (3:1, v v^{-1}). Each digested sample was transferred to vials, diluted to 15 mL with Milli-Q water and triplicate subsamples were used to determine the mean total Hg after reduction with $SnCl_2$ in a Buck Scientific model 410 (Buck Scientific, U.S.A.) mercury analyzer (Ruelas-Inzunza et al., 2011).

All material and glassware used in sampling and metal analysis were acid-washed according to Moody and Lindstrom (1977). Blanks using the same procedure of the samples were included to check possible contamination, and certified reference material (TORT 2, NRCC, Hg content: 0.292 ± 0.022 μg g^{-1}, dw) was used to check the precision and accuracy of the method. The resulting reading was 0.327 μg g^{-1}, dw, giving a percentage of recovery of 112%.

2.3. Statistical analysis

The mean Hg concentration obtained in the three ponds of each farm was compared to those of the remaining farms. Since data were not normal (Kolmogorov Smirnov tests), the existence of significant differences among farms as well as among the mean values of the three states was determined using non parametric ANOVA (Kruskall–Wallis) and Dunn's multiple comparison tests. A paired non parametric *t* test (Wilcoxon test) was used to detect possible differences between the mean Hg contents of the two tissues. Spearmańs correlations were used to determine the relation between the Hg concentrations of the two tissues, and between the mean size of the 30 shrimp of each pond and the respective

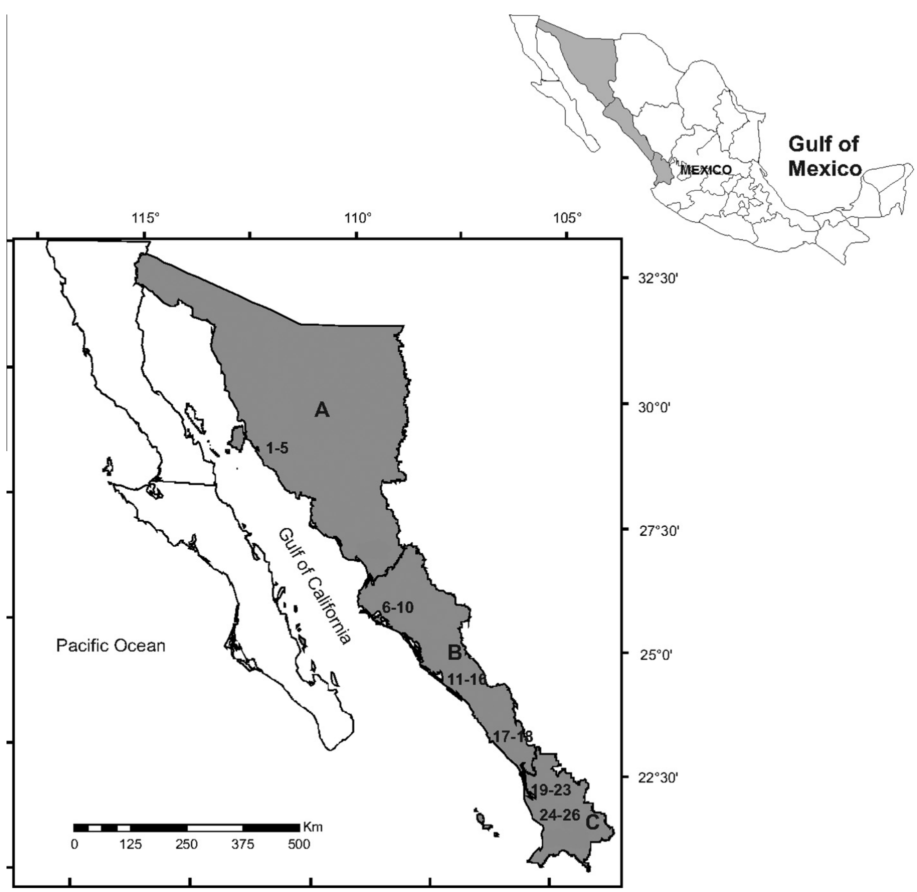

Fig. 1. Study area (A): Sonora State (sampling sites 1–5), (B) Sinaloa State (sampling sites 6–18), and (C) Nayarit State (sampling sites 19–26).

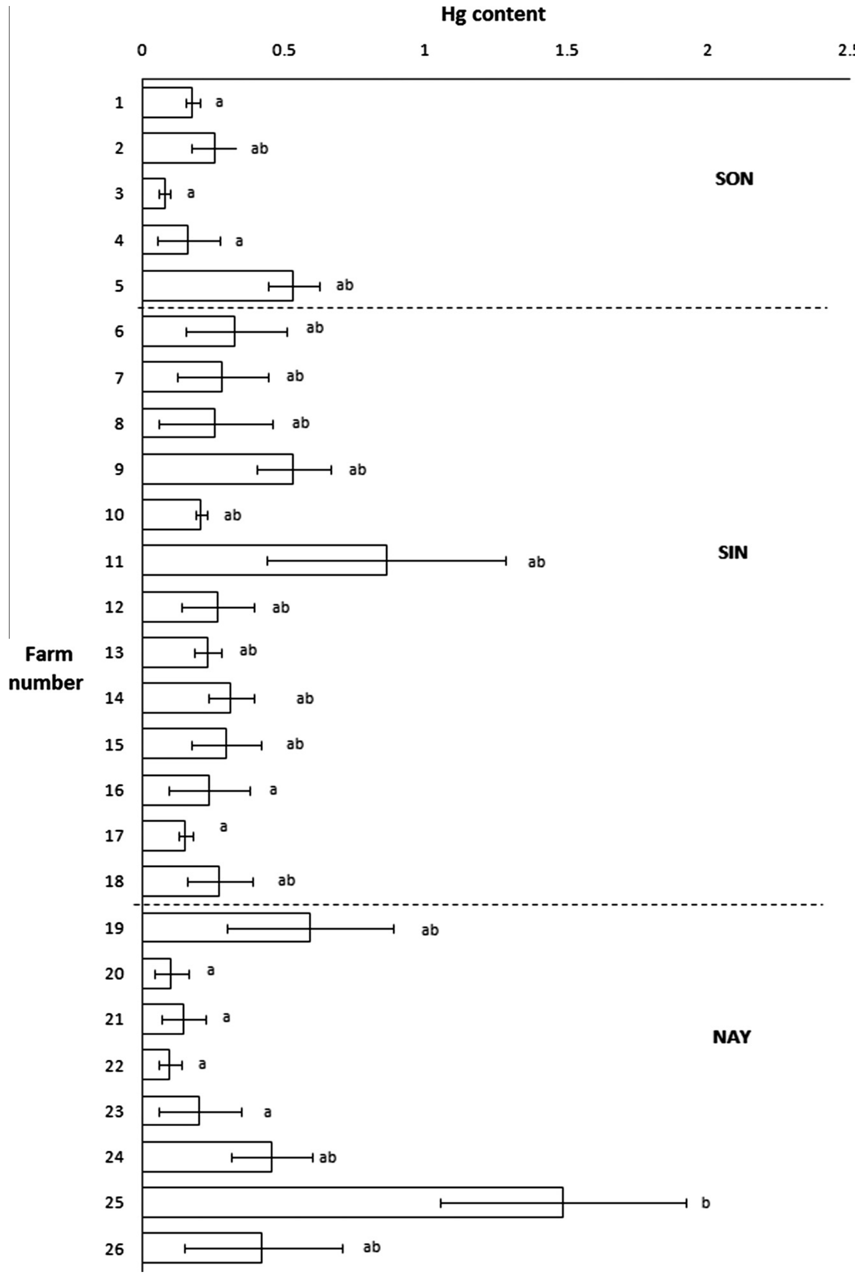

Fig. 2. Mean mercury content ($\mu g\ g^{-1}$, dw) in muscle of *L. vannamei* of shrimp farmed in NW Mexico. SON, SIN and NAY: States of Sonora, Sinaloa and Nayarit, respectively. The horizontal dotted lines separate data of the three states. Equal or common letters indicate lack of significant differences (a ⩽ ab; ab ⩽ b and a < b).

muscle and hepatopancreas Hg content. All analysis were carried out with the statistical package SigmaStat 3.5, at a significance level $p < 0.05$ (Zar, 1999).

2.4. Risk assessment

The risk to human health according to consumption rate and Hg concentration of the edible portion of shrimp was assessed by the hazard quotient (HQ). This indicator relates the level of exposure to a single substance to a reference dose (Newman and Unger, 2002), and was estimated with the equation:

$$HQ = E(\mathrm{RfD})^{-1}$$

where E is the exposure to Hg, RfD is the reference dose for total Hg ($0.5\ \mu g\ kg^{-1}\ day^{-1}$). The level of exposure E is calculated as $E = C \times I\ W^{-1}$, where C is the total concentration of mercury in shrimp, I is the ingestion rate of shrimp (1.37 kg person^{-1} year^{-1}: CONAPESCA, 2011) and W is the average weight of an adult (71.7 kg: CANAIVE, 2012).

3. Results

The Hg contents of muscle of shrimp cultured in Sinaloa and Nayarit ranged from 0.154 ± 0.03 to 0.861 ± 0.423 $\mu g\ g^{-1}$ and from

Table 1
Mean concentration (±standard deviation, $\mu g\ g^{-1}$, dry weight) of total Hg in muscle and hepatopancreas of white shrimp *L. vannamei* from NW Mexico.

State	Muscle	Hepatopancreas
Sonora	0.194 ± 0.143^{a}	0.205 ± 0.168^{a}
Sinaloa	0.310 ± 0.213^{b}	0.206 ± 0.201^{a}
Nayarit	0.451 ± 0.509^{b}	0.234 ± 0.244^{a}

Different superscripts indicate significant differences between data in the same column (Kruskall–Wallis and Dunn's tests, $p < 0.05$, a < b).

0.121 ± 0.041 to 1.48 ± 0.44 μg g^{-1}), respectively. The range in Sonora was from 0.078 ± 0.02 to 0.539 ± 0.09 μg g^{-1}. In the hepatopancreas, values ranged from 0.101 ± 0.03 to 0.184 ± 0.13 in Sonora, between 0.077 ± 0.055 and 0.813 ± 0.363 in Sinaloa, and in Nayarit the range was 0.139 ± 0.037–0.791 ± 0.33 μg g^{-1} (Fig. 2). The highest and lowest values in Nayarit were associated to the same lagoon system (Agua Brava), which extends from the northern to the central part of the state.

There was no significant difference between the mean Hg contents of the muscle of shrimp cultured in Sinaloa and Nayarit, and both means were significantly ($p < 0.001$, Kruskall–Wallis) higher than that of the shrimps grown in Sonora. In the case of the hepatopancreas, there was no significant difference among the mean values of the three states (Table 1).

The mean muscle content, calculated using the values obtained in the 26 farms was 0.339 ± 0.347 μg g^{-1}, and was significantly higher ($p < 0.001$, Wilcoxon's test for related samples) than the mean value of the hepatopancreas content (0.221 ± 0.219 μg g^{-1}). There was a significant correlation between muscle and hepatopancreas Hg contents (Spearman's $r = 0.366$, $p < 0.001$). Those between shrimp size and total Hg were not significant ($r = -0.0675$ and -0.183 for muscle and hepatopancreas, respectively, $p > 0.05$ in both cases). All values of the hazard quotient HQ calculated for the 26 shrimp farms were well below the critical level (HQ = 1), and ranged from 0.002 to 0.038 for farms 3 and 25, located in the states of Sonora and Nayarit (Fig. 3).

4. Discussion

4.1. Hg content in tissues

Accumulation of metals in different organs depends on the physiological role of the organs, on its tissue composition and on their affinity for different metals. In particular, the hepatopancreas is considered the target organ for metal accumulation, because of its high content of metal-binding metallothionein (Legras et al., 2000; Pourang and Dennis, 2004). However, although some results on the Hg content of crustacean tissues are in agreement with the

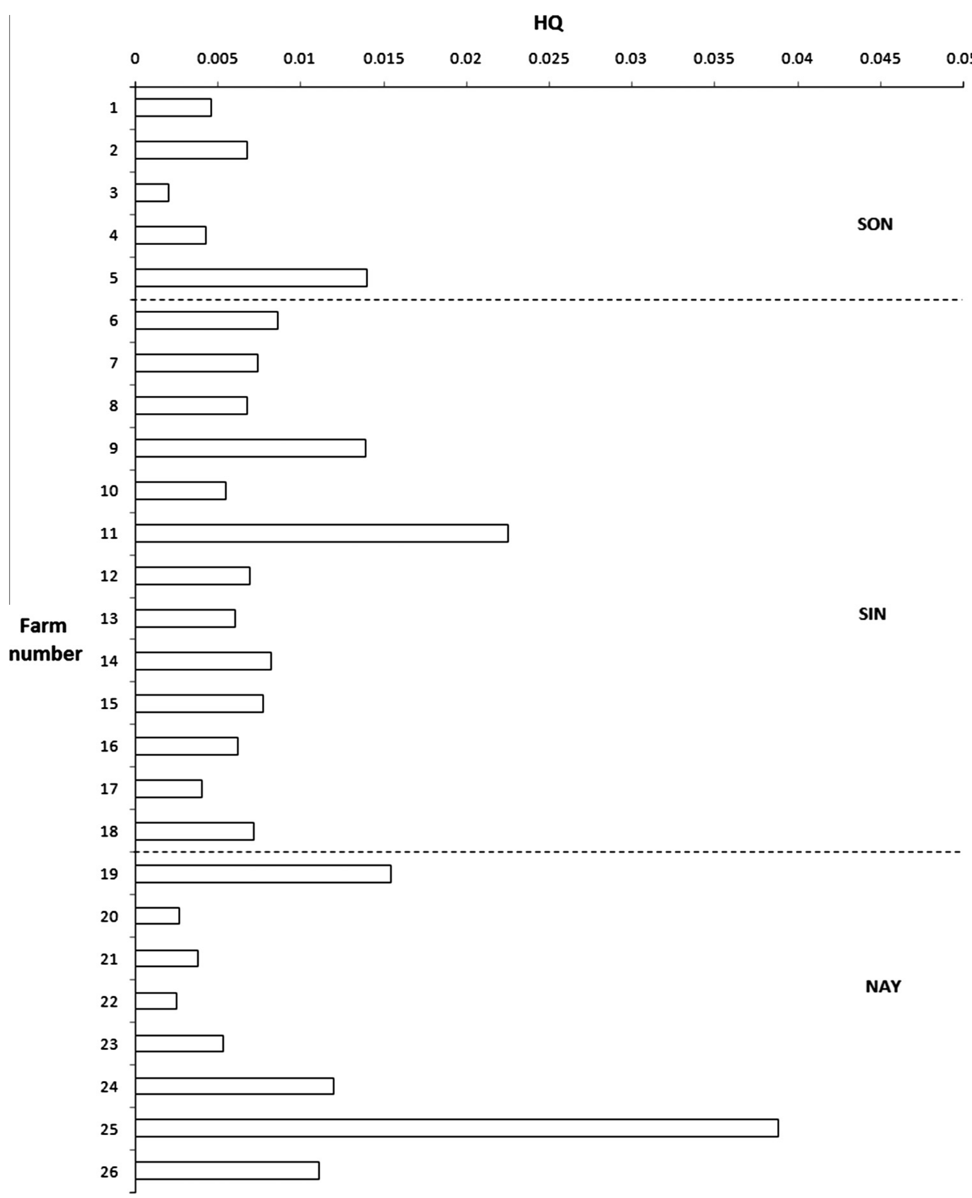

Fig. 3. Hazard quotient (HQ) via muscle consumption of shrimp farmed in the Sonora, Sinaloa and Nayarit States of NW Mexico (SON, SIN and NAY, respectively). The horizontal dotted lines separate data of the three states.

Table 2
Comparison of concentration of total mercury in muscle and hepatopancreas (μg g^{-1}, dry weight) of shrimp in different regions of the world.

Organism	Zone	Muscle	Hepatopancreas
Wild shrimp			
Penaeus semisulcatus[a]	Persian Gulf	0.15–0.25	0.14–0.18
Penaeus monodon[b]	South Vietnam	<0.05–0.12	<0.05–0.14
Aristeus antennatus[c]	NW Mediterranean	4.75 ± 2.83	NA
Litopenaeus stylirostris[d]	AEP lagoon, NW Mexico	0.30 ± 0.36	0.57 ± 0.01
Litopenaeus vannamei[d]	AEP lagoon, NW Mexico	0.20 ± 0.01	0.72 ± 0.07
Penaeus merguiensis[e]	Gresik coast, Indonesia	0.002–0.03	NA
Metapenaeus monoceros[f]	Harbour Egypt	0.04–2.16	NA
Farmed shrimp			
Penaeus monodon[b]	South Vietnam	<0.05–0.10	<0.05–0.12
Litopenaeus vannamei[g]	East Florida	0.1–0.3	0.1–2.0
Metapenaeus ensis[h]	Mai Po, Hong Kong	0.13–0.16	NA
Litopenaeus vannamei[i]	Brazil	0.006–0.016	0.005–0.022
Litopenaeus vannamei[j]	NW Mexico	0.333 ± 0.336	0.216 ± 0.212

[a] Elahi et al. (2012).
[b] Tu et al. (2008b).
[c] Drava et al. (2004).
[d] Ruelas-Inzunza et al. (2004).
[e] Soegianto et al. (2010).
[f] Soliman (2006).
[g] Landau and Pierce (1986).
[h] Cheung and Wong (2006).
[i] Soares et al. (2011).
[j] This study. NA = Not available.

role of this organ in metal storage and detoxification (Andersen and Baatrup, 1988; Ruelas-Inzunza et al., 2004; Tu et al., 2008a), there are several exceptions pointing out that this is not a general rule. Hosseini et al. (2013), for instance, described wide sex- and season-related variations, with similar Hg contents in exoskeleton, hepatopancreas and muscle during winter in the males of one Persian Gulf crab species, Tu et al. (2008b) did not find a significant difference in the Hg concentration of the muscle and hepatopancreas of *Penaeus monodon*, while Karouna-Renier et al. (2007) found consistently higher Hg levels in the muscle than in the hepatopancreas of Pensacola Bay blue crabs.

The most probable explanation for these discrepancies is the contribution of the Hg content of formulated feed (mostly in its organic form) to the total Hg body burden of cultured shrimp. Under normal culture conditions this tends to accumulate with a lower rate in the hepatopancreas than in the muscle, probably because of the different degree of affinity of their tissues for organic Hg (Soares et al., 2011).

The highly significant correlation between the Hg concentration of hepatopancreas and muscle implies that, although rates of accumulation may differ in different tissues, it is dose-dependent in all cases. This coincides with the highly significant correlations found by Soares et al. (2011) between the Hg content of shrimp feed and those of different shrimp tissues, as well as between the Hg concentration of hepatopancreas and muscle of *L. vannamei* grown under typical outdoors culture conditions.

Although not in agreement with the results obtained with by Drava et al. (2004) and Elahi et al. (2012), who found a significant direct relationship between length and total Hg levels of wild shrimp, the lack of significant correlations between shrimp size and the Hg concentration of their tissues was not unexpected, in view of the wide variations in concentration and of the similar size of the shrimp used in this work, which implies similar times of residence in their respective growout ponds.

Most of the farms of NW Mexico draw the water used for pond filling and daily replacements from the coastal lagoons or estuarine systems to which they are associated. Since these systems receive the effluents from the intensive agriculture activity of the fertile areas of the Pacific coastal plain, their water as well as atmospheric deposition might be important, or possibly the main sources of Hg to shrimp farms (Ruelas-Inzunza et al., 2013). Dissolved metals (like Hg) which enter shrimp farms are adsorbed or absorbed by seston and plankton and eventually deposited in the pond sediments, where they become available to benthic organisms, including shrimp (Lacerda et al., 2011).

The highest and lowest Hg content in the samples from Nayarit state were determined at different sites of the same lagoonal system (Agua Brava), which may be explained by the different riverine inputs in the northern (Acaponeta River) and southern (San Pedro and Lerma Rivers) parts of the system since the first drains areas mostly dedicated to dryland agriculture, while the land to the south is dedicated to highly intensive, pesticide and fungicide requiring, irrigated cultures (INEGI, 2012).

With the exception of the Hg content of the wild deep sea shrimp *A. antennatus* (Drava et al., 2004), the values we determined in the muscle of *L. vannamei* is higher than those found in other wild and cultured shrimp around the world, but similar to those determined in the wild white and blue shrimp *L. vannamei* and *L. stylirostris* of some Mexican coastal lagoons (Ruelas-Inzunza et al., 2004), and in *L. vannamei* cultured in Florida (Landau and Pierce, 1986). In the case of the hepatopancreas, our results are higher than those determined in cultured *P. monodon* in South Vietnam and Brazil, but lower than the wild shrimps of some NW Mexican coastal lagoons (Ruelas-Inzunza et al., 2004) (Table 2).

4.2. Risk assessment

The values of HQ calculated in this work show that in Mexico there is a low level of risk caused by shrimp consumption, which is mainly due to the low mean yearly shrimp ingestion. However, this low value, calculated for the whole population of Mexico, might be misleading given that people of coastal areas are likely to consume more fishery products than inland people. Age, costumes, family income and other factors are other sources of variation, due to which potential health hazards could exist for some consumers. This suggests that additional health risk assessments should be carried out, identifying the specific populations at risk.

5. Conclusions

The tendency of the mean Hg concentrations in both tissues tend to be higher in Nayarit than in Sinaloa and the lower values are in Sonora, but the only significant difference is the higher mean Hg content of the muscle of shrimp cultured in Nayarit. According to the calculated HQ values, consumption of shrimp farmed in NW Mexico does not represent a risk for human health. However, additional assessments should consider the relevant factors which might modify shrimp consumption in different sectors of the population, in order to avoid long-term deleterious effects.

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