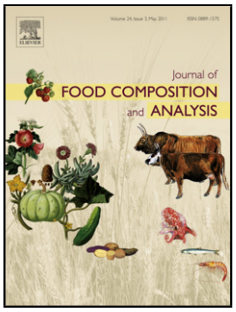

Contribution of commercial fish species to human mercury exposure: an evaluation near the Mid-Atlantic Ridge

H.C. Vieira (Conceptualization) (Methodology) (Investigation) (Formal analysis) (Writing - original draft), J. Rendón-von Osten (Supervision) (Methodology) (Writing - review and editing), A.M.V.M. Soares (Resources) (Funding acquisition) (Writing - review and editing), F. Morgado (Supervision) (Resources) (Writing - review and editing), S.N. Abreu (Supervision) (Methodology) (Writing - review and editing)

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Contribution of commercial fish species to human mercury exposure: an evaluation near the Mid-Atlantic Ridge

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Highlights:

- Only 2 of the 28 fish species analysed exceeded the Hg limits for fish consumption.
- The 28 fish species contribute every year to about 1.8 kg of Hg for human exposure.
- Amount of fish landing plays a more determinant role than [Hg] in human Hg exposure.
- An exposure at this level (THQ<1) is not likely to cause any negative health effects.

Abstract

Fish consumption is frequently associated with the prevention of some human diseases, being simultaneously a major pathway of mercury (Hg) exposure. Therefore, the aim of the study was to evaluate the contribution of 28 commercial fish species to the human Hg exposure in the Azores archipelago (Portuguese region with highest fish consumption per capita). These species potentially contributed on average to 7.47mg of Hg per capita, although low Hg levels had been detected in fish. *Mora moro* and *Zeus faber* exceeded the maximum permitted for fish consumption (> 0.5 µg g^{-1} ww) even though they were not the species contributing the most to human Hg exposure. On the other hand, *Katsuwonus pelamis* was the main contributor due to increased fish landings. Furthermore, an increase in Hg content with trophic level has been suggested, as carnivore fish exhibited higher Hg levels than omnivores. In addition, demersal fish generally presented higher Hg concentration (although non-significant) than pelagic ones, possibly related with increased Hg values of their prey at this depth. Notwithstanding, THQ (Target Hazard Quotient) being < 1 for all species indicates that the daily human exposure to Hg via fish consumption is not likely to cause any negative health risks.

Keywords: Fish consumption; Food composition; Target Hazard Quotient; Risk assessment

1. Introduction

Fish consumption is frequently linked to the prevention of some human diseases, especially regarding cardiac and circulatory disorders, being also associated with the reduction of mortality in patients with coronary diseases (Kris-Etherton et al., 2002; Mozaffarian et al., 2003). These advantages are mainly owing to their contents of high-quality proteins, vitamins, content on n-3 fatty acids, such as docosahexaenoic acid (22:6, n-3, DHA), eicosapentaenoic acid (20:5, n-3, EPA) and other essential nutrients (Egeland and Middaugh, 1997; WHO, 2003; FAO, 2012). At the same time, in contrast with the health benefits, there is a risk derived from exposure to chemical pollutants contained in fish and shellfish that also needs to be taken into account (Domingo et al., 2007). For instance, fish consumption is considered as the major pathway of mercury (Hg) exposure in humans, being more than 90% of total Hg present in fish tissue found essentially in its organic form (methylmercury – MeHg) (Hall et al., 1997; Liang et al., 2013), the most toxic form of Hg (Storelli et al., 2002).

Most of the Hg released into the marine environment is inorganic (Storelli et al., 2002) from either natural or anthropogenic sources (Steenhuisen and Wilson, 2015). Natural emissions include volcano eruptions and geothermal sources, whereas anthropogenic releases are mostly from chloro-alkali production and fossil fuels combustion (Pirrone et al., 2010). Once in the aquatic systems, the inorganic Hg can be converted into MeHg by anaerobic bacteria in sediments (Baeyens et al., 2003; Forsyth et al., 2004).

A great percentage of MeHg ingested by human consumers is absorbed by the body (Hightower and Moore, 2003) potentially reflecting in serious health problems, when chronically exposed to this heavy metal. These problems include a variety of symptoms such as headaches, emotional changes, insomnia, and cognitive function deficits (Hanna et al., 2015). Furthermore, due to its potential to biomagnify along trophic chains, Hg may achieve hazardous concentrations in fish and shellfish species, fish-eating wildlife and human populations (Southworth et al., 2000; Chan et al., 2003). For this reason, the European Union has determined limits for fish and fish products consumption, concerning Hg exposure. The European Commission Regulation (EC) No 466/2001 of 8th March 2001 established maximum levels of 0.5 µg g^{-1} ww Hg permitted for human consumption in foodstuffs, excluding an "exception list" where the accepted tolerance level raises to 1 µg g^{-1} ww, comprising some species with high trophic level (EU, 2001). On the other hand, Food and Agriculture Organization (FAO)/ World Health Organization (WHO) Joint Expert Committee on Food Additives (JECFA) and US Environmental Protection Agency (USEPA) have established reference doses (RfD) for MeHg intake based on epidemiological studies conducted in New Zealand, Seychelles and the Faeroe (Rice, 2004; Li et al., 2015). At last, JECFA considered a RfD named "provisional tolerable weekly intake" (PTWI) for MeHg of 1.3 µg kg body weight $(bw)^{-1}$ $week^{-1}$ (EFSA Scientific Committee, 2015) and USEPA set a RfD in 0.7 µg MeHg kg bw^{-1} $week^{-1}$ (USEPA, 1997).

The Azores archipelago located near the mid-Atlantic ridge (MAR) is an area of high fish consumption rate "per capita" as each Azorean consumes around 80 Kg of fish per year (Megapesca, 2007). Through a search in Web of Science (May 2019), using the keywords "Mercury AND Azores", several studies were found reporting the Hg concentration in the muscle of fish captured in this area (Monteiro et al., 1991; Monteiro et al., 1996; Andersen and Depledge, 1997; Afonso et al., 2007; Magalhães et al., 2007; Costa, 2009; Torres et al., 2015). However, none of them take into account the dietary guidelines of international agencies for human Hg exposure. Such analysis may provide the necessary information about the Hg availability in commercial fish, allowing the consumers to make informed decisions about which fish to ingest. Taking this into consideration, the present work aims to: i) report the Hg concentration in different commercial fish species (landing from 1994 to 2018) in an area with high fish consumption near the MAR, ii) determine the contribution of these fish species to the Hg ingestion for human consumers, and iii) evaluate the human health implications of such Hg exposure using the non-carcinogenic target hazard quotient (THQ).

2. Materials and Methods

2.1. Study area

The study area (Fig. 1) is located near MAR, North Atlantic Ocean, where an isolated group of nine volcanic islands, the Azores archipelago, extends along the south east–north–west strip near the triple junction of Eurasian, African, and North American plates. As a result, the archipelago has a complex tectonic setting, where seismic–volcanic phenomena are common, being responsible for natural inputs of Hg to the aquatic environment (Depledge et al., 1992; Vieira et al., 2013).

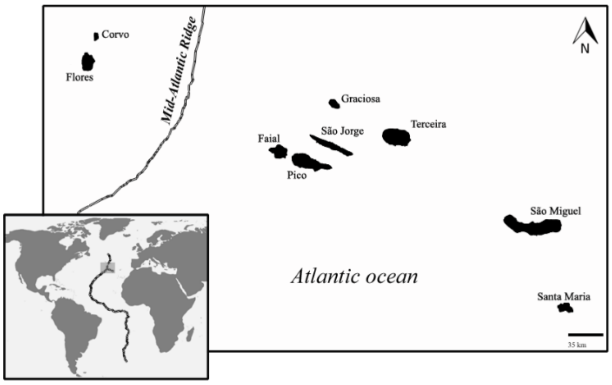

Fig. 1 Map of study area (Azores archipelago) enhancing the proximity of the archipelago to the MAR

2.2. Data analysis

Hg has been quantified in samples from 28 fish species caught in the Azorean Exclusive Economic Zone (AzEEZ). The present review was based on all found published papers presenting an evaluation of Hg concentrations in fish muscle (Table. 1). Table 1 also includes additional data resulting from Hg quantification in samples from recreational fishing, performed in "This study" in species where no previous data was available. Altogether, 28 commercial fish species were considered.

2.3. Lifestyle and trophic level

The 28 fish species present in this work were grouped according to their lifestyle and trophic level (Fig. 2). Regarding their lifestyle, fish species can be classified as demersal or pelagic fish.

Demersal fish species are those who live near the sea substrate, and may have dependent behaviour of the bottom (benthic) or dwell in the interface between the bottom and the water column (benthopelagic) (Pinho and Menezes, 2009). On the other hand, pelagic fish species are those that spend much of their lives swimming in open water away from the bottom (Castro and Huber, 2008). Accordingly, the lifestyle of the fish species was determined conforming to Menezes et al. (2006) and Almada et al. (2015). The trophic level for each species was determined using FishBase information. Furthermore, the identification of the functional trophic groups was performed according to Stergiou and Karpouzi (2002), who established five trophic groups: pure herbivores, omnivores with a preference for vegetable material, omnivores with a preference for animal material, carnivores with a preference for decapods and fish and carnivores with a preference for cephalopods and fish, based on the dietary habits of 332 Mediterranean Sea individuals belonging to 146 species, 59 families and 21 orders, these groups have estimated fractional trophic levels (TROPHs) ranging from 2.0 to 4.5.

2.4. Hg quantification

Hg quantification in fish samples from recreational fishing was performed with the Advanced Mercury Analyzer (AMA-254, made by ALTEC and distributed by LECO). This process does not require a previous digestion of the sample; the procedure is based on a pyrolysis process of the tissue using a combustion tube heated at 750 °C under an oxygen atmosphere and the released Hg is trapped in a gold amalgamator and subsequently detected and quantified by atomic absorption spectrometry (Costley et al., 2000).

Sample analysis were triplicated to check the reproducibility of the results and three blank analyses (analysis without sample) were performed between samples to verify that Hg was not being accumulated over the samples. In this study, blank readings typically correspond to values < 0.02 ng of Hg. Analytical quality of the procedure was checked using the reference material TORT-2 (Lobster Hepatopancreas Reference Material for Trace Metals, National Research Council of

Canada). Obtained data (0.251±0.001 μg g^{-1} of Hg) and reference (0.27±0.06 μg g^{-1} of Hg) values were not statistically different ($p>0.05$).

2.5. Risk assessment in human population

As stated by Groth III (2010), the average Hg concentration may be combined with the market share percentages of each fish species to generate Hg input factors. These factors are not precise measures of exposure; however, they indicate the relative contributions of each fish species in the overall population's Hg intake (Groth III, 2010).

Moreover, there are two main methods of estimating risks: one is based on carcinogenic effects, and the other is based on non-carcinogenic effects (Chien et al., 2002). In accordance with Barone et al. (2015), for non-carcinogenic effects, the risk can be expressed as a target hazard quotient (THQ). THQ indicates the ratio between exposure and the reference dose. If the ratio is less than 1, it means that the level of exposure is smaller than the reference dose, suggesting that a daily exposure at this level is not likely to cause any deleterious effects during the lifetime of a human consumer. In other words, a THQ below 1 means that the adverse effects are negligible. The THQ is based on the following equation (Chien et al., 2002; Barone et al., 2015; Bortey-Sam et al., 2015):

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times ABW \times AT} \times 10^{-3}$$

where *EF* is the exposure frequency (365 days $year^{-1}$);

ED is the exposure duration (adults, 70 years, equivalent to the average lifetime);

FIR is the food ingestion rate (g $person^{-1}$ day^{-1});

C is the metal concentration in fish (μg g^{-1}, wet weight);

RfD is the oral reference dose (μg g^{-1} day^{-1}); *ABW* is the average body weight (60kg);

AT is the averaging exposure time for non-carcinogens (365 days $year^{-1}$ × ED).

2.6. Statistical analysis

Data normality was tested using Kolmogorov-Smirnov test. Data did not follow a normal distribution, and the normality was established after log-transformation; therefore, the parametric statistical t-tests were used to compare the mean Hg concentration between functional trophic (omnivores and carnivores) and lifestyle (pelagic and demersal fish species). Statistical analyses were performed using Sigmaplot (version 11.0). Statistical significance was defined as $p<0.05$. Hg concentration data is presented as mean value ± standard error value (mean ± SE).

3. Results and Discussion

3.1. Interspecific differences of Hg in commercial fish

Hg concentration present in the muscle from the 28 commercial fish species ranged from 0.01 µg g^{-1} (ww) in the parrot fish *Sparisoma cretense* to 0.81 µg g^{-1} (ww) in the common mora *Mora moro* (Fig. 2).

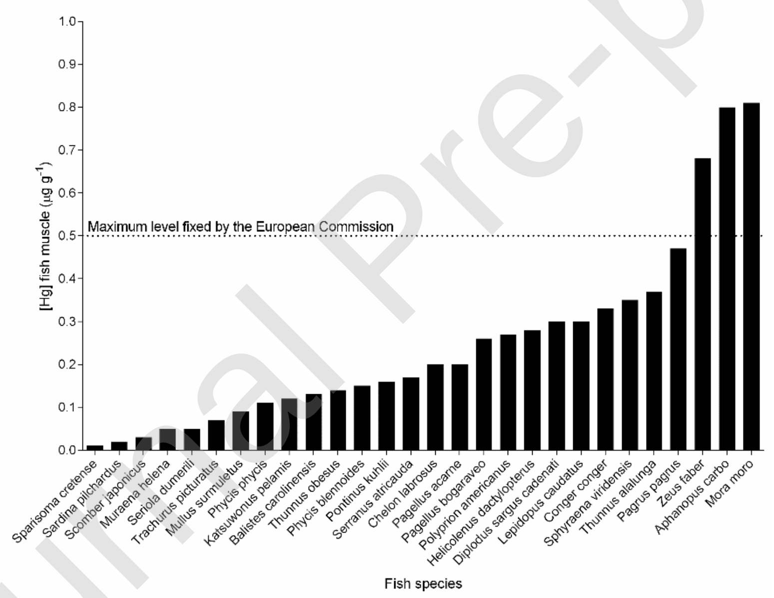

Fig. 2 Hg concentration (µg g^{-1}, ww) present in the muscle from 28 commercial fish species.

Hg concentration of each species was compared with the permissible limits established in Commission Regulation (EC) no. 629/2008 of July 2008 (EU, 2008). This regulation establishes, for most fish species, the value of 0.5 µg g^{-1} as the maximum Hg concentration for consumption, except for the species present in the "exception list" where the maximum allowed concentration raises to 1 µg g^{-1}. Regarding the permissible limits for fish consumption, only *Mora moro* and the *Zeus faber* exhibited higher values than the permitted (0.81 µg g^{-1} and 0.68 µg g^{-1}, respectively, exceeding the maximum value of 0.5 µg g^{-1}) but were lower than the values reported in previous studies for *Mora moro* (2.40 µg g^{-1}) from the NW Mediterranean (Koenig et al., 2013) and for *Zeus faber* (0.75 µg g^{-1}) captured in the Central Adriatic (CA) and Central Tyrrhenian (CT) Seas, Italy (Di Lena et al., 2017). Although the Hg concentration in *Aphanopus carbo* was the second highest in this study (0.80 µg g^{-1}), and similar with the Hg concentration (0.89±0.27 µg g^{-1}) reported by Afonso et al. (2008), this species belongs to the "exception list" and thus does not exceeds the permitted limit (1 µg g^{-1}).

The interspecific Hg variation in fish is the result of trophic position, growth rate, fish age and food web complexity (Magalhães et al., 2007; Koenig et al., 2013), thus; different fish species contain distinct Hg contents. Based on the combined fish and shellfish Hg content of 51 different commercially important varieties in the US seafood supply (U.S. Food and Drug Administration, 2009), a classification system of six categories was created: "very low" < "below average" < "above average" < "moderately high" < "high" < "very high" (Groth III, 2010). Taking as a starting point the value of 0.086 µg g^{-1} (weighted average Hg level in the US seafood supply as a whole), each limit between groups is the result of multiplying the weighted average Hg level per 0.5, 1, 2, 4 and 8 times, respectively.

This mathematical scheme is simple and should be relatively easy for consumers to grasp, facilitating risk communication (Groth III, 2010). In this way, each fish species present in this study was grouped (Table 2) based on those six categories.

Consequently, the first category classified as "very low" Hg category comprises only three fish species and represents 4.9% of the total landing per year. The maximum Hg concentration (0.03 µg g^{-1}) found in this category belongs to the *Scomber japonicus.* The category "below average" also includes three species: the Hg concentration determined in these species was 0.05 µg g^{-1} in the *Muraena helena* and the *Seriola dumerili* and 0.07 µg g^{-1} for the *Trachurus picturatus*. This category contributes to 10.3% of the landings. Seven other species have Hg concentration "above average". In this group, Hg concentration ranged between 0.09 µg g^{-1} and 0.17 µg g^{-1}, being the higher Hg concentration attributed to the *Serranus atricauda*. These seven species correspond to 48.4% of landings in the Azorean ports, 32.7% of which belong to the *Katsuwonus pelamis*. The vast majority of fish species belongs to the "moderately high" category. Eight fish species contribute to 20.2% for the total landing and the maximum Hg concentration (0.33 µg g^{-1}) in this category belongs to the *Conger conger*. The last two Hg categories "high" and "very high" represent 3.6% and 1.5% of landings in the Azorean ports per year, respectively. For these categories the *Zeus faber* and *Mora moro* are the species with higher Hg concentration with 0.68 µg g^{-1} and 0.81 µg g^{-1}, respectively.

3.2. Hg concentration according to lifestyle and trophic level

According to Stergiou and Karpouzi (2002), the TROPHs calculations based on prey items in the diet, express the position of organisms within the food webs that largely defines aquatic ecosystems. In the present study, the 28 fish species were classified and distributed to five trophic groups based on their trophic level (Fig. 3). The group of "pure herbivores" with the TROPH values between 2.0 and 2.1 was not represented by any species. The group of omnivores with a preference for vegetable material (2.1 < TROPH < 2.9) was represented by a single species (*Chelon labrosus*), whereas the category of omnivores with a preference for animal material (2.9 < TROPH < 3.7) was represented by 7 fish species (*Diplodus sargus cadenati*, *Helicolenus dactylopterus*, *Mullus surmuletus*, *Scomber japonicus*, *Sparisoma cretense*, *Sardina pilchardus* and *Trachurus picturatus*). On the other hand, the group of carnivores (3.7 < TROPH < 4.5) was subdivided according to the preference either for decapods and fish (3.7 < TROPH < 4.0) or preference for fish and cephalopods (4.0 < TROPH < 4.5). The first subgroup of carnivores was represented by 5 fish species (*Lepidopus caudatus*, *Mora moro*, *Pagellus acarne*, *Pagrus pagrus* and *Phycis blennoides)* while the majority of species (15) belonged to the second subgroup (*Aphanopus carbo*, *Balistes carolinensis*, *Conger conger*, *Katsuwonus pelamis*, *Muraena helena*, *Pagellus bogaraveo*, *Phycis phycis*, *Polyprion americanus*, *Pontinus kuhlii*, *Serranus atricauda*, *Thunnus alalonga*, *Zeus faber*, *Seriola dumerili*, *Sphyraena viridensis* and *Thunnus obesus*), respectively.

Due to the large variation in the number of species present in each trophic group, the five groups were reduced to two major ones: “omnivores” including fish species with a trophic level greater than 2.1 and less than 3.7, and “carnivores” consisting of fish species with TROPH values between 3.7 and 4.5.

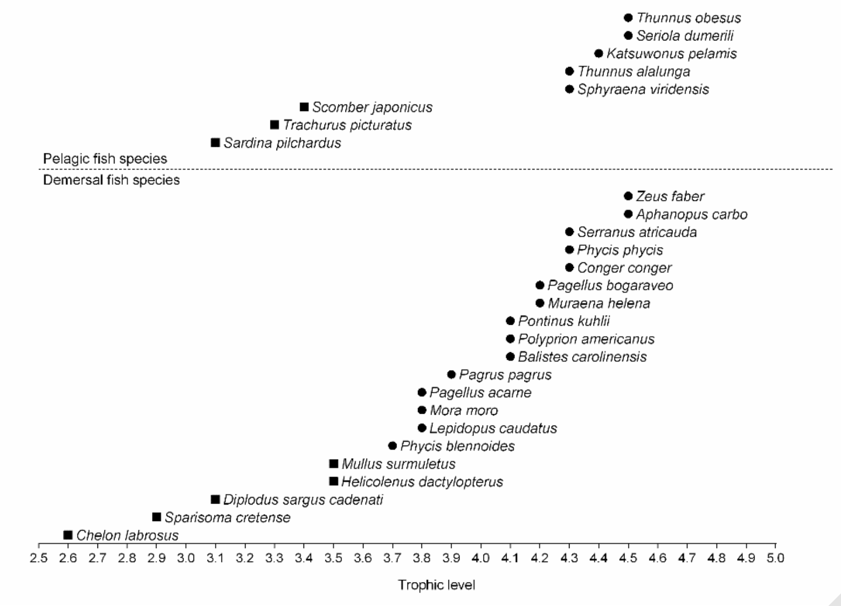

Fig. 3 Trophic level, functional trophic groups (■ Omnivores and ● Carnivores) and lifestyle information (pelagic and demersal fish species) of the 28 fish species evaluated in this study

On average, the Hg concentration found in carnivores fish species (0.30±0.04 µg g^{-1}) was significantly higher ($p<0.05$) than the Hg concentration present in omnivorous fish species (0.13±0.04), which goes in line with previous studies (Li et al., 2009; Kasper et al., 2012; Costa and Lacerda, 2014; Bastos et al., 2015). The increased Hg concentration with the trophic level (omnivores vs carnivores fish species) reinforces the notion that Hg biomagnifies along the trophic chain resulting in higher Hg concentrations in fish with more predatory feeding habits than those feeding at lower trophic levels (Ruelas-Inzunza et al., 2008; Li et al., 2009).

Regarding lifestyle, the average Hg concentrations of pelagic and demersal fish species were 0.14±0.08 and 0.29±0.05 µg g^{-1}, respectively. Despite the higher Hg levels found in demersal fish species, no significant difference ($p>0.05$) was found between the Hg concentration in pelagic and demersal fish species. Other authors have also reported higher Hg concentrations in demersal species when compared with pelagic species. For instance, Saei-Dehkordi et al. (2010) showed that demersal fish from the Persian Gulf had higher Hg quantities than those measured in pelagic species. Choy et al. (2009) have also reported that the increase of Hg concentration can be explained by the depth at which the species inhabit. In fact, the foraging habitat is a determining factor influencing the accumulation of Hg (Azevedo et al., 2019), since higher Hg levels are expected in prey that inhabit deeper environments when compared to shallower environments. Therefore, species with a predatory behaviour obtaining Hg essentially from their prey and living in deeper (demersal) zones are also expected to accumulate higher Hg levels through biomagnification than pelagic species (Choy et al., 2009).

3.3. Hg exposure and risk assessment of human fish consumption

The 28 commercial fish species present in this study contribute to 75.9% of the total fish landings in the Azorean ports. According to the fish landing reports (1994-2018) of Azores Fisheries Statistics (SREA) (http://srea.azores.gov.pt/conteudos/Relatorios/lista_relatorios.aspx?idc=29&idsc=1131&lang_id=1), an average of 10289 tons of these species is discharged every year, which indicates that each year these species provide approximately 1.8 kg of Hg for the fish consumers.

Despite being represented by a small number of species (8), the pelagic fish contribute to half (~50%) of the Hg exposure risk to humans, due to the high fish landing of these species. Furthermore, an average of about 75% of *Katsuwonus pelamis* discharges are directed for the canning industry (unpublished Azores Regional Government data), meaning that muscle tissue from this species will also become available to the population in the form of canned tuna. Therefore, raw or canned food, *Katsuwonus pelamis* is responsible for about 22.8% of the Hg exposure (Fig. 4). However, considering that the canning process leads to an increase in the Hg concentration in the muscle due to the loss of moisture by the tissue (Vieira et al., 2017), the referred percentage may be even greater.

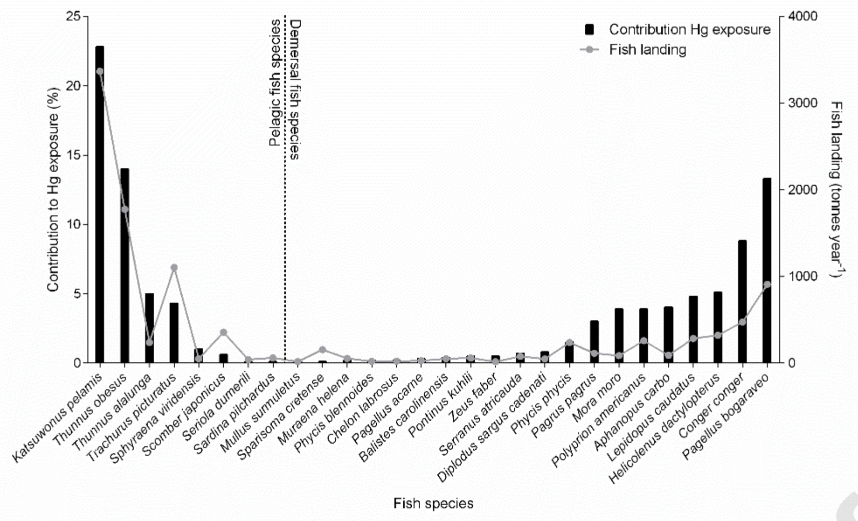

Fig. 4 Contribution to Hg exposure and fish landing of each fish species

Encompassing all data, and according to the Hg input factor (Fig. 5), the species that most contribute to Hg exposure are not those with the highest Hg concentrations. Considering the 4 fish species with the highest inputs of Hg, the first two (*Katsuwonus pelamis* and *Thunnus obesus*) belong to the "above average" category (ranging between 0.087 and 0.172 µg g^{-1}) whereas the other two (*Pagellus bogaraveo* and *Conger conger*) belong to the "moderately high" category (Hg concentration between 0.173 and 0.344 µg g^{-1}). A very large cumulative fraction (58.9%) of the Hg inputs is therefore represented by a relatively small number of fish species with lower Hg concentration, which, on the other hand has a significant percentage of the total fish landing in the Azorean ports. It is thus suggested that the quantity of fish landed plays an important role in human exposure to Hg.

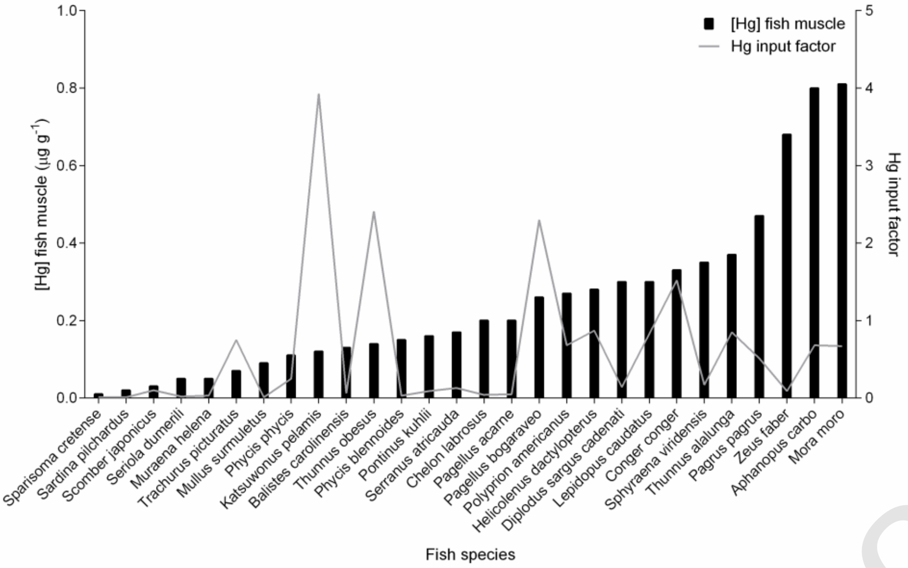

Fig. 5 Estimated Hg input factor for each fish species and comparison with the Hg concentration

In marine fish, about 90-95% of the Hg concentration present in fish muscle exists in the methylated form (Fitzgerald et al., 2007; WHO, 2008); however, the European Food Safety Authority (EFSA) Panel on Contaminants in the Food Chain uses the worst case scenario hypothesis to calculate the MeHg dietary exposure; therefore they assume that 100% of Hg present in fish is in its methylated form (Ceccatto et al., 2015; Di Lena et al., 2018). Consequently, the THQ was calculated assuming the Hg concentration as 100% MeHg for both RfD's (USEPA RfD and JECFA RfD).

Hg THQ values (Table 3) ranged between 0.02 and 0.13 for USEPA RfD and 0.001 and 0.007 for JECFA RfD. These THQ values were much lower than 1 for all fish species regarding both RfD's, indicating that the consumers are unlikely to develop health problems due to consumption of these fish species.

4. *Conclusion*

The evaluation of the contribution of commercial fish species to human Hg exposure (mostly urged in high fish consumption area) requires the review of published literature, and complementary quantifications to fulfil the gaps. Additional data on fish captures and landings, plus fish consumptions habits, including knowing the most representative species are also essential. Encompassing all data will provide the base tools to assess the potential risk to human health in an area with higher rates of fish consumption per capita such as near the MAR.

The present study demonstrates that only 2 of the 28 analysed fish species exceeded the permissible limits for fish consumption. Despite the low Hg levels detected in fish, every year the population of this area is exposed to about 1.8 Kg of Hg (7.47mg of Hg per capita) via fish consumption. Carnivores fish species exhibited higher concentration of Hg than omnivores fish species suggesting trends of biomagnification. Furthermore, demersal species generally presented higher Hg concentration than pelagic ones. Fish species containing the highest Hg concentration in their tissues are not those that contribute the most to higher levels of human exposure. Despite having increased Hg levels, these species are discharged in smaller quantities explaining a lower contribution to human Hg exposure. Thus, fish landing seems to have a greater role in the human exposure than the Hg concentration found in the fish species.

Despite being included in an area near the MAR, where seismic–volcanic phenomena are common, and which is responsible for natural inputs of Hg to the aquatic environment, the THQ was < 1 for all fish species caught in the AzEEZ. This means that the level of exposure is lower than the reference dose, indicating that a daily exposure to fish at this level is not likely to cause any negative health effects during a lifetime in a human population.

This kind of study have some limitations; however, they can provide useful information for future health risk assessments.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author statement

Vieira, H.C.: Conceptualization; Methodology; Investigation; Formal analysis, Writing - Original Draft
Rendón-von Osten, J.: Supervision; Methodology; Writing - Review & Editing
Soares, A.M.V.M.: Resources; Funding acquisition; Writing - Review & Editing
Morgado, F.: Supervision; Resources; Writing - Review & Editing
Abreu, S. N.: Supervision; Methodology; Writing - Review & Editing

All authors contributed gave final approval for publication.

Conflict of interest

The authors declare that they have no conflict of interests (financial or non-financial).

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Table 1 Average of Hg concentrations (µg g^{-1}), number of sample (n) individual per study and reference of the 28 fish species caught near the Azores archipelago

Scientific name	**Common name**	**n**	**Average$_{[Hg]}$** (µg g-1, ww)	**References**
Aphanopus carbo	Black scabbard fish	20; 135	0.80	Afonso et al. (2007); Costa et al. (2009)
Balistes carolinensis	Triggerfish	5	0.13	This study
Chelon labrosus	Thick-lipped grey mullet	10	0.20	Andersen and Depledge (1997)
Conger conger	Conger eel	5; 39	0.33	Andersen and Depledge (1997); Magalhães et al. (2007)
Diplodus sargus cadenati	White sea bream	55	0.30	Andersen et al. (1997)
Helicolenus dactylopterus	Blue-mouth	105; 31	0.28	Monteiro et al. (1991); Andersen and Depledge (1997)
Katsuwonus pelamis	skipjack tuna	53; 15	0.12	Andersen and Depledge (1997); Torres et al. (2015)
Lepidopus caudatus	silver scabbard fish	24; 55	0.30	Andersen and Depledge (1997); Magalhães et al. (2007)
Mora moro	Common mora	42	0.81	Magalhães et al. (2007)
Mullus surmuletus	Red mullet	13; 6	0.09	Andersen and Depledge (1997); This study
Muraena helena	Moray eel	1	0.05	Andersen and Depledge (1997)
Pagellus acarne	Axillary sea bream	24	0.20	Magalhães et al. (2007)
Pagellus bogaraveo	Red sea bream	11	0.26	Andersen and Depledge (1997)
Pagrus pagrus	red porgy	1	0.47	Andersen and Depledge (1997)
Phycis blennoides	Greater forkbeard	17	0.15	Magalhães et al. (2007)
Phycis phycis	Forkbeard	31; 56	0.11	Andersen and Depledge (1997); Magalhães et al. (2007)
Polyprion americanus	Wreckfish	14	0.27	Magalhães et al. (2007)
Pontinus kuhlii	Offshore rockfish	99	0.16	Monteiro et al. (1991)
Sardina pilchardus	Sardine	6	0.02	This study
Scomber japonicus	Chub mackerel	4	0.03	Monteiro et al. (1996)
Seriola dumerili	Greater amberjack	2	0.05	This study
Serranus atricauda	Blacktail Comber	8	0.17	This study
Sparisoma cretense	Parrotfish	9	0.01	This study
Sphyraena viridensis	Yellowmouth barracuda	3	0.37	This study
Thunnus alalunga	Albacore	46	0.37	Andersen and Depledge (1997)
Thunnus obesus	bigeye tuna	15	0.14	Torres et al. (2015)
Trachurus picturatus	Blue jack mackrel	20; 39; 48; 7	0.07	Monteiro et al. (1996); Andersen and Depledge (1997); Magalhães et al. (2007); This study
Zeus faber	Jonh dory	*4*	*0.68*	This study

Table 2 Hg classification system of the studied fish species in six categories based on Hg content.

Hg category	**Hg range ($\mu g\ g^{-1}$)**	**Fish species**
Very low	≤0.043	*Scomber japonicus, Sparisoma cretense, Sardina pilchardus*
Below average	0.044-0.086	*Muraena helena, Trachurus picturatus, Seriola dumerili*
Above average	0.087-0.172	*Balistes carolinensis, Katsuwonus pelamis, Phycis blennoides, Phycis phycis, Pontinus kuhlii, Serranus atricauda, Thunnus obesus, Mullus surmuletus*
Moderately high	0.173-0.344	*Chelon labrosus, Conger conger, Diplodus sargus cadenati, Helicolenus dactylopterus, Lepidopus caudatus, Pagellus acarne, Pagellus bogaraveo, Polyprion americanus*
High	0.345-0.688	*Pagrus pagrus, Thunnus alalunga, Sphyraena viridensis, Zeus faber*
Very high	>0.688	*Aphanopus carbo, Mora moro*

Table 3 Estimated target hazard quotient (THQ) for each fish species for both RfD's (USEPA RfD and JECFA RfD)

Scientific name	**Mercury level [Hg](μg g^{-1})**	**Fish landing (kg year^{-1})**	**Fish available for consumption per capita (g day^{-1})**	**THQ**	
				USEPA	**JECFA**
Aphanopus carbo	0.8	88021	0.98	0.1303	0.0072
Balistes carolinensis	0.13	50341	0.56	0.0121	0.0007
Chelon labrosus	0.2	21839	0.24	0.0081	0.0004
Conger conger	0.33	474060	5.26	0.2895	0.0161
Diplodus sargus cadenati	0.3	46533	0.52	0.0258	0.0014
Helicolenus dactylopterus	0.28	320020	3.55	0.1658	0.0092
Katsuwonus pelamis	0.12	3367006	37.38	0.7476	0.0415
Lepidopus caudatus	0.3	285083	3.17	0.1583	0.0088
Mora moro	0.81	84685	0.94	0.1269	0.0071
Mullus surmuletus	0.09	15919	0.18	0.0027	0.0001
Muraena helena	0.05	53369	0.59	0.0049	0.0003
Pagellus acarne	0.2	25832	0.29	0.0096	0.0005
Pagellus bogaraveo	0.26	908611	10.09	0.4371	0.0243
Pagrus pagrus	0.47	111761	1.24	0.0972	0.0054
Phycis blennoides	0.15	18724	0.21	0.0052	0.0003
Phycis phycis	0.11	237268	2.63	0.0483	0.0027
Polyprion americanus	0.27	257825	2.86	0.1288	0.0072
Pontinus kuhlii	0.16	58948	0.65	0.0175	0.0010
Sardina pilchardus	0.02	59713	0.66	0.0022	0.0001
Scomber japonicus	0.03	354450	3.94	0.0197	0.0011
Seriola dumerili	0.05	40357	0.45	0.0037	0.0002
Serranus atricauda	0.17	76213	0.85	0.0240	0.0013
Sparisoma cretense	0.01	154196	1.71	0.0029	0.0002
Sphyraena viridensis	0.35	50565	0.56	0.0327	0.0018
Thunnus alalunga	0.37	237402	2.64	0.1625	0.0090
Thunnus obesus	0.14	1774389	19.70	0.4597	0.0255
Trachurus picturatus	0.07	1101999	12.23	0.1427	0.0079
Zeus faber	0.68	13878	0.15	0.0175	0.0010