



**HAL**  
open science

## **Benefit-risk associated with the consumption of fish bycatch from tropical tuna fisheries**

Fany Sardenne, Nathalie Bodin, Anais Medieu, Marisa Antha, Rona Arrisol, Fabienne Le Grand, Antoine Bideau, Jean-Marie Munaron, François Le Loc'H, Emmanuel Chassot

► **To cite this version:**

Fany Sardenne, Nathalie Bodin, Anais Medieu, Marisa Antha, Rona Arrisol, et al.. Benefit-risk associated with the consumption of fish bycatch from tropical tuna fisheries. *Environmental Pollution*, 2020, 267, pp.115614. 10.1016/j.envpol.2020.115614 . hal-03311941

**HAL Id: hal-03311941**

**<https://hal.science/hal-03311941v1>**

Submitted on 26 Sep 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Benefit-risk associated with the consumption of fish bycatch from tropical tuna fisheries**

2

3 Fany Sardenne<sup>1</sup>, Nathalie Bodin<sup>2,3,4</sup>, Anaïs Médieu<sup>1,3</sup>, Marisa Antha<sup>2</sup>, Rona Arrisol<sup>2</sup>,  
4 Fabienne Le Grand<sup>1</sup>, Antoine Bideau<sup>1</sup>, Jean-Marie Munaron<sup>1</sup>, François Le Loc'h<sup>1</sup>, Emmanuel  
5 Chassot<sup>2,3</sup>

6

7 <sup>1</sup> Univ Brest, CNRS, IRD, Ifremer, LEMAR, F-29280 Plouzané, France

8 <sup>2</sup> Seychelles Fishing Authority (SFA), Fishing Port, Victoria, Mahé, Seychelles

9 <sup>3</sup> Institute for Research and Sustainable Development (IRD), Fishing Port, Victoria, Mahé,  
10 Seychelles

11 <sup>4</sup> Sustainable Ocean Seychelles (SOS), BeauBelle, Mahé, Seychelles

12 **Abstract**

13 Mercury, omega-3 (docosahexaenoic acid, DHA and eicosapentaenoic acid, EPA) and  
14 macronutrients (fat and proteins) were quantified on a wet weight (ww) basis in 20 species of fish  
15 taken as bycatch in tropical tuna fisheries. Based on a hazard quotient taking into account  
16 mercury and omega-3 contents, a benefit-risk assessment for the consumption of these pelagic  
17 species was conducted for three people categories: young children, children and adults. All fish  
18 bycatch were found to be an excellent source of proteins (min–max = 14.4–25.2 g/100g fillet),  
19 had low omega-6/omega-3 ratios (< 1, except for silky shark), and had mercury content below the  
20 safety limits defined by sanitary agencies. Silky shark and Istiophoridae had the highest mercury  
21 contents (min–max = 0.029–0.317 ppm ww). Omega-3 contents were the lowest in silky shark  
22 ( $0.2\pm 0.2$  mg/100g fillet) and the highest in striped marlin ( $3.6\pm 3.2$  g/100g fillet). Billfishes  
23 (Istiophoridae, including striped marlin), minor tunas (Scombridae), and Carangidae had the  
24 highest omega-3 contents (min–max = 0.68–7.28 g/100g fillet). The highest hazard quotient  
25 values obtained for silky shark and great barracuda reflected a lower nutritional benefit (i.e., low  
26 omega-3 source) than risk (i.e., mercury exposure), making them not advisable for consumption.  
27 Eight species had low hazard quotients, and among them cottonmouth jack and flat needlefish  
28 were found of high health interest (high protein, moderate fat contents, and low omega-6/omega-  
29 3 ratio). A daily serving portion of 85–200 g (according to people category) can be recommended  
30 for these species. Batfish, and to a lower extent pompano dolphinfish and brassy chub, can also  
31 be consumed safely and would provide greater health benefits than risks. These results advocate  
32 for a better access of these species to local populations.

33

34 **Capsule**

35 Based on omega-3, fat, protein, and mercury contents, most fish bycatch from tuna fisheries  
36 would be good food sources to reduce nutritional insecurity for local populations.

37

38 **Keywords:** *Contaminant, Polyunsaturated Fatty acids, Hazard quotient, Pelagic fish, Western*  
39 *Indian Ocean*

## 40 1. Introduction

41 Commercial fisheries generate different levels of bycatch (i.e. incidental catch of non-targeted  
42 fish), accounting for a global annual estimate of discards larger than nine million metric tons  
43 (Pérez-Roda et al., 2019; Zeller et al., 2018). The reduction of fish discards has become a global  
44 concern over the last decades as high discarding mortality can play an important role in  
45 population and biodiversity decline (Gilman, 2011; Viana et al., 2013). Furthermore, discarding  
46 constitutes a substantial waste of food while the consumption of fish bycatch may reduce food  
47 insecurity, particularly in developing and least-developed coastal countries (Bell et al., 2015;  
48 Pilling et al., 2020). Consequently, many countries have implemented public policies to enforce  
49 the landing of fishing discards over the last decade although the outcomes of such policies remain  
50 debated (e.g., Sardà et al., 2015).

51 Global high seas fisheries targeting tuna and tuna-like species produce substantial bycatch, with  
52 about 170,000 and 100,000 metric tons discarded annually by longline and purse seine fisheries,  
53 respectively (Fonteneau et al., 2013; Hall et al., 2017). Although non-targeted small oceanic  
54 tunas and neritic tunas constitute the bulk of the purse seine bycatch across all ocean basins,  
55 bycatch is also composed of a highly diverse assemblage of > 50 edible fish species from several  
56 families, predominated by Istiophoridae, Carangidae, Balistidae, Coryphaenidae, Scombridae,  
57 and Carcharhinidae (Lezama-Ochoa et al., 2015; Torres-Irineo et al., 2014). In the western Indian  
58 Ocean, recent discard rates derived from fisheries observer programs suggest the total bycatch of  
59 these species could vary around 8,000 and 10,000 metric tons annually (Ruiz Gondra et al.,  
60 2018). Following the ban on discards of non-target fish caught with purse seine that entered into  
61 force in January 2018 (IOTC Resolutions 17/04 and 19/05), most fish bycatch from the western  
62 Indian Ocean tuna fishery are now landed in Port Victoria, Seychelles, where they are (i) mostly  
63 transhipped in containers for export to African and Asian countries and further processed (all  
64 species mixed), (ii) processed by local companies (e.g. smoked fish) for the most valuable species  
65 such as dolphinfishes (Coryphaenidae) and billfishes (Istiophoridae) for export, and (iii) locally  
66 consumed for the valuable species such as tripletail *Lobotes surinamensis*.

67 Fish is critical to food and nutrition security as the primary source of animal protein, especially in  
68 tropical countries and for coastal communities (Béné et al., 2015). Fish is also the most important  
69 source of essential fatty acids and a unique source of minerals, micronutrients often reported as  
70 deficient in the diets of vulnerable populations (Haddad et al., 2016; Hicks et al., 2019). Tropical  
71 countries mainly depend on small-scale coastal fisheries, which are highly impacted by

72 overfishing and climate change (Bell et al., 2018; Dulvy and Allison, 2009; Robinson et al.,  
73 2020). Consumption of fish bycatch from industrial tropical tuna fisheries could then be a  
74 complementary or an alternative source of essential nutrients for tropical coastal communities  
75 (Bodin et al., 2017; Pilling et al., 2020). In the western Indian Ocean for instance, high levels of  
76 zinc and selenium have been reported in several istiophoriformes (Bodin et al., 2017;  
77 Kojadinovic et al., 2007), but information is still lacking regarding the content of fish bycatch  
78 from the tuna fisheries in other healthy nutrients such as essential fatty acids.

79 Omega-3 fatty acids such as eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid  
80 (DHA; 22:6n-3) have important human health benefits, including brain and retina development  
81 and coronary heart disease prevention (Swanson et al., 2012; FAO/WHO, 2010). Adequate  
82 dietary intake of omega-3 fatty acids is recommended due to inadequate biosynthesis capacities  
83 (Plourde and Cunnane, 2007). The most abundant natural dietary source of EPA and DHA is fish,  
84 especially pelagic fish (Gladyshev et al., 2018). Omega-6 fatty acids such as arachidonic acid  
85 (ARA; 20:4n-6) are also essential to human health, although they may be responsible for  
86 inflammation and cardiovascular diseases when present in excess (Mori and Hodgson, 2012). The  
87 omega-6 to omega-3 ratio could thus balance health outcomes (the lower the ratio the better)  
88 (Simopoulos, 2002) and is often considered in nutrition studies (e.g., Nišević et al., 2019; Strain  
89 et al., 2008). Mercury may also be a concern when investigating the nutritional value of fish.  
90 Indeed, mercury is neuro-, nephro-, and immunotoxic for humans in its methylated form (Bose-  
91 O'Reilly et al., 2010). Its content in most consumed fish should not exceed maximum limits of 1  
92 mg.kg<sup>-1</sup> wet weight (ww) for large predatory fish and 0.5 mg.kg<sup>-1</sup> ww for other fish (FAO Codex  
93 Alimentarius Commission, 2011). Avoiding the consumption of fish because of mercury might  
94 however reduce its essential health benefits (Strain et al., 2008; Hu et al., 2017). In this context, a  
95 benefit-risk assessment appears essential to determine which fish species to consume and how  
96 much, in order to promote better health outcomes, i.e., to ensure adequate omega fatty acids  
97 intakes while minimizing exposure to mercury.

98  
99 This study aimed to assess the nutritional value of 20 pelagic fish species belonging to 10  
100 families and caught as bycatch in tropical tuna fisheries from the western Indian Ocean. We  
101 focused on their beneficial contents in proteins, fats and essential omega-3, and considered also  
102 the omega-6/omega-3 ratio and mercury content. The benefit-risk assessment used a hazard  
103 quotient for three people categories: young children, children and adults. The influence of fish  
104 length on the nutritional composition of muscle was also assessed.

105

## 106 2. Material and methods

### 107 2.1. Fish and tissue collection

108 Common fish bycatch from the western Indian Ocean were sampled between April and October  
109 2018 (18 fishing dates/geographical positions). A total of 168 individuals from 18 species were  
110 collected during the unloading of purse seiners at Port Victoria, Seychelles, and complemented  
111 with seven billfishes (from two species) collected during the unloading of longliners. Fish length  
112 was measured with a caliper to the nearest cm: in lower-jaw-fork length for the Indo-Pacific  
113 sailfish *Istiophorus platypterus* and striped marlin *Tetrapturus audax*, in total length for silky  
114 shark *Carcharhinus falciformis*, tripletail *L. surinamensis*, unicorn leatherjacket *Aluterus*  
115 *monoceros*, and rough triggerfish *Canthidermis maculata*, and in fork length for all other species.  
116 Then, a piece of dorsal muscle (left side, under the fish dorsal spine) was sampled from each  
117 individual. Immediately after collection, samples were stored in cryotubes at -80°C at the  
118 Seychelles Fishing Authority Research Laboratory, Victoria, Seychelles, for several months  
119 before analysis.

120

### 121 2.2. Moisture

122 Moisture (i.e. water content) was used to convert concentrations from dry weight (dw) to wet  
123 weight (ww), as all biochemical analyses were performed on dry samples. The percentage of  
124 moisture was determined gravimetrically as the difference between wet and dry masses of  
125 samples after a 72-hour freeze drying using a Christ Alpha 1-2 LD plus lyophilizer. The mean  
126 analytical variability of the method was < 1%. After freeze-drying, samples were ground to a  
127 homogeneous powder with a ball mill and stored again at -80°C at the Seychelles Fishing  
128 Authority Research Laboratory, Victoria, Seychelles, for a month before subsequent analysis.

129

### 130 2.3. Crude protein content

131 Non-protein nitrogenous compounds found in high amounts in sharks (urea and trimethylamine  
132 oxide) were removed from an aliquot of silky shark dry powder with three distilled water rinses  
133 (Li et al., 2016). Aliquots of about 500 µg of dry powder (urea-free for silky shark and bulk for  
134 all other bycatch fish) were weighted to the nearest µg on an analytical balance, and analysed for  
135 nitrogen content by continuous flow on a Flash EA2000 elemental analyser (Thermo Fisher  
136 scientific) at the Pôle Spectrométrie Océan, University of Brest, France. The analytical variability  
137 of the method was 0.1%, based on reference material checked every six samples (acetanilide;

138 nitrogen content = 10.3%). Nitrogen content was converted into crude protein using a conversion  
139 factor of 5.58 adapted to fish muscle (Mariotti et al., 2008). Crude protein content was expressed  
140 in  $\text{mg.g}^{-1}$  ww.

141

#### 142 2.4. Fatty acids and total fat content

143 Aliquots of dry bulk powders were treated as described in Sardenne et al. (2019). Lipids were  
144 extracted from ca. 100 mg of powder with 6 mL of the modified Folch mixture directly added  
145 into glass vials. Extracts were flushed with gas nitrogen, vortexed, sonicated, and stored over 24  
146 hours at  $-20^{\circ}\text{C}$ . Tricosanoic acid (23:0; 2.3  $\mu\text{g}$ ) was added as internal standard to 1 mL of lipid  
147 extract. Lipids were transesterified with 800  $\mu\text{L}$  of  $\text{H}_2\text{SO}_4$  (3.8 % in MeOH) at  $100^{\circ}\text{C}$  for 10 min  
148 then washed with hexane-saturated distilled water. Fatty acid methyl esters (FAME) were  
149 separated and quantified on a Varian CP8400 gas chromatograph equipped with a Zebron ZB-  
150 WAX and a ZB-5HT column (both 30 m length, 0.25 mm internal diameter, 0.25  $\mu\text{m}$  film  
151 thickness; Phenomenex) and a flame ionisation detector at the Lipidocean facility, University of  
152 Brest, France. Samples (2  $\mu\text{L}$ ) were injected in splitless mode at  $280^{\circ}\text{C}$  and carried by hydrogen  
153 gas. The oven temperature was raised from  $60^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  at  $50^{\circ}\text{C.min}^{-1}$ , to  $170^{\circ}\text{C}$  at  $3.5^{\circ}\text{C.min}^{-1}$ ,  
154  $^{\circ}\text{C}$ , to  $185^{\circ}\text{C}$  at  $1.5^{\circ}\text{C.min}^{-1}$ , to  $225^{\circ}\text{C}$  at  $2.4^{\circ}\text{C.min}^{-1}$  and then to  $250^{\circ}\text{C}$  at  $5.5^{\circ}\text{C.min}^{-1}$ . FAME  
155 were identified by comparing sample retention times to those of commercial standard mixtures  
156 (37-component FAME mix and PUFA no. 1 and 3 mix; Supelco) on both columns using Galaxie  
157 1.9.3.2 software (Varian). The mean analytical variability of the method was 8.1%, based on  
158 Supelco 37-component FAME mix routinely checked. FAME content was converted into fatty  
159 acids content. Total fat content was calculated as the sum of individual fatty acids, and expressed  
160 in TAG-equivalents using WHO conversion factors (Ratnayake, 2018). Individual fatty acids  
161 contents and total fat content were expressed in  $\text{mg.g}^{-1}$  ww. Omega-6/omega-3 ratio is unitless.

162

#### 163 2.5. Total mercury content (THg)

164 Aliquots of all dry bulk powders (10–50 mg dw) were analysed in duplicate ( $n=336$ ) by thermal  
165 decomposition, gold amalgamation and atomic absorption detection (DMA-80, Milestone, Italy)  
166 at the Seychelles Fishing Authority Research Laboratory, Victoria, Seychelles. Calibration blanks  
167 were run in between each sample to ensure THg levels were reset to 0.1 ng. Analytical  
168 performance was checked every 15–20 samples against two laboratory control analyses  
169 (performed on large homogenized samples of white muscle and liver from *Thunnus obesus*, THg

170 = 0.141±0.004 and 0.986±0.036 mg.kg<sup>-1</sup>, respectively) and the certified reference material, tuna  
171 fish flesh homogenate (IAEA-436; THg = 4.19±0.39 mg.kg<sup>-1</sup>) (Bodin et al., 2017). Satisfactory  
172 accuracy (97–104%) was calculated with an analytical variability below 5% (n = 29). Limits of  
173 quantification were calculated from blank measurements, with THg values of 0.0016 ppm (i.e.  
174 µg.g<sup>-1</sup>). The results (means of duplicate values) were reported in ppm ww. Note the contribution  
175 of methylmercury to total mercury is about 80-100% in most marine fish, depending on species,  
176 size, age and diet (EFSA, 2012a).

177

## 178 2.6. Data analysis

### 179 2.6.1. Hazard quotient calculation

180 Benefit-risk ratio, or hazard quotient (HQ), was computed for all individuals based on the  
181 equation of Gladyshev et al. (2009). HQ was already applied for several fish species (e.g.,  
182 Anishchenko et al., 2017; Briones and Lazaro-Llanos, 2016; Razavi et al., 2014) and is computed  
183 as follows:

$$184 \quad HQ = \frac{R_{EFA} \times c}{C \times RfD \times W}$$

185 where R<sub>EFA</sub> (mg.d<sup>-1</sup>), for Reference dose for essential fatty acids, is the daily dose recommended  
186 for EPA+DHA for a human person according to the sanitary agencies, c (µg.g<sup>-1</sup>) is the mercury  
187 content for a given fish, C (mg.g<sup>-1</sup>) is the EPA+DHA content for a given fish, RfD (µg.kg.d<sup>-1</sup>), for  
188 oral Reference Dose, is the maximum tolerable daily intake of mercury according to the sanitary  
189 agencies, and W (kg) is the average weight of the human group of interest.

190 HQ parameters were set based on FAO/WHO and European Food Safety Agency (EFSA)  
191 recommendations, for three weight/age classes corresponding to young children (2–4 y), children  
192 (4–10 y), and adults (> 10 y) (Table 1). ‘Adults’ category includes pregnant and lactating  
193 females. EFSA aligned with WHO recommendations for EPA+DHA intakes but lowered the  
194 tolerable intake of methylmercury for a conservative reason, set to 1.3 µg.kg.week<sup>-1</sup> (expressed as  
195 mercury) (i.e., 0.186 µg.kg.d<sup>-1</sup>) for all age classes (EFSA, 2014; FAO/WHO 2010). EFSA default  
196 values were used for the average body weight of the age classes (EFSA, 2012b). The parameters  
197 setup used for HQ calculation are presented in Table 1, for R<sub>EFA</sub>, RfD and W, and in Table 2 for c  
198 and C (fish contents in EPA+DHA and mercury). HQ is unitless and has the advantage to be  
199 independent from the servings size, as it is only based on the recommendation limits of sanitary  
200 agencies for good health. HQ > 1 means the consumption benefit is lower than the risk, and HQ <  
201 1 means the consumption benefit is greater than the risk. A nutritional rating was attributed to



202 each species based on HQ values: ‘Best alternative’ when all individuals have HQ < 1, ‘Good  
203 alternative’ when the average HQ < 1 but the range includes individuals with HQ > 1,  
204 ‘Acceptable alternative’ when the average HQ > 1 but the range includes individuals with HQ <  
205 1, and ‘Not advisable’ when all individuals have HQ > 1.

206

### 207 2.6.2. Influence of species and fish length

208 First, correlations among fish length, THg, EPA+DHA, fat and protein contents, and omega-  
209 6/omega-3 ratio were investigated across the entire dataset (n = 175) using Spearman’s rank  
210 correlation, with  $\rho$  the correlation coefficient. Then, the effects of species, fish length, and their  
211 interactions on the variability (i.e. variance) in fat, protein, THg, EPA+DHA contents, omega-  
212 6/omega-3 ratio, and HQ were tested with F-tests. For HQ, only one age/weight category was  
213 considered as the results would be identical for the three categories. All data were log-  
214 transformed to improve normality. Normality and homogeneity of the variance were checked on  
215 model residuals, with Shapiro and Breush-Pagan tests, respectively. Despite transformation,  
216 residuals from all datasets did not reach normality but they were homogeneous. ANOVAs were  
217 applied on the multiple regression models, as it is robust to normality violation. Simple linear  
218 regressions were used to refine variability with fish length.

219 Data analyses were performed using R software 3.5.0 (R Core Team, 2016). All results are  
220 reported as means  $\pm$  standard deviation.

221

## 222 3. Results

### 223 3.1. Correlations among nutritional contents

224 Across the entire dataset, the strongest positive correlations were observed between fat and  
225 EPA+DHA contents ( $\rho = 0.86$ ,  $p < 0.001$ ) and between THg content and fish length ( $\rho = 0.71$ ,  $p$   
226  $< 0.001$ ), then between EPA+DHA content and omega-6/omega-3 ratio (negative correlation,  $\rho =$   
227  $-0.58$ ,  $p < 0.001$ ), and between THg and protein contents (positive correlation,  $\rho = 0.55$ ,  $p <$   
228  $0.001$ ) (Fig. 1). A weak negative correlation was obtained between omega-6/omega-3 ratio and  
229 protein content ( $\rho = -0.46$ ,  $p < 0.001$ ). No relationship was observed between THg and fat  
230 contents ( $\rho = 0.02$ ,  $p = 0.835$ ), and THg content and omega-6/omega-3 ratio ( $\rho = -0.14$ ,  $p = 0.08$ ).

231

### 232 3.2. Variability in fat and protein contents and omega-6/omega-3 ratio

233 Variability in total fat and protein contents was mainly observed among species (Table 2).  
234 Species explained 82% of the variability in protein content ( $df = 19$ ,  $F = 39.5$ ,  $p < 0.001$ ), with the  
235 highest protein contents observed for neritic tunas ( $231 \pm 5 \text{ mg.g}^{-1}$  and  $223 \pm 12 \text{ mg.g}^{-1}$  for frigate  
236 tuna and kawakawa, respectively) and the lowest for batfishes and unicorn leatherjacket ( $155 \pm 6$   
237  $\text{mg.g}^{-1}$  and  $162 \pm 7 \text{ mg.g}^{-1}$ , respectively). Similarly, species explained 51% of the variability in fat  
238 content ( $df = 19$ ,  $F = 12.2$ ,  $p < 0.001$ ), and the interaction between species and fish length  
239 explained 15% ( $df = 19$ ,  $F = 3.6$ ,  $p < 0.01$ ). The highest fat contents were observed for neritic  
240 tunas ( $0.29 \pm 0.01 \text{ mg.g}^{-1}$  for both species), and the lowest for tripletail, unicorn leatherjacket, and  
241 batfishes (from  $0.22 \pm 0.01 \text{ mg.g}^{-1}$  to  $0.23 \pm 0.01 \text{ mg.g}^{-1}$ ) (Table 2). Species explained 82% of the  
242 variability in omega-6/omega-3 ratio ( $df = 19$ ,  $F = 55.0$ ,  $p < 0.001$ ), with omega-6/omega-3 ratio  
243  $< 1$  for all teleost species but  $2.6 \pm 1.4$  for silky shark (Table 2), and the interaction between  
244 species and fish length explained 7% ( $df = 19$ ,  $F = 5.0$ ,  $p < 0.001$ ).

245

### 246 3.3. Variability in mercury and omega-3 contents

247 Species was the main source of variability for both THg and EPA+DHA contents, i.e. it  
248 explained 71% and 76% of the variability, respectively. Fish length explained 10% and 1% of the  
249 variability for THg and EPA+DHA contents, respectively, and the interaction between species  
250 and fish length explained 6% of the variability for both THg and EPA+DHA contents (Table 3).  
251 The highest THg contents were obtained for silky shark ( $0.167 \pm 0.073 \text{ ppm ww}$ ), the three  
252 Istiophoridae species, in particular great barracuda ( $0.277 \pm 0.056 \text{ ppm ww}$ ), and for Scombridae,  
253 in particular kawakawa ( $0.152 \pm 0.068 \text{ ppm ww}$ ). The lowest contents were obtained for batfishes  
254 ( $0.005 \pm 0.002 \text{ ppm ww}$ ), unicorn leatherjacket ( $0.007 \pm 0.004 \text{ ppm ww}$ ) and the two Kyphidae  
255 species ( $0.007 \pm 0.010 \text{ ppm ww}$ ). THg content increased with fish length in seven fish species, and  
256 especially in kawakawa (from 0.021 to 0.263 ppm ww, for specimens ranging between 23 and 55  
257 cm in fork length; slope of 16%). For rough triggerfish, common dolphinfish, frigate tuna,  
258 tripletail, rainbow runner, and cottonmouth jack, the increase of THg content over the studied  
259 range sizes (i.e. slope) was  $< 1\%$  (Fig. 2).

260 The contribution of EPA+DHA to total omega-3 ranked from  $82 \pm 3\%$  in silky shark to  $96 \pm 1\%$  in  
261 wahoo. After DHA and EPA, the third main omega-3 was 22:5n-3 (docosapentaenoic acid),  
262 which contributed to  $5.9 \pm 3.8\%$  of total omega-3 ( $0.09 \pm 0.08 \text{ mg.g}^{-1} \text{ ww}$  in average for the whole  
263 dataset,  $n=175$ ). The highest contents in EPA+DHA were obtained for striped marlin ( $3.12 \pm 2.84$   
264  $\text{mg.g}^{-1} \text{ ww}$ ), kawakawa ( $2.64 \pm 1.48 \text{ mg.g}^{-1} \text{ ww}$ ), Indo-Pacific sailfish ( $1.79 \pm 0.61 \text{ mg.g}^{-1} \text{ ww}$ ), and  
265 frigate tuna ( $1.77 \pm 0.74 \text{ mg.g}^{-1} \text{ ww}$ ), and for some Carangidae, especially cottonmouth jack

266 (1.76±0.69 mg.g<sup>-1</sup> ww). The lowest EPA+DHA contents were observed for silky shark  
267 (0.19±0.13 mg.g<sup>-1</sup> ww) and tripletail (0.80±0.20 mg.g<sup>-1</sup> ww) (Table 3). EPA+DHA contents  
268 increased with fish length in cottonmouth jack (from 0.97 mg.g<sup>-1</sup> ww at 21 cm to 3.29 mg.g<sup>-1</sup> ww  
269 at 34 cm; slope of 14%), wahoo (from 0.87 mg.g<sup>-1</sup> ww at 79 cm to 1.14 mg.g<sup>-1</sup> ww at 105 cm;  
270 slope of 1%), and silky shark (from 0.19 mg.g<sup>-1</sup> ww at 64 cm to 0.43 mg.g<sup>-1</sup> ww at 91 cm; slope <  
271 1%) (Fig. 2).

272

### 273 3.4. Variability in hazard quotient

274 HQ values varied mainly with species (74% of explained variability) and to a lesser extent with  
275 fish length (5% of explained variability), and species-fish length interaction (6% of explained  
276 variability) (Table 3). Overall, HQ values were the highest for silky shark (84±64, 56±43, and  
277 29±22 for young children, children and adults, respectively) and the lowest for batfish (HQ < 0.4)  
278 and blue sea chub (HQ < 0.6) (Fig. 3). Eight species had a greater benefit than risk (average HQ  
279 < 1) for the three population categories, with similar HQ values (unicorn leatherjacket, flat  
280 needlefish, batfishes, pompano dolphinfish, blue sea chub, brassy chub, cottonmouth jack, and  
281 longfin yellowtail), while nine species always had a lower benefit than risk (silky shark > great  
282 barracuda > Indo-Pacific sailfish > wahoo > tripletail > striped marlin > kawakawa > frigate tuna  
283 > common dolphinfish) (Fig. 3). HQ values increased with fish length and always exceeded 1 in  
284 the largest sizes for five species: rough triggerfish, common dolphinfish, frigate tuna, tripletail,  
285 and Indo-Pacific sailfish (Fig. 4). In contrast, HQ values decreased with length in striped marlin  
286 mainly due to the increase in EPA+DHA content (not significant); this result however must be  
287 taken with caution in view of the low number of specimens (n = 3) and low size range (min-max  
288 fork length = 180-186 cm). Based on range and average values of HQ for adults, eight fish  
289 species were ranked as 'Best alternative', four as 'Good alternative', six as 'Acceptable  
290 alternative' and two were 'Not advisable' (Fig. 3). 'Best alternative' was attributed to four  
291 species (batfishes, blue sea chub, unicorn leatherjacket, and flat needlefish) for young children  
292 (Fig. 3).

293

## 294 4. Discussion

295 Twenty species of fish bycatch from the western Indian Ocean tropical tuna fisheries were  
296 analysed for moisture, protein, fat, fatty acid (omega-3 and omega-6) and mercury contents, and a  
297 benefit-risk evaluation based on hazard quotients was conducted. Despite high interspecies

298 variability, all species are excellent protein sources (min–max = 14.4–25.2 g/100g fillet), low  
299 total fat sources (min–max = 0.2–2.4 g/100g fillet), low to good sources of omega-3 (min–max =  
300 10–730 mg/100g fillet), and are relatively low in total mercury (min–max = 0.003–0.317 ppm  
301 ww). Striped marlin was the richest species in both fats and omega-3, frigate tuna was the richest  
302 species in proteins, and great barracuda the most contaminated with mercury. Based on hazard  
303 quotients for adults, 12 species were ranked best or good nutritional alternatives, while two  
304 species, the silky shark and the great barracuda, were not advisable for consumption. Six species  
305 were ranked as acceptable alternatives and should be considered in priority for complementary  
306 nutrition studies. Hazard quotients increased with fish length in five species, mainly due to  
307 increasing mercury contents with length.

308  
309 4.1. Nutritional composition of fish bycatch from the tropical tuna fisheries in the western  
310 Indian Ocean

311 Across the entire dataset, no individual had mercury content above the maximum limits of 1 and  
312 0.5 ppm ww defined by sanitary agencies for large fish and other fish, respectively. The most  
313 contaminated species (Istiophoridae and silky shark) were high order predators with trophic  
314 levels > 4.3 (FishBase, 2019), while the less contaminated were herbivorous (Kyphosidae) or first  
315 order predators (unicorn leatherjacket and batfishes) with trophic levels from 2.0 to 3.8  
316 (FishBase, 2019). A positive relationship between mercury contamination and trophic position  
317 was indeed highlighted for several species from the Seychelles Exclusive Economic Zone (EEZ)  
318 (Bodin et al., 2017; Sardenne et al., 2017) due to mercury biomagnification in food webs (Kidd et  
319 al., 2011). However, the trophic position alone does not explain the mercury contamination of a  
320 species. Mercury content also increases with individual fish length, as previously measured in the  
321 western Indian Ocean for some of the studied species (Bodin et al., 2017; Kojadinovic et al.,  
322 2007). The low contamination of the common dolphinfish in the present study is more likely  
323 related to the small-sized individuals analysed (fork length = 42–71 cm, THg = 0.011–0.078 ppm  
324 ww, n = 13) and may not be representative of the overall THg range for this bycatch species  
325 caught by purse-seiners in the region. First, average size for common dolphinfish caught as  
326 bycatch is  $80 \pm 20$  cm, with individuals larger than 100 cm commonly observed in the fishery  
327 (SFA, unpublished data); secondly, largest individuals of dolphinfish targeted by longliners were  
328 around 4 and 6 times more contaminated in Seychelles EEZ (fork length = 92–106 cm, THg =  
329  $0.177 \pm 0.043$  ppm, n = 10; Bodin et al., 2017) and Mozambique Channel (fork length=100–115  
330 cm, THg= $0.245 \pm 0.230$  ppm, n=5; Kojadinovic et al., 2007), respectively. The same issue might

331 occur for silky shark, rainbow runner, and wahoo for each of which our samples might not well  
332 reflect the maximum levels of contamination expected from the consumption of larger  
333 individuals caught in the fishery. The highest mercury content was however obtained for great  
334 barracuda ( $0.277 \pm 0.056$  ppm ww) with body length close to the average length measured for this  
335 species in the purse seine tuna fishery ( $92 \pm 18$  cm; SFA, unpublished data), suggesting the  
336 observed contamination level might be representative for the species in the fishery. While all  
337 studied species are pelagic, differences in habitat use (e.g. coastal, neritic, epipelagic) can also  
338 affect mercury contamination, as found for several large pelagic fish (Choy et al., 2009).  
339 Structure of the planktonic food web can also influence mercury contamination in fish, since  
340 lower trophic levels (e.g. organic matter, invertebrate species such copepods) can be  
341 contaminated by mercury at different levels (Kainz et al., 2008; Signa et al., 2019), as well as fish  
342 age: regardless of size, older fish are generally more contaminated than their younger congeners  
343 (van der Velden et al., 2012).

344  
345 This study provides baseline values for the western Indian Ocean as data on omega-3, DHA, and  
346 EPA contents were scarce for the studied species in the area, especially data expressed in  
347 concentrations. Overall, our values of EPA+DHA contents are within the medium range reviewed  
348 by Gladyshev et al. (2018) for 172 species which ranked from 0.1 to 25.6 mg.g<sup>-1</sup> ww, the highest  
349 contents being generally obtained for Clupeiformes. Fish phylogeny and eco-morphology seem  
350 indeed the two main factors explaining variability in EPA+DHA contents (Gladyshev et al.,  
351 2018). Among the 10 families studied here, Istiophoridae and Scombridae generally contained  
352 more EPA and DHA than the other families. However, in comparison to other world regions,  
353 most studied species had lower EPA and DHA contents. Higher contents in EPA and DHA were  
354 found for coastal frigate tuna from Philippines, eastern Indian Ocean, with  $1.1 \pm 0.0$  and  $3.9 \pm 0.3$   
355 mg.g<sup>-1</sup> ww (n=3) vs.  $0.2 \pm 0.1$  and  $1.6 \pm 0.7$  mg.g<sup>-1</sup> ww here, respectively (Briones and Lazaro-  
356 Llanos, 2016). These differences might be related to the location of the sampled tissue: tuna  
357 dorsal muscle analysed in our study is leaner than the ventral one (total muscle was analysed in  
358 the Philippines) (Nakamura et al., 2007). EPA and DHA contents for the common dolphinfish  
359 were similar to those obtained in the United States of America (unspecified ocean) by Cladis et  
360 al. (2014):  $0.2 \pm 0.1$  and  $1.4 \pm 0.4$  mg.g<sup>-1</sup> ww (n = 11) vs.  $0.1 \pm 0.0$  and  $1.0 \pm 0.2$  mg.g<sup>-1</sup> ww in the  
361 present study, although the species was leaner in the present study (fat content of  $8.5 \pm 2.5$  vs.  
362  $3.3 \pm 0.6$  mg.g<sup>-1</sup> ww here). Wahoo contained less EPA and DHA in the present study than in the  
363 eastern Pacific:  $0.1 \pm 0.0$  and  $0.9 \pm 0.1$  mg.g<sup>-1</sup> ww vs.  $0.5 \pm 0.2$  and  $3.6 \pm 1.6$  mg.g<sup>-1</sup> ww (n = 2),  
364 respectively (Cladis et al., 2014). The same trend was observed for tripletail from Mexico,

365 western Atlantic ocean, with EPA and DHA contents of 0.7 and 3.2 vs. 0.1 and 0.7 mg.g<sup>-1</sup> ww in  
366 the present study (Castro-González et al., 2013). These differences among areas could stem from  
367 partial oxidation during on-board storage, differences in method among laboratories (e.g. location  
368 of muscle sample, analytical differences), and/or differences related to species' ecological and  
369 biological factors such as habitat, season, and reproductive status. Variability in EPA and DHA  
370 proportions (in %) and omega-6/omega-3 ratio were indeed observed with season in tuna species  
371 from the western Indian Ocean which co-occur with the studies species (Dhurmeea et al., 2020;  
372 Sardenne et al., 2016). EPA and DHA are mainly produced by diatoms and dinoflagellates at the  
373 food webs basis and their proportions in tuna were correlated to sea surface temperature  
374 (Dhurmeea et al., 2020; Pethybridge et al., 2015). Due to global climate change, the omega-3  
375 production at the food webs basis is predicted to be reduced by ca. 8% and 28% for EPA and  
376 DHA, respectively (Hixson and Arts, 2016). Phytoplankton communities have already changed in  
377 the northwest of the Indian Ocean with a reduction of diatoms biomass during winter, eventually  
378 impacting the composition of higher trophic level species (Do Rosário Gomes et al., 2014). In  
379 this context, the composition in macronutrients and micronutrients of fish should be routinely  
380 monitored to ensure adequate recommendations in terms of fish consumption.

381

#### 382 4.2. Fish bycatch consumption recommendations based on hazard quotients

383 Hazard quotients (HQ) based on mercury and EPA+DHA contents were highly variable among  
384 species. Highest HQ were obtained for the top predators (silky shark and great barracuda in  
385 particular) and often for the largest individuals, due to an increase in mercury content with fish  
386 size/age in several species (see previous section). Silky shark was found with very low omega-3  
387 contents (i.e. the daily serving portion required to supply 300 mg of EPA+DHA would be 1.6 kg,  
388 which would lead to a mercury consumption of 268 µg). For these reasons, benefit is lower than  
389 risk for the consumption of these species. Eight species were ranked as 'Best alternative' or  
390 'Good alternative' for the three people categories: batfishes, brassy chub, blue sea chub, unicorn  
391 leatherjacket, cottonmouth jack, flat needlefish, longfin yellowtail, and pompano dolphinfish.  
392 Among them, cottonmouth jack was lipid-rich (about 10 mg.g<sup>-1</sup> ww) and flat needlefish was  
393 protein-rich (about 198 mg.g<sup>-1</sup> ww). Based on mercury and EPA+DHA contents, these two  
394 species can be particularly recommended for human consumption, especially for young children  
395 and children, with respective daily serving portions of 85 g and 142 g (cottonmouth jack) and 117  
396 g and 196 g (flat needlefish) (Table 4). Other species, such as pompano dolphinfish and brassy  
397 chub are also good food sources, especially for adults as some individuals can have higher risk

398 than benefit (daily serving portion between 99 g and 264 g according to people category and fish  
399 species; Table 4). The consumption of species ranked 'Not advisable' (Fig. 3) should not be  
400 daily, especially for young children, children, and pregnant women, as prenatal exposure to  
401 mercury might affect children development (Nišević et al., 2019).

402

#### 403 4.3. Caveats about hazard quotient and recommendations

404 For the benefit-risk assessment to be complete, other positive and negative nutritional  
405 components must be included in the HQ calculation: e.g. essential nutrients such iodine and  
406 selenium, but also organic contaminants such dioxins-like compounds, and toxins such as  
407 ciguatera. For instance, selenium, a mineral constituting proteins involved in the antioxidant  
408 system, might be important to balance the negative effects of mercury on health (Ralston et al.,  
409 2016), but this potential remediation remain to be confirmed (Gerson et al., 2020). In contrast,  
410 ciguatera poisoning was reported for some of the studied species, caught from Atlantic and  
411 Pacific Oceans: e.g. ciguatera toxins were found in blue sea chub from French Polynesia (57% of  
412 29 tested fish; Gaboriau et al., 2014) and in longfin yellowtail and wahoo from Canary islands  
413 (17% of 793 tested fish and 3% of 32 tested fish, respectively; Sanchez-Henao et al., 2019). The  
414 consumption of these species from the western Indian Ocean should thus be cautious until the  
415 risks are fully evaluated. Persistent organic pollutants were found in relatively low levels in  
416 swordfish and tuna from the western Indian Ocean, except for fishes from the Mozambique  
417 Channel which showed higher dichlorodiphenyltrichloroethane levels (DDT; Munsch et al.,  
418 2020). An evaluation of these pollutants in fish bycatch from tropical tuna fisheries would also be  
419 useful to improve the consumption recommendations.

420 WHO states adequate intakes for EPA+DHA are 250-2000 mg.day<sup>-1</sup>, while specifying there is no  
421 evidence of gain for health to consume 2000 mg.day<sup>-1</sup>, unless for secondary prevention of  
422 coronary health disease (FAO/WHO, 2010). HQ calculation was set on EFSA and WHO  
423 optimum recommendations (300 mg.day<sup>-1</sup> for adults, but see Nagasaka et al., 2014) because an  
424 unnecessary increase in fish consumption of ca. 6 fold would not be sustainable for fish stocks,  
425 most of them being already fully exploited or overfished worldwide (Link and Watson, 2019;  
426 Worm et al., 2006). Such an increase in fishing effort would be particularly counterproductive as  
427 overfishing, in association with climate change, has been shown to increase mercury content in  
428 predator fish by causing dietary shifts (Schartup et al., 2019). The best option to obtain DHA and  
429 EPA from marine fisheries would be to increase by-product utilization and reduce food waste  
430 (Hamilton et al., 2020). Assessing the risks and benefits associated with the consumption of

431 fisheries bycatch is a step in this direction.

432

### 433 **Conclusion**

434 Every year, more than 10,000 metric tons of edible fish species are landed in the Seychelles as  
435 bycatch of tuna fisheries, with little or no value. However, most of these species were found to be  
436 good sources of nutrients (omega-3, fat and protein contents) and little exposed to mercury.  
437 Among the 20 studied species, silky shark and great barracuda should be consumed with  
438 moderation, while eight species (batfishes, brassy chub, blue sea chub, unicorn leatherjacket,  
439 cottonmouth jack, flat needlefish, longfin yellowtail, and pompano dolphinfish) were classified as  
440 best alternative. Those species would be good food sources to reduce nutritional insecurity for  
441 local populations, including for young children. Evaluation and monitoring on further  
442 contaminants, toxins and micronutrients would be useful to strengthen the consumption  
443 recommendations.

444

### 445 **Acknowledgments**

446 The authors thank all fishermen and crews of the fishing companies CFTO and SAPMER who  
447 gave the fish, observers who assisted with fish sampling, and the Research section of the  
448 Seychelles Fishing Authority for using the wet laboratory during fish processing. We also thank  
449 two anonymous reviewers for their comments on an earlier draft of this work. The present work  
450 is a contribution to the SEYFISH project led by the Seychelles Fishing Authority (SFA), with the  
451 financial support of the French Research Institute for Sustainable Development (IRD) and the  
452 European Fisheries Partnership Agreement (EU-FPA). The Regional Council of Brittany, France  
453 (SAD program) is acknowledged for its support to F. Sardenne.

454

### 455 **Author contributions**

456 Fany Sardenne: methodology, software, validation, investigation, writing – original draft.  
457 Nathalie Bodin: conceptualization, methodology, investigation, resources, data curation,  
458 validation, writing – review & editing, supervision, funding acquisition. Anaïs Médiou:  
459 investigation, writing – review & editing. Marisa Antha: investigation. Rona Arrisol:  
460 investigation. Fabienne Le Grand: validation, resources. Antoine Bideau: investigation. Jean-  
461 Marie Munaron: investigation. François Le Loc'h: validation, investigation - review & editing.



462 Emmanuel Chassot: writing – review & editing.

463

## 464 **References**

465 Anishchenko, O.V., Sushchik, N.N., Makhutova, O.N., Kalachova, G.S., Gribovskaya, I.V.,  
466 Morgun, V.N., Gladyshev, M.I., 2017. Benefit-risk ratio of canned pacific saury (*Cololabis*  
467 *saira*) intake: Essential fatty acids vs. heavy metals. *Food Chem. Toxicol.* 101, 8–14.  
468 <https://doi.org/10.1016/j.fct.2016.12.035>

469 Bell, J.D., Allain, V., Allison, E.H., Andréfouët, S., Andrew, N.L., Batty, M.J., Blanc, M.,  
470 Dambacher, J.M., Hampton, J., Hanich, Q., Harley, S., Lorrain, A., McCoy, M., McTurk, N.,  
471 Nicol, S., Pilling, G., Point, D., Sharp, M.K., Vivili, P., Williams, P., 2015. Diversifying the  
472 use of tuna to improve food security and public health in Pacific Island countries and  
473 territories. *Mar. Policy* 51, 584–591. <https://doi.org/10.1016/j.marpol.2014.10.005>

474 Bell, J.D., Cisneros-Montemayor, A., Hanich, Q., Johnson, J.E., Lehodey, P., Moore, B.R.,  
475 Pratchett, M.S., Reygondeau, G., Senina, I., Viridin, J., Wabnitz, C.C.C., 2018. Adaptations to  
476 maintain the contributions of small-scale fisheries to food security in the Pacific Islands. *Mar.*  
477 *Policy* 88, 303–314. <https://doi.org/10.1016/j.marpol.2017.05.019>

478 Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G.I.,  
479 Williams, M., 2015. Feeding 9 billion by 2050 – Putting fish back on the menu. *Food Secur.*  
480 7, 261–274. <https://doi.org/10.1007/s12571-015-0427-z>

481 Bodin, N., Lesperance, D., Albert, R., Hollanda, S.J., Michaud, P., Degroote, M., Churlaud, C.,  
482 Bustamante, P., 2017. Trace elements in oceanic pelagic communities in the western Indian  
483 Ocean. *Chemosphere* 174, 354–362. <https://doi.org/10.1016/j.chemosphere.2017.01.099>

484 Bose-O'Reilly, S., McCarty, K.M., Steckling, N., Lettmeier, B., 2010. Mercury exposure and  
485 children's health. *Curr. Probl. Pediatr. Adolesc. Health Care.*  
486 <https://doi.org/10.1016/j.cppeds.2010.07.002>

487 Briones, D.P., Lazaro-Llanos, N., 2016. Omega-3 fatty acids versus heavy metals: a quantitative  
488 estimation of the benefit-risk ratio for the consumption of commonly-consumed fish and  
489 products in Metro, Manila. *KIMIKA* 26, 39–50. <https://doi.org/10.26534/kimika.v26i2.39-50>

490 Castro-González, I., Maafs-Rodríguez, A.G., Silencio-Barrita, J.L., Galindo-Gómez, C., Pérez-  
491 Gil, F., 2013. Evaluation of the possible inclusion of certain fish species in chronic kidney  
492 disease diets based on their adverse and beneficial nutrient ratios. *Int. J. Food Sci. Nutr.* 64,  
493 82–88. <https://doi.org/10.3109/09637486.2012.700921>

494 Choy, C.A., Popp, B.N., Kaneko, J.J., Drazen, J.C., 2009. The influence of depth on mercury  
495 levels in pelagic fishes and their prey. *Proc. Natl. Acad. Sci.* 106, 13865–13869.  
496 <https://doi.org/10.1073/pnas.0900711106>

497 Cladis, D.P., Kleiner, A.C., Freiser, H.H., Santerre, C.R., 2014. Fatty acid profiles of  
498 commercially available finfish fillets in the United States. *Lipids* 49, 1005–1018.  
499 <https://doi.org/10.1007/s11745-014-3932-5>

500 Dhurmeea, Z., Pethybridge, H., Langlais, C., Somes, C.J., Nikolic, N., Appadoo, C., Bodin, N.,  
501 Studies, O., 2020. Spatial variation in stable isotopes and fatty acid trophic markers in  
502 albacore tuna (*Thunnus alalunga*) from the western Indian Ocean. *Deep Sea Res. Part I*  
503 *Oceanogr. Res. Pap.* 1–31.

504 Do Rosário Gomes, H., Goes, J.I., Matondkar, S.G.P., Buskey, E.J., Basu, S., Parab, S., Thoppil,  
505 P., 2014. Massive outbreaks of *Noctiluca scintillans* blooms in the Arabian Sea due to spread  
506 of hypoxia. *Nat. Commun.* 5, 1–8. <https://doi.org/10.1038/ncomms5862>

507 Dulvy, N., Allison, E., 2009. A place at the table? *Nat. Clim. Chang.* 1, 68–70.  
508 <https://doi.org/10.1038/climate.2009.52>

509 EFSA, 2012a. Scientific Opinion on the risk for public health related to the presence of mercury  
510 and methylmercury in food. *EFSA J.* 10, 2985.

511 [EFSA, 2012b. Guidance on selected default values to be used by the EFSA Scientific Committee,  
512 Scientific Panels and Units in the absence of actual measured data. EFSA J. 10,2579.  
513 https://doi:10.2903/j.efsa.2012.2579.](https://doi.org/10.2903/j.efsa.2012.2579)

514 EFSA, 2014. Scientific Opinion on health benefits of  
515 seafood (fish and shellfish) consumption in relation to health risks associated with exposure  
516 to methylmercury. *EFSA J.* 12, 3761. <https://doi.org/10.2903/j.efsa.2014.3761>

517 FAO Codex Alimentarius Commission, 2011. Working document for Information and use in  
518 discussion related to contaminants and toxins in the GSCTFF, Joint FAO/WHO Food  
519 Standards Programme Codex Committee on Contaminants in Foods. Rome, Italie.  
520 <https://doi.org/10.3768/rtipress.2014.rb.0007.1405>

521 FAO/WHO, 2010. Report of the Joint FAO/WHO Expert Consultation on the Risks and Benefits  
522 of Fish Consumption. Rome, 25-29 january 2010. Rome.

523 FAO, I.O.T.C., 2019. RESOLUTION 19/05 On a ban on discards of bigeye tuna, skipjack tuna,  
524 yellowfin tuna, and non- targeted species caught by purse seine vessels in the iotc area of  
525 competence. [https://iotc.org/cmm/resolution-1905-ban-discards-bigeye-tuna-skipjack-tuna-  
526 yellowfin-tuna-and-non-targeted-species](https://iotc.org/cmm/resolution-1905-ban-discards-bigeye-tuna-skipjack-tuna-yellowfin-tuna-and-non-targeted-species)

527 Fonteneau, A., Chassot, E., Bodin, N., 2013. Global spatio-temporal patterns in tropical tuna  
528 purse seine fisheries on drifting fish aggregating devices (DFADs): Taking a historical

528 perspective to inform current challenges. *Aquat. Living Resour.* 26, 37–48.

529 Froese, R., Pauly, D., 2019. FishBase [WWW Document]. World Wide Web Electron. Publ.  
530 URL [www.fishbase.org](http://www.fishbase.org), version

531 Gaboriau, M., Ponton, D., Darius, H.T., Chinain, M., 2014. Ciguatera fish toxicity in French  
532 Polynesia: Size does not always matter. *Toxicol.* 84, 41–50.  
533 <https://doi.org/10.1016/j.toxicol.2014.03.006>

534 Gerson, J.R., Walters, D.M., Eagles-Smith, C.A., Bernhardt, E.S., Brandt, J.E., 2020. Do two  
535 wrongs make a right? Persistent uncertainties regarding environmental Selenium–Mercury  
536 interactions. *Environ. Sci. Technol.* 54, 9228–9234. <https://doi.org/10.1021/acs.est.0c01894>

537 Gilman, E.L., 2011. Bycatch governance and best practice mitigation technology in global tuna  
538 fisheries. *Mar. Policy* 35, 590–609. <https://doi.org/10.1016/J.MARPOL.2011.01.021>

539 Gladyshev, M.I., Sushchik, N.N., Anishchenko, O. V., Makhutova, O.N., Kalachova, G.S.,  
540 Gribovskaya, I. V., 2009. Benefit-risk ratio of food fish intake as the source of essential fatty  
541 acids vs. heavy metals: A case study of Siberian grayling from the Yenisei River. *Food*  
542 *Chem.* 115, 545–550. <https://doi.org/10.1016/j.foodchem.2008.12.062>

543 Gladyshev, M.I., Sushchik, N.N., Tolomeev, A.P., Dgebuadze, Y.Y., 2018. Meta-analysis of  
544 factors associated with omega-3 fatty acid contents of wild fish. *Rev. Fish Biol. Fish.* 28,  
545 277–299. <https://doi.org/10.1007/s11160-017-9511-0>

546 Haddad, L., Hawkes, C., Waage, J., Webb, P., Godfray, C., Toulmin, C., 2016. Food systems and  
547 diets: Facing the challenges of the 21st century.

548 Hall, M., Gilman, E., Minami, H., Mituhasi, T., Carruthers, E., 2017. Mitigating bycatch in tuna  
549 fisheries. *Rev. Fish Biol. Fish.* 27, 881–908. <https://doi.org/10.1007/s11160-017-9478-x>

550 Hamilton, H.A., Newton, R., Auchterlonie, N.A., Müller, D.B., 2020. Systems approach to  
551 quantify the global omega-3 fatty acid cycle. *Nat. Food* 1, 59–62.  
552 <https://doi.org/10.1038/s43016-019-0006-0>

553 Hicks, C.C., Cohen, P.J., Graham, N.A.J.J., Nash, K.L., Allison, E.H., D’Lima, C., Mills, D.J.,  
554 Roscher, M., Thilsted, S.H., Thorne-Lyman, A.L., MacNeil, M.A., 2019. Harnessing global  
555 fisheries to tackle micronutrient deficiencies. *Nature* 574, 95–98.  
556 <https://doi.org/10.1038/s41586-019-1592-6>

557 Hixson, S.M., Arts, M.T., 2016. Climate warming is predicted to reduce omega-3, long-chain,  
558 polyunsaturated fatty acid production in phytoplankton. *Glob. Chang. Biol.* 22, 2744–2755.  
559 <https://doi.org/10.1111/gcb.13295>

560 Hu, X.F., Laird, B.D., Chan, H.M., 2017. Mercury diminishes the cardiovascular protective effect  
561 of omega-3 polyunsaturated fatty acids in the modern diet of Inuit in Canada. *Environ. Res.*

562 152, 470–477. <https://doi.org/10.1016/j.envres.2016.06.001>

563 Kainz, M., Arts, M.T., Mazumder, A., 2008. Essential versus potentially toxic dietary substances:  
564 A seasonal comparison of essential fatty acids and methyl mercury concentrations in the  
565 planktonic food web. *Environ. Pollut.* 155, 262–270.  
566 <https://doi.org/10.1016/j.envpol.2007.11.021>

567 Kidd, K., Clayden, M., Jardine, T., 2011. Bioaccumulation and Biomagnification of Mercury  
568 through Food Webs, in: *Environmental Chemistry and Toxicology of Mercury*. John Wiley &  
569 Sons, Inc., Hoboken, NJ, USA, pp. 453–499. <https://doi.org/10.1002/9781118146644.ch14>

570 Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R.P., Bustamante, P., 2007. Bioaccumulation  
571 of trace elements in pelagic fish from the Western Indian Ocean. *Environ. Pollut.*, 146, 548–  
572 566. <https://doi.org/10.1016/j.envpol.2006.07.015>

573 Lamborg, C.H., Hammerschmidt, C.R., Bowman, K.L., Swarr, G.J., Munson, K.M., Ohnemus,  
574 D.C., Lam, P.J., Heimbürger, L.E., Rijkenberg, M.J.A., Saito, M.A., 2014. A global ocean  
575 inventory of anthropogenic mercury based on water column measurements. *Nature* 512, 65–  
576 68. <https://doi.org/10.1038/nature13563>

577 Lezama-Ochoa, N., Murua, H., Chust, G., Ruiz, J., Chavance, P., de Molina, A.D., Caballero, A.,  
578 Sancristobal, I., 2015. Biodiversity in the by-catch communities of the pelagic ecosystem in  
579 the Western Indian Ocean. *Biodivers. Conserv.* 24, 2647–2671.  
580 <https://doi.org/10.1007/s10531-015-0951-3>

581 Li, Y., Zhang, Y., Hussey, N.E., Dai, X., 2016. Urea and lipid extraction treatment effects on  
582  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values in pelagic sharks. *Rapid Commun. Mass Spectrom.* 30, 1–8.  
583 <https://doi.org/10.1002/rcm.7396>

584 Link, J.S., Watson, R.A., 2019. Global ecosystem overfishing: Clear delineation within real limits  
585 to production. *Sci. Adv.* 5, eaav0474. <https://doi.org/10.1126/sciadv.aav0474>

586 Mariotti, F., Tomé, D., Mirand, P.P., 2008. Converting nitrogen into protein - Beyond 6.25 and  
587 Jones' factors. *Crit. Rev. Food Sci. Nutr.* 48, 177–184.  
588 <https://doi.org/10.1080/10408390701279749>

589 Médiéu, A., Sabarros, P., P., Bodin, N., Chassot, E., Cauquil, P., Njaratiana, R., Bach, P., 2018.  
590 Biological and ecological traits of non-targeted species caught by the tuna purse seine fishery  
591 in the western Indian Ocean. *IOTC–2018–WPEB14* 1–16.

592 Mori, T.A., Hodgson, J.M., 2012. Fatty acids: Health effects of omega-6 polyunsaturated fatty  
593 acids, in: *Encyclopedia of Human Nutrition*. Elsevier Inc., pp. 209–214.  
594 <https://doi.org/10.1016/B978-0-12-375083-9.00100-8>

595 Munsch, C., Vigneau, E., Bély, N., Héas-Moisan, K., Olivier, N., Pollono, C., Hollanda, S.,  
596 Bodin, N., 2020. Legacy and emerging Persistent Organic Pollutant (POP) levels and profiles  
597 in top predator fish from the western Indian Ocean in relation to their trophic ecology.  
598 Environ. Res. in press.

599 Nagasaka, R., Gagnon, C., Swist, E., Rondeau, I., Massarelli, I., Cheung, W., Ratnayake,  
600 W.M.N., 2014. EPA and DHA status of South Asian and white Canadians living in the  
601 National Capital Region of Canada. *Lipids* 49, 1057–1069. [https://doi.org/10.1007/s11745-](https://doi.org/10.1007/s11745-014-3942-3)  
602 [014-3942-3](https://doi.org/10.1007/s11745-014-3942-3)

603 Nakamura, Y.-N.N., Ando, M., Seoka, M., Kawasaki, K. ichi, Tsukamasa, Y., 2007. Changes of  
604 proximate and fatty acid compositions of the dorsal and ventral ordinary muscles of the full-  
605 cycle cultured Pacific bluefin tuna *Thunnus orientalis* with the growth. *Food Chem.* 103,  
606 234–241. <https://doi.org/10.1016/j.foodchem.2006.07.064>

607 Nišević, J.R., Prpić, I., Kolić, I., Baždarić, K., Tratnik, J.S., Prpić, I.Š., Mazej, D., Špirić, Z.,  
608 Barbone, F., Horvat, M., 2019. Combined prenatal exposure to mercury and LCPUFA on  
609 newborn's brain measures and neurodevelopment at the age of 18 months. *Environ. Res.* 178,  
610 108682. <https://doi.org/10.1016/j.envres.2019.108682>

611 Pérez-Roda, A., Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P., Chaloupka, M.,  
612 Medley, P., 2019. A third assessment of global marine fisheries discards, FAO Fisheries and  
613 Aquaculture Technical Paper. No. 633. FAO Fisheries and Aquaculture Technical Paper No.  
614 633., Rome, Italy. <http://www.fao.org/3/CA2905EN/ca2905en.pdf>

615 Pethybridge, H.R., Parrish, C.C., Morrongiello, J., Young, J.W., Farley, J.H., Gunasekera, R.M.,  
616 Nichols, P.D., 2015. Spatial patterns and temperature predictions of tuna fatty acids: tracing  
617 essential nutrients and changes in primary producers. *PLoS One* 10, e0131598.  
618 <https://doi.org/10.1371/journal.pone.0131598>

619 Pilling, G.M., Harley, S.J., Nicol, S., Williams, P., Hampton, J., 2020. Can the tropical Western  
620 and Central Pacific Tuna purse seine fishery contribute to Pacific Island population food  
621 security?, in: *Food Security in Small Island States*. Springer Singapore, pp. 133–156.  
622 [https://doi.org/10.1007/978-981-13-8256-7\\_8](https://doi.org/10.1007/978-981-13-8256-7_8)

623 Plourde, M., Cunnane, S.C., 2007. Extremely limited synthesis of long chain polyunsaturates in  
624 adults: implications for their dietary essentiality and use as supplements. *Appl. Physiol. Nutr.*  
625 *Metab.* 32, 619–634. <https://doi.org/10.1139/H07-034>

626 R Core Team, 2016. R Development Core Team. *R A Lang. Environ. Stat. Comput.* 55, 275–286.  
627 <https://doi.org/http://www.R-project.org>

628 Ralston, N.V.C., Ralston, C.R., Raymond, L.J., 2016. Selenium health benefit values: updated

629 criteria for mercury risk assessments. *Biol. Trace Elem. Res.* 171, 262–269.  
630 <https://doi.org/10.1007/s12011-015-0516-z>

631 Ratnayake, N., 2018. Protocol for measuring trans fatty acids in foods. WHO-2018.  
632 [https://www.who.int/docs/default-source/documents/replace-transfats/a-food-analysis-lab-](https://www.who.int/docs/default-source/documents/replace-transfats/a-food-analysis-lab-protocol.pdf?sfvrsn=b27e4111_2)  
633 [protocol.pdf?sfvrsn=b27e4111\\_2](https://www.who.int/docs/default-source/documents/replace-transfats/a-food-analysis-lab-protocol.pdf?sfvrsn=b27e4111_2)

634 Razavi, N.R., Arts, M.T., Qu, M., Jin, B., Ren, W., Wang, Y., Campbell, L.M., 2014. Effect of  
635 eutrophication on mercury, selenium, and essential fatty acids in Bighead Carp  
636 (*Hypophthalmichthys nobilis*) from reservoirs of eastern China. *Sci. Total Environ.* 499, 36–  
637 46. <https://doi.org/10.1016/j.scitotenv.2014.08.019>

638 Robinson, J.P.W., Robinson, J., Gerry, C., Govinden, R., Freshwater, C., Graham, N.A.J., 2020.  
639 Diversification insulates fisher catch and revenue in heavily exploited tropical fisheries. *Sci.*  
640 *Adv.* 6, eaaz0587. <https://doi.org/10.1126/sciadv.aaz0587>

641 Ruiz Gondra, J., Lopez, J., Abascal, F.J., Pascual Alayon, P.J., Amandè, M.J., Bach, P., Cauquil,  
642 P., Murua, H., Ramos Alonso, M.L., Sabarros, P.S., 2018. Bycatch of the European and  
643 associated flag purse-seine tuna fishery in the Indian ocean for the period 2008-2017, IOTC-  
644 2018-WPEB14-15, 15p

645 Sanchez-Henao, J.A., García-Álvarez, N., Fernández, A., Saavedra, P., Silva Sergent, F., Padilla,  
646 D., Acosta-Hernández, B., Martel Suárez, M., Diogène, J., Real, F., 2019. Predictive score  
647 and probability of CTX-like toxicity in fish samples from the official control of ciguatera in  
648 the Canary Islands. *Sci. Total Environ.* 673, 576–584.  
649 <https://doi.org/10.1016/j.scitotenv.2019.03.445>

650 Sardà, F., Coll, M., Heymans, J.J., Stergiou, K.I., 2015. Overlooked impacts and challenges of  
651 the new European discard ban. *Fish Fish.* 16, 175–180. <https://doi.org/10.1111/faf.12060>

652 Sardenne, F., Bodin, N., Chassot, E., Amiel, A., Fouché, E., Degroote, M., Hollanda, S.,  
653 Pethybridge, H., Lebreton, B., Guillou, G., Ménard, F., 2016. Trophic niches of sympatric  
654 tropical tuna in the Western Indian Ocean inferred by stable isotopes and neutral fatty acids.  
655 *Prog. Oceanogr.* 146, 75–88. <https://doi.org/10.1016/j.pocean.2016.06.001>

656 Sardenne, F., Bodin, N., Metral, L., Crottier, A., Le Grand, F., Bideau, A., Brisset, B., Bourjea,  
657 J., Saraux, C., Bonhommeau, S., Kerzérho, V., Bernard, S., Rouyer, T., 2019. Effects of  
658 extraction method and storage of dry tissue on marine lipids and fatty acids. *Anal. Chim. Acta*  
659 1051, 82–93. <https://doi.org/10.1016/J.ACA.2018.11.012>

660 Sardenne, F., Hollanda, S., Lawrence, S., Albert-Arrisol, R., Degroote, M., Bodin, N., 2017.  
661 Trophic structures in tropical marine ecosystems: a comparative investigation using three  
662 different ecological tracers. *Ecol. Indic.* 81, 315–324.



663 <https://doi.org/10.1016/j.ecolind.2017.06.001>

664 Schartup, A.T., Thackray, C.P., Qureshi, A., Dassuncao, C., Gillespie, K., Hanke, A.,  
665 Sunderland, E.M., 2019. Climate change and overfishing increase neurotoxicant in marine  
666 predators. *Nature*. <https://doi.org/10.1038/s41586-019-1468-9>

667 Signa, G., Calizza, E., Costantini, M.L., Tramati, C., Sporta Caputi, S., Mazzola, A., Rossi, L.,  
668 Vizzini, S., 2019. Horizontal and vertical food web structure drives trace element trophic  
669 transfer in Terra Nova Bay, Antarctica. *Environ. Pollut.* 246, 772–781.  
670 <https://doi.org/10.1016/j.envpol.2018.12.071>

671 Simopoulos, A.P., 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids.  
672 *Biomed. Pharmacother.* 56, 365–379. [https://doi.org/10.1016/S0753-3322\(02\)00253-6](https://doi.org/10.1016/S0753-3322(02)00253-6)

673 Strain, J.J., Davidson, P.W., Bonham, M.P., Duffy, E.M., Stokes-Riner, A., Thurston, S.W.,  
674 Wallace, J.M.W., Robson, P.J., Shamlaye, C.F., Georger, L.A., Sloane-Reeves, J.,  
675 Cernichiari, E., Canfield, R.L., Cox, C., Huang, L.S., Janciuras, J., Myers, G.J., Clarkson,  
676 T.W., 2008. Associations of maternal long-chain polyunsaturated fatty acids, methyl mercury,  
677 and infant development in the Seychelles Child Development Nutrition Study.  
678 *Neurotoxicology* 29, 776–782. <https://doi.org/10.1016/j.neuro.2008.06.002>

679 Swanson, D., Block, R., Mousa, S.A., 2012. Omega-3 Fatty Acids EPA and DHA: Health  
680 Benefits Throughout Life. *Adv. Nutr.* 3, 1–7. <https://doi.org/10.3945/an.111.000893>

681 Torres-Irineo, E., Amandè, M.J., Gaertner, D., Molina, A.D. de, Murua, H., Chavance, P., Ariz,  
682 J., Ruiz, J., Lezama-Ochoa, N., de Molina, A.D., Murua, H., Chavance, P., Ariz, J., Ruiz, J.,  
683 Lezama-Ochoa, N., 2014. Bycatch species composition over time by tuna purse-seine fishery  
684 in the eastern tropical Atlantic Ocean. *Biodivers. Conserv.* 23, 1157–1173.  
685 <https://doi.org/10.1007/s10531-014-0655-0>

686 Tremain, D.M., Adams, D.H., 2012. Mercury in groupers and sea basses from the gulf of mexico:  
687 Relationships with size, age, and feeding ecology. *Trans. Am. Fish. Soc.* 141, 1274–1286.  
688 <https://doi.org/10.1080/00028487.2012.683232>

689 van der Velden, S., Reist, J.D., Babaluk, J.A., Power, M., 2012. Biological and life-history  
690 factors affecting total mercury concentrations in Arctic charr from Heintzelman Lake,  
691 Ellesmere Island, Nunavut. *Sci. Total Environ.* 433, 309–317.  
692 <https://doi.org/10.1016/j.scitotenv.2012.06.055>

693 Viana, M., McNally, L., Graham, N., Reid, D.G., Jackson, A.L., 2013. Ignoring discards biases  
694 the assessment of fisheries' ecological fingerprint. *Biol. Lett.* 9, 20130812.  
695 <https://doi.org/10.1098/rsbl.2013.0812>

696 Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C.,  
697 Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R.,  
698 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science*. 314, 787–790.  
699 <https://doi.org/10.1126/science.1132294>

700 Zeller, D., Cashion, T., Palomares, M., Pauly, D., 2018. Global marine fisheries discards: A  
701 synthesis of reconstructed data. *Fish Fish.* 19, 30–39. <https://doi.org/10.1111/faf.12233>

702



703 **Table 1.** Parameters setup for hazard quotient calculation, based on reference values from  
 704 sanitary agencies (FAO/WHO and EFSA).  $R_{EFA}$  = Reference dose for essential fatty acids  
 705 (EPA+DHA); RfD = oral Reference Dose for mercury. Adults and teens with body weight below  
 706 70 kg should be referred to children category. \*arbitrary set to the upper range limit.

Categories	$R_{EFA}$ (mg.d <sup>-1</sup> )		Mercury RfD ( $\mu$ g.kg.d <sup>-1</sup> )	Weight (kg)
	Optimum	Range		
Young children (2-4 y)	150*	100-150	0.186	12
Children (4-10 y)	250*	150-250	0.186	30
Adults & teens (> 10 y)	300	250-2000	0.186	70

708 **Table 2.** Nutritional composition of dorsal muscle for 20 bycatch fish species collected in the  
 709 western Indian Ocean in 2018. Total fat is in triacylglycerol equivalents. DHA =  
 710 docosahexaenoic acid (22:6n-3), EPA = Eicosapentaenoic acid (20:5n-3), ww = wet weight. See  
 711 Material and Method section for the length measurement method of each species.

Family	Scientific name	English name	Code	n	Length	Mercury	DHA	EPA	Omega 3	Total fat	Crude protein	Water	Omega-6 /
					(cm)	(ppm ww)	(mg.g <sup>-1</sup> ww)	(mg.g <sup>-1</sup> ww)	(mg.g <sup>-1</sup> ww)	(mg.g <sup>-1</sup> ww)	(mg.g <sup>-1</sup> ww)	(mg.g <sup>-1</sup> ww)	(%)
					Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Balistidae	<i>Canthidermis maculata</i>	Rough triggerfish	CNT	13	29.6 ± 3.3	0.028 ± 0.021	0.80 ± 0.15	0.18 ± 0.04	1.06 ± 0.16	3.6 ± 0.5	170 ± 8	77 ± 0	0.4 ± 0.1
Belonidae	<i>Ablennes hians</i>	Flat needlefish	BAF	4	87.0 ± 15.7	0.012 ± 0.004	1.18 ± 0.29	0.09 ± 0.03	1.40 ± 0.37	3.8 ± 1.1	198 ± 16	73 ± 1	0.2 ± 0.0
Carangidae	<i>Decapterus macarellus</i>	Mackerel scad	MSD	9	33.2 ± 3.4	0.030 ± 0.021	1.24 ± 0.28	0.19 ± 0.07	1.53 ± 0.39	4.2 ± 1.1	219 ± 18	72 ± 1	0.2 ± 0.0
	<i>Elagatis bipinnulata</i>	Rainbow runner	RRU	11	58.0 ± 13.0	0.054 ± 0.059	1.30 ± 0.24	0.21 ± 0.08	1.64 ± 0.36	5.2 ± 1.6	202 ± 9	74 ± 1	0.2 ± 0.0
	<i>Seriola rivoliana</i>	Longfin yellowtail	YTL	4	28.9 ± 5.5	0.021 ± 0.016	1.29 ± 0.20	0.18 ± 0.03	1.57 ± 0.24	4.4 ± 0.6	205 ± 11	73 ± 1	0.2 ± 0.0
	<i>Uraspis secunda</i>	Cottonmouth jack	USE	14	28.5 ± 3.5	0.018 ± 0.012	1.51 ± 0.56	0.24 ± 0.14	2.12 ± 0.96	10.1 ± 6.7	188 ± 15	72 ± 2	0.3 ± 0.0
Carcharhinidae	<i>Carcharhinus falciformis</i>	Silky shark	FAL	8	74.5 ± 9.8	0.167 ± 0.073	0.16 ± 0.12	0.02 ± 0.02	0.23 ± 0.17	3.2 ± 0.4	221 ± 18	74 ± 2	2.6 ± 1.4
Coryphaenidae	<i>Coryphaena equiselis</i>	Pompano dolphinfish	CFW	4	42.8 ± 3.8	0.019 ± 0.007	1.28 ± 0.26	0.23 ± 0.03	1.61 ± 0.28	4.2 ± 0.6	205 ± 5	74 ± 0	0.3 ± 0.1
	<i>Coryphaena hippurus</i>	Common dolphinfish	DOL	9	59.8 ± 9.1	0.043 ± 0.022	0.96 ± 0.22	0.11 ± 0.03	1.13 ± 0.26	3.3 ± 0.6	195 ± 8	75 ± 1	0.2 ± 0.0
Ephippidae	<i>Platax spp</i>	Batfishes	BAT	2	20.5 ± 7.8	0.005 ± 0.002	1.06 ± 0.30	0.25 ± 0.09	1.46 ± 0.46	5.7 ± 2.7	155 ± 6	78 ± 1	0.3 ± 0.0
Istiophoridae	<i>Istiophorus platypterus</i>	Indo-Pacific sailfish	SFA	4	188.0 ± 26.4	0.151 ± 0.101	1.60 ± 0.52	0.19 ± 0.09	1.94 ± 0.70	6.0 ± 2.4	184 ± 13	77 ± 1	0.3 ± 0.0
	<i>Sphyrna barracuda</i>	Great barracuda	GBA	2	88.0 ± 5.7	0.277 ± 0.056	0.98 ± 0.04	0.08 ± 0.02	1.13 ± 0.08	3.5 ± 0.6	189 ± 3	76 ± 0	0.3 ± 0.0
	<i>Tetrapturus audax</i>	Striped marlin	MLS	3	182.7 ± 3.1	0.130 ± 0.030	2.68 ± 2.32	0.44 ± 0.52	3.58 ± 3.21	13.8 ± 9.1	178 ± 14	76 ± 4	0.3 ± 0.1
Kyphosidae	<i>Kyphosus cinerascens</i>	Blue sea chub	KYC	11	23.3 ± 2.3	0.007 ± 0.002	1.13 ± 0.23	0.20 ± 0.05	1.58 ± 0.36	6.3 ± 2.9	182 ± 6	76 ± 0	0.3 ± 0.0
	<i>Kyphosus vaigiensis</i>	Brassy chub	KYV	21	26.9 ± 3.5	0.007 ± 0.010	0.96 ± 0.16	0.18 ± 0.04	1.33 ± 0.25	5.3 ± 1.4	178 ± 13	76 ± 1	0.4 ± 0.1
Lobotidae	<i>Lobotes surinamensis</i>	Tripletail	LOB	10	44.2 ± 7.9	0.061 ± 0.043	0.72 ± 0.19	0.08 ± 0.01	0.87 ± 0.22	2.9 ± 0.8	171 ± 6	78 ± 1	0.3 ± 0.1
Monacanthidae	<i>Aluterus monoceros</i>	Unicorn leatherjacket	ALM	10	39.2 ± 6.7	0.007 ± 0.004	0.78 ± 0.07	0.15 ± 0.04	0.99 ± 0.07	3.1 ± 0.3	162 ± 7	77 ± 1	0.4 ± 0.1
Scombridae	<i>Acanthocybium solandri</i>	Wahoo	WAH	5	94.4 ± 10.7	0.086 ± 0.046	0.91 ± 0.13	0.11 ± 0.01	1.06 ± 0.14	2.9 ± 0.3	204 ± 6	74 ± 1	0.3 ± 0.0
	<i>Auxis thazard</i>	Frigate tuna	FRI	18	38.7 ± 4.2	0.092 ± 0.042	1.55 ± 0.65	0.22 ± 0.09	1.88 ± 0.80	6.3 ± 2.9	231 ± 5	71 ± 0	0.2 ± 0.0
	<i>Euthynnus affinis</i>	Kawakawa	KAW	13	48.1 ± 7.9	0.152 ± 0.068	2.28 ± 1.24	0.37 ± 0.25	2.88 ± 1.66	9.9 ± 6.1	223 ± 12	71 ± 1	0.3 ± 0.0

712

713

714 **Table 3.** ANOVA results testing the influence of species, fish length and their interactions on  
 715 total mercury and EPA+DHA contents, and hazard quotient values, obtained for 20 bycatch fish  
 716 species from the western Indian Ocean in 2018. DHA = docosahexaenoic acid (22:6n-3); EPA =  
 717 Eicosapentaenoic acid (20:5n-3); df = degrees of freedom; Sum Sq = sum square error; F = Fisher  
 718 statistic; p = p-value.

Factors	Mercury				EPA+DHA				Hazard Quotient			
	df	Sum Sq	F	p	df	Sum Sq	F	p	df	Sum Sq	F	p
Species	19	167.8	40.5	<0.001	19	50.1	32.2	<0.001	19	216.8	34.5	<0.001
Length	1	23.5	107.7	<0.001	1	0.9	11.4	0.001	1	15.1	45.6	<0.001
Species*Length	19	14.4	3.5	<0.001	19	4.2	2.7	0.001	19	17.2	2.7	0.001
Residuals	135	29.5			135	11.0			135	44.6		

719

720

721

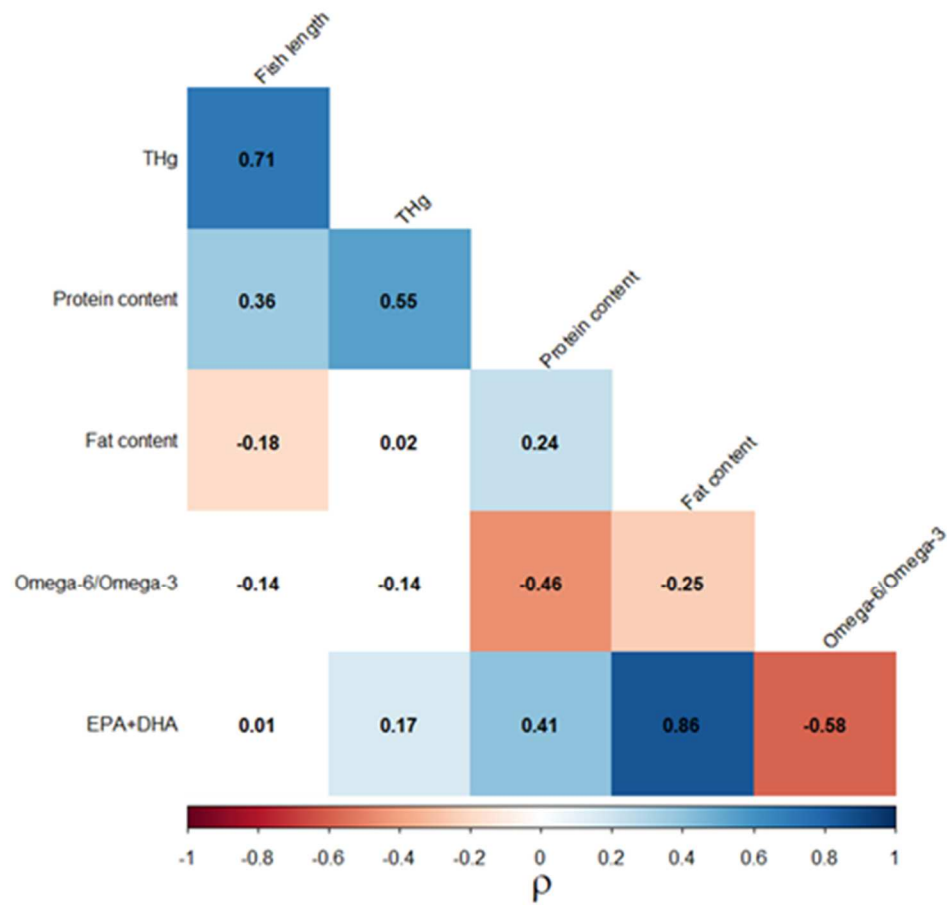
722

723 **Table 4.** Daily serving of fish fillet (g) required to cover eicosapentaenoic + docosahexaenoic  
 724 acids (EPA+DHA) needs for young children, children, and adults (FAO/WHO, 2008).

English name	Code	Daily serving portion (g)		
		Young children	Children	Adults
Rough triggerfish	CNT	140	234	280
Flat needlefish	BAF	117	196	235
Mackerel scad	MSD	57	94	113
Rainbow runner	RRU	84	140	168
Longfin yellowtail	YTL	154	257	309
Cottonmouth jack	USE	48	80	96
Silky shark	FAL	99	166	199
Pompano dolphinfish	CFW	99	165	198
Common dolphinfish	DOL	105	176	211
Batfishes	BAT	801	1335	1602
Indo-Pacific sailfish	SFA	142	236	283
Great barracuda	GBA	132	220	264
Striped marlin	MLS	84	141	169
Blue sea chub	KYC	102	170	204
Brassy chub	KYV	85	142	171
Tripletail	LOB	147	246	295
Unicorn leatherjacket	ALM	115	191	229
Wahoo	WAH	162	269	323
Frigate tuna	FRI	112	187	225
Kawakawa	KAW	187	311	374

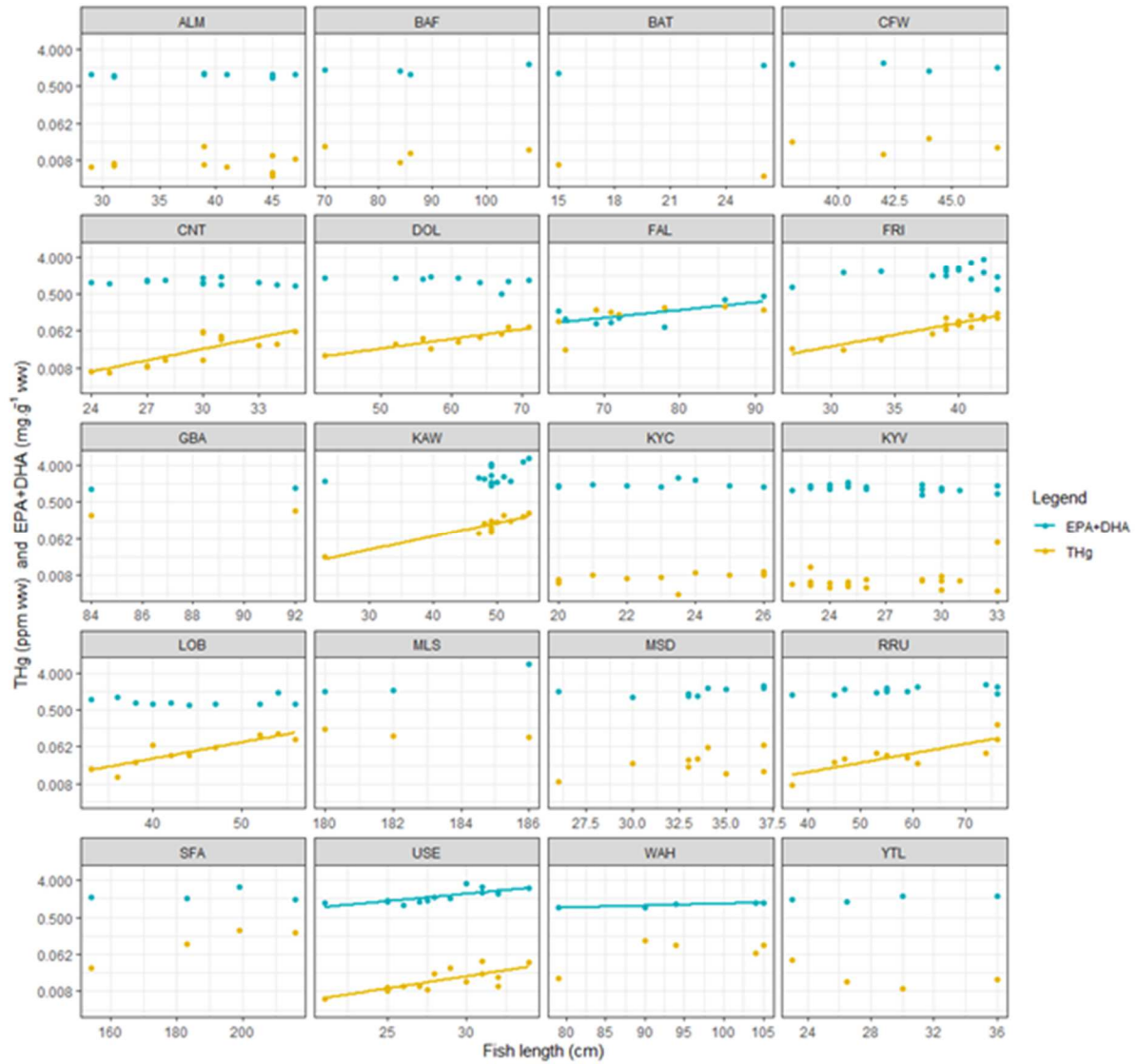
725

726 **Figure 1.** Correlation plot among individuals length, mercury (THg) and nutritional contents  
 727 (protein, fat, EPA+DHA contents and omega-6/omega-3 ratio) of 20 bycatch fish species  
 728 collected from the western Indian Ocean in 2018. The coloured cells indicate a significant  
 729 correlation between the two tracers ( $p < 0.05$ ) while the blank cells indicate a non-significant  
 730 correlation. The numbers in the cells are the associated Spearman's correlation coefficient ( $\rho$ )  
 731 calculated for each pair and the cell's colour intensity is proportional to  $\rho$ . DHA =  
 732 docosahexaenoic acid (22:6n-3), EPA = Eicosapentaenoic acid (20:5n-3).



733  
734

735 **Figure 2.** Changes in total mercury levels (THg, ppm ww) and eicosapentaenoic +  
 736 docosahexaenoic acid contents (EPA+DHA, mg.g<sup>-1</sup> ww) with fish length (cm) for 20 bycatch fish  
 737 species collected from the western Indian Ocean in 2018. Linear regressions are plotted when  
 738 significant (p < 0.05). See Table 2 for definition of species acronyms. Y-axis is log scale.



739

740

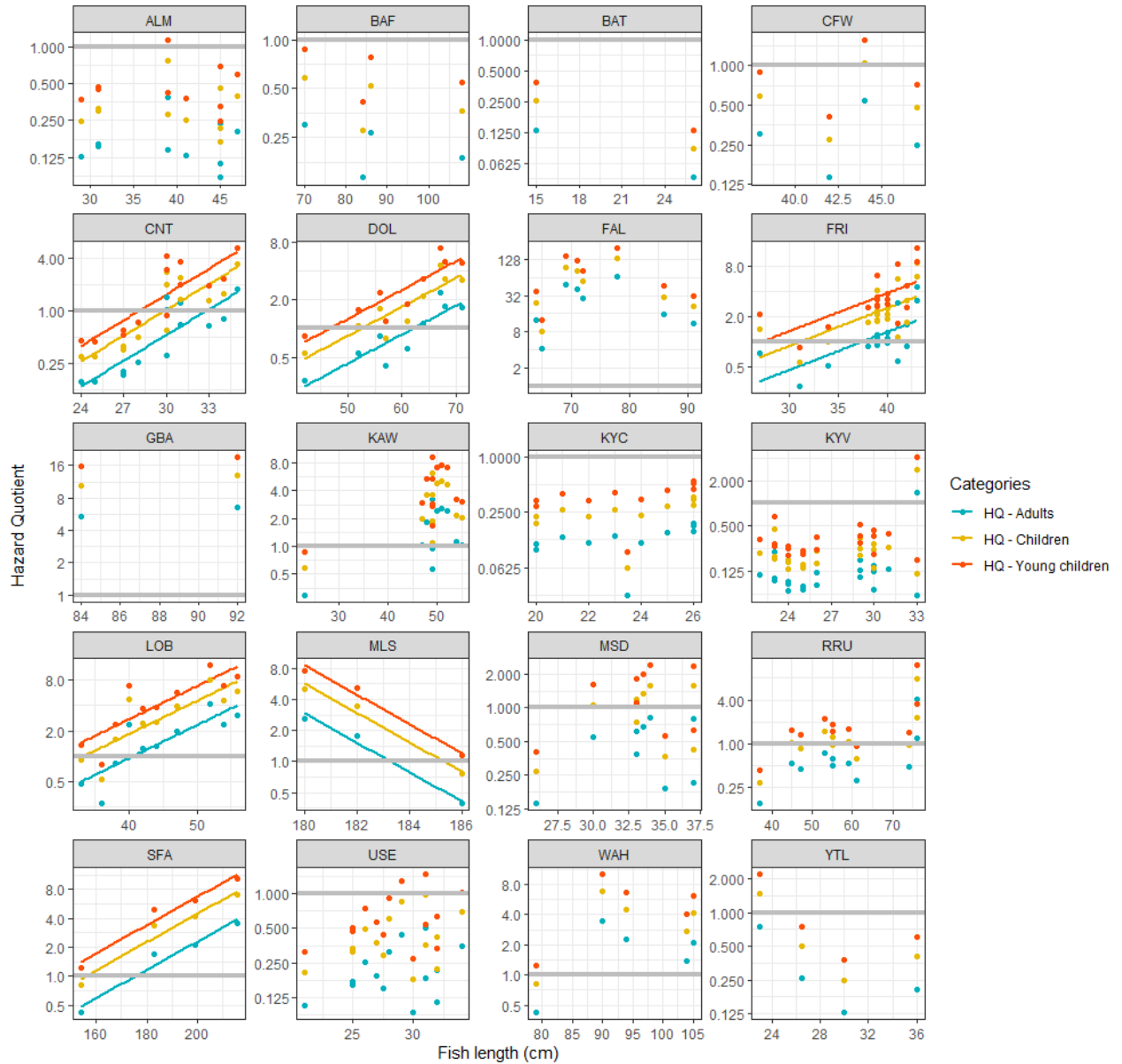
741 **Figure 3.** Boxplots of hazard quotient values (HQ) based on total mercury levels and  
 742 eicosapentaenoic + docosahexaenoic acid (EPA+DHA) contents for 20 bycatch fish species  
 743 collected from the western Indian Ocean in 2018. HQ were computed for 3 people categories  
 744 (young children, children and adults; see Table 1 for parameters). The horizontal grey line  
 745 defines the HQ threshold of 1, and species (X-axis) are ordered according to their mean  
 746 nutritional rank. See Table 2 for definition of species acronyms and details on nutritional  
 747 composition. Y-axis is log scale.



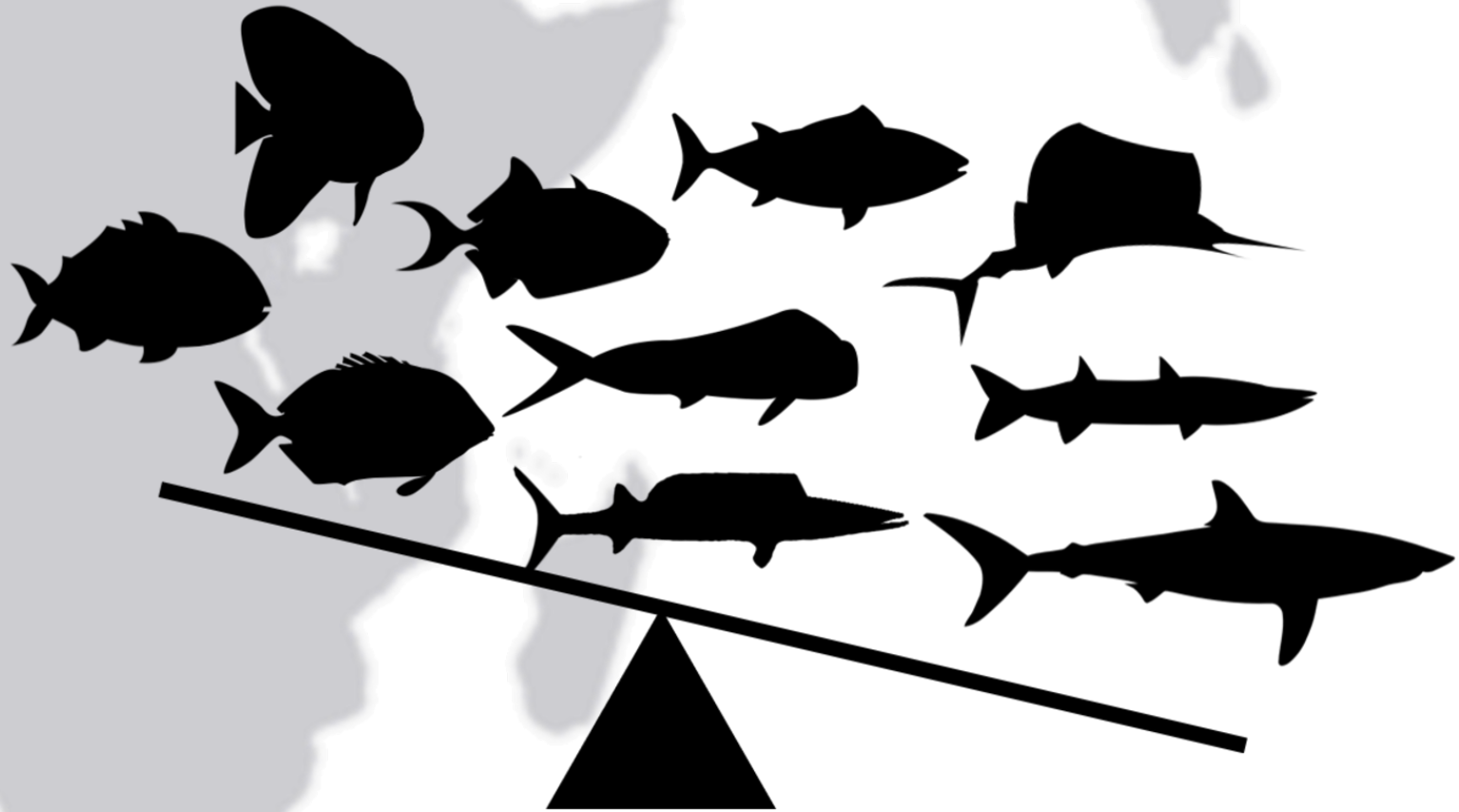
748

749

750 **Figure 4.** Changes in hazard quotient (HQ) with fish length (cm) for 20 bycatch species collected  
 751 from the western Indian Ocean in 2018. Scales are adjusted to each species. The horizontal grey  
 752 line defines the HQ threshold of 1 (HQ < 1 when benefit is greater than risk and vice versa).  
 753 Linear regressions are plotted when significant (p < 0.05). See Table 2 for definition of species  
 754 acronyms. Y-axis is log scale.



755



Hazard quotient