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Bioaccumulation of arsenic and selenium in bycatch fishes *Diapterus peruvianus*, *Pseudupeneus grandisquamis*, and *Trachinotus kennedyi* from shrimp trawling in the continental shelf of Guerrero, México

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Abstract With the aim of determining arsenic (As) and selenium (Se) concentrations in bycatch fishes from SW Mexico and comparing elemental concentrations with limits for human consumption set in the national and international legislation, three fish species (*Diapterus peruvianus*, *Pseudupeneus grandisquamis*, and *Trachinotus kennedyi*) were collected from Guerrero state during trawling operations. Additionally, As and Se levels in muscle tissue were compared with similar species from diverse areas. The order of As and Se concentrations was *T. kennedyi* > *P. grandisquamis* > *D. peruvianus*. In Mexico, there is no regulation of As and Se levels in fish. In comparison to the legal limit (0.1 μg g^{-1} wet weight) set by legislation in Venezuela, As levels in the edible portion of *T. kennedyi* (0.632 μg g^{-1} wet weight), *P. grandisquamis* (0.166 μg g^{-1} wet weight), and *D. peruvianus* (0.157 μg g^{-1} wet weight) were above this limit. In the case of Se, average concentrations in *T. kennedyi* (0.323 μg g^{-1} wet weight) were above the maximum permissible limit (0.30 μg g^{-1} wet weight) set in the Chilean legislation. Se concentrations in *Carangoides bajad* from Saudi Arabia were comparable to values in *T. kennedyi* (this study). In relation to As, concentrations varied in magnitude orders; the highest As concentration (range 10.35 to 23.71 μg g^{-1} wet weight) corresponded to *Mullus barbatus* from the Iberian Mediterranean.

Keywords Fish · Bycatch shrimp fishery · Guerrero state · Continental shelf · Metal bioaccumulation

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Introduction

In Mexican waters, the shrimp trawl fishery is the main source of bycatch; it is mainly composed of fish, crustaceans and mollusks that are discarded every year (Madrid-Vera et al. 2007) during trawling operations. Among bycatch species, fishes are the most abundant group (Rábago-Quiroz et al. 2008); e.g., for a kilogram of shrimp, 10 kg of fish can be caught (Alverson et al. 1994). Among bycatch fish species, the Peruvian mojarra *Diapterus peruvianus*, the bigscale goatfish *Pseudupeneus grandisquamis*, and the blackblotch pompano *Trachinotus kennedyi* are of interest for human consumption. In the Eastern Pacific Ocean, *D. peruvianus* (Gerreidae) is distributed from Mazatlán, Mexico, to Callao, Perú; its total length (TL) may reach 30.0 cm but its common length is 15.0 cm, adults feed on benthic invertebrates and fishes,

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and its flesh is considered of good quality. *P. grandisquamis* (Mullidae) is distributed from California to Chile. Its maximum TL is 30.0 cm; published information related to the commercialization and consumption of *P. grandisquamis* is not existent. Finally, *T. kennedyi* (Carangidae) is commonly distributed from Bahía Magdalena (southern gulf of California) in Mexico to Ecuador; its maximum TL is 90 cm but the most common length is 40 cm; this species feeds not only on mollusks but also on crustaceans and small fish, and it is commercialized fresh and also salted/dried (Fishbase).

Trace metals are considered as a major problem of aquatic systems, constituting an important threat for the health of the environment, including humans, since they are included in our food supply. This problem is receiving more and more attention worldwide, but in a lesser extent in developing countries (including Mexico). The biological half-lives of trace metals are long; they have the potential to bioaccumulate in different body organs and eventually produce adverse effects (Kahn et al. 2005). In the ocean, the trace metals are bioaccumulated on different organisms and sediments, and some of the toxic metals are subsequently transferred to humans through the food chain (Giordano et al. 1991). On the other hand, seafood is very important in the human diet worldwide because it represents a good-quality protein source, but it can also bioaccumulate metals, including those that are potentially toxic (Plessi et al. 2001).

It has been documented the trace metals occur naturally in the environment; however, they are also mobilized through anthropogenic activities. Arsenic (As) is an element which occurs naturally in the earth's crust. It ranks 20th in natural abundance, 4th in seawater, and 12th in the human body (Mandal and Suzuki 2002). More than 245 minerals contain As and although its ultimate source is geological, human activities such as mining, burning of fossil fuels, and pesticide application may cause As pollution (Bissen and 2003). The As toxicity for organisms is mainly derived from inorganic species (Bissen and Frimmel 2003). Arsenic studies are important because this element is highly toxic and carcinogenic (DeGieter et al. 2002).

Selenium (Se) is an essential trace element for humans due to its biochemical role as part of the active site in selenoproteins such as glutathione peroxidase; it is abundant in ocean fishes and is known to be highly active in counteracting Hg toxicity (Yang et al. 2008); on the other hand, some micronutrients like calcium, iron, and zinc decrease the arsenic toxicity by the simultaneous interaction at the action site (Nrashant et al. 2007). The influence of dietary Se upon the activity of glutathione peroxidase is evident, and minimum Se requirements (RDA 1989) have been set (70 and 55 μg day^{-1} for males and females, respectively). However, it should be borne in mind that Se plays an ambivalent role on the body depending on its concentration; i.e., elevated concentrations may have toxic effects. Considering that food is the main source of certain metals to organisms and that bycatch fishes are important for animal and human consumption, the objectives of the study were (a) to determine As and Se in the edible portion of three fish species from Guerrero state, (b) to compare elemental concentrations with the maximum permissible limits in the national and international legislation, and (c) to contrast As and Se levels in the analyzed fish with specimens of similar species from diverse areas.

Materials and methods

Study area

Guerrero state has a territory of 63,794 km^2, it accounts for 3.2 % of the total area of Mexico. The coastline of the state of Guerrero is located in the Mexican tropical Pacific (Fig. 1); this coastline has an approximate length of 470 km; the climate is warm and subhumid with considerable summer rains (Aw type). The Aw climate type is the driest of the subhumid, with an average annual temperature of 25.5 °C and an average annual rainfall of 1067 mm, with rainfall in summer (June to September) and presence of intermittent drought in July and August (García 1981). According to regional characteristics, Guerrero state is located in the morphotectonic unit number VIII with a very narrow continental shelf. The coastline is parallel to the Mesoamerican Mexican pit. It is classified as a continental collision coast, dominated by primary coasts formed by diastrophic movements, with faults and fault scarps. The surface water temperature fluctuates between 26 and 28 °C along a year, the semidiurnal tides are mixed and show a variation of ±1 m. The average sea level has a seasonal variation with a decline between December and May and a rise from June to November (Flores-Rodriguez et al. 2012).

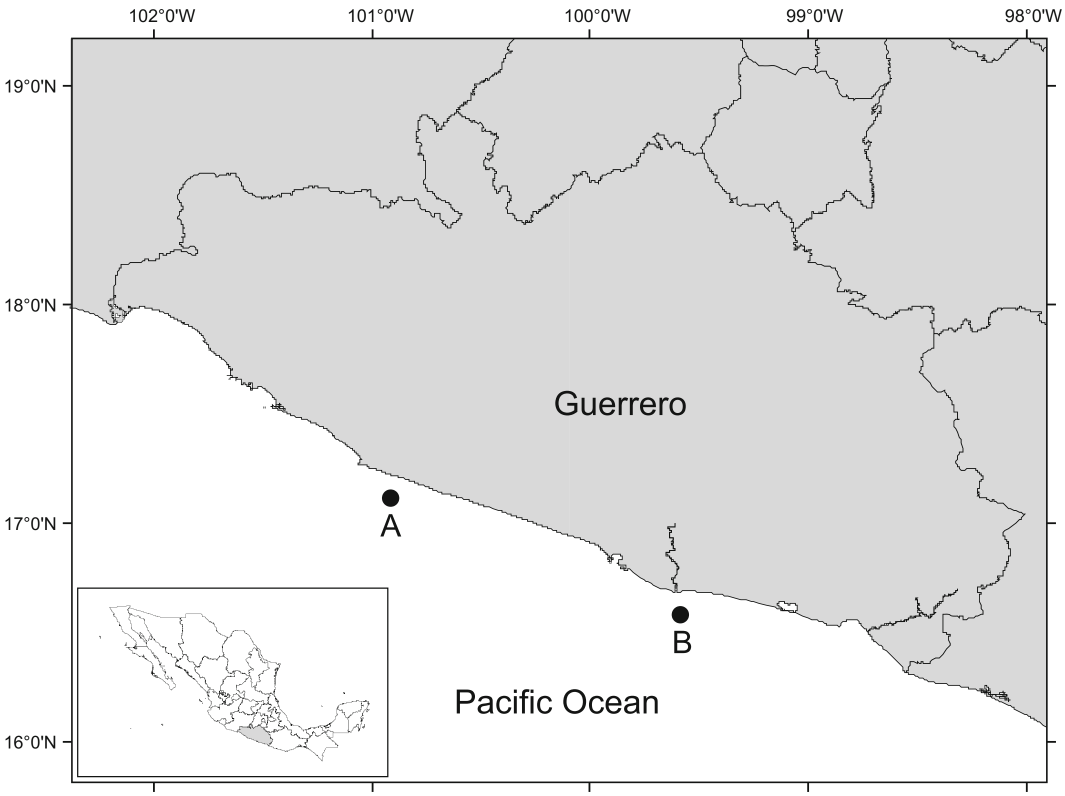

Fig. 1 Location of bycatch fish collection (from site A to site B) in Guerrero state, SW Mexico

Fish sampling

Specimens of the fishes *D. peruvianus* (n = 62), *T. kennedyi* (n = 30), and *P. grandisquamis* (n = 32) were collected in two sites in Guerrero state (SW Mexico) on November 25, 2011, from the shrimp boats based in Mazatlán harbor (23° 12.6′ N; 106° 23.3′ W) at a depth range of 30–46 m.

Analytical procedure

After taxonomic identification (Allen et al. 1995a, b) and dissection of specimens, muscle samples were freeze-dried in a Labconco (model Freezone 6) freeze-drying system for 72 h (−49 °C and 133 × 10^{-3} mBar) then ground in an agate mortar (Fisher Scientific). For digestion, 0.25 g of freeze-dried tissue was weighed and placed in a Teflon bomb (Savillex) and 5 mL of concentrated HNO_3 (JT Baker, trace metal grade) added and let in predigestion overnight. Closed Teflon bombs were placed on a hot plate and digested during 3 h at 120 °C. Analyses of As and Se were performed by hydride generation atomic absorption spectrophotometry (HG-AAS) in a Varian equipment (Model SpectrAA FS-240). Results are expressed in micrograms per gram on a dry weight basis. For quality control, plastic utensils and Teflon bombs were acid washed (Moody and Lindstrom 1997); ultrapure water (18.2 MΩ cm), blanks, and certified reference material (DOLT-4, liver of dogfish *Squalus acanthias* from the National Research Council, Canada) were used. The results of As (8.85 ± 0.31 μg g^{-1}) and Se (7.97 ± 0.78 μg g^{-1}) measurements in reference material were within certified intervals (As = 9.66 ± 0.62 μg g^{-1}; Se = 8.30 ± 1.3 μg g^{-1}); coefficients of variation (CV) and recovery percentages of As (CV = 1.44 %; 92 %) and Se (CV = 3.46; 96 %) were satisfactory. The limits of detection were 0.16 μg g^{-1} for As and 0.17 μg g^{-1} for Se.

Elemental concentrations were transformed by an arcsine function. Concentrations of As and Se in analyzed ichthyofauna were compared by a Kruskal-Wallis one-way analysis of variance test. Since the mean values among the treatment groups of data were statistically different, a Dunn's post was used. Conversion of elemental levels from dry weight (dw) to wet weight (ww)

Table 1 Biometric information and elemental concentrations (μg g^{-1} dry weight) in the muscle of bycatch fishes from the state of Guerrero, Mexico

Species	Common name	*N*	Total length (cm)	Total weight (g)	As (mean ± SD)	Se (mean ± SD)
Trachinotus kennedyi	Blackblotch pompano	30	20.7 ± 1.5	103.6 ± 19.5	2.105 ± 1.189a	1.075 ± 0.515a
Diapterus peruvianus	Peruvian mojarra	62	16.8 ± 1.3	63.7 ± 16.3	0.524 ± 0.476b	0.547 ± 0.134b, c
Pseudupeneus grandisquamis	Bigscale goatfish	32	16.0 ± 1.1	56.8 ± 16.6	0.554 ± 0.265b	0.664 ± 0.064b, d

For a given column, different letters indicate significant ($p < 0.05$) differences

basis was made according to the equation: $Element_{ww} = Element_{dw} \times (100 - \%humidity)/100$ (Magalhaes et al. 2007).

Results and discussion

Average As and Se concentrations in muscle tissue and biometric information of bycatch fish species from the state of Guerrero are shown in Table 1. The sequence of As and Se concentrations was *T. kennedyi* > *P. grandisquamis* > *D. peruvianus*. Mean As concentrations in muscle were significantly ($p < 0.05$) higher in *T. kennedyi* than in *D. peruvianus* and in *P. grandisquamis*. Regarding average Se concentrations in muscle, values in *T. kennedyi* were significantly higher ($p < 0.05$) than those in *D. peruvianus* and in *P. grandisquamis*; values in *P. grandisquamis* were significantly higher ($p < 0.05$) than those in *D. peruvianus*. In diverse studies (Brigelius-Flohé 1999), it has been concluded that essential elements (like Se) are kept within certain limits because of their participation in metabolic activities. In this context, it can be noted that Se concentrations in every studied fish species were less variable than corresponding As concentrations. Another aspect related to metal variation in fishes is the trophic level (TL) of individuals. Although the three studied fishes are carnivores, published information (Fishbase) of their TL indicates that *T. kennedyi* has the most elevated level (3.8), followed by *D. peruvianus* (3.7) and *P. grandisquamis* (3.3). It can be seen that As and Se levels in the studied ichthyofauna varied accordingly with the TL; i.e., the highest As and Se concentrations were found in *T. kennedyi*; nevertheless, in diverse studies, it has

Table 2 Concentrations of As and Se (μg g^{-1} wet weight) in muscle tissue of related ichthyofauna

Family	Species	*N*	As	Se	Site	Reference
Carangidae						
	Trachurus trachurus	48	0.032	NA	Granada, Spain	Rivas et al. 2014
	Trachurus picturatus	49	0.025	NA	Granada, Spain	Rivas et al. 2014
	Trachurus mediterraneus	45	0.043	NA	Granada, Spain	Rivas et al. 2014
	Carangoides bajad	10	1.64–3.86	0.527–0.671	Jeddah, Saudi Arabia	Burger et al. 2014
	Trachinotus kennedyi	30	0.632	0.323	Pacific coast of Mexico	This study
Mullidae						
	Mullus surmuletus	1	11.4	NA	French coast	DeGieter et al. 2002
	Mullus barbatus	35	0.081	NA	Gulf of Antalya, Mediterranean Sea	Yarsan et al. 2014
	Mullus barbatus	30	27.01	NA	Channel of Sicily, Italy	Conti et al. 2012
	Mullus barbatus	10	10.35–23.71	NA	Iberian Mediterranean	Benedicto et al. 2007
	Pseudupeneus grandisquamis	32	0.166	0.199	Pacific coast of Mexico	This study
Gerreidae						
	Diapterus peruvianus	62	0.157	0.164	Pacific coast of Mexico	This study

NA, not available

been concluded that Se is biomagnified (Biddinger and Gloss 1984) but not As (Rahman et al. 2012).

The comparison of total As in the studied fishes with the Mexican and international legislation is difficult because of the lack of norms. In Mexico, the maximum permissible level of total As in fresh fishery products (crustaceans and mollusks) is 80 μg g^{-1} wet weight (NOM-242-SSA1-2009). It can be seen that none of the individuals had As values above regulations. However, according to the record of releases and transfers of pollutants in Mexico, in the state of Guerrero, 5.3311 t $year^{-1}$ were discharged into water bodies (RETC 2013). In the case of seawater, the concentration of arsenic is usually less than 2 μg L^{-1}. On the other hand, if we consider a strict limit (0.1 μg g^{-1} wet weight) set by legislation in Venezuela (Nauen 1983), As levels in the edible portion of *T. kennedyi* (0.632 μg g^{-1} wet weight), *P. grandisquamis* (0.166 μg g^{-1} wet weight), and *D. peruvianus* (0.157 μg g^{-1} wet weight) are above this limit (from 1.6 to 6 times higher). Nevertheless, it is known that in seafood, arsenic is present in its organic form (organic species are considerably less toxic than inorganic arsenic) at elevated concentrations. In the case of Se, average concentrations in *T. kennedyi* (0.323 μg g^{-1} wet weight) were above the maximum permissible limit (0.30 μg g^{-1} wet weight) set in the Chilean legislation (Nauen 1983).

Concentrations of Se and As in studied fish were compared with related species from diverse areas (Table 2). Reports with results of Se levels in fish of studied families are scarce; concentrations reported in *Carangoides bajad* (Carangidae) by Burger et al. (2014) were comparable levels in *T. kennedyi*. In relation to As, concentrations varied in magnitude orders; the lowest value (0.025 μg g^{-1} wet weight) was reported in *Trachiurus picturatus* from Granada, Spain, and the highest As concentration (range 10.35 to 23.71 μg g^{-1} wet weight) corresponded to *Mullus barbatus* from the Iberian Mediterranean. Our results of As levels were within limits (up to 30 μg g^{-1} wet weight) reported in diverse fish species by Eisler (2010).

Conclusions

Average concentrations of As and Se in the muscle of studied fishes were significantly higher in *T. kennedyi*; this species has the most elevated trophic level. In Mexico, maximum permissible limits of As and Se in edible portion of fishes are non-existent; the only legal limit for As (80 μg g^{-1} wet weight) refers to crustaceans and mollusks. In comparison to the value set for crustaceans and mollusks, none of the fish specimens had As concentrations above the limit. In comparison to the As limit (0.1 μg g^{-1} wet weight) set in Venezuela, all the fishes studied here were above the legal threshold. With respect to Se, only *T. kennedyi* had concentrations over the limit set by the Chilean legislation. Reports of As and Se in related fishes are scarce. In the case of Se, levels were comparable to values reported here; with respect to As, the highest value was reported in fishes from the channel of Sicily, our fishes had lower concentrations by two orders of magnitude.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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