Received: 11 Apr. 2016
Accepted: 28 Jun. 2016
Editor: R. Causse

# Using body mass index (BMI) to estimate mercury contamination of the blue shark (*Prionace glauca*) and the shortfin mako (*Isurus oxyrinchus*)

by

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**Résumé**. – Utilisation de l'indice de masse corporelle (BMI) pour estimer la contamination en mercure du requin peau bleue (*Prionace glauca*) et du requin mako (*Isurus oxyrinchus*).

Des requins peau bleue (*Prionace glauca*) et mako (*Isurus oxyrinchus*) ont été capturés par des palangriers espagnols et portugais en Atlantique nord-est, débarqués et vendus à la criée de Vigo en Galice (Espagne). Ces espèces sont des prédateurs supérieurs particulièrement susceptibles d'accumuler le mercure (Hg). Les valeurs moyennes en Hg dans le muscle des requins peau bleue et mako étaient de 0,4 (écart-type = 0,3 $mg.kg^{-1}$) et de 0,5 (écart-type = 0,9 $mg.kg^{-1}$), respectivement. L'indice de masse corporelle (BMI) a été testé pour montrer l'effet cumulatif du Hg chez ces deux prédateurs. Il permet de mesurer le niveau de Hg chez les individus en considérant simultanément la taille (cm) et la masse (kg). Une analyse comparée de ces trois méthodes a permis de montrer que le BMI peut être un bon indicateur biologique du processus de bioaccumulation du mercure chez les requins et pour déterminer les individus impropres à la consommation.

**Keywords**. – Carcharinidae - *Prionace glauca* - Lamnidae - *Isurus oxyrinchus* - Northeast Atlantic - Mercury - Body Mass Index (BMI).

Spanish and Portuguese long-line fishing fleets, which exploit offshore Northeastern Atlantic waters near the Azores archipelago, target blue shark *Prionace glauca* (Linnaeus, 1758) and shortfin mako *Isurus oxyrinchus* Rafinesque, 1810. The Azores archipelago is a volcanic region and a natural source of mercury (Guest *et al*., 1999). The European Union (EU) has defined mercury (Hg) as among "priority dangerous substances" (Decision 2455/2001/CE in an amendment of the European Directive on water 2000/60/CE). Blue and shortfin sharks, sold for human consumption (meat and fin), are considered top-predators in marine food webs (Ferretti *et al*., 2010) and are particularly susceptible to bioaccumulation of mercury (Hg) (Storelli *et al*., 2002).

Condition factors, calculated on length-weight ratios, are commonly considered to be closely related to fitness, determining the survival and reproductive capacity of individuals (Jakob *et al*., 1996). They are influenced by individual diet and behaviour (Harmelin-Vivien *et al*., 2012). Among these condition factors, the body mass index (BMI) is an indicator of body fat, based on height and weight, described by Adolfe Quintelet in 1832 and termed "Body Mass Index" in 1972 by Ancel Keys (Eknoyan, 2008).

The aim of this paper was to test whether BMI could be used as an overall indicator measuring the accumulative process of mercury (Hg) in shark muscles.

## MATERIAL AND METHODS

Thirty-seven blue sharks and 46 shortfin makos were caught in 2012 and 2013 by longline vessels between the Iberian Peninsula and the Azores archipelago (15º-35ºW and 30º-45ºN) and landed in the fish market at Vigo (Spain). Total length and mass were measured in the fish market. Total lengths (TL, cm) for blue shark and shortfin mako ranged between 74 and 284 cm, and between 99 and 219 cm, respectively. Total mass (W, kg) for blue shark and shortfin mako ranged between 1.2 and 77 kg, and between 7.0 and 77 kg, respectively. Most individuals were juveniles, according to the size at sexual maturity (blue shark: 180 cm for male and 220 cm for female; shortfin mako: 200 cm for male and 280 cm for female) (Moreno, 2004).

Muscle samples were extracted from each individual landed and in accordance with the European legislation regarding the control of heavy metal levels in food samples (Commission Regulation EC No 333/2007 of 29 March 2007). For each sample, 20 mg were extracted with a sterile scalpel, 1 cm beneath the skin. All samples were preserved at –20°C. Once at the laboratory, samples were cleaned with distilled water and lyophilized. The samples were sent to the Ifremer laboratory at La Seyne-sur-Mer (France) for Hg analyses using a mercury analyzer (AMA 254), according to the method described in Biton Porsmoguer (2015).

The Body Mass Index (BMI, $kg/cm^2$) is defined by:

(1) $\text{BMI} = \text{Mass} / (\text{TL})^2$

Exponential regressions between BMI and TL (2) and Mass (2'):

(2) $\text{BMI} = a \times \text{Exp}(b \times \text{TL})$,

(2') $\text{BMI} = a' \times \text{Exp}(b' \times \text{Mass})$,

and second order polynomial regression between Hg and BMI were performed:

(3) $\text{Hg} = \alpha\,(\text{BMI})^2 + \beta\,(\text{BMI}) + \gamma$

Hg can thus be expressed in function of BMI using the regression expression obtained. Normality and homogeneity of variances were checked (Shapiro and Levene tests) for Hg ($mg\ kg^{-1}$ Fresh Meat) and BMI.

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## RESULTS

Hg concentrations in shark muscle were variable between individuals and ranged from 0.1 to 1.2 mg. $kg^{-1}$ fresh meat (mean = 0.4, sd = 0.3) for blue shark and from 0.1 to 5.7 mg $kg^{-1}$ fresh meat (mean = 0.5, sd = 0.9) for shortfin mako.

The correlation was significant between BMI and size (TL, cm) and between BMI and mass (W, kg) for blue shark and shortfin mako ($R^2 = 0.74$ and $R^2 = 0.67$; $R^2 = 0.82$ and $R^2 = 0.65$, respectively). For same size and mass animals, BMI level was higher for the shortfin mako than for the blue shark (Fig. 1A, B).

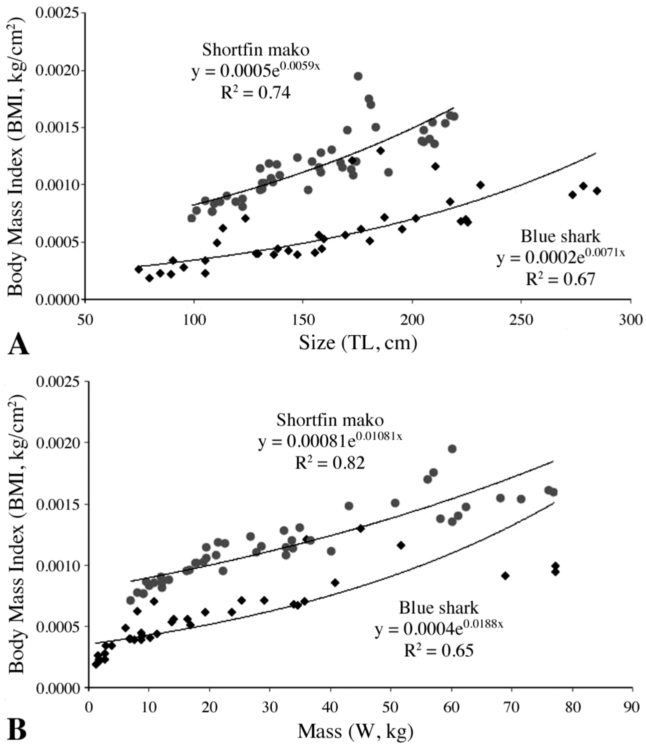


Figure 1. – **A**: Body mass index (BMI, $kg/cm^2$) and size (TL, cm) in blue shark (N = 37) and shortfin mako (N = 46). **B**: Body mass index (BMI, $kg/cm^2$) and total mass (W, kg) in blue shark (N = 37) and shortfin mako (N = 46).

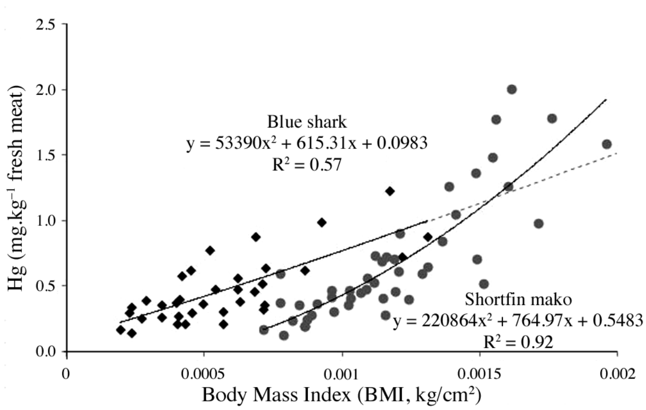


Figure 2. – Mercury level (mg $kg^{-1}$ fresh meat) and body mass index (BMI, $kg/cm^2$) in blue shark (◆, N = 37) and shortfin mako (●, N = 46). Dotted line section of the curve represents the extrapolation from regression analysis for blue sharks.

Higher levels of Hg concentration in muscle were observed for the largest individuals (Fig. 2). The correlation was significant between Hg (mg $kg^{-1}$ fresh meat) and BMI for both blue shark and shortfin mako ($R^2 = 0.57$, $p < 0.001$ and $R^2 = 0.92$, $p < 0.001$, respectively). Although the largest blue sharks caught never

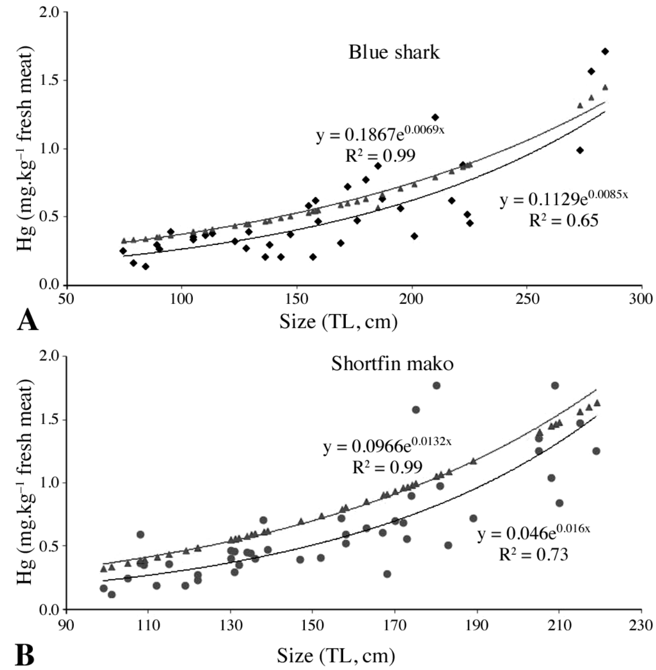


Figure 3. – Observed mercury level (Hg) (◆, ●) and estimated values (▲) using body mass index (BMI, $kg/cm^2$) as a function of size (TL, cm). **A**: Blue shark (N = 37); **B**: Shortfin mako (N = 46).

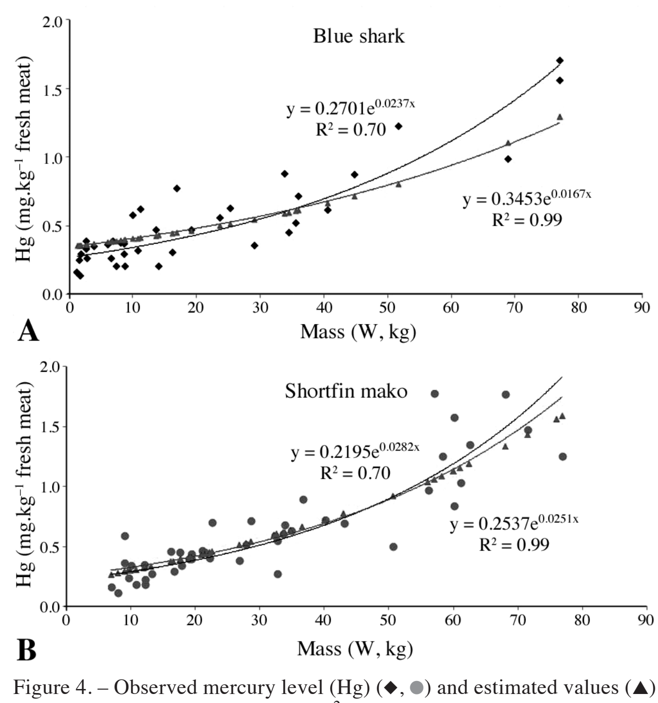


Figure 4. – Observed mercury level (Hg) (◆, ●) and estimated values (▲) using body mass index (BMI, $kg/cm^2$) as a function of mass (TL, cm). **A**: Blue shark (N = 37); **B**: Shortfin mako (N = 46).

reached the greater size of shortfin mako, regressions suggest that shortfin mako are probably more contaminated than blue shark at BMI values higher than 0.0016.

Figure 3 and figure 4 compare the exponential regressions obtained directly from the observation sets (Hg, TL and Hg, W) (Fig. 3: curve a; Fig. 4: curve a) with Hg in function of BMI, obtained by relation (3) using (1) and (2), which is also a second order polynomial expression (Fig. 3: curve b; Fig. 4: curve b).

Hg levels measured were correlated with size and mass but were also correlated with values estimated by BMI. Comparing the three methods, the results showed that Hg levels correlated to size were close to those estimated by BMI for blue shark and shortfin mako ($R^2 = 0.65$ and $R^2 = 0.99$; $R^2 = 0.73$ and $R^2 = 0.99$, respectively) (Fig. 3). For shortfin mako, Hg levels correlated with mass ($R^2 = 0.77$) and Hg levels estimated by BMI ($R^2 = 0.99$) were also similar (Fig. 4). In contrast, blue shark with mass greater than 36 kg showed Hg levels correlated with mass ($R^2 = 0.70$) that were higher in comparison with Hg levels estimated by BMI ($R^2 = 0.99$) (Fig. 4).

## DISCUSSION

Our study found that blue and shortfin mako sharks had different BMI values. These differences can be explained by their morphological and physiological particularities. The shortfin mako is more strongly built than the blue shark and has a more streamlined body (Moreno, 2004).

There is a strong relationship between BMI and Hg levels in muscle of these shark species. While growing, sharks consume larger prey, consequently increasing their trophic level. A positive relationship between the trophic level and Hg concentration in muscle has already been observed in teleost fish (Cossa *et al.*, 2012) and sharks (Vas, 1991). Our results are in accordance with these results. The higher Hg levels found in juvenile blue shark compared to juvenile shortfin mako could be explained by the fact that this volcanic archipelago, which provides a natural source of high concentration of Hg, represents a nursery area for blue shark but not for shortfin mako, and that juvenile blue sharks may remain in this area for two or more years (Vandeperre *et al.*, 2014), accumulating high concentrations of Hg from the local trophic chain.

We found higher Hg levels in shortfin mako than in blue shark at BMI levels exceeding 0.0016 $kg/cm^2$. Shortfin mako sharks have evolved with the ability to maintain body temperature (muscles, brain and stomach) above the temperature of the surrounding water (Carey et al., 1985). Consequently, they need to feed more frequently on prey with higher trophic level, increasing their level of contamination in Hg (Biton Porsmoguer, 2015), which may explain our results.

The Hg levels correlated with size and mass and were similar to those estimated by BMI. This means that BMI can be a relevant biological indicator to study the cumulative effect of Hg in shark organism. We can use indifferently size, mass or BMI. However, blue sharks with mass greater than 36 kg, displayed differences between the Hg levels correlated with mass and those estimated by BMI. This could be explained by a higher inter-individual variability of mass. Blue shark is not an endothermic species and, compared with shortfin mako, it has a lower metabolism and can accumulate fat in excess. Consequently, for a similar size, blue sharks can display higher intraspecific variability in mass and Hg levels than shortfin mako based on differential rate of fat deposition.

However, for practical reasons, size is in fact chosen for both species to determine the specimen that exceeds the limit (1 mg/kg fresh meat) allowed by the European Union (Commission Regulation (EC) No 1881/2006): 255 cm for blue shark (Fig. 3) and 192 cm for shortfin mako (Fig. 4). This choice can be explained by two factors: (i) fishermen measure the sharks on board to estimate the daily quantity caught, and (ii) they consider there is a correlation between Hg levels and size. As shown, BMI is a relevant biological indicator of the accumulative Hg process for sharks and other species. Moreover, it may be expected to be a relevant indicator for all top predators. It could be a complementary indicator to explain the accumulation of any trace metal with the growth of the organisms taking into account size (TL, cm) and mass (W, kg) simultaneously. The blue shark length with unauthorized Hg level is 256 cm considering size factor, and 243 cm considering BMI factor. For shortfin mako, length with unauthorized Hg level is 193 cm considering size factor, and 177 cm considering BMI factor. In fact, BMI provides a more reliable estimator than size and mass considered separately as it accounts for individual differential variation in body fat at larger sizes.

**Acknowledgments**. – We gratefully acknowledge the Port Authority of Vigo (Spain), which authorized sampling, together with captains of the fishing boats who allowed us to measure and dissect landed sharks prior to selling them. Thanks are also due to Michael Paul for improvement of the English. Finally, we acknowledge the anonymous reviewer for valuable comments and suggestions.

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