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Mercury in blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) from north-eastern Atlantic: Implication for fishery management

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ABSTRACT

Pelagic sharks (blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus*) caught by long-line Spanish and Portuguese fleets in the NE Atlantic, were sampled at Vigo fish market (Spain) for total mercury (Hg) analysis. Hg concentration in white muscle increased with size and weight in both species, but at a higher rate in shortfin mako than in the blue shark. No difference was found with sex, year and season. Spatial variation was observed in the blue shark with higher Hg values in the North of the Azorean archipelago, but not in the shortfin mako. These high-level predators are particularly susceptible to bioaccumulate contaminants (Hg) in their tissues (muscle). However, a significant positive relationship between Hg concentration and trophic level ($\delta^{15}N$) of individuals was observed only in the shortfin mako. Most sharks landed were juveniles which presented Hg concentration lower than the maximum limit allowed by the European Union (1 mg kg^{-1} wet weight) for marketing. However, concentrations above this threshold were most recorded in blue sharks larger than 250 cm total length (TL) and in shortfin makos larger than 190 cm TL, raising the question of the commercialization of large-sized individuals.

1. Introduction

Long-line Spanish and Portuguese fleets which exploit offshore north-eastern Atlantic waters target pelagic sharks, particularly the blue shark *Prionace glauca* (Linnaeus, 1758) and the shortfin mako *Isurus oxyrinchus,* Rafinesque, 1810, along with the swordfish *Xiphias gladius* Linnaeus, 1758 (Torres et al., 2016). For the past 15 years (2001–2015), the mean landings per year of blue shark represented 2167 tonnes (63% of long-line landings) and 501 tonnes (14%) for the shortfin mako at the fish market of Vigo in Galicia, Spain (Xunta da Galicia, 2008, pers. comm.; ICCAT, 2015). Sharks are essentially sold for human consumption (meat and fin).

The blue shark can reach 380 cm in total length (TL) and could live up to 20 years in the North Atlantic (Skomal and Natanson, 2003). Blue shark females are sexually mature at 220 cm TL (5–6 years) and males at 180 cm TL (4–5 years) (Moreno, 2004; Compagno et al., 2005). The shortfin mako presents a heavier body at similar size than the blue shark, a longer maximum size (440 cm) and a longer life span (30 years max) (Natanson et al., 2006). Median size and age at maturity would be about 280 cm TL and 7–10 years for females, which present a larger size than males, and 200 cm TL, 5–6 years for males (Moreno, 2004; Barreto et al., 2016). However, information on age and growth of both shark species is conflicting and still a matter of debate due to difficult and random sampling of these predators (Skomal and Natanson, 2003; Barreto et al., 2016). These two shark species are highly mobile predators able to migrate over thousands of kilometers in the north Atlantic Ocean (Kohler et al., 2002). Spanish and Portuguese long-liners catch mostly small individuals therefore juveniles represent the major part of shark landings at Vigo fish market for both species (73% of blue sharks and 94% of shortfin makos) (Biton-Porsmoguer, 2015).

Sharks position as high-level predators in the marine food web (Ferretti et al., 2010) makes them especially susceptible to contain high concentration of contaminants and particularly mercury (Hg) (Storelli et al., 2002), as Hg is known to bioamplify along food webs, increasing with the trophic level of organisms (Harmelin-Vivien et al., 2009, 2012; Lavoie et al., 2013). Trophic level of organisms is routinely estimated by the nitrogen isotopic ratio ($^{15}N/^{14}N$), expressed relative to a standard as $\delta^{15}N$, which tends to increase with the size of individuals and

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from prey to predator. $\delta^{15}N$ is then used to follow the transfer and accumulation of contaminants like Hg or PCB in organisms and food webs (Cabana and Rasmussen, 1994; Booth and Zeller, 2005; Cossa et al., 2012). Mercury is a highly toxic trace element present in all compartments of the biosphere. It enters marine food webs from natural and anthropogenic sources (Cossa et al., 2009), and foraging pathway is recognized as being the main Hg contamination way (Mathews and Fisher, 2009). Hg is susceptible to impact aquatic ecosystems including commercial species (McKinley and Johnston, 2010), which could result to adverse health effects on humans like toxic effects on the nervous, digestive, cardiovascular and immune systems, and alterations of fetal neurodevelopment (Castalodi et al., 2003; Díez, 2008). As consumption of marine organisms contributes to most Hg intake in humans, a maximum acceptable level in marine products have been laid down by European Commission regulations and set at 1 mg kg^{-1} wet weight (ww) for high-level pelagic predators (European Commission, 2006: Regulation N° 1881/2006). Fisheries Department from Galician region is supposed to apply the European regulation and must control sanitary state for all landed sea products (Law 11/2008, December 3rd 2008; Xunta da Galicia, 2008). But are the sharks landed and commercialized in Galicia fulfil all these requirements?

The main goals of the present study were thus to: (i) measure the total mercury concentration in the muscle of sharks caught in the north-eastern Atlantic Ocean and sold at Vigo fish market, (ii) determine the influence of size, weight, sex, trophic level, zones, season and year on Hg content in these sharks, and (iii) consider the possible implications for the fishery management.

2. Material and methods

2.1. Sampling and stomach content analysis

Sharks were caught by Spanish and Portuguese long-line vessels in the north-eastern Atlantic in five zones (A to F) between the Iberian Peninsula and the Azores archipelago (15°–35°W and 30°–45°N), in 2012 and 2013 (Fig. 1). A total of 40 blue shark (*Prionace glauca*) and 48 shortfin mako (*Isurus oxyrinchus*) landed at the fish market of Vigo (Spain) were sampled (Table 1). Blue shark and shortfin mako respectively measured from 74 to 284 cm and from 99 to 219 cm total length (TL). White muscle samples were extracted 1 cm beneath the skin from each individual, put in plastic bags and stored frozen at − 20 °C. Once at the laboratory, samples were cleaned with distilled water before freeze-drying, grinding and analyzing for total mercury (Hg) and nitrogen stable isotopes ($\delta^{15}N$). Shark stomachs were extracted and stored at − 20 °C. After identification and weighing (wet weight, ww) of the prey found in stomach contents, those recently consumed (in good state of conservation) were freeze-dried and analyzed for Hg and $\delta^{15}N$ in the same way as shark muscle samples. Total wet weights of partially digested prey were reconstructed according to the size of their hard pieces (beaks for cephalopods and otoliths or vertebrae for teleost fish) using pre-established relationships (Biton-Porsmoguer, 2015). Reconstructed weight percentages (% ww) of the main prey types found in stomach contents were then determined for both shark species.

Table 1
Number of individuals analyzed by sex, season, year and zone for blue shark and shortfin mako. M: Male, F: Female.

Species	Sex		Season		Year		Zone					
	M	F	Winter	Summer	2012	2013	A	B	C	D	E	F
Blue shark	20	20	18	22	19	21	18	11	0	9	0	2
Shortfin mako	26	22	18	30	18	30	9	16	13	0	7	3

2.2. Mercury and stable isotope analyses

Total Hg concentrations were determined with a semi-automated atomic absorption spectrophotometer AMA 254 (Altec Ltd., Prague, Czech Republic) with a detection limit of 0.003 ng/mg, following the procedure described in Cossa et al. (2009). Hg quantification procedure consisted in three automatic sequences: (1) ashing at 550 °C of the freeze-dried sample for Hg volatilisation, (2) evolved elemental Hg amalgamation on a gold trap, (3) atomic absorption spectrophotometric measurement of the Hg collected after heating the gold trap at 800 °C. The accuracy of measurement was assessed every ten samples using certified reference materials from the National Research Council of Canada (fish muscle tissues DORM-4). Hg concentration level of samples was initially expressed as Hg dry weight (dw) concentration in fish muscle or prey muscle samples. However, as Hg concentrations are expressed in wet weight (ww) in international and European regulations, dry weight concentrations were converted into wet weight

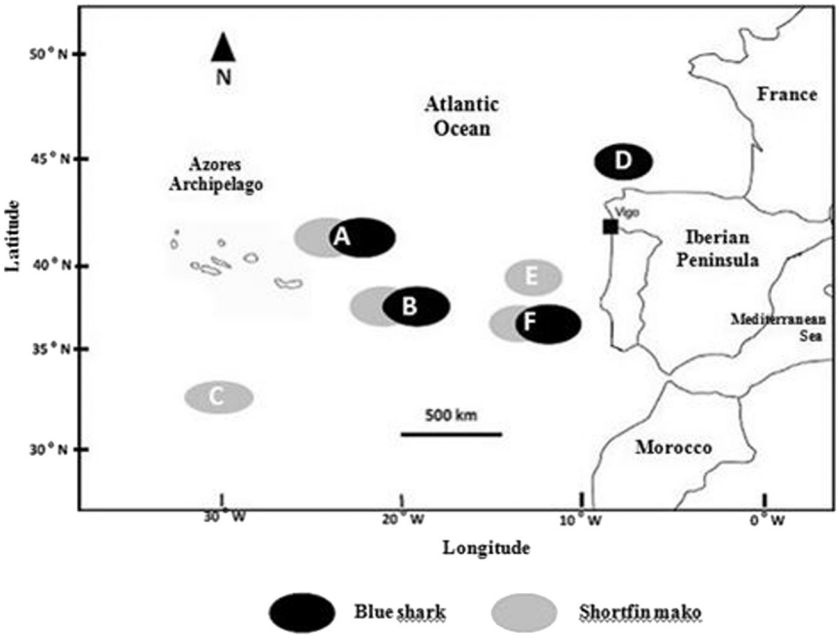

Fig. 1. Map of the 6 sampling areas (A to F) between the Azores Archipelago and the Iberian Peninsula (North-eastern Atlantic Ocean) and two sampled species (the blue shark in black areas and the shortfin mako in grey areas).