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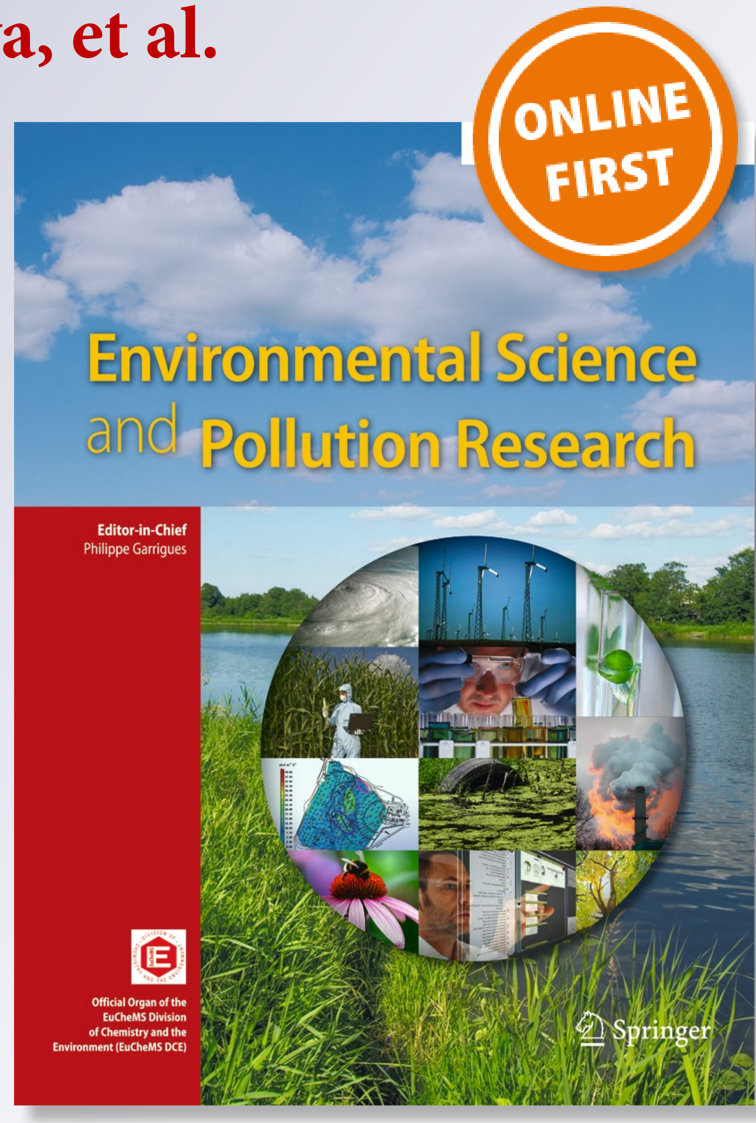

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RESEARCH ARTICLE

Distribution and health risk assessment of Cd and Pb in two marine fishes (*Haemulopsis axillaris* and *Diapterus peruvianus*) from the Eastern Pacific

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Abstract

The aim of this study was to determine the distribution of cadmium (Cd) and lead (Pb) in muscle and liver tissue of *Haemulopsis axillaris* and *Diapterus peruvianus* from the Eastern Pacific in Mexico and to assess the health risk to consumers. Fish were collected as bycatch on the continental shelf between the coasts of Sinaloa and Guerrero (Eastern Pacific). Cd and Pb were quantified in muscle and liver tissue using graphite-furnace atomic absorption spectrophotometry (GF-AAS).

Concentration of Cd was greater in muscle tissue than in liver tissue; with Pb, however, the opposite pattern was found. The highest concentration of Cd (0.177 $\mu g\ g^{-1}$) was found in muscle tissue of *H. axillaris* from Sinaloa. For Pb, the highest level (0.692 $\mu g\ g^{-1}$) was found in the liver tissue of *H. axillaris* also from Sinaloa. Levels of Cd and Pb in muscle tissue were both below Mexican Guidelines (0.5, 1.0 $\mu g\ g^{-1}$ wet weight for Cd and Pb respectively) and International Guidelines. The hazard index (HI) for both metals in the edible portion of studied considering metal levels in the edible portion and the rate of fish consumption by the Mexican population (in adults and children) was less than 1 (HI < 1), values which do not represent a health risk to consumers.

Keywords Cd · East Pacific · Health risk assessment · Pb · Tissue distribution

Introduction

Mexico is considered one of 11 mega diverse countries. It hosts between 60 and 70% of the planet biodiversity, and it is estimated that Mexico is home to 10% of the global biodiversity (Mittermeier and Goettsch 1992). The Mexican coastal zone is geomorphologically diversified, with tropical, subtropical, and temperate zones. Thus, a large number of marine habitats have developed and a large (and often rich) variety of resources can be found, from sandy and rocky beaches to seagrass beds, mangroves, coral reefs, estuaries, and a large number of coastal lagoons. However, contamination of water systems with heavy metals has become an important problem even at low concentrations (Van den Broek et al. 2002; Sobhanardakani et al. 2012). Harmful trace metal pollution of the aquatic environment, and its subsequent impact on organisms, is more dramatic within estuaries, lagoons, and semi-closed coastal zones, especially when they are near highly populated or industrial areas.

Some studies have shown that fish accumulate and retain heavy metals from their environment. Metals accumulate as fish absorb metal-enriched sediments through their epidermis, gills, or digestive tract. The bioaccumulation of trace metals can be attributed to the feeding and swimming habits of different fish species as well as the physical/chemical conditions of the water column (Metian et al. 2013; Jonathan et al. 2015). Once heavy metals have been accumulated by an aquatic organism, they can be transferred into the higher levels of the food web. Carnivores, including humans, obtain most of their

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heavy metal load via food from the aquatic ecosystem, especially fish, so there exists the potential for considerable biomagnification (Mance 1987; Langston 1990; Sobhanardakani 2017) and potential negative effects (Copat et al. 2012; Kareem et al. 2015). Of the list of priority contaminants from the Environmental Protection Agency (U.S. Environmental Protection Agency 2002), thirteen trace elements including cadmium and lead are the most toxic and available (Hosseini et al. 2015).

The increased use of Cd as well as emissions from its production, together with emissions from steel and Pb production, burning of fossil fuels, use of phosphate fertilizers, and waste dumping in past decades, combined with the long-term persistence of Cd in the environment, have all reinforced the concerns first signaled by the outbreak of itai-itai disease, a painful result of chronic cadmium poisoning. Indeed, many studies consider Cd to be one of the most toxic elements in the environment (Ming-Ho 2005). However, Cd is considered a normal component of marine sediments in some sites and of phosphoric rocks (Páez-Osuna 2001). But Cd accumulates mainly in the liver and kidney of organisms and is known to damage the mechanisms of ion regulation in them (Hellawell 1989).

Small levels of Pb occur naturally in the air, surface waters, soils, sediments, and rocks. Because of its properties, Pb has been used for thousands of years in a variety of products, including glass, paint, pipes, building materials, and weapons. Starting in the industrial revolution, and particularly since World War II, the use of Pb has accelerated. Such widespread use has led to elevated Pb concentrations in various ecosystems. Until recently, the primary source of environmental Pb was the combustion of leaded gasoline (Ming-Ho 2005; Sobhanardakani et al. 2018). Pb is a metal of high toxicity for humans (ATSDR 1992). Pb is toxic to the central and peripheral nervous system, inducing neurological damage and behavioral effects (Tong et al. 2015). It is also a toxic element that accumulates in the skeleton. Similarly, it has been found that Pb may damage muscle fibers in fish (Sia Su et al. 2013); it might cause population alteration due to the inability of fish to escape from predators and catch preys.

The fish *H. axillaris* and *D. peruvianus* are distributed from Sonora, Mexico, to Peru (Jiménez -Prado and Beárez 2004). They live mainly in shallow waters close to the coast on sandy and silty bottoms, although juvenile *D. peruvianus* may be found in mangrove swamps and tidal current areas. *H. axillaris* feeds on fish and crustaceans, while *D. peruvianus* consumes polychaetes and crustaceans. *D. peruvianus* is commonly captured in gill nets and trawls and, frequently, on baited hooks. *D. peruvianus* is sold fresh and its meat is of high quality and medium price. *H. axillaris* is captured in gill nets and trawls and with baited hooks; it is sold fresh and its meat, like that of all members of its family, is highly valued (Jiménez -Prado and Beárez 2004). Annually, in Mexico, about 2400 t and 5500 t, respectively, of each fish, are captured and distributed in the local and national markets. However, it is important to clarify that commonly, other four species are also included under the name "mojarra" (ISAPESCA. Instituto Sinaloense de Acuacultura y Pesca 2013).

Human consumption of fish is desirable because fish provide an excellent source of high-quality proteins and fatty acids such as omega-3 (Hosseini et al. 2013a). Currently, omega-3 fatty acids in fish oil are preferred in cardiovascular disease prevention (Sharma and Katz 2011). In fact, worldwide fish consumption increased from 9.9 kg per capita in 1960 to 19.2 kg in 2012 (FAO. Organización de las Naciones Unidas para la Alimentación y la Agricultura 2014).

The consumption of food has been identified as the primary route of human exposure to trace metals (Hosseini et al. 2013b). Risk to human health by Cd and Pb can also include non-cancerous pathologies (U.S. Environmental Protection Agency 1989). The hazard quotient (HQ) allows an estimation of human health risk considering the rate of consumption and pertaining metal concentration in food stuffs, and a reference dose (RfD). The RfD is the degree of metal exposure below which no adverse effects occur. In the case of Cd and Pb, the RfDs are 1 μg/body weight/day and 4 μg/body weight/day respectively. When determining HQ, values above one indicate potential effects on health of consumers.

Considering the lack of food of high quality in terms of protein supply, it is of high concern that shrimp fisheries catch 10 kg of bycatch for 1 kg of shrimp (Alverson et al. 1994). It is necessary to generate information related to the presence of toxic metals in fishery products for human and animal consumption. In this context, the purposes of this study are (a) to quantify Cd and Pb in the muscle and liver tissue of *H. axillaris* and *D. peruvianus*; and (b) to estimate the potential risk to consumer health relative to the levels of Cd and Pb in the edible portion.

Materials and methods

The west coast of the state of Guerrero is located in the Marine Ecoregion of North America number 17, known as the Mexican Pacific Transition region, located between 16° 35′ 24″ and 17° 28′ 12″ N, and between 99° 25′ 12″ and 100° 33′ W coordinates (Fig. 1). It is a coastal zone with marshes, wetlands, dunes, beaches, and lagoons. Oceanographically, the Costa Rica and North Equatorial surface marine currents have a dominant effect in this region, where a regime of semi daily mixed tides with high swell are present (Arriaga et al. 1998). Sinaloa is located in northwest Mexico. Its littoral zone is 640-km long and its estuaries and coastal lagoons occupy an area of 221,600 ha. Although both states receive a large number of visitors, Sinaloa has a larger population (2.97 million

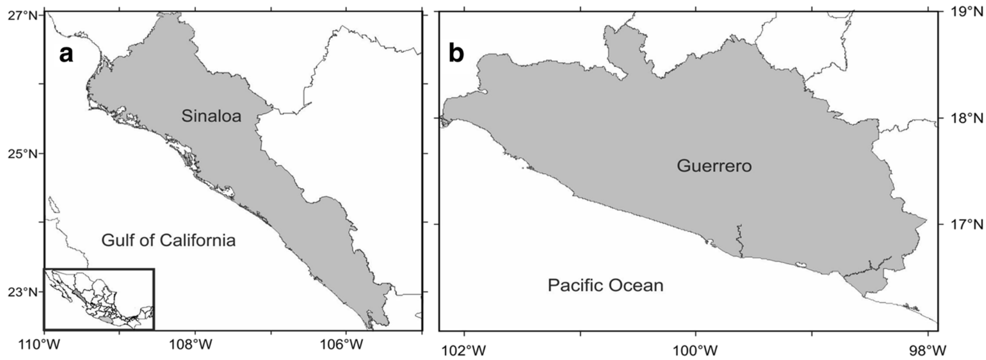

Fig. 1. Location of bycatch fish collection on two sites on the Eastern Pacific

people, INEGI. Instituto Nacional de Estadística y Geografía 2016) and greater agricultural, livestock, and fishing activity. Sinaloa is the country's leading agricultural state, sometimes known as the "breadbasket of Mexico." In Sinaloa, 1.25 million ha are cultivated, producing around 9.4 million tons of corn, beans, and vegetables (Páez-Osuna et al. 2007).

Fish were collected as bycatch using trawl nets in the coastal waters of the continental shelf (depth range 30 to 46 m) in front of Sinaloa and Guerrero using shrimp boats based out of Mazatlán (Fig. 1). A total of 191 fish samples from Guerrero were collected in November 2011; 80 fish samples from Sinaloa were collected in March 2011.

Liver tissue and muscle tissue from the dorsal area were used for the analysis. Biological samples were freeze-dried for 72 hours (− 49 °C and 133 × 10^{-3} mBar) then ground and homogenized in an agate mortar. Powdered samples were acid digested (5 mL concentrated nitric acid, trace metal grade) using Teflon vials with caps (Savillex) at 120 °C for 3 h (MESL 1997). Trace elements were quantified by graphite-furnace atomic absorption spectrophotometry (GF-AAS); all determinations were made in a Varian SpectrAA220. The analytical conditions for Cd and Pb analyses were established according to the manufacturer manual. The quality of the analyses was evaluated using reference materials for muscle (DORM-3) and liver (DOLT-4). Successful recoveries were obtained for cadmium (DORM-3 95.2%, DOLT-4 81.6%) and lead (DORM-3 86.1%, DOLT-4 109.2%). The detection limits were 0.009 and 0.075 μg g^{-1} for Cd and Pb respectively.

Levels of Cd and Pb in muscle tissue were compared with maximum permissible limits in fish for human consumption under Mexican legislation. Hazard index (HI) was estimated to assess health risk from fish intake by using the equation $HI = HQ_{Cd} + HQ_{Pb}$ (Newman and Unger 2002) where HQ = E/RfD, and E is the level of exposure or metal intake of Cd and Pb and RfD is the reference dose (U.S. Environmental Protection Agency 2002) for the elements (Cd = 1.0 and Pb = 3.5 μg kg^{-1} body weight day^{-1}). The level of exposure, E, is calculated as E = C × I/W, where C is the concentration of the element in fish (μg g^{-1} wet weight), I is the ingestion rate of fish per capita (32 g day^{-1}, assuming an ingestion of 11.7 kg per year, SAGARPA. Secretaría de Agricultura and Ganadería y Desarrollo Rural Pesca y Alimentación 2013), and W is the average weight of an adult (70 kg). Additionally, the level of exposure was calculated for children, with an average body weight of 15 kg. The estimation of the HQ is done for an individual element; however, it is desirable to determine simultaneously the potential risk that the presence of more than one toxic element implies. In order to estimate the potential risk to human health from a heavy metal combination (HI), the following equation was used (Zheng et al. 2007): HI = HQ (metal 1) + HQ (metal 2) + HQ (metal 3). The interpretation of HI is similar to that of HQ; values above one indicate potential negative effects on health.

Metal concentrations were converted from dry weight (dw) to wet weight (ww) according to the humidity percentage using the equation $Element_{ww} = element_{dw} \times (100 - \%\ humidity)/100$ (Magalhães et al. 2007). Concentrations of Cd and Pb in analyzed ichthyofauna were compared using a Mann-Whitney test ($p < 0.05$ was considered statistically significant). Additionally, the variation of Cd and Pb concentrations in muscle and liver with length and weight of fish were estimated through the Pearson correlation test. All statistical analyses were performed using IBM SPSS Statistics 19.

Results and discussion

Biometric characteristics of fish species collected from the coastal waters of the states of Guerrero and

Sinaloa are presented in Table 1. Average length and weight of *H. axillaris* fish ranged from 19.4 to 27.0 cm and from 86.2 to 234.0 g, respectively; in the case of *D. peruvianus*, mean length and weight varied from 16.8 to 21.0 cm and from 63.7 to 149.0 g respectively. In both sampling areas, *D. peruvianus* was more abundant than *H. axillaris*. Based on total length, *H. axillaris* and *D. peruvianus* from Sinaloa were adults; individuals of both species from Guerrero were juveniles (Jiménez-Rosenberg et al. 2003).

On average, Pb concentrations were more elevated than Cd (Table 2). Concentrations of Cd followed a sequence muscle > liver, while with Pb, the opposite pattern was found.

Table 1 Biometric characteristics of fish species collected on coastal waters of Guerrero and Sinaloa (Mexico)

Species	Common name	N	Trophic level	Total length (cm)	Total weight (g)
Sinaloa					
Haemulopsis axillaris	Yellowstripe grunt	47	3.5	27.0 ± 3.0	234.0 ± 92.0
Diapterus peruvianus	Peruvian mojarra	64	3.15	21.0 ± 2.0	149.0 ± 34.0
Guerrero					
Haemulopsis axillaris	Yellowstripe grunt	27	3.5	19.4 ± 1.9	86.2 ± 16.1
Diapterus peruvianus	Peruvian mojarra	53	3.15	16.8 ± 1.2	63.7 ± 16.3

Concentrations of Cd ranged from 0.004 μg g^{-1} in the liver tissue of *D. peruvianus* from Guerrero to 0.177 μg g^{-1} in the muscle tissue of *H. axillaris* from Sinaloa. In the case of Pb, concentrations ranged from 0.063 μg g^{-1} in muscle of *D. peruvianus* from Sinaloa to 0.692 μg g^{-1} in liver of *H. axillaris* from Sinaloa. Cd concentrations were significantly higher ($p < 0.05$) in muscle and liver tissue of *H. axillaris* from Sinaloa than in individuals from Guerrero. With respect to Pb, concentrations in liver tissue of *H. axillaris* from Sinaloa were higher than in specimens from Guerrero. The more elevated concentrations of Cd and Pb in fish from Sinaloa may be related to the high degree of urbanization and the variety of economic activities taking place in the coastal plain. Sinaloa is considered to suffer the worst impacts, mainly due to the fact that more than 70% of the national aquaculture infrastructure is located there (Páez-Osuna 2001); on the other hand, the impact in Guerrero state is light to moderate (Ortiz-Lozano et al. 2005) because of reduced aquaculture activity. The other factor that may account for the significant differences of metal concentrations in ichthyofauna from Sinaloa and Guerrero is the age of specimens; i.e., older fish from Sinaloa accumulated more elevated concentrations than the equivalent specimens from Guerrero (juvenile individuals).

Table 2 Mean cadmium (Cd) and lead (Pb) concentrations (± standard deviation in μg g^{-1} dry weight) in similar bycatch fish collected in waters of the Eastern Pacific Ocean (Sinaloa and Guerrero states)

Species	State	Tissue	Concentration
Cd			
H. axillaris	Sinaloa	Muscle	0.177^{a} ± 0.200
		Liver	0.098^{b} ± 0.168
	Guerrero	Muscle	0.049^{a} ± 0.024
		Liver	0.005^{b} ± 0.003
D. peruvianus	Sinaloa	Muscle	0.057 ± 0.039
		Liver	0.019^{c} ± 0.025
	Guerrero	Muscle	0.047 ± 0.022
		Liver	0.004^{c} ± 0.004
Pb			
H. axillaris	Sinaloa	Muscle	0.225 ± 0.170
		Liver	0.692^{d} ± 0.196
	Guerrero	Muscle	0.264 ± 0.126
		Liver	0.492^{d} ± 0.233
D. peruvianus	Sinaloa	Muscle	0.063 ± 0.038
		Liver	0.670 ± 0.192
	Guerrero	Muscle	0.088 ± 0.073
		Liver	0.621 ± 0.211

For a given tissue, same superscript letters indicate significant ($p < 0.05$) differences

Mean concentrations of Cd and Pb in the muscle and liver tissue of the fish studied here were compared with specimens of the same families from elsewhere (Table 3). As for Haemulidae, the highest concentration of Cd and Pb in muscle was found in *Pomadasys maculatus* from Pakistan. Perhaps this fish reveals the existing pollution around Karachi harbor due to the fast industrialization and economic development there. In the liver tissue, the highest concentration of Cd (2.165 μg g^{-1}) and Pb (0.695 μg g^{-1}) was found in *P. macracanthus* from Teacapán and Urías (Sinaloa, Mexico) respectively. Cd and Pb concentrations in muscle and liver of Haemulidae used in our study were comparable to the other reports. In the case of Gerridae, the highest concentration of Cd (0.057 μg g^{-1}) and Pb (0.570 μg g^{-1}) in muscle was found in *D. peruvianus* from Sinaloa (this study) and Urias respectively. In liver, the highest levels of both elements (Cd 6.145 μg g^{-1}; Pb 4.215 μg g^{-1}) were detected in *D. peruvianus* from Huizache (Sinaloa, Mexico). With the exception of Cd and Pb in liver of *D. peruvianus* from Huizache, our results of Cd and Pb in muscle and liver of Gerridae fish were comparable to the reported studies.

Average concentrations of Cd and Pb in the edible portion of fish were below the maximum permissible limits for human consumption under Mexican legislation (Cd 0.5, Pb 1.0 μg g^{-1} wet weight) (Norma Oficial Mexicana 1993) and international legislation (Table 4). The hazard index (HI) for the two fish species was estimated by looking at Cd and Pb concentrations in the edible portion of fish and the rate of fish consumption (Table 5). The values of HQ for both elements were very low; i.e., they did not reach levels considered to be the threshold for non-cancer effects in adults and children. With respect to the HI, values ranged from 0.009 in *D. peruvianus* from Sinaloa to 0.124 in *H. axillaris* from Sinaloa. Reports of health risk assessments in fish similar to our species are scarce. This is similar to values obtained in our study (HI = 0.16) for

Table 3 Mean Cd and Pb concentrations (μg g^{-1} dry weight) in fish of the same family collected in diverse areas of the world

Species	Tissue	Cd	Pb	Area	Reference
Haemulidae					
Pomadasys maculatus	M	0.590	0.540	Pakistan (Karachi)	Ahmed and Bat (2016)
Pomadasys macracanthus	M	0.032	0.435	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017))
Pomadasys macracanthus	M	0.012	0.350	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Pomadasys macracanthus	M	0.048	0.170	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. 2017)
Pomadasys macracanthus	L	0.735	0.695	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017)
Pomadasys macracanthus	L	1.510	0.415	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Pomadasys macracanthus	L	2.165	0.610	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. (2017)
Haemulopsis axillaris	M	0.177	0.225	Mexico (Sinaloa)	This study
Haemulopsis axillaris	M	0.049	0.264	Mexico (Guerrero)	This study
Haemulopsis axillaris	L	0.098	0.692	Mexico (Sinaloa)	This study
Haemulopsis axillaris	L	0.005	0.492	Mexico (Guerrero)	This study
Gerridae					
Diapterus peruvianus	M	0.008	0.570	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	M	0.031	0.225	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	M	0.009	0.215	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	L	1.430	2.660	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	L	6.145	4.215	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	L	1.175	1.350	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	M	0.011	0.195	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	M	0.008	0.155	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	M	0.011	0.380	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	L	0.365	0.780	Mexico (Urías, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	L	0.310	0.485	Mexico (Huizache, Sinaloa)	Gil-Manriquez et al. (2017)
Eugerres axillaris	L	1.065	1.560	Mexico (Teacapán, Sinaloa)	Gil-Manriquez et al. (2017)
Diapterus peruvianus	M	0.057	0.063	Sinaloa	This study
Diapterus peruvianus	M	0.047	0.088	Guerrero	This study
Diapterus peruvianus	L	0.019	0.670	Sinaloa	This study
Diapterus peruvianus	L	0.047	0.621	Guerrero	This study

M muscle, *L* liver

the same species in Guerrero, but lower than values obtained for the same species in Sinaloa (HI = 0.009) (Gil-Manriquez et al. 2017). For both fish species, correlations of elemental concentrations in muscle and liver tissue with length and weight of specimens were not significant ($p > 0.05$). This may be due to abiotic and biotic factors that may influence

Table 4 Comparison of average values of Cd and Pb in fish muscle (μg g^{-1} wet weight) of studied ichthyofauna against national and international standards

Species	Cd			Pb		
	Measured	Limits		Measured	Limits	
H. axillaris	0.034	0.5[a]	0.05[b]	0.073	1.0[a]	0.2[b]
D. peruvianus	0.016	0.5[a]	0.05[b]	0.022	1.0[a]	0.2[b]

[a] NOM-027-SSA1-1993, [b] Nauen (1983)

Table 5 Hazard quotient (HQ) of Cd and Pb in muscle tissue of *D. peruvianus* and *H. axillaris* and related hazard index (HI)

Coastal area	Species	HQ_{Cd}	HQ_{Pb}	HI
Adults				
Sinaloa	*D. peruvianus*	0.007	0.002	0.009
	H. axillaris	0.020	0.006	0.026
Children				
Sinaloa	*D. peruvianus*	0.031	0.008	0.039
	H. axillaris	0.094	0.030	0.124
Adults				
Guerrero	*D. peruvianus*	0.006	0.003	0.009
	H. axillaris	0.007	0.009	0.016
Children				
Guerrero	*D. peruvianus*	0.030	0.012	0.042
	H. axillaris	0.031	0.040	0.071

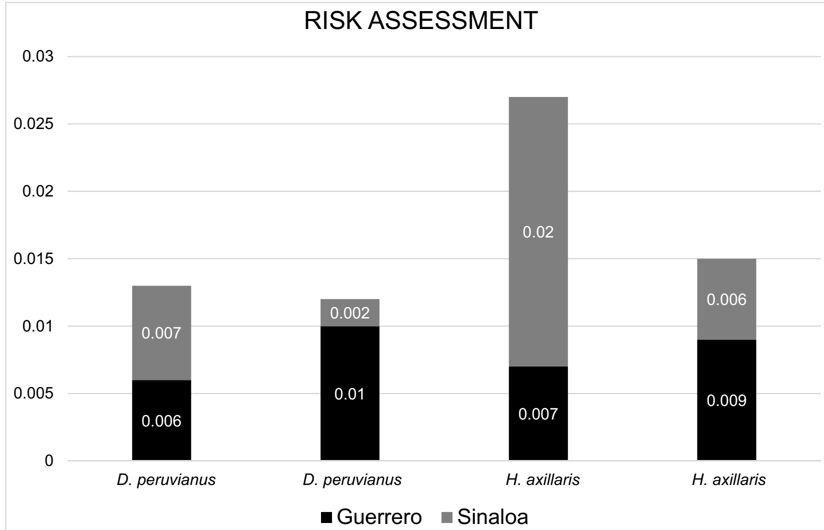

Fig. 2. HI in *Haemulopsis axillaris* and *Diapterus peruvianus* from the Eastern Pacific: as per Cd and Pb concentrations in the edible portion, and rate of fish consumption

the accumulation of metals in the fish. It is important to highlight that adaptation of organisms to the presence of contaminating substances allows for certain values to be tolerated due to various mechanisms such as decreased sorption, increased excretion, and accumulation of toxic substances in lysosomal vesicles (Heath 1995) (Fig. 2).

Conclusions

Metal levels in analyzed tissues were muscle > liver in the case of Cd, and liver > muscle in the case of Pb. Cd concentrations were significantly higher ($p < 0.05$) in muscle and liver of *H. axillaris* from coastal waters of Sinaloa, whereas, Pb concentrations in liver of *H. axillaris* from Sinaloa were higher than in specimens from Guerrero coastal waters.

Higher levels of Cd and Pb in fish from Sinaloa may be linked to the degree of urbanization and economic activity and the age of specimens since fishes from Sinaloa were adults and had perhaps accumulated more elevated concentrations of the elements than juvenile specimens from Guerrero. The estimations of HI were below the value of one so none of the studied fish species present a health risk when it comes to Cd and Pb concentrations in muscle and the rate of fish consumption in the Mexican population.

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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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