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Changes in metal contents in shrimp cultured in NW Mexico (2000–2010)

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Abstract This study shows the concentrations of Cd, Cu, Pb, and Zn in the muscle and hepatopancreas of Pacific white shrimps, *Litopenaeus vannamei*, cultured during 2010 in 26 commercial farms of the three main producer states of the Mexican NW, Sonora, Sinaloa, and Nayarit and compares the results to those obtained in 2000 using samples collected in16 farms of the same states. No significant changes were detected in Cd concentrations, but the 2010 Zn levels were significantly higher in all states in the hepatopancreas and in Sinaloa in the case of the muscle. Cu showed a tendency to higher hepatopancreas values in 2010, but differences were significant only in Sonora and for the global mean value. In contrast, Pb was one order of magnitude lower in both organs in 2010, possibly because of the almost 15 years since leaded gasoline was discontinued in Mexico.

Keywords Cultured shrimp · NW Mexico · Metal contents · Decadal changes

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Introduction

The 2012 Mexican cultured shrimp production was 100,321 metric tons (live weight) and represented about 25 % of the commercial value of the total landings of the national fishing fleets (1.5×10^9 US$). Approximately 78 % (78,106 metric tons) of this production came from the >75,000 ha dedicated to the semi-intensive culture of *Litopenaeus vannamei* in the coastal areas of the Pacific states of the Mexican NW, Sonora, Sinaloa, and Nayarit (CONAPESCA 2012).

The Mexican Pacific coastal zone receives contaminants from natural and anthropogenic sources. Among these, Frías-Espericueta et al. (2009) observed relatively high concentration of metals in the shrimp landings of traditional fishery in some coastal lagoons of NW Mexico, probably related to the significant metal inputs of the intensive agriculture-associated activities of the Mexican Pacific coastal plains and by the effluents of shrimp farms, which receive artificial feed, fertilizers, and other chemicals (disinfectants, therapeutics, pH correctors, and algaecides: Lyle-Fritch et al. 2006). Among these, fertilizers (Dissanayake and Chandrajith 2009) and feed (Amaraneni 2006; Lacerda et al. 2009) have been identified as significant sources of heavy metals, which might be of concern because, even if essential, their presence in excess may result in increased susceptibility to stress agents and become a source of slow growth and disease (Yeh et al. 2004).

The aims of this study were a revision of the Cd, Cu, Pb, and Zn contents of hepatopancreas and muscle of the Pacific white shrimp, *L. vannamei* cultured in three states of the Mexican Pacific NW in 2000 and 2010, to detect any time-related changes as well as determine whether they are within the permissible limits for human consumption.

Material and methods

A total of 16 shrimp farms were sampled in the states of Sonora, Sinaloa, and Nayarit in 2000 (6, 6, and 4 farms, respectively). Those sampled in 2010 were 26 (5 in Sonora, 13 in Sinaloa, and 8 in Nayarit) (Fig. 1). To obtain shrimps of approximately similar size, sampling in both years was performed between 10 and 12 weeks from stocking. All farms were semi-intensive, with initial densities ranging from 25 to 30 shrimps per square meter in Sonora and 8–20 in Sinaloa and Nayarit. Water

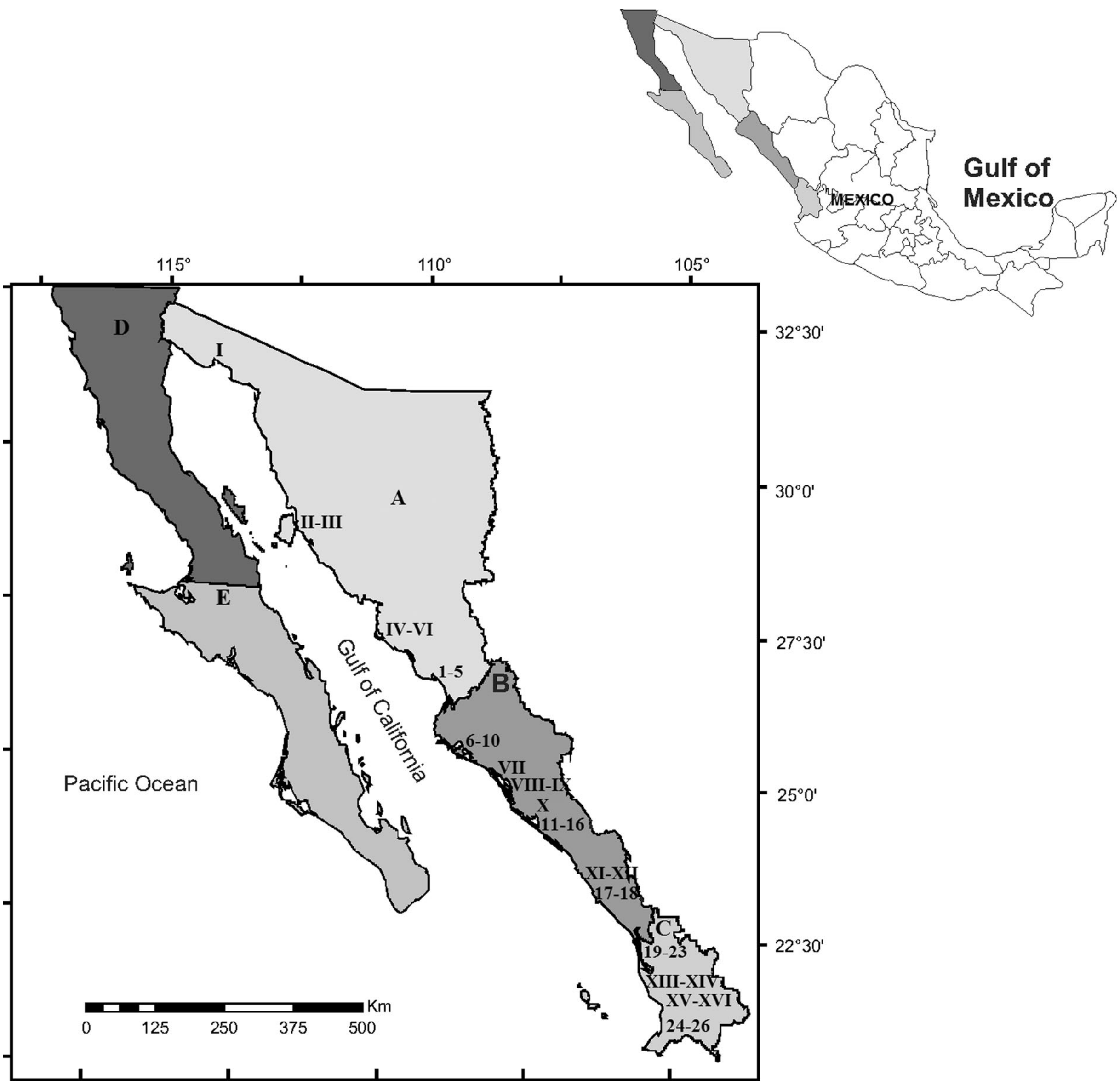

Fig. 1 Study area. *Arabic numbers*: 2010 samples. *Roman numbers*: 2000 samples. The *capital letters* indicate the NW Mexican states: *A*: Sonora. *B*: Sinaloa. *C*: Nayarit. *D*: Baja California. *E*: Baja California Sur

exchange rates were from 10 to >20 % daily in Sonora, generally with water of marine origin, while in Sinaloa and Nayarit, the most common water sources were estuaries and coastal lagoons, and the exchange rates were 3–5 % (Miranda et al. 2009). In both years, the protein content of shrimp feed ranged from 30 to 35 %, and the most common feeding protocol was on demand, according to the indications of feeding trays.

Three ponds (~2 ha) were chosen in each farm according to their historic yield records (highest, average, and lowest). The sample from each pond was 30 shrimps of similar size. Samples were transported to the laboratory in individual metal-free plastic bags kept in coolers at 4 °C and stored at −20 °C until processing.

In the laboratory, the organisms of each pond were dissected and the abdominal muscle and hepatopancreas were separated, freeze-dried, ground, and homogenized in a Teflon mortar, giving three composite samples of each tissue for each pond. Tissues were digested during 4 h in mod-block units (ModBlock™ Digestion System, Evisa, Netherlands) with 5 ml of concentrated HNO_3 (trace metal grade) at 130 °C in 30-ml Teflon vessels, transferred to polypropylene vials, diluted to 15 ml with Milli-Q water, and the metal content of each sample was determined by atomic absorption spectrophotometry (Varian Spectra AA). Samples were in triplicate, the accuracy of the analytical method was evaluated with DORM-3 (NRCC) certified reference material with recovery percentages ranging from 82.4 to 96.3 %. All materials used for sampling and sample treatments were acid washed, blanks were run with samples to check possible contamination, and all chemicals used were analytical grade (Frías-Espericueta et al. 2009).

Metal contents of each tissue determined in each state in 2000 and in 2010 were compared using two-way ANOVA and Tukey's tests, after RT-1 rank transformation when the data were not normal or homoscedastic (Conover and Iman 1981; Conover 2012). The mean values calculated with the data obtained in the three states in 2010 were compared to those of the year 2000 with Student's t tests, whereas the mean contents of the muscle and hepatopancreas were compared with paired t or Wilcoxon's tests. The relations between the contents of each metal and shrimp size were determined with Spearman's correlations. All tests were performed at significance level $\alpha = 0.05$ (Zar 1999).

Table 1 Mean total lengths (cm) and wet weights (g) of *L. vannamei* from shrimp farms of NW Mexico (2000: n=18, 18, 12 for Sonora, Sinaloa, and Nayarit, respectively; 2010: n= 15, 39, and 24 for Sonora, Sinaloa, and Nayarit, respectively)

	2000		2010	
	Size	Weight	Size	Weight
Sonora	12.0±0.9	8.6±1.9	12.4±0.9	9.7±2.2
Sinaloa	12.4±1.6	9.5±2.2	12.8±1.7	11.2±5.3
Nayarit	11.6±0.7	7.8±1.4	12.0±0.7	8.8±1.6
Mean	12.1±2.9	8.9±3.3	12.5±1.3	10.0±3.7

Results

The mean shrimp sizes and weights obtained in each state were not significantly different (two-way ANOVA, p>0.05), and the respective mean values were 12.1±2.9 and 12.5±1.3 cm and 8.9±3.3 and 10.0±3.7 g in 2000 and 2010, respectively (Table 1). Spearman's correlation coefficients (ρ) calculated between shrimp size and metal content of each state ranged between −0.294 and 0.559, both obtained in 2010 in Nayarit for Cu and Zn, respectively (p=0.340 and 0.055). The ρ values calculated using the data of Cd, Cu, Pb, and Zn of both years were −0.063, 0.006, 0.052, and 0.199, and the respective p values ranged from 0.971 to 0.249.

There were no significant differences in the metal content of shrimp grown in the three states, but in most cases, the year of sampling was a significant source of variation. In the case of Cd, concentrations found in both years in hepatopancreas and muscle ranged from 0.46 to 1.98 and from 0.29 to 0.50 μg g^{-1} (dry weight), respectively, and the differences between 2000 and 2010 were not significant (p>0.05 in all cases) (Table 2).

The mean hepatopancreas and muscle Pb contents ranged from 0.69 to 8.72 and between 0.27 and 7.86 μg g^{-1} (dry weight), respectively. The means determined in 2000 were one order of magnitude higher than those of 2010, and the difference was significant in all cases with the exception of the hepatopancreas data of the state of Sonora (Table 2).

The mean Cu contents of the muscle ranged from 18.17 to 29.21 μg g^{-1}, and there were no significant differences between years of sampling, while hepatopancreas values ranged from 98.01 to 239.90 μg g^{-1}. In this case, although the only significant difference was between the means determined in Sonora, there was a general tendency to higher concentrations in 2010 than in 2000, which explains the significant difference

Table 2 Mean metal contents (μg g^{-1}, dw) in the muscle and hepatopancreas of *L. vannamei* from shrimp farms of NW Mexico

State	Muscle		Hepatopancreas	
	2010	2000	2010	2000
Cd				
Sonora	0.31±0.18	0.29±0.14	0.46±0.45	0.58±0.19
Sinaloa	0.42±0.25	0.50±0.18	1.98±1.47	0.69±0.21
Nayarit	0.33±0.22	0.37±0.17	0.53±0.54	0.89±0.40
Mean	0.37±0.23	0.39±0.18	1.27±1.33	0.70±0.29
Cu				
Sonora	26.66±17.62	18.17±3.44	197.32±51.83*	98.01±23.91
Sinaloa	20.30±3.93	29.21±14.41	239.90±80.27	159.50±92.45
Nayarit	25.98±6.14	21.09±13.75	228.50±182.4	104.06±48.43
Mean	23.02±8.22	27.18±13.76	229.09±113.61**	110.29±37.93
Pb				
Sonora	0.74±0.71*	2.96±2.30	0.97±0.77	4.77±3.28
Sinaloa	0.57±0.63*	7.86±3.47	0.81±0.97*	5.91±2.40
Nayarit	0.27±0.20*	5.14±1.48	0.69±0.71*	8.72±1.39
Mean	0.51±0.56**	5.53±3.42	0.80±0.83**	6.06±3.08
Zn				
Sonora	31.48±23.06	19.99±14.97	68.98±10.68*	58.01±10.85
Sinaloa	47.63±10.89*	32.43±21.56	69.90±11.29*	51.06±1.06
Nayarit	52.84±4.65	39.67±12.62	228.86±182.07*	49.69±4.95
Mean	46.46±13.75**	29.57±18.13	118.12±121.36**	54.073±8.79

Differences between states were not significant

*$p<0.05$, significant difference between 2000 and 2010 (two-way ANOVA).

**$p<0.05$, significant difference between the general means of 2000 and 2010 (Student's t tests)

between the general mean values calculated for the 2 years of sampling (Table 2).

As was the case for Cu, Zn concentrations showed a general tendency to slightly higher values in 2010 than in 2000. In the muscle, the range was 19.99 to 52.84 μg g^{-1}, and there was a significant difference only for the values calculated for the Sinaloa samples, while all states had significantly higher hepatopancreas contents, which ranged widely, between 68.98 and 228.86 μg g^{-1} in 2010, in comparison to the narrower range detected in 2000 (49.69 to 58.01 μg g^{-1}) (Table 2).

Discussion

Cadmium is usually associated with zinc, less frequently with lead and copper ores, and is also contained in minor percentages in phosphate rocks (Butterman and Plachy 2013). Mexico is one of the main producers of Cd, Zn, and Pb (4th, 4th, and 5th producer worldwide in 2013, respectively), and although its Cu and phosphate rock productions are not as important, these are centered in the Sierra Madre Occidental (Cu) and on the eastern side of the Baja California peninsula (CAMIMEX 2014).

Thus, the presence of Cd-rich ores, the high Cd titer of the Baja California phosphate rocks (14–16 ppm: Álvarez-Arellano and Páez-Osuna 1995), as well as the constant demand of fertilizers of the intensive agriculture activities of Sonora, Sinaloa, and Nayarit, are the most likely explanation of the fairly uniform Cd concentrations observed in the tissues of the shrimp cultured in these states.

Lead-containing products have been used since ancient times worldwide, and although the problems related to their use are already well known, the demand for

Table 3 Ranges of metal concentrations (μg g^{-1}, d.w.) in cultured shrimp from other farms of the world

Zone	Species	Cd	Cu	Pb	Zn
SE India[a] (M)	*P. monodon*	1.07*	13.8*	17.4*	10.7*
SE China[b] (M)	*L. vannamei*	<LD	12.82–42.50	<LD	87.1–448
SE China[b] (H)	*L. vannamei*	1.81–5.53	44.8–344	<LD	75.4–177
North Borneo[c] (M)	*P. monodon*	0.48–1	1–3.2	1.2–02.8	7–12
Sunderbans, India[d] (M)	*P. monodon*	0.11–3.22		22.9–42.1	7.3–4810
Central America[e] (M)	*L. vannamei*	0.08–0.12	8.4–24	0.14–2	76–120
NE Brazil[f] (M)	*L. vannamei*	–	23.2–63.4	–	–
NW Mexico[g] (M)	*L. vannamei*	<0.05	18.5–19.2	–	54–56
NW Mexico[g] (H)	*L. vannamei*	0.11–1.02	33.5–95.3	–	88–156
NW Mexico[h] (M)	*L. vannamei*	0.37–0.39	23.0–27.2	0.51–5.53	46.5–29.6
NW Mexico[h] (H)	*L. vannamei*	1.27–0.70	229–110	0.80–6.1	118–54.1

M muscle, *H* hepatopancreas, <*LD* below the limit of detection

*maximum values

[a] Amaraneni (2006)

[b] Wu and Yang (2011)

[c] Hashmi and Tariq (2002)

[d] Guhathakurta and Kaviraj (2000)

[e] Carbonell et al. (1998)

[f] Lacerda et al. (2009)

[g] Páez-Osuna and Tron-Mayen (1996)

[h] This study (2010 and 2000 mean values, in the order)

this metal is still strong and production in Mexico has been steadily increasing since at least 6 or 7 years (CAMIMEX 2014). In spite of this trend, concentrations in farmed shrimp were one order of magnitude lower in the 2010 samples. Assuming that other Pb sources remained stable, such as atmospheric transport from mining-related activities or continental and surface run-off of agricultural or municipal wastewaters (Duman and Kar 2012; Frías-Espericueta et al. 2014), the most likely explanation for this change seems to be the discontinuation of leaded gasoline in Mexico in 1997–1998 and the immobilization of residual Pb in soils and sediments.

Cu and Zn are essential for shrimp nutrition, and for this reason, they are added as enrichments in formulated fish and shrimp diets, in recommended amounts varying between 8 and 12 μg g^{-1} for Cu and one order of magnitude higher in the case of Zn (Ikem and Egilla 2008). Both are also ubiquitous metals present in several products used in agricultural activities, as active ingredients in pesticides and antimycotic agents or as impurities in fertilizers (Dissanayake and Chandrajith 2009). Additionally, metals are continuously added to the Mexican Pacific coastal environments by the several rivers and waterways draining the alluvial lateritic soils of the Pacific coastal plains (Frías-Espericueta et al. 2014), which might explain the general tendency to higher hepatopancreas and muscle Zn contents in 2010 than in 2000 and in the hepatopancreas in the case of Cu.

Information on the metal content of wild shrimp in coastal and marine Mexican waters is relatively abundant (Frías-Espericueta et al. 2009 and literature therein), but as far as we are aware that on

Table 4 Suggested daily consumption of edible muscle of cultured shrimp from NW Mexico (in grams, wet weight) in different year of sampling according to provisional tolerable daily intake (PTDI) in microgram per person per day (FDA 1993; WHO 1998)

Sampling	Cu	Zn	Cd	Pb
PTDI	3000	45,000	55	750
2000	442	6089	564	542
2010	521	3823	594	5894

cultured shrimp is limited and the only information available for Mexico is that obtained in one shrimp farm by Páez-Osuna and Tron-Mayen (1996) who determined Cd and Cu contents lower than those of the present study, probably because that particular farm is located in a virtually agriculture-free area of southern Sinaloa.

Elsewhere and with the exception of Zn, Carbonell et al. (1998) reported lower metal contents than those of this study in shrimp cultured in Nicaragua and Honduras (recalculated from the original values using a wet-to-dry weight ratio = 4.5). The highest values of Pb were reported for farmed *Penaeus monodon* grown in heavily impacted areas of eastern India (Guhathakurta and Kaviraj 2000; Amaraneni 2006) (Table 3).

Human consumption of fish and other seafood may entail a significant exposure to contaminants (Cole et al. 2009). Our results show that, because of the Cd and Cu levels, the daily consumption needed to reach the provisional tolerable daily intake (PTDI) suggested at international level (FDA 1993; WHO 1998) would be in the order of 500–600 g of fresh shrimps (Table 4). In view of the per capita yearly average shrimp consumption (1.2 Kg year^{-1} per person, CONAPESCA 2012), this limit does not seem of special concern, although this limit would be far lower for people who consume whole shrimp (usually as reconstituted whole dried shrimp), in view of the far lower metal content in headless shrimp.

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