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RESEARCH ARTICLE

Tracking mercury in the southwestern Atlantic Ocean: the use of tuna and tuna-like species as indicators of bioavailability

Bárbara Moura Reis Manhães[1,2] · **Alice de Souza Picaluga**[1] · **Tatiana Lemos Bisi**[1] · **Alexandre de Freitas Azevedo**[1] · **João Paulo Machado Torres**[2] · **Olaf Malm**[2] · **José Lailson-Brito**[1]

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Abstract

Mercury is a trace element that is potentially dangerous due its high toxicity and tendency to bioaccumulate in organisms. Currently, high mercury concentrations are seen in the environment especially due climate changes. Studies regarding mercury bioavailability in the southwestern Atlantic Ocean using tuna and tuna-like species are rare. The aim of the present study was to use tuna and tuna-like species (*Thunnus atlanticus*, *Thunnus albacares*, *Katsuwonus pelamis*, *Euthynnus alletteratus*, *Coryphaena hippurus* and *Sarda sarda*) as indicators of the availability of total mercury (THg) in oceanic food webs of the southwestern Atlantic Ocean. THg concentrations varied significantly among species for both muscle and liver (Kruskal–Wallis test; $H_{5,130} = 52.7$; $p < 0.05$; $H_{5,130} = 50.1$; $p < 0.05$, respectively). The lowest concentrations were found in *C. hippurus* (0.008 mg kg^{-1} wet weight in the muscle and 0.003 mg kg^{-1} wet weight in the liver), and the highest concentrations were reported in the muscle of *T. atlanticus* (1.3 mg kg^{-1} wet weight) and in the liver of *S. sarda* (2.5 mg kg^{-1} wet weight). The continued monitoring of tuna and tuna-like species is necessary to assist in their conservation since tuna can be sentinels of mercury pollution.

Keywords Pelagic fish · Trace elements · Pollution · Sentinels

Introduction

Mercury is a global contaminant potentially dangerous in the marine environment due to its high toxicity and tendency to bioaccumulate in organisms (Storelli et al. 2001). Methylmercury is the most toxic form (ATSDR 1999) and suffers from biomagnification throughout food webs (Booth and Zeller 2005; Gray 2002). In this sense, organisms that occupy high trophic levels, such as tuna, may exhibit high mercury concentrations (Burger et al. 2001; Peterson et al. 1973). Anthropogenic mercury input is a concern around many regions of the world since methylation rates are predicted to increase due global warming and acidification in sea waters (Booth and Zeller 2005; Downs et al. 1998; Krabbenhoft and Sunderland 2013). Approximately 2% of mercury flux in the ecosystem undergoes the methylation process per year (Fitzgerald and Mason 1997). Current studies of data collected from water column profiles showed that anthropogenic emissions in the oceans increase mercury concentrations by 2.6× (since the 1500s) in waters shallower than 1000 m (Lamborg et al. 2014). In the Pacific Ocean, a study in *Thunnus albacares* has shown that mercury concentrations were higher in 2008 than in previous periods (1971 and 1998) (Drevnick et al. 2015).

Despite this increase in anthropogenic mercury input, there are few studies in the southwestern Atlantic regarding mercury bioaccumulation in tuna and tuna-like species (e.g., Ferreira et al. 2012; Medeiros et al. 2008). In the northern hemisphere, there are some studies (e.g., Storelli et al. 2002; Yamashita et al. 2005), but few focused on the same species as those evaluated in the present study (e.g., Burger et al. 2011; Kojadinovic et al. 2006). Tuna and tuna-like species are fast-

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✉ Bárbara Moura Reis Manhães
barbaraa.manhaes@yahoo.com.br

[1] Laboratório de Mamíferos Aquáticos e Bioindicadores "Profa. Izabel Gurgel" (MAQUA), Faculdade de Oceanografia, Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier, 524, sala 4002, 20550-013, Maracanã, Rio de Janeiro, RJ, Brazil

[2] Instituto de Biofísica Carlos Chagas Filho, Universidade Federal do Rio de Janeiro, Av. Carlos Chagas Filho, 373 Sala G0-61, Rio de Janeiro, RJ 21941-902, Brazil

swimming opportunistic top predators (FAO 1994, 1997), and their diet is diverse (Collette and Nauen 1983). Due to the fact that the diet is the major route of trace element accumulation in marine organisms (Morel et al. 1998; Silva et al. 2011; Wang 2002), these fish may exhibit increased concentrations of mercury in their tissues (Voegborlo et al. 2006). Since they are highly migratory species (Collette and Nauen 1983; Zagaglia et al. 2004), tuna and tuna-like species can be sentinels of mercury global pollution and other pollutants, providing information on the contamination status of offshore waters and open seas (Endo et al. 2016; Ueno et al. 2003).

Regarding the conservation status of tuna and tuna-like species, Near Threatened is the status for *Thunnus albacares* (IUCN 2011) due to population decline, especially in the Atlantic Ocean (Fonteneau and Soubrier 1996; ICCAT 1994). The other species in the present study are classified as Least Concerned (IUCN 2011). It is important to highlight that tropical coastal species have a smaller number of stock assessments available, which can overestimate the number of individuals (Juan-Jordá et al. 2011). The geographical distribution of some species is restricted, such as *Euthynnus alleteratus* and *Sarda sarda*, which are limited almost exclusively to the Atlantic Ocean, and *Thunnus atlanticus* is found only in the western Atlantic Ocean (Collette and Nauen 1983). Therefore, mercury pollution can be another threat to tuna and tuna-like species (Ueno et al. 2003) since a mercury increase in oceans has been shown (Drevnick et al. 2015).

The objectives of the present study were as follows: (1) evaluate mercury bioavailability in the southwestern Atlantic Ocean using tuna and tuna-like species as sentinels; (2) compare the total mercury concentrations among the muscle and liver of tuna and tuna-like species from the southwestern Atlantic Ocean; and (3) investigate possible relationships between biological data and the total mercury concentrations in the muscle and liver of tuna and tuna-like species from the southwestern Atlantic Ocean.

Materials and methods

Sampling

Six tuna and tuna-like species ($N = 130$) were acquired from the commercial fleet that operates in the southwestern Atlantic Ocean in Brazil between February 2009 and January 2010, covering all seasons. The species were *Thunnus atlanticus* (blackfin tuna, $n = 28$); *Thunnus albacares* (yellowfin tuna, $n = 20$); *Katsuwonus pelamis* (skipjack tuna, $n = 29$); *Euthynnus alletteratus* (little tunny, $n = 8$); *Coryphaena hippurus* (dolphinfish, $n = 22$), and *Sarda sarda* (Atlantic bonito, $n = 22$). The specimens were caught with longlining, seine nets, drift nets and fishing rods in locations with depths ranging from 17 to 2000 m and distances from the shore of 1 to 190 km. The species identification was according to Menezes and Figueiredo (2000), and each specimen was weighed, measured, and dissected. The samples collected for all analyses were the dorsal muscle and liver of all species. An aliquot of each tissue was stored in polyethylene bags and frozen at − 20 °C until analysis.

Total mercury (THg) determination

The total mercury (THg) determination followed the procedure of Malm (1989) and Bastos et al. (1998). To aliquots of approximately 0.4 g (wet weight) of each tissue, 1 mL of hydrogen peroxide and 5 mL of a sulfuric:nitric acid mixture (1:1) were added. The solution was heated to 60 °C for 2 h in a water bath until its total solubilization. Posteriorly, 5 mL of 5%potassium permanganate solution was added and heated to 60 °C for more than 15 min. After sitting overnight, 1 mL of hydroxylamine hydrochloride was added to the extract, and THg concentrations were determined by cold vapor/atomic absorption (FIMS-400, Perkin-Elmer) with sodium borohydride as a reducing agent. The accuracy and precision of the analytical methods were determined by using the standard reference materials DORM-3 and DOLT-4 (National Research Council, Canada), and the results were in good agreement with certified values (mean values ± SD: DOLT-4 = 2.72 ± 0.12 and DORM-3 = 0.354 ± 0.01) The detection limit of the equipment was 0.088 $\mu g\ L^{-1}$, and the detection limit of the method was 3.79 $\mu g\ kg^{-1}$ for liver and 3.67 $\mu g\ kg^{-1}$ for the muscle. The quality control was also performed through analysis of procedural blanks and replicate samples (coefficient of variation < 20%).

Statistical analysis

Statistical analyses were performed through the program STATISTICA 7.0 for Windows (StatSoft, Inc. 1984–2004, USA). Data normality was tested using the Kolmogorov–Smirnov test ($p < 0.05$). The non-parametric Kruskal–Wallis test was applied, followed by the Unequal N HSD post hoc test to verify differences in the total mercury concentrations (THg) among tuna and tuna-like species. The Wilcoxon test was used to compare the THg muscular and hepatic concentrations of all species. Spearman's correlation test was applied to investigate the correlation between THg muscular and hepatic concentrations and biological parameters (total length and weight).

Results and discussion

General aspects and interspecific comparison

Summaries and representations of the biological parameters are presented in Table 1, while the muscular and hepatic total

Table 1 Mean and standard deviation (SD), median, minimum, and maximum values (Min-Max) of the biological parameters of six tuna and tuna-like species in the present study

Species	N	Weight (kg) Mean ± SD	Min-Max	Total length (cm) Mean ± SD	Min-Max
Thunnus atlanticus	28	3.5 ± 5.4	0.8–27.8	52 ± 16	37–115
Thunnus albacares	20	6.6 ± 10.2	1.3–47.6	72 ± 28	45–176
Katsuwonus pelamis	29	2.9 ± 2.8	0.6–16	51 ± 11	32–82
Euthynnus alletteratus	8	1.4 ± 0.1	0.3–2.8	44 ± 12	27–60
Coryiphaena hippurus	22	1.9 ± 1.6	0.3–6.3	64 ± 21	31–108
Sarda sarda	22	1.3 ± 0.5	0.8–2.3	48 ± 7	41–59

mercury (THg) concentrations in tuna and tuna-like species are shown in Table 2. The THg muscular concentrations ranged from a minimum of 0.008 mg kg^{-1} (ww) in *C. hippurus* to a maximum of 1.3 mg kg^{-1}(ww) in *T. atlanticus*, and the THg hepatic concentrations ranged from a minimum of 0.003 mg kg^{-1} (ww) in *C. hippurus* to a maximum of 2.4 mg kg^{-1}(ww) in *S. sarda*. These concentrations found in the present study are high and in agreement with the available literature (Table 4). The THg concentrations varied between tuna and tuna-like species for both muscle (Kruskal–Wallis test; $H_{5,130} = 52.7$; $p < 0.00001$) and liver (Kruskal–Wallis test; $H_{5,130} = 50.1$; $p < 0.00001$). Among all species, *C. hippurus* showed a difference from the others species for muscle and liver (Tukey's test for unequal N applied on ranks; $p = 0.0001$), with the exception of *E. alletteratus* ($p = 0.2562$). Additionally, differences were also found in the hepatic concentrations between *S. sarda* and *T. albacares* ($p = 0.0140$) (Table 3).

The highest THg concentrations were found in *T. atlanticus* and *S. sarda*. Both of these species have a piscivorous diet (Campo et al. 2006; Collette and Nauen 1983; Fletcher et al. 2013; Headley et al. 2009; Kuklyte and Rowe 2012), occupying high trophic levels that undergo high mercury bioaccumulation (Storelli et al. 2005). For *S. sarda*, cannibalism is also known (Zusser 1954), resulting in higher concentrations. Additionally, *T. atlanticus* forages and feeds in the mesopelagic zone (Fenton et al. 2014). Being an epipelagic species, *T. atlanticus* has the ability to dive up to 200 m for feeding (Fenton et al. 2014), thus accessing prey from the mesopelagic zone. Organisms found in this region may exhibit high mercury concentrations, especially methylmercury, due to microbial-mediated methylation (Choy et al. 2009; Croizier et al. 2019). In these sub-thermocline low oxygen oceanic waters, there are higher methylmercury concentrations, enhancing mercury bioaccumulation in these organisms (Mason and Fitzgerald 1990; Monteiro et al. 1996). This gradient in the water column increases from the surface to the bottom, with demersal and benthopelagic fish showing higher Hg concentrations than pelagic species (Croizier et al. 2019). Deep ocean waters contain approximately 74% of the global total of mercury concentrations, compared with 24% and 2% in the shallow waters of the ocean and atmosphere, respectively (Mason and Sheu 2002; Morel et al. 1998). The photodemethylation by radiation also plays an important role in bioaccumulation in pelagic fish, thus reducing the methylmercury available for epipelagic species (Croizier et al. 2019). On the other hand, the low THg concentrations in *C. hippurus* are in agreement with other studies (Adams 2009; Adams

Table 2 Mean and standard deviation (SD), median, minimum and maximum values (Min-Max) of the total mercury concentrations (THg) in the muscle (M) and liver (L) of six tuna and tuna-like species, expressed in mg kg^{-1} wet weight

Species	*N*	Tissue	Mean ± SD	Median	Min-max
Thunnus atlanticus	28	M	0.28 ± 0.34	0.16	0.04–1.30
		L	0.33 ± 0.43	0.17	0.06–1.86
Thunnus albacares	20	M	0.12 ± 0.07	0.11	0.03–0.28
		L	0.13 ± 0.08	0.10	0.01–0.27
Katsuwonus pelamis	29	M	0.20 ± 0.08	0.18	0.04–0.39
		L	0.17 ± 0.08	0.16	0.05–0.39
Euthynnus alletteratus	8	M	0.22 ± 0.13	0.19	0.02–0.38
		L	0.11 ± 0.07	0.11	0.01–0.20
Coryiphaena hippurus	22	M	0.04 ± 0.02	0.03	0.008–0.01
		L	0.04 ± 0.04	0.03	0.003–0.17
Sarda sarda	22	M	0.26 ± 0.21	0.13	0.07–0.79
		L	0.46 ± 0.55	0.20	0.09–2.45

Table 3 Results of the Tukey Test for unequal *N* applied on ranks for multiple comparisons of the total mercury concentrations in the muscle (upper right) and liver (lower left) of tuna and tuna-like species from the Atlantic Ocean

	Tatl	Talb	Kpel	Ealle	Chip	Ssar
Tatl		0.316	0.957	0.999	0.0001	0.996
Talb	0.345		0.060	0.583	0.0001	0.118
Kpel	0.988	0.730		0.999	0.0001	0.999
Ealle	0.434	0.989	0.678		0.0001	1.000
Chip	0.0001	0.0001	0.0001	0.256		0.0001
Ssar	0.785	0.014	0.393	0.089	0.0001	

Thunnus atlanticus (Tatl), *Thunnus albacares* (Talb), *Katsuwonus pelamis* (Kpel), *Euthynnus alletteratus* (Ealle), *Coryphaena hippurus* (Chip) and *Sarda sarda* (Ssar)

2004; Cai et al. 2006; Kuklyte and Rowe 2012). *C. hippurus* has a rapid growth rate (Adams 2009) and short life expectancy (less than 2 years) (Oxenford 1999), which results in a shorter time to bioaccumulate mercury compared with long-lived species (Oxenford and Hunte 1999). The low trophic level occupied by *C. hippurus,* measured through the nitrogen stable isotope ratio ($\delta^{15}N$) (Cai et al. 2007), compared to other species (e.g., *Makaira nigricans* and *E. alletteratus*) may also be related to these low concentrations.

The intermediate concentrations found in *T. albacares*, *K. pelamis*, and *E. alleteratus* are probably due to their habits. These species do not tolerate low oxygen concentrations and low temperatures, spending most of their time in shallow waters above the thermocline (Collette and Nauen 1983; ICCAT 2010) and assessing prey with lower THg concentrations (Choy et al. 2009). As mentioned above, lower THg concentrations can be found in shallow waters. Additionally, *T. albacares* and *K. pelamis* feed on smaller prey compared to other tuna and tuna-like species (e.g., Adams 2004; Vaske-Júnior and Castello 1998). These preys include crustaceans and cephalopods, especially squids (Adams 2004; Santos and Haimovici 2002). In fact, Atlantic squid species show low THg concentrations (< 0.04 mg kg^{-1}) (Bisi et al. 2012; Hall et al. 1978). *E. alletteratus* also presented intermediate THg concentrations, which can be associated with sampling consisting of small individuals (TL: from 27 to 60 cm) (Table 1). This size restriction enables them to catch smaller prey, such as sardines and anchovies (García and Posada 2013), which tend to show low THg concentrations (Voegborlo et al. 2006; Storelli et al. 2005).

Comparison among tissues

There were significant differences between the THg muscular and hepatic concentrations for *S. sarda*, *K. pelamis* and *E. alletteratus* (Wilcoxon test, $p < 0.05$). For *S. sarda*, the hepatic concentrations (0.46 ± 0.55 mg kg^{-1} ww) were higher than the muscular concentrations (0.26 ± 0.21 mg kg^{-1} ww), while for *K. pelamis* and *E. alletteratus*, the muscular THg concentrations (0.20 ± 0.08 mg kg^{-1} ww and 0.22 ± 0.13 mg kg^{-1} ww, respectively) were higher than the liver THg concentrations (0.017 ± 0.08 mg kg^{-1} ww and 0.11 ± 0.07 mg kg^{-1} ww, respectively). For the other species, there was not a significant difference between the muscular and hepatic THg concentrations (Wilcoxon test, $p > 0.05$). In general, the total mercury concentrations are expected to be higher in liver than muscle due trace element storage and detoxification carried out in the liver through methallothioneins (Avenant-Oldewage and Marx 2000; Ordiano-Flores et al. 2012). However, some studies have already reported higher concentrations in muscle than in liver for different fish species (e.g., Goldstein et al. 1996; Licata et al. 2005). This result can be related to the formation of covalent interactions of methylmercury with proteins in the muscle (Carty and Malone 1979) and how methylmercury is processed and stored in the liver, which is associated with morphologic variation in the livers of many species (Hajeb et al. 2010).

Biological parameters

Positive correlation was shown between muscular THg concentrations and biological parameters (total length and weight) for all species (Spearman correlation, $p < 0.05$) (Fig. 1). These correlations suggest mercury bioaccumulation according to tuna and tuna-like species growth and they have been reported in other studies (e.g., Kojadinovic et al. 2006; Kuklyte and Rowe 2012). Mercury bioaccumulation in fish tends to increase with age, especially when older fish assess larger and more contaminated prey (Kuklyte and Rowe 2012; Trudel and Rasmussen 2006). These positive correlations are probably due the fast intake rate of methylmercury and its long half-life, resulting in a low elimination rate of methylmercury, which tends to increase its concentration (Trudel and Rasmussen 1997). Hepatic THg concentrations and biological parameters were positively correlated for all species (Spearman correlation, $p < 0.05$), with the exception of *K. pelamis* and *E. alleteratus* (Spearman Correlation, $p > 0.05$) (Fig. 2). This lack of correlation is because of the small size of the individuals. In juveniles, the metabolic cost and growth rate are higher than for adults (Trudel and Rasmussen 2006), leading to the biodilution of mercury concentrations in tissues of the fish (Sharma et al. 2008).

Environmental approach

From a global perspective, the concentrations found in the present study are comparable with other regions around the world and can be related to the high mercury availability in the Atlantic Ocean (especially in deep waters) (Mason and Sullivan 1999; Mason and Fitzgerald 1991, 1993; Mason and Sheu 2002; Mason and Sullivan 1999). Anthropogenic enrichment is also higher in Atlantic waters, varying from less than 1% in the Pacific and Indian Oceans to approximately 60% in northern Atlantic deep waters (Sunderland and Mason 2007). Kraepiel et al. (2003) assumed that the mercury concentration in tuna is proportional to the mercury concentrations in the ocean reservoir (mixed layer, thermocline or deep ocean waters). In this sense, tuna and tuna-like species may exhibit enhanced accumulation, especially due to anthropogenic sources of mercury (Drevnick et al. 2015). For *C. hippurus*, no changes in the THg concentrations have been seen since 2002 (Table 4), having the lowest concentrations among tuna and tuna-like species, probably due to its biological aspects, as mentioned above. However, for other species, such as *T. albacares*, there was a different pattern. In the same

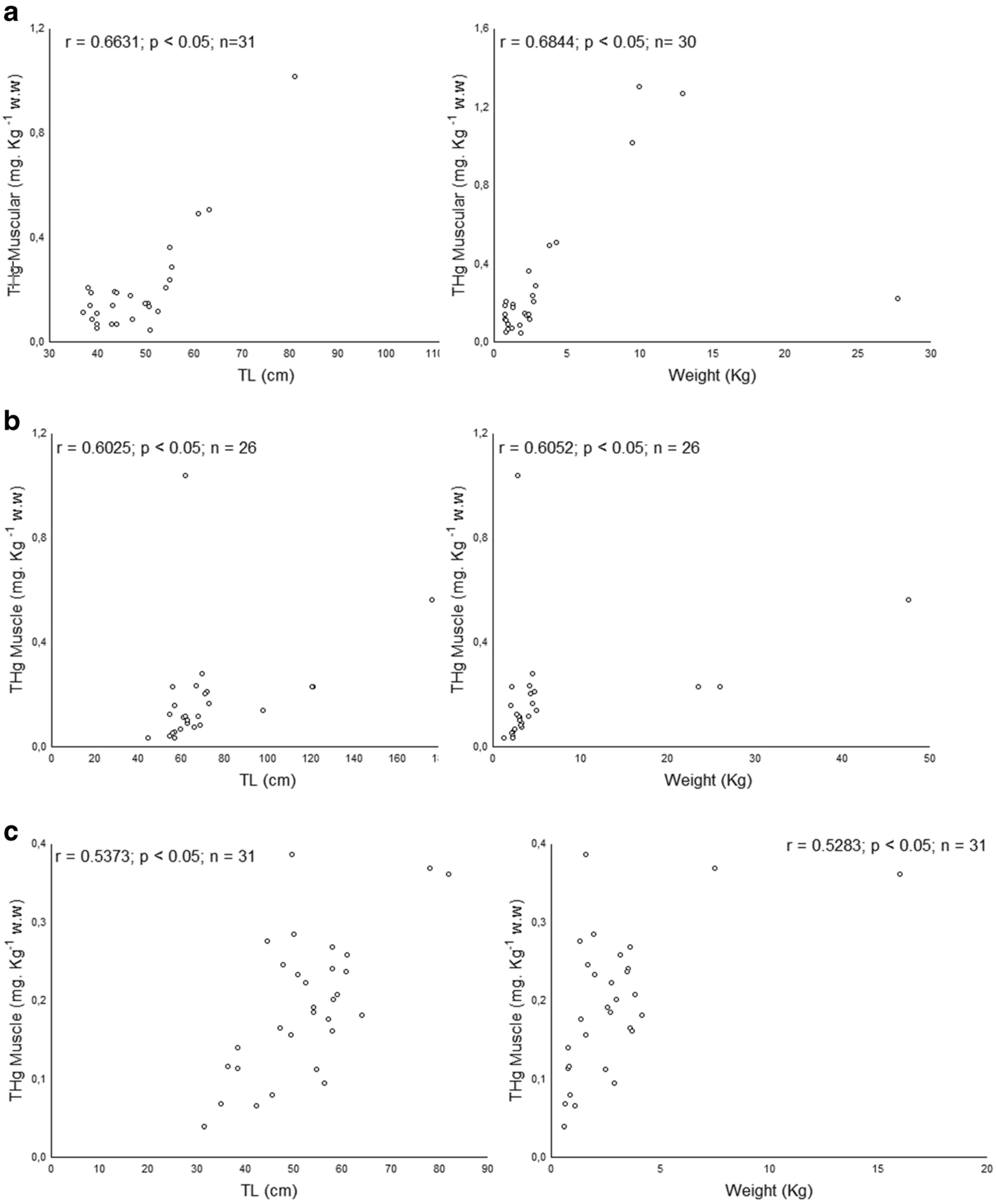

Fig. 1 Correlation between total mercury concentrations in the muscle (expressed in mg.Kg^{-1}, wet weight) and biological parameters (total length (TL) and weight) for tuna and tuna-like species. (A) *Thunnus atlanticus*, (B) *Thunnus albacares*, (C) *Katsuwonus pelamis*, (D) *Euthynnus alletteratus*, (E) *Coryphaena hippurus*, and (F) *Sarda sarda*

studied area, the THg concentrations found in *T. albacares* in 2008 were lower than those found in the present study, showing enhanced bioaccumulation in this species (Table 4). For the other species analyzed, there was no previous study in the same region to compare THg concentrations.

Besides anthropogenic enhancement, global changes can also affect the biogeochemical cycle of mercury. Elevated temperatures, for example, could affect atmospheric oxidation rates and patterns of mercury deposition globally (Krabbenhoft and Sunderland 2013). From this perspective, according to predictions done for two centuries, considering ocean warming rates of 0.4 to 1.0 °C per century, the increase in methylmercury concentrations showed averages of 1.7 and 4.4% per century, respectively (Booth and Zeller 2005). A

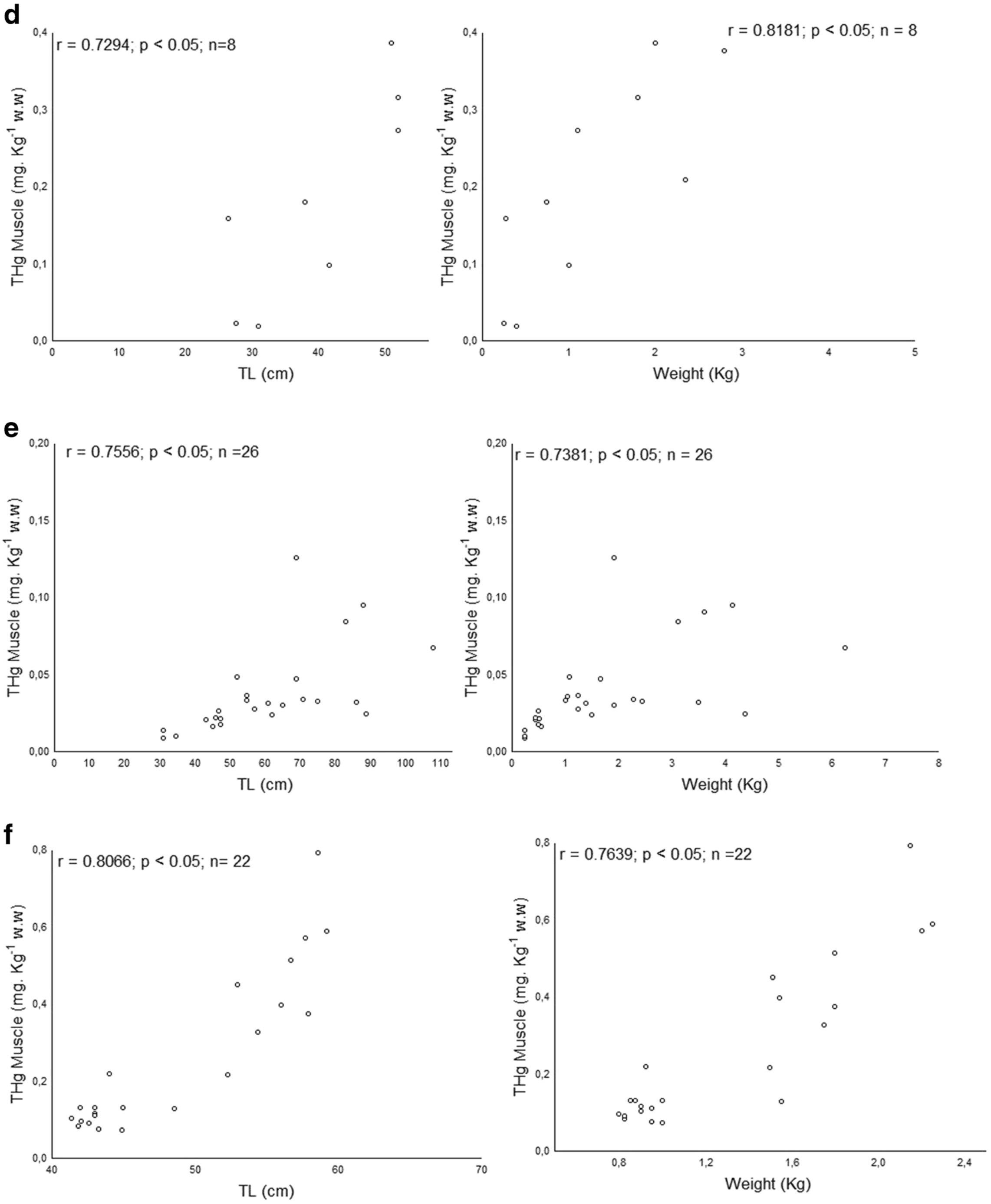

Fig. 1 continued.

recent study with *T. albacares* in the Pacific Ocean showed that mercury concentrations were higher in 2008 than in previous periods (1971 and 1998) (Drevnick et al. 2015). This increase is in agreement with a significant rise in the mercury concentrations in Pacific waters (Sunderland et al. 2009) at depths until 1000 m from 2002 to 2006. It stands out that the largest increase (estimated at 3% per year between 1995 and 2006) was found to occur in intermediate waters (150–1000 m) (Sunderland et al. 2009), which is where *T. albacares* is found in the water column (Collette and Nauen 1983; Drevnick et al. 2015). Since in the present study *T. albacares* showed increased mercury bioaccumulation, these concentrations can be of concern.

Recent models have shown that if the current mercury deposition rates are maintained, in the intermediate waters of the northern Pacific, double the in mercury concentration by 2050

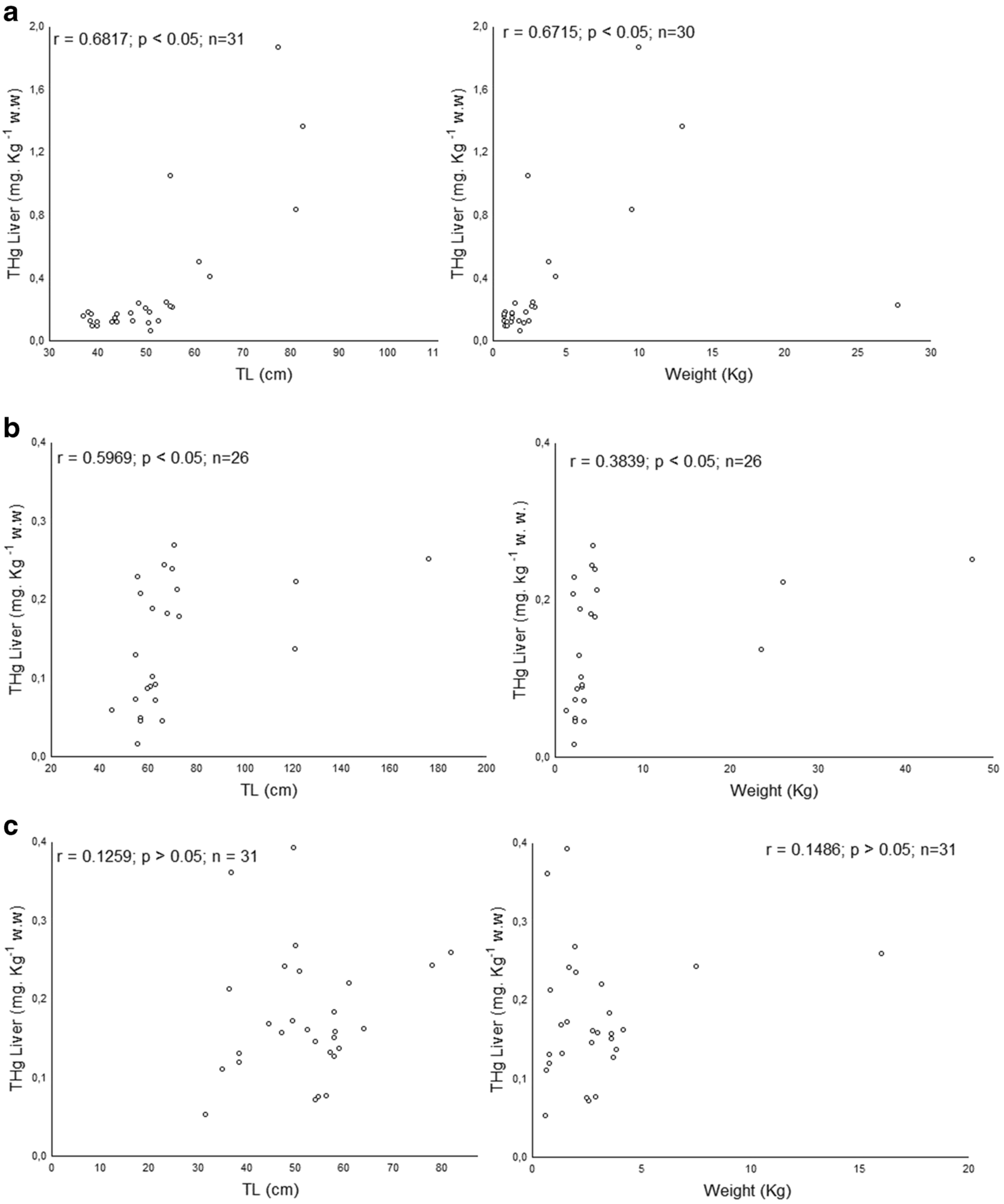

Fig. 2 Correlation between total mercury concentrations in the liver (expressed in mg Kg^{-1}, wet weight) and biological parameters (total length (TL) and weight) for tuna and tuna-like species. (A) *Thunnus atlanticus*, (B) *Thunnus albacares*, (C) *Katsuwonus pelamis*, (D) *Euthynnus alletteratus*, (E) *Coryphaena hippurus*, and (F) *Sarda sarda*

would be expected (Sunderland et al. 2009). However, the mercury emissions from anthropogenic sources are predicted to increase at a rate faster than for the previous few centuries (Lamborg et al. 2014).

These increased mercury concentrations should also be expected in other ocean waters since most mercury released into the atmosphere is in the gaseous elemental chemical form, allowing it to be widely dispersed around the globe (even between hemispheres), and it presents a long atmospheric lifetime (6 to 12 months) (Fitzgerald and Clarckson 1991; Krabbenhoft and Sunderland 2013; Lamborg et al. 2014). Since atmospheric deposition determines mercury

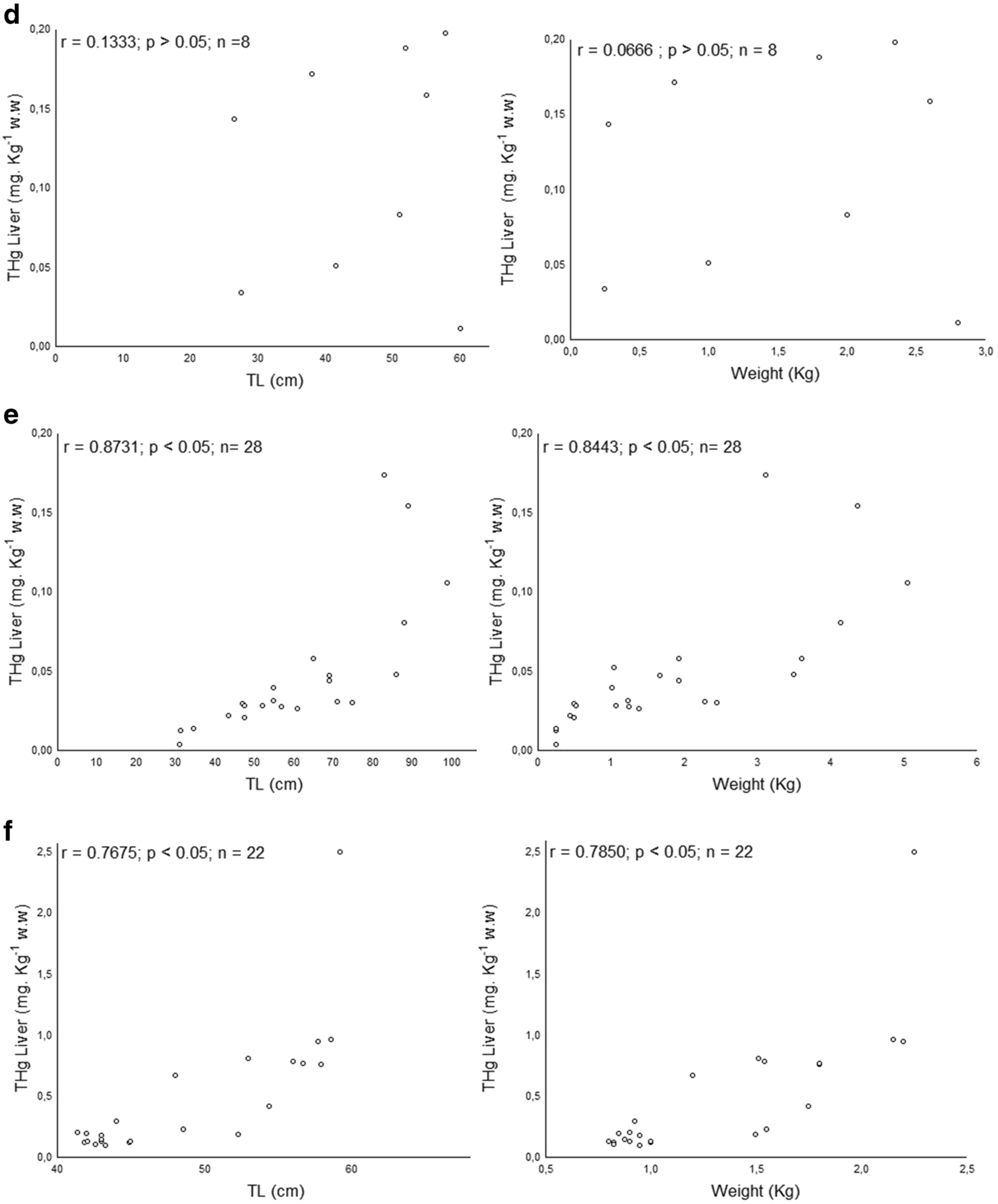

Fig. 2 continued.

accumulation in water, sediments, and organisms (Fitzgerald and Clarckson 1991), increased mercury concentrations in tuna and tuna-like species should be expected.

Conclusion

The present study provides additional information regarding total mercury concentrations in the muscle and liver of six tuna and tuna-like species captured in the southwestern Atlantic. Although there are studies regarding mercury in tuna, usually, they use the true tuna, such as bluefin tuna and yellowfin tuna (e.g., Endo et al. 2016; Storelli et al. 2005). Therefore, other species such as those analyzed in the present study exhibit little information, especially in the southern hemisphere. Tuna and tuna-like species in the present study showed high total mercury concentrations in their tissues, with the lowest concentrations found in *C. hippurus* and the highest

Table 4 Mercury levels (mean ± standard deviation, mg kg^{-1} wet weight) in muscle of tuna and tuna-like species from all over the world

Species	*N*	Origin	Mean ± SD	References
Coryphaena hippurus	57	Gulf of Mexico	0.07 ± 0.09	Cai et al. (2007)
	48	Western Indian Ocean	0.01	Kojadinovic et al. (2007)
	385	United States	0.10	Adams (2009)
	44	Western Indian Ocean	0.01 ± 0.05	Kojadinovic et al. (2006)
	27	Gulf of Mexico	0.21	Kuklyte and Rowe (2012)
	12	United States	0.17 ± 0.20	Burger and Gochfeld (2011)
	20	Southwestern Atlantic Ocean	0.05 ± 0.01	Selanes et al. 2002
	22	Southwestern Atlantic Ocean	0.03 ± 0.02	This study
Thunnus atlanticus	48	Gulf of Mexico	0.66 ± 0.31	Cai et al. (2007)
	37	United States	1.07 ± 0.54	Adams (2004)
	11	Gulf of Mexico	0.39	Kuklyte and Rowe (2012)
	22	Gulf of Mexico	0.73 ± 0.22	Senn et al. (2010
	28	Southwestern Atlantic Ocean	0.28 ± 0.34	This study
Thunnus albacares	56	United States	0.25 ± 0.12	Adams (2004)
	103	Gulf of Mexico	0.18 ± 0.15	Cai et al. (2007)
	18	Gulf of Mexico	0.19 ± 0.15	Senn et al. (2010)
	45	Western Indian ocean	0.65 ± 0.52	Kojadinovic et al. (2007)
	39	Western Indian ocean	0.13 ± 0.09	Kojadinovic et al. (2006)
	56	United States	0.20 ± 0.17	Burger and Gochfeld (2011)
	45	Gulf of Mexico	0.36	Kuklyte and Rowe (2012)
	99	Indian and Pacific Ocean	0.37 ± 0.2	Endo et al. (2016)
	14	Southeastern Atlantic Ocean	0.73 ± 0.22	Bosch et al. (2016)
	56	Southwestern Atlantic Ocean	0.18 ± 0.11	Ferreira et al. (2012)
	8	Southwestern Atlantic Ocean	0.08 ± 0.05	Medeiros et al. (2008)
	20	Southwestern Atlantic Ocean	0.12 ± 0.07	This study
Katsuwonus pelamis	2	Japan	0.47 ± 0.24	Yamashita et al. (2005)
	38	Western Indian Ocean	0.51 ± 0.28	Kojadinovic et al. (2007)
	39	Indian Ocean	0.19 ± 0.66	Kojadinovic et al. (2006)
	29	Southwestern Atlantic Ocean	0.19 ± 0.08	This study
Euthynnus alletteratus	114	United States	0.94 ± 0.60	Adams (2004)
	9	Gulf of Mexico	1.08 ± 0.72	Cai et al. (2007)
	9	Gulf of Mexico	0.69	Kuklyte and Rowe (2012)
	8	Southwestern Atlantic Ocean	0.21 ± 0.13	This study

found in *T. atlanticus* and *S. sarda*. Differences in their diet, feeding ecology and habitat preferences were important factors associated with these differences. Size and weight were important biological parameters in mercury bioaccumulation, which increased with growth. In this sense, these elevated mercury concentrations found are of concern since may represent serious damage in many organisms. Since anthropogenic mercury is continuous and estimated to increase in ocean waters, tuna and tuna-like species are useful sentinels of mercury bioavailability in ocean waters.

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