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RESEARCH ARTICLE

# Cadmium and lead concentrations in hepatic and muscle tissue of demersal fish from three lagoon systems (SE Gulf of California)

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**Abstract** We determined the levels of Cd and Pb in liver and muscle of demersal fish from three lagoon systems (Urías, Huizache, and Teacapán) in the SE Gulf of California with the purpose of comparing the studied metals in fish from the three ecosystems and to assess the potential human health risk. Considering the number of individuals, the sequence of fish abundance was Teacapán > Huizache > Urías. Length and size at maturity of collected species showed that 76.5% of the individuals were juveniles. Overall, Cd and Pb were more accumulated in liver than in muscle. After multivariate analyses, considering fish tissue and locality, Cd and Pb levels were different ($p < 0.05$) between fish from Teacapán and Huizache. In general, the hazard quotients (HQs) of Pb were higher than the corresponding values of Cd; the highest HQ for Cd (0.0051) corresponded to *Mugil curema*, and the highest HQ for Pb (0.0099) was estimated in *Diapterus peruvianus*. With respect to the hazard index (accumulative risk from Cd and Pb), the most elevated value (HI = 0.0124) was estimated for *Pomadasys macracanthus*. Estimated HI does not represent a health risk at the consumption rates of the Mexican population.

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## Introduction

Trace metals reach the aquatic environment as releases from natural processes and from human activities (Jordao et al. 2002). Many trace metals are potentially harmful to aquatic organisms at varying levels of exposure; for example, Cd and Pb may exhibit extreme toxicity even at low levels, so it is necessary to monitor sensitive aquatic environments (Cohen et al. 2001). Pollution of aquatic environments with harmful trace metals, and its subsequent impact on organisms, is more dramatic within estuaries, lagoons, and semi-closed coastal zones, especially when they are near to highly populated or industrial areas. Trace metals may enter a lagoon from different natural and anthropogenic sources, including industrial or domestic sewage, agriculture, aquaculture, storm runoff, leaching from landfills, shipping and harbor activities, and atmospheric deposition (Yilmaz 2003; Marcovecchio 2004; Páez-Osuna and Osuna-Martínez 2015).

The use of organisms as monitors of water quality has several advantages over the chemical analysis of abiotic compartments. Chemical, toxicological, and ecological approaches have been studied extensively for assessing impacts of trace metal pollution in aquatic environments. A large amount of the papers published on organisms as pollution biomonitors have used fish (Storelli and Marcotrigiano 2001; Usero et al. 2004; Yilmaz 2005; Moreno-Sierra et al. 2016). Fish have the advantage that are often at the top of the aquatic food chains and may concentrate large amounts of some metals from the water; in the case of fish for human consumption, they are frequently used to assess human health risk (Rashed 2001).

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The studied lagoon systems are located in the SE part of the Gulf of California; they are economically important for small scale fisheries, with fin fish as an important target for the local fishermen. The three lagoons are impacted by diverse activities (agriculture, aquaculture, deforestation, mining, and dam construction) that may increase metal loads, favor biota accumulation (Ruelas-Inzunza et al. 2013; Páez-Osuna and Osuna-Martínez 2015), and affect the survival and growth of organisms including commercial fish. Since polluted fish from this area may become a public health concern, information on elemental concentration in fish species in these lagoon systems becomes of great importance.

The objectives of this study were (a) to determine the distribution of Cd and Pb in liver and muscle of 11 demersal fish species with different trophic levels from three estuarine systems, (b) to compare the levels of the studied metals among the three studied areas, and (c) to assess the potential human health risk according to the elemental concentrations in the edible portion of studied fish and the rate of consumption of fish in Mexico.

## Materials and methods

### Study area

The fish were collected at the lagoon systems of Urías, Huizache-Caimanero, and Teacapán-Agua Brava (Fig. 1); the three ecosystems are located in the southern part of Sinaloa state (NW Mexico). Urías is located in the southern portion of Mazatlán harbor; it has an extension of 800 ha and the water residence time is from 5 to 7 days (Soto-Jiménez and Páez-Osuna 2001). Urías lagoon receives urban wastewaters from some parts of Mazatlán harbor, cooling waters from a thermoelectric power plant, and discharges from food industry; such impacts become a severe environmental pressure. Also, the upper lagoon receives untreated shrimp pond effluents. This lagoon has been considered to be highly vulnerable because it exhibits a circulation pattern that favors the accumulation of pollutants (Cardoso-Mohedano et al. 2016a, b). Huizache-Caimanero is also located in the south of Sinaloa state and receives freshwater inputs from Presidio and Baluarte rivers. This system has a mean surface of 17,100 ha, the water residence time is about 67 days. The most relevant impacts derived from anthropogenic activities are related to agriculture, water course deviations, mining, and mangrove deforestation. Teacapán-Agua Brava is located in the southern part of the state of Sinaloa and northern part of the state of Nayarit. The surface of the system is around 38,000 ha, the water residence time is 22.8 days (Flores-Verdugo et al. 1997). Significant anthropogenic impacts are destruction of mangrove ecosystems to convert the areas into agricultural fields and cattle lands.

### Fish sampling

Fish were collected bimonthly by local fishermen during two sampling campaigns (2011–2012 and 2013–2014); samplings from June to October corresponded to the rainy season ($n$ = 223), the rest of the months were considered as dry season ($n$ = 251). With every fish sampling in the months of dry and rainy seasons, salinity, water temperature, and dissolved oxygen were measured in the morning with a multiparameter equipment (YSI model 6600V2-02). Fish specimens were transported to the laboratory in ice boxes. Taxonomic identification (Fischer et al. 1995), total length, fork length, and total weight were determined in the laboratory. Fish were kept frozen (−19 °C) until dissection and processing. Glassware and plastic utensils were acid washed according to the procedure described by Moody and Lindstrom (1977). A portion of muscle tissue from the median dorsal area and the liver was extracted from every individual.

### Analytical procedure

Individual liver and muscle samples were freeze-dried in a Labconco Freeze-dry-System-FreeZone 6 (−49 °C and $133 \times 10^{-3}$ mbar for 72 h); duplicate dried samples were ground and homogenized in an agate mortar. Digestion of powdered samples was made with concentrated nitric acid (trace metal grade) in capped vessels (Savillex TM) on a hot plate at 120 °C for 3 h (MESL 1997; Moreno-Sierra et al. 2016). Cd and Pb were measured by graphite furnace atomic absorption spectrophotometry (GF-AAS, Varian SpectrAA 220). Quality control of analytical runs was assessed by using certified reference materials of fish muscle (DORM-3, NRC-Canada) and liver (DOLT-4, NRC-Canada). The limits of detection (μg $g^{-1}$) were 0.003 for Cd and 0.040 for Pb. Recovery percentages (Pb 103.7; Cd 94.5) and relative standard deviations (RSD; Pb 10%, Cd 0.7%) of DORM-3 and recovery percentages (Pb 103.9; Cd 101.4) and RSD (Pb 18%, Cd 0.4%) of DOLT-4 were acceptable. Results are expressed as micrograms per gram on a dry weight basis.

### Human health risk

Human health risk was assessed by using the hazard index (HI) according to Newman and Unger (2002): $HI = HQ_{Cd} + HQ_{Pb}$. where $HQ_{Cd}$ is the hazard quotient related to Cd concentrations in the edible portion of fish and $HQ_{Pb}$ is the hazard quotient associated to Pb levels in the muscle tissue of fish. For the estimation of hazard from every element we used $HQ = E/RfD$, where $E$ is the exposure level or intake of Cd and Pb, and RfD is the reference dose for Cd (1.0 μg $kg^{-1}$ body weight $day^{-1}$)

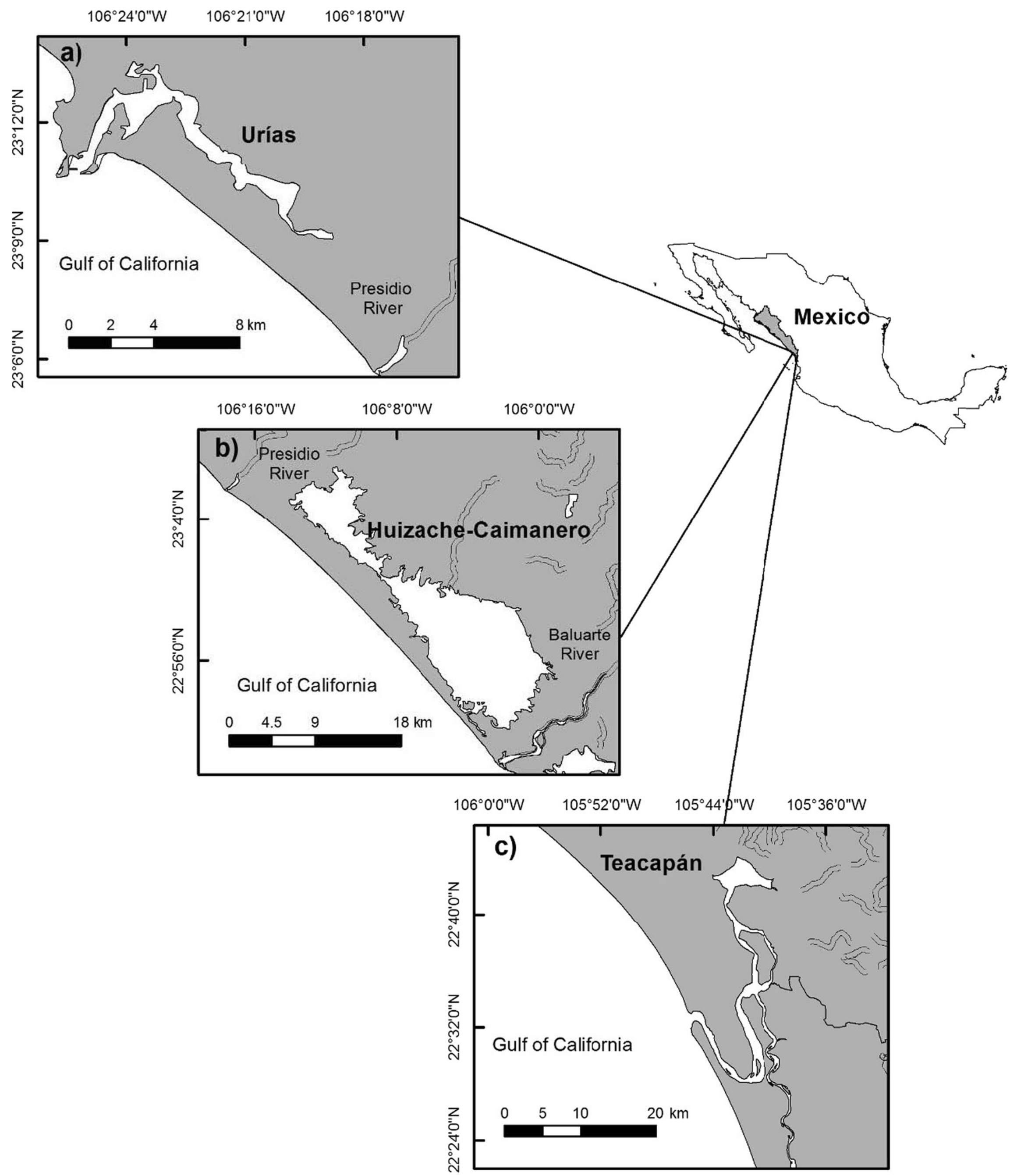



**Fig. 1** Location of the sampling sites in the SE Gulf of California: *a* Urías, *b* Huizache-Caimanero, and *c* Teacapán

(US EPA 2002) and Pb (3.5 μg $kg^{-1}$ body weight $day^{-1}$) (JECFA 1993). The exposure level ($E$) was calculated as $E = C \times I/W$; where $C$ is the concentration of Cd and Pb (on a wet weight basis) in the muscle tissue of fish, $I$ is the ingestion rate of fish (30 g $day^{-1}$) in Mexico, and $W$ is the weight of an average adult (65 kg). Conversion of Cd and Pb concentrations from dry weight (dw) to fresh weight (fw) was made according to the following: $Element_{fw} = Element_{dw} \times (100 - \%\ humidity)/100$, using the humidity percentage in the muscle tissue of every fish species (range 73.8 to 79.4%).

## Statistical analysis

Descriptive statistics (average and standard deviation) of total length and weight of fish and elemental concentrations of studied tissues were calculated; the length at maturity for each species was obtained from length-maturity relationships in previous studies (Amezcua et al. 2009; Muro and Amezcua 2011; Amezcua and Muro-Torres 2012; Froese and Pauly 2016). Variations among metal concentrations according to fish tissue and estuarine system were examined based on a Bray-Curtis similarity matrix of Pb and Cd concentrations.

A non-metric multidimensional scaling (nMDS) was used for the purpose of showing and determining the similarities and dissimilarities of Pb and Cd concentrations according to site and tissue. A crossed, two-way analysis of similarity (ANOSIM) was used to determine if Pb and Cd concentrations differed significantly between tissue and lagoon systems. ANOSIM output is a sample statistic (global R); if the output is close or equal to 1, there is strong dissimilarity between two assemblages, while if it is 0, there is no dissimilarity found between two assemblages (Paramo et al. 2012). If ANOSIM detected differences, then a similarity percentage analysis (SIMPER) was used to determine which fish species contributed most to driving these differences. Analyses were conducted using Primer-E v.6 software (Clarke and Warwick 2001).

## Results and discussion

### Biometric variables

Biometric information of collected ichthyofauna from the three studied areas is shown in Table 1. Eleven fish species from eight families were collected in the three lagoon systems. Considering the number of fish specimens, the sequence of fish abundance was Teacapán > Huizache > Urías. The average total length ranged from 35.7 cm in *Chanos chanos* from Urías to 13.5 cm in *Diapterus peruvianus* from Huizache; in the case of the weight, values ranged from 430.9 g in *Sciades seemani* from Teacapán to 39.8 g in *D. peruvianus* from Huizache. According to length and size at maturity of the collected species, 76.5% of the individuals were juveniles and the rest (23.5%) were adults. However, depending on the fish species, the percentage of juveniles varied: 100.0% of the analyzed individuals of *Cathorops fuerthii*, *Caranx caninus*, *Elops affinis*, and *C. chanos*, 94.5% of *Mugil cephalus*, 78.1% of *Centropomus robalito*, 76.5% of *S. seemanni*, 74.0% of *Pomadasys macracanthus*, 55.6% of *Mugil curema*, 42.0% of *D. peruvianus*, and 21.0% of *Eugerres axillaris*.

### Hydrology characteristics

For all the lagoons, the values of dissolved oxygen and water temperature were higher during the rainy season (summer) than in the dry season; in the case of salinity, it was lower in the rainy season than during the dry months (Table 2). Diverse environmental factors may influence metal absorption and accumulation in fish. Kock et al. (1996) proved that Cd and Pb in liver and kidney of *Salvelinus alpinus* were higher in the summer when water temperature was higher. It appears that elevated water temperatures accelerate fish metabolism that enhances metal accumulation in tissues like kidney and liver (Yang and Chen 1996). Contrary to temperature, water salinity reduces elemental accumulation by fish; in a study with *Gillichthys mirabilis*, it was found that Pb concentration was inversely related to water salinity (Somero et al. 1977). In the case of dissolved oxygen, it appears that there is a negative relationship, i.e., at high levels of dissolved oxygen, there is a low metal accumulation in fish. In a report by Singh et al. (2008), it was found that Cd in water was negatively correlated with dissolved oxygen and this turns in a lower metal availability for fish. In *Urías*, dissolved oxygen ranged from 2.42 in the dry season to 2.50 mg $L^{-1}$ in the rainy season; in 2010, a similar behavior was observed by Izaguirre-Flores et al. (2014) in this lagoon system, i.e., average concentrations of dissolved oxygen in the rainy season (5.99 mg $L^{-1}$) were higher than in the dry season (5.62 mg $L^{-1}$). Water temperature ranged from 25.4 °C (dry season) to 29.3 °C (rainy season); the same pattern (27.1 °C in the dry season and 30.5 °C in the rainy season) was reported in 2010 in this estuarine ecosystem (Izaguirre-Flores et al. 2014). With respect to salinity (units of practical salinity, UPS), values in this study (from 32.0 UPS in the rainy season to 35.7 UPS in the dry season) were comparable to results (29.6–36.1 UPS in the rainy season) given by Izaguirre-Flores et al. (2014). In *Huizache*, dissolved oxygen ranged from 4.65 mg $L^{-1}$ (dry season) to 5.84 mg $L^{-1}$ (rainy season); for the same area, Contreras (1985) reported that this parameter ranged from 3.89 to 8.19 mg $L^{-1}$. Water temperature ranged from 29.9 °C in the rainy season to 25.3 in the dry season; in this lagoon, wide fluctuations of water temperature have been reported in the dry (23 °C) and rainy (33.8 °C) seasons (Contreras 1985). Salinity was the most variable parameter in this water body; the lowest value (8.5 UPS) was registered during the rainy season while the highest (15.0 UPS) corresponded to the dry season. Variability of salinity in this area is related to the climatic conditions and hydrodynamics; during the dry season, some parts of the water body may reach 60 UPS (Botello et al. 2014).

In *Teacapán*, dissolved oxygen concentrations were similar during the dry (4.84 mg $L^{-1}$) and rainy (4.86 mg $L^{-1}$) seasons. Water temperature varied from 26.0 °C (dry season) to 31.2 °C (rainy season), while salinity varied from 24.7 UPS during the rainy season to 28.0 UPS in the dry season; in a study in the same place, dissolved oxygen, temperature, and salinity registered comparable values (López-Aguiar 2006).

### Trace metal concentrations

The levels of Cd in muscle and liver of the studied fish are presented in Table 3. Considering Cd concentrations in the dry and rainy seasons, liver had higher levels than muscle. If sites are compared, fish from Teacapán had higher Cd concentrations in muscle and liver than specimens from the other two lagoons. With respect to individual values, the highest Cd concentration in muscle (0.092 μg $kg^{-1}$ dw) corresponded to

**Table 1** Mean total length (cm), weight (g), and mean length (cm) at sexual maturity of collected specimens from the study sites in the SE Gulf of California

| Species | Common name | Length at maturity | Site | Number | Length | Weight |
|---|---|---|---|---|---|---|
| Ariidae | | | | | | |
| *Cathorops fuerthii* | Congo sea catfish | 35.0 | Urías | 9 | 22.8 ± 1.5 | 129.1 ± 23.5 |
| | | | Huizache | 16 | 24.3 ± 4.3 | 128.6 ± 66.0 |
| | | | Teacapán | 9 | 20.3 ± 3.8 | 78.9 ± 43.8 |
| *Sciades seemanni* | Tete sea catfish | 36.0 | Urías | 15 | 30.0 ± 4.6 | 244.5 ± 152.6 |
| | | | Huizache | 17 | 27.2 ± 5.4 | 200.4 ± 167.7 |
| | | | Teacapán | 18 | 34.4 ± 3.0 | 430.9 ± 173.2 |
| Carangidae | | | | | | |
| *Caranx caninus* | Pacific crevalle Jack | 49.8 | Urías | 9 | 22.4 ± 4.9 | 164.3 ± 120.3 |
| | | | Huizache | 18 | 17.8 ± 2.5 | 87.0 ± 32.8 |
| | | | Teacapán | 8 | 18.9 ± 3.0 | 106.7 ± 58.5 |
| Centropomidae | | | | | | |
| *Centropomus robalito* | Yellowfin snook | 23.5 | Urías | 11 | 22.1 ± 1.5 | 115.0 ± 28.1 |
| | | | Huizache | 12 | 20.8 ± 3.2 | 96.8 ± 34.5 |
| | | | Teacapán | 9 | 22.2 ± 2.4 | 144.7 ± 33.2 |
| Chanidae | | | | | | |
| *Chanos chanos* | Milkfish | 65.0[a] | Urías | 14 | 35.7 ± 2.1 | 370.3 ± 113.8 |
| | | | Huizache | 5 | 31.5 ± 8.4 | 301.6 ± 108.9 |
| | | | Teacapán | 46 | 33.2 ± 4.5 | 296.4 ± 143.0 |
| Elopidae | | | | | | |
| *Elops affinis* | Machete fish | 50.0 | Urías | 15 | 29.8 ± 3.9 | 134.7 ± 54.9 |
| | | | Huizache | 10 | 28.5 ± 4.6 | 126.0 ± 61.9 |
| | | | Teacapán | 15 | 26.3 ± 4.4 | 110.8 ± 53.0 |
| Gerridae | | | | | | |
| *Diapterus peruvianus* | Peruvian mojarra | 15.5 | Urías | 11 | 18.0 ± 1.8 | 92.1 ± 28.1 |
| | | | Huizache | 13 | 13.5 ± 1.1 | 39.8 ± 11.7 |
| | | | Teacapán | 15 | 15.7 ± 1.5 | 57.4 ± 9.5 |
| *Eugerres axillaris* | Black axillary Mojarra | 14.5 | Urías | 13 | 18.6 ± 2.7 | 107.1 ± 57.2 |
| | | | Huizache | 12 | 15.7 ± 1.8 | 62.6 ± 26.6 |
| | | | Teacapán | 14 | 14.5 ± 3.7 | 61.1 ± 44.3 |
| Haemulidae | | | | | | |
| *Pomadasys macracanthus* | Longspine grunt | 22.5 | Urías | 11 | 20.3 ± 1.7 | 124.1 ± 75.4 |
| | | | Huizache | 8 | 19.3 ± 3.2 | 102.7 ± 31.4 |
| | | | Teacapán | 12 | 22.1 ± 3.0 | 162.7 ± 64.9 |
| Mugilidae | | | | | | |
| *Mugil cephalus* | Gray mullet | 37.5[a] | Urías | 11 | 28.2 ± 6.9 | 231.8 ± 126.3 |
| | | | Huizache | 33 | 28.1 ± 3.3 | 201.4 ± 61.9 |
| | | | Teacapán | 11 | 31.2 ± 2.7 | 325.9 ± 232.4 |
| *Mugil curema* | White mullet | 27.6[a] | Urías | 12 | 26.7 ± 3.5 | 187.5 ± 75.4 |
| | | | Huizache | 17 | 24.8 ± 1.7 | 149.0 ± 72.6 |
| | | | Teacapán | 25 | 28.2 ± 5.6 | 218.1 ± 52.3 |

[a] Data taken from fishbase.org

*M. curema* collected during the rainy season in Urías; in the liver, the highest Cd value (10.67 μg $kg^{-1}$ dw) was measured in *D. peruvianus* collected from Huizache during the rainy season. The issue of a differential metal accumulation in fish tissues is related to the function that the organs and tissues play; in the case of liver, its metabolic and detoxifying functions (Yilmaz 2009) enhance higher Cd levels than other tissues. The differences of Cd levels among fish species may be

**Table 2** Results of dissolved oxygen (mg $L^{-1}$), salinity (UPS), and water temperature (°C) in the studied sites during the dry and rainy seasons

| Site | Parameter | Dry season | Rainy season |
|---|---|---|---|
| Urías | Dissolved oxygen | 2.42 ± 1.01 | 2.50 ± 1.77 |
| | Salinity | 35.66 ± 2.71 | 31.96 ± 2.77 |
| | Water temperature | 25.41 ± 2.71 | 29.31 ± 0.43 |
| Huizache | Dissolved oxygen | 4.65 ± 2.20 | 5.84 ± 2.14 |
| | Salinity | 15.02 ± 11.96 | 8.46 ± 7.95 |
| | Water temperature | 25.30 ± 3.49 | 29.9 ± 2.10 |
| Teacapán | Dissolved oxygen | 4.84 ± 1.44 | 4.86 ± 1.85 |
| | Salinity | 27.96 ± 11.10 | 24.66 ± 8.49 |
| | Water temperature | 25.98 ± 3.29 | 31.18 ± 0.72 |

closely related to the feeding behavior, as mentioned by Allen-Gil et al. (1997) who found that fish species with a diet enriched in mollusks have elevated levels of Cd.

With respect to Pb, tissue distribution in analyzed ichthyofauna is presented in Table 4. Similar to Cd concentrations, levels of Pb were higher in liver than in muscle; with respect to the sites, mean levels of Pb were higher in Huizache than in Urías and Teacapán. Regarding individual values, the highest Pb concentrations were measured during the rainy season in the muscle (1.01 μg $kg^{-1}$ dw) and liver (6.01 μg $kg^{-1}$ dw) of *D. peruvianus* from Urías and Huizache, respectively. Fish liver participates in diverse metabolic processes and protection against xenobiotics (Arockia et al. 2013; Sia Su et al. 2013), such involvement implies that this organ accumulates more pollutants; although the fish under study showed no macroscopic damages, it has been demonstrated that Pb has the potential to exert toxicity to cell and genetic material through the formation of reactive oxygen species in the freshwater fish *Prochilodus lineatus* (Monteiro et al. 2011).

To determine if differences existed in the concentrations of Cd and Pb according to tissue (muscle and liver) and locality (Urías, Huizache, and Teacapán), multivariate analyses were performed. The nMDS analysis for Cd showed a clear

**Table 3** Concentrations of Cd (μg $g^{-1}$ dry weight) in muscle and liver of fish from the studied areas

| Species | Urías | | Huizache | | Teacapán | |
|---|---|---|---|---|---|---|
| | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Muscle | | | | | | |
| *Chanos chanos* | 0.026 | 0.011 | 0.015 | 0.009 | 0.032 | 0.036 |
| *Mugil curema* | 0.092 | 0.013 | 0.025 | 0.047 | 0.042 | 0.048 |
| *Mugil cephalus* | 0.039 | 0.011 | 0.015 | 0.037 | 0.011 | 0.013 |
| *Diapterus peruvianus* | 0.009 | 0.006 | 0.046 | 0.015 | 0.007 | 0.011 |
| *Pomadasys macracanthus* | 0.050 | 0.013 | 0.016 | 0.007 | 0.083 | 0.013 |
| *Eugerres axillaris* | 0.012 | 0.009 | 0.011 | 0.004 | 0.015 | 0.007 |
| *Cathorops fuerthii* | 0.015 | 0.006 | 0.051 | 0.014 | 0.013 | 0.012 |
| *Centropomus robalito* | 0.013 | 0.016 | 0.009 | 0.003 | 0.035 | 0.032 |
| *Cynoscion xanthulus* | NA | 0.018 | 0.026 | 0.024 | NA | 0.031 |
| *Elops affinis* | 0.035 | <LD | 0.058 | 0.006 | 0.003 | 0.011 |
| *Caranx caninus* | 0.006 | 0.003 | 0.014 | 0.050 | 0.032 | 0.026 |
| *Sciades seemanni* | 0.070 | <LD | 0.008 | 0.036 | 0.009 | 0.035 |
| Liver | | | | | | |
| *C. chanos* | 0.21 | 0.38 | 0.56 | 0.21 | 0.41 | 0.31 |
| *M. curema* | 0.77 | 3.36 | 1.48 | 2.84 | 0.73 | 1.13 |
| *M. cephalus* | 0.93 | 1.80 | 2.89 | 2.26 | 1.17 | 1.45 |
| *D. peruvianus* | 1.93 | 0.93 | 10.67 | 1.62 | 0.96 | 1.39 |
| *P. macracanthus* | 0.48 | 0.99 | 1.51 | 1.51 | 0.98 | 3.35 |
| *E. axillaris* | 0.32 | 0.41 | 0.23 | 0.39 | 1.47 | 0.66 |
| *C. fuerthii* | 0.18 | 0.35 | 1.30 | 1.35 | 0.87 | 1.70 |
| *C. robalito* | 0.89 | 0.56 | 0.20 | 0.45 | 7.16 | 0.43 |
| *C. xanthulus* | NA | 0.13 | 0.32 | 0.29 | NA | 2.85 |
| *E. affinis* | 0.16 | 0.86 | 0.40 | 0.44 | 0.25 | 0.11 |
| *C. caninus* | 0.92 | 1.30 | 1.63 | 1.54 | 4.07 | 1.99 |
| *S. seemanni* | 0.17 | 0.32 | 0.79 | 1.68 | 2.10 | 0.63 |

*NA* not available, *LD* limit of detection of Cd (0.003 μg $g^{-1}$)

**Table 4** Concentrations of Pb (μg g$^{-1}$ dry weight) in muscle and liver of fish from the studied areas

| Species | Urías | | Huizache | | Teacapán | |
|---|---|---|---|---|---|---|
| | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Muscle | | | | | | |
| *Chanos chanos* | 0.12 | 0.13 | 0.16 | 0.12 | 0.18 | 0.24 |
| *Mugil curema* | 0.14 | 0.10 | 0.34 | 0.24 | 0.14 | 0.19 |
| *Mugil cephalus* | 0.34 | 0.11 | 0.23 | 0.22 | 0.12 | 0.15 |
| *Diapterus peruvianus* | 1.01 | 0.13 | 0.24 | 0.21 | 0.33 | 0.10 |
| *Pomadasys macracanthus* | 0.74 | 0.13 | 0.07 | 0.63 | 0.29 | 0.05 |
| *Eugerres axillaris* | 0.20 | 0.19 | 0.18 | 0.13 | 0.45 | 0.31 |
| *Cathorops fuerthii* | 0.29 | 0.05 | 0.11 | 0.07 | 0.18 | 0.10 |
| *Centropomus robalito* | 0.06 | 0.09 | 0.11 | 0.11 | 0.15 | 0.17 |
| *Cynoscion xanthulus* | NA | 0.23 | 0.35 | 0.13 | NA | 0.50 |
| *Elops affinis* | 0.30 | 0.06 | 0.48 | 0.29 | 0.30 | 0.23 |
| *Caranx caninus* | 0.24 | 0.07 | 0.24 | 0.18 | 0.11 | 0.11 |
| *Sciades seemani* | 0.13 | 0.05 | 0.26 | 0.14 | 0.11 | 0.11 |
| Liver | | | | | | |
| *C. chanos* | 0.41 | 0.14 | 0.15 | 0.15 | 0.35 | 0.55 |
| *M. curema* | 0.34 | 0.29 | 0.25 | 0.48 | 0.56 | 0.34 |
| *M. cephalus* | 0.25 | 0.32 | 0.62 | 0.36 | 0.27 | 0.28 |
| *D. peruvianus* | 4.26 | 1.06 | 6.01 | 2.42 | 1.31 | 1.39 |
| *P. macracanthus* | 0.51 | 0.88 | 0.42 | 0.41 | 0.95 | 0.27 |
| *E. axillaris* | 0.58 | 0.98 | 0.33 | 0.64 | 1.52 | 1.60 |
| *C. fuerthii* | 0.51 | 0.72 | 0.39 | 0.57 | 2.24 | 0.62 |
| *C. robalito* | 0.21 | 0.06 | 0.29 | 0.33 | 0.08 | 0.11 |
| *C. xanthulus* | NA | <LD | 0.09 | 0.13 | NA | 0.30 |
| *E. affinis* | 0.27 | 0.49 | 0.33 | 1.65 | 0.68 | 0.50 |
| *C. caninus* | 0.15 | 0.06 | 0.84 | 0.11 | 0.24 | 0.17 |
| *S. seemani* | 0.54 | 0.25 | 0.51 | 0.49 | 0.92 | 0.29 |

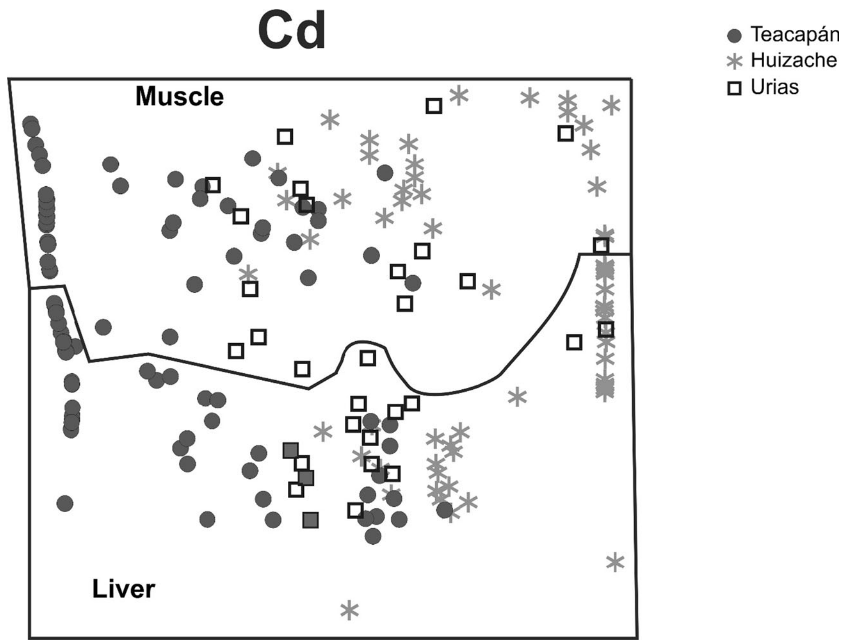
*NA* not available, *LD* limit of detection of Pb (0.040 μg g$^{-1}$)

separation between the concentrations in fish from Teacapán and Huizache, but the group Urías did not show a clear separation, although all the samples from the former system seemed to be grouped together (Fig. 2). However, the concentrations of Cd in liver and muscle did show a clear cut separation. ANOSIM corroborated the observed differences with nMDS analysis. The Cd concentrations between all localities were statistically different, as were the concentrations between liver and muscle (Table 5). According to SIMPER, the differences between places were caused because the concentration of Cd was lower in Teacapán than in the other two systems for most of the species with the exception of *C. chanos*, which showed higher values in the southern system. Between Huizache and Urías, the differences were caused by the mullets; *M. curema* showed higher concentration of Cd in Urías, while *M. cephalus* showed a larger Cd concentration in Huizache. In the case of the tissues, the differences observed were due to a higher Cd concentration in liver than in muscle, especially for both species of mullets (Table 5).

Regarding Pb concentration, nMDS showed a similar accommodation to the one of Cd, with clear cut groups formed according to the locality, specifically for Teacapán and Huizache, and a cluster for the organisms in Urías, which although are mixed with the organism from the other two systems, the individuals from this system are quite close (Fig. 3). Clear cut groups were formed according to the tissue, with a clear separation between the concentrations in liver and muscle. These groups were also corroborated by ANOSIM, as this analysis indicated that Pb concentration between all localities and between tissues were statistically different (Table 5). From SIMPER, it was determined that in Teacapán, the Pb concentrations in fish tissue were in general lower than in the other systems, with the exception of *C. chanos* which also showed higher Pb concentrations in this system than in the other two. Between Urías and Huizache, the differences were caused by *S. seemani* and *E. axillaris* which had higher Pb concentrations in Urías, while *D. peruvianus* had a higher Pb concentration in Huizache. Regarding tissue, Pb concentrations were higher in liver than in muscle, similar to what occurred with Cd.

Among the studied systems, Urías lagoon is the smallest and the one that presents major anthropogenic impacts (agriculture, mining, municipal and port waste, seafood processing, thermoelectric and commercial, touristic, and fishing harbor). According to the impact agents, it was expected to find a major concentration of both metals in this area. However, some species had higher concentrations in Huizache. This may be due to the hydrodynamics of Huizache lagoon; it has the longest turnover time (67 days) in comparison to Urías (5–7 days) and Teacapán (22.8 days), due to a restricted connection with the sea, which does not allow a fast water flow, generating a larger residence of the waters and metals in the system (Del Río 2003). It is important to visualize that for certain species, the concentration of both metals was higher in the Huizache system, which is most likely related with fish behavior and feeding habits and the hydrodynamics of the lagoon. Finally, the fact that *Chanos chanos* showed elevated concentrations of both metals in Teacapán lagoon (where overall concentrations were low but there are agricultural fields and mining activities in the upper basin) might be indicating that in certain areas of the system, the concentrations of these metals are higher and coincide with the sites where this species is feeding and metals are not as available to all the fish species as in other areas. Teacapán is a system close to agricultural fields, and also related to mining; therefore, it is possible that certain parts of the system have higher concentrations of trace metals, but these are not available to all the fish species, but to certain fish depending on their habits and feeding

Fig. 2 Results of two-way analysis of similarity (ANOSIM) of Cd in the studied lagoon systems




behavior. However, to draw such a conclusion, further studies are needed focusing on certain species; such studies are beyond the scope of this work.

The higher concentration of both metals in liver may be due to their affinity for accumulating in this tissue since it is a metabolically active organ (Yilmaz 2009). Liver has also a depurative function that increases the exposure to contaminants; besides having a complex mechanism of protection against contaminants such as lead, it prevents metals from reaching other organs by the presence of fat granules, glutathione, or the formation of metallothioneins (Arockia et al. 2013; Sia Su et al. 2013). The muscle accumulation, on the other hand, depends on different routes of absorption and biotransformation that change its availability and toxicity (Mormede and Davies 2001; Fisher and Hook 2002) before reaching this tissue (Jebali et al. 2014). Muscle tissue plays no role in blood detoxification; because of this, cadmium and lead do not accumulate in muscle in the same extent as in liver (Karadede and Unlü 2000).

Table 5 ANOSIM test for total concentration of cadmium (Cd) and lead (Pb) in all species analyzed in relation to the factors locality and tissue

| Factor | | Cd | | Pb | |
|---|---|---|---|---|---|
| | | *R* | % | *R* | % |
| Locality | General | 0.443 | 0.001 | 0.537 | 0.1 |
| | Huizache–Teacapán | 0.623 | 0.001 | 0.708 | 0.1 |
| | Huizache-Urías | 0.096 | 0.2 | 0.175 | 0.1 |
| | Teacapán-Urías | 0.31 | 0.001 | 0.419 | 0.1 |
| Tissue | Muscle-liver | 0.311 | 0.001 | 0.780 | 0.1 |

## Health risk assessment

Considering that Cd and Pb are detrimental to human health, the hazard quotients (HQs) for every element and the hazard index (combined elements; HI) were estimated according to the elemental concentrations in the edible tissue and the rate of fish consumption in Mexico (Table 6). In general, HQ values were higher for Pb than for Cd; it means that the risk from consuming fish with the actual elemental concentrations is higher for Pb than for Cd. The highest HQ values for Cd (0.0051) were detected in *M. curema*; in the case of Pb, the highest figure (0.0099) corresponded to *D. peruvianus.* With respect to HI, the most elevated value (0.0124) was estimated for *P. macracanthus*. If it is considered that an HI >1 is

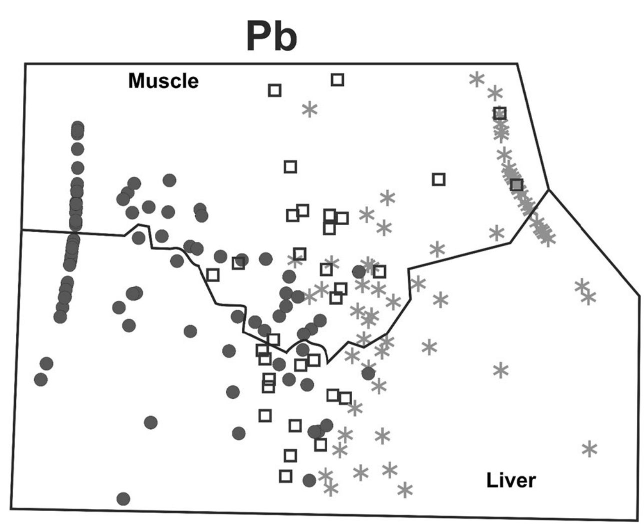



Fig. 3 Results of two-way analysis of similarity (ANOSIM) of Pb in the studied lagoon systems

**Table 6** Averaged values of Cd and Pb (μg $g^{-1}$) in muscle tissue of studied fish and corresponding hazard quotients (HQ) and hazard index (HI)

| Species | Cddw | Pbdw | Humidity (%) | Cdfw | Pbfw | HQCd | HQPb | HI |
|---|---|---|---|---|---|---|---|---|
| *Chanos chanos* | 0.022 | 0.158 | 73.8 | 0.0057 | 0.0413 | 0.0026 | 0.0054 | 0.0080 |
| *Mugil curema* | 0.045 | 0.192 | 74.3 | 0.0110 | 0.0493 | 0.0051 | 0.0065 | 0.0116 |
| *Mugil cephalus* | 0.021 | 0.195 | 75.1 | 0.0052 | 0.0485 | 0.0024 | 0.0064 | 0.0088 |
| *Diapterus peruvianus* | 0.016 | 0.337 | 77.5 | 0.0036 | 0.0758 | 0.0017 | 0.0099 | 0.0116 |
| *Pomadasys macracanthus* | 0.030 | 0.318 | 77.7 | 0.0067 | 0.0709 | 0.0031 | 0.0093 | 0.0124 |
| *Eugerres axillaris* | 0.010 | 0.243 | 79.4 | 0.0021 | 0.0501 | 0.0010 | 0.0066 | 0.0076 |
| *Cathorops fuerthii* | 0.019 | 0.133 | 77.3 | 0.0043 | 0.0302 | 0.0020 | 0.0039 | 0.0059 |
| *Centropomus robalito* | 0.018 | 0.115 | 75.1 | 0.0045 | 0.0286 | 0.0021 | 0.0038 | 0.0059 |
| *Cynoscion xanthulus* | 0.025 | 0.303 | 77.3 | 0.0057 | 0.0687 | 0.0026 | 0.0091 | 0.0117 |
| *Elops affinis* | 0.019 | 0.277 | 77.2 | 0.0043 | 0.0631 | 0.0020 | 0.0083 | 0.0103 |
| *Caranx caninus* | 0.022 | 0.158 | 75.0 | 0.0055 | 0.0395 | 0.0025 | 0.0052 | 0.0077 |
| *Sciades seemani* | 0.027 | 0.133 | 76.6 | 0.0063 | 0.0311 | 0.0029 | 0.0041 | 0.0070 |

*dw* dry weight, *fw* fresh weight

indicative of a high exposure in relation to the reference doses of both elements, even the highest HI values were low, i.e., there is no potential risk of non-carcinogenic effects at the fish ingestion rates in the current study. In a monitoring of trace metals using fish from a polluted wetland in Louisiana (USA), an HQ for Cd of 0.051 was found; the authors considered an average weight of an adult (70 kg) and a fish ingestion of 30 g $day^{-1}$ (Tchounwou et al. 1996) similar to our study; though the estimated HQ was an order of magnitude higher than in our study, it is also very far from being a risk for consumers. In fish from the Eastern Pacific bordering Mexico, studies dealing with health risk assessments due to metal exposure are scarce; HQ values for Hg in bycatch fish from the continental shelf ranged from 0.02 (*Prionotus* sp.) to 0.75 (*Micropogonias ectenes*); the authors concluded that at the consumption rate of theses bycatch fish and Hg levels in their muscle, there was no risk of adverse effects (Spanopoulos-Zarco et al. 2014).

## Conclusion

According to biometric results, specimens of some species were mostly in the juvenile stage and others were adults. From 94 to 100% of *C. fuerthii*, *C. caninus*, *E. affinis*, *C. chanos*, and *M. cephalus* were juveniles. From 55 to 78% of *C. robalito*, *S. seemanni*, *P. macracanthus*, and *M. curema* were also juveniles. For *D. peruvianus* and *E. axillaris*, most of the specimens were adults (58 and 79%, respectively). With respect to tissue distribution of metals, levels of Cd and Pb were higher in liver than in muscle. Considering the studied lagoons, in Teacapán, the average Cd concentrations were the highest in both tissues; for Pb, ichthyofauna from Huizache had higher levels than individuals from the other sites. Multivariate analyses showed a clear separation of Cd concentrations between fish from Teacapán and Huizache. For Pb, concentrations in fish were different among the three lagoons. According to HI values considering the combination of Cd and Pb, the health risk for fish consumers is very low.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

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