Bioavailability

Human exposure to trace elements via farmed and cage aggregated wild Axillary seabream (Pagellus acarne) in a copper alloy cage site in the Northern Aegean Sea

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ABSTRACT

Axillary seabream (Pagellus acarne) farmed in a copper alloy mesh pen and wild individuals of P. acarne aggregated near the copper-alloy cages presented higher concentrations of trace metals in the liver, skin and gills than in fish muscle tissues in two batches of small and large fish sizes. Elevated mean levels of metals (mg kg⁻¹) in muscle tissues in both small and large fish size groups were observed in the rank order of Zn(3.43) > Fe(3.01) > Cu(0.59) > Mn(0.13) and Fe(3.82) > Zn(3.32) > Cu(0.62) > Mn(0.17) for copper cage-farmed fish, relative to ranked mean levels for Zn(2.64) > Fe(1.95) > Cu(0.25) > Mn(0.09) and Fe(5.79) > Zn(3.58) > Cu(0.58) > Mn(0.28) for the copper cage-aggregated wild fish. Nevertheless, trace metal concentrations in fish harvested from the copper cage or those of the cage-aggregated wild individuals in both size groups were far below maximum levels of seafood safety recommended by USEPA and FAO/WHO. Target hazard quotients, calculated to estimate the non-carcinogenic health risks of metals by consuming these fish, were below “1” (THQ < 1), indicating that there were no potential health risks for humans when consuming copper-caged fish or wild-caught individuals aggregated around the copper mesh pen, with respect to the limits suggested by US Food and Drug Administration and EU Regulations for Seafood Consumption.

1. Introduction

Copper-treated polymer net pens are widely used for the prevention of biofouling at many European marine farm sites, however these antifouling paints can only postpone the development of biofouling by no more than eight months [1,2]. The antifoulant gradually leaches into the marine environment with possible toxic effects on non-target marine life due to accumulation of the active ingredients from the paints into the water column and sediments below cages [3–5]. It is likely that the use of copper-based anti-fouling paints in cage farms has been increased with the expansion and capacity increases of marine farm operations. Moreover, the prohibition of tributyl-tin (TBT) as an antifouling agent in 1990 markedly increased the use of copper based anti-fouling paints in cage farms [6].

Recently a new net technology, “copper alloy mesh” (made from brass wire), has attracted farmers as a potential solution for some of the potential impacts associated with the expansion of cage farms in more exposed marine sites. Despite the increasing number of recent reports on the benefits of copper alloy mesh pens for cage aquaculture [7–15], there is only one study available [16] to our knowledge, regarding the health risks for human consumers associated with the use of copper alloy mesh in fish farming. Thus, the issue of the safety for human consumers

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consumption of fish grown in the copper alloy cages, and wild marine life harvested from waters in the nearby environment, has not yet been addressed. Therefore, the present study aimed to investigate trace metal concentrations in fish harvested from copper alloy mesh-pens and in natural fish populations aggregating around these pens in terms of human dietary exposures to metals via fish consumption and associated potential health risks.

2. Materials and methods

2.1. Farm location and experimental fish

An offshore cage farm located in the northern part of the Aegean Sea, 0.6 nautical miles off the coast of Guzelyali town in the Strait of Canakkale (40°03′42″N - 26°20′36″E, 40°03′51″N - 26°20′45″E, 40°03′45″N - 26°20′55″E, 40°03′36″N - 26°20′48″E) was used in this study. Water quality parameters in the study area such as temperature, salinity, dissolved oxygen, and pH ranged between 16.5–24.0 °C, 23.7–29.8 ‰, 7.2–10.6 mg L⁻¹, and 8.2–8.85, respectively during the course of the farm operation from May to September 2014.

The analyses results (mean ± SD, %) of the antimicrobial wrought copper-zinc brass alloy (ASTM designation of C44500), used as a mesh in the copper cage, was presented by the German Copper Institute as follows: 71.50 ± 2.12, 27.38 ± 2.55, 1.00 ± 0.28, 0.06 ± 0.06, 0.07 ± 0.00, and 0.06 ± 0.0 for Cu, Zn, Sn, P, Pb, and Fe, respectively.

2.2. Fish sampling and analytical methods

A total of 40 axillary seabream (P. acarne) were randomly collected from the harvest batch of the copper alloy cage at the end of September 2014, after an operational period of 150 days. Fish samples were then separated into two size groups, each with 20 fish, hereinafter called as “small size fish (SF)” and “large size fish (LF)”. Average weights of fish (mean ± SD) were 196.4 ± 17.4 g (SF) and 251.2 ± 15.3 g (LF) for the copper cage-farmed fish, while 82.0 ± 6.0 g (SF) and 102.20 ± 18.5 g (LF) for cage-aggregated wild fish. Wild individuals of P. acarne were obtained from local fishermen in the area who were fishing by baited trotlines between depths of 0–10 m near the cage farm facility throughout September 2014. These cage-aggregated wild representatives of axillary seabream were also divided into two size groups as SF and LF, with 20 fish in each size group.

The farmed fish samples were collected from the harvest batch in the fish farm, and the wild fish samples obtained from fishermen’s catches, both within 2 h of harvest. All of the fish were dead by the time of our post-harvest sampling hence the present study did not involve any legal or ethical issues for animal welfare before or during the normal commercial harvest activities.

All samples of farmed and cage-aggregated wild fish were stored in polyethylene bags with ice immediately after collection and frozen at -20 °C for further analysis of fish muscle composition (dry matter, protein, lipid, ash), fish body indices, and metal concentrations in different fish body tissues (liver, gills, skin, and muscle). Non-metallic tools such as scissors and tweezers were used to reduce any possible metal contamination during sampling and tissue dissection. Muscle tissues sampled between the lateral line and the dorsal fin from both sides of the fish were prepared for analyses by homogenizing the muscle tissue in a blender and all analyses were performed in triplicate.

The proximate analyses of fish muscle tissue were conducted according to AOAC [17] guidelines. Dry matter was determined after drying the samples in an oven at 105 °C for 24 h until a constant weight. Protein (N 6.25) was analyzed by the Kjeldahl method after acid digestion and the lipids by ethyl ether extraction in a Soxhlet System, whereas ash was determined by incineration in a muffle furnace at 550 °C for 12 h. The NFEs were calculated by difference. Visceromass index (VSI), hepatosomatic index (HSI), the accumulation of lipids around the viscera (mesenteric fat index, MFI), spleen somatic index (SSI), and gonado-somatic index (GSI) were recorded using following equations: Visceromass index (%VS) = (Viscera weight / Body weight) x 100; Hepatosomatic Index (HSI, %) = (Liver weight / Body weight) x 100; Mesenteric fat index (MFI, %) = (Lipids weight around viscera (g) / Body weight) x 100; Spleen somatic index (SSI, %) = (Spleen weight / Body weight) x 100; Gonado-somatic index (GSI, %) = (Gonad weight / Body weight) x 100.

Trace metals (Cu, Zn, Fe, Mn) in various fish tissues were determined using Atomic Adsorption Spectrophotometry (AA6300, Shimadzu - Japan). The muscle tissue data were used to evaluate possible uptake of trace metals into the human body via fish consumption, while the data of other tissue samples were used in the determination of the status and uptake levels of these four trace metals in the fish body. Fish body tissues were rinsed and dried in an oven until constant weight, and then digested in 5 mL of concentrated nitric acid, diluted thereafter to 20 mL with deionized water. The same process was performed for a blank digest as well. Lamp wavelengths for the Atomic Absorption Spectrophotometry were 324.754 for Cu, 206.191 for Zn, 259.941 for Fe, and 259.373 for Mn. Prior to the metal analysis, Dogfish muscle (certified reference material DORM-2) was used for the calibration of Atomic Absorption Spectrophotometry. DORM-2 and lobster hepatopancreas reference material for metals (TORT-2) were purchased from the National Research Council (NRC) in Canada. The concentrations found were within 90–115% of the certified values for all measured trace metals. Percentage tissue moisture levels were calculated based on wet and dry tissue weight and all metal concentrations were given as mg kg⁻¹ dry weight, except when otherwise stated.

2.3. Exposure of human to trace metals via fish consumption, and health risk assessment

Human health risk assessments were conducted by using consumption rates of metals calculated based on trace element concentrations in muscle tissue and daily fish consumption rate per capita (23 kg capita⁻¹ per year, 0.063 kg day⁻¹) [18] in Europe. Consumption rates and patterns were determined based on an average meal size of 0.227 kg [19] for an adult human consumer of 70 kg body weight, the average for adult males and females in Europe [20]. Estimated daily intake (EDI, mg day⁻¹ person) of a single metal based on trace metal levels in fish muscle and intake rates were calculated as follows:

\[
\text{EDI} = (\text{MC} \times \text{DI})
\]

where, MC: metal concentration in the edible part of fish (mg kg⁻¹), DI: mean daily intake rate of fish (0.063 kg day⁻¹). This was used to calculate mg kg⁻¹ per day by dividing the outcome by average adult human body weight (HBW, 70 kg):

\[
\text{EDI}_{\text{HBW}} = (\text{MC} \times \text{DI}) / \text{HBW}
\]

Maximum allowable daily intake limits (ADIL, kg fish day⁻¹) were estimated on the basis of total upper limits (TULs) and MCs in the edible part of fish using following equation [21]:

\[
\text{ADIL} = (\text{TUL}) / \text{MC}
\]

where, TUL: total upper limit (mg day⁻¹ person) of the dietary reference intake (DRI) according to US-IOM [22] guidelines.

Allowable intake rates (AIR, meals per week) is expressed as follows:

\[
\text{AIR} = \text{ADIL} \times T / \text{MS}
\]

where, T: time in days (7 d week⁻¹), MS: average meal size (0.227 kg fish⁻¹ meal) for fish [19].

Assessing non-carcinogenic effects, target hazard quotients (THQ), another expression of individual risk ratio (IRR), were calculated to evaluate the risks based on the ratio between the exposure to individual
metals and the TUL that is the maximum reference dose for dietary intake. In the present study, extreme exposure conditions were applied, hence the TULs were used in the calculations as the benchmark for dietary risks. THQs were estimated using following formulae [23]:

\[
\text{THQ} = \frac{\text{EDI}}{\text{TUL}}
\]

(5)

The total hazard index (THI) represents the risk of multiple metals via fish consumption and was expressed using the equation reported earlier [16,23]:

\[
\text{THI} = \sum \text{THQ}_{\text{im}}
\]

(6)

where, \(\text{THQ}_{\text{im}}\) = target hazard quotient of an individual metal measured, and \(n\) = the number in the present study is 4.

The THI assesses the risk due to excess of one or more metals. Since the four metals are all essential dietary trace elements, the contributions of each of the metals to meeting dietary requirements can be assessed as follows. The ingestion rates needed for the compensation of minimum daily requirements (CMDR) for each of the investigated metals via fish consumption were calculated based on EDIs and RDAs:

\[
\text{CMDR} = \left( \frac{\text{EDI}}{\text{RDA}} \right) \times 100
\]

(7)

2.4. Statistical analyses

Each of the measured variables were expressed as mean ± SD. Statistical significance \((p < 0.05)\) of trace metal levels were evaluated by one-way ANOVA followed by Duncan’s multi-comparison test [24] with the SPSS 17.0 software package. Prior to analyses, Kolmogorov-Smirnov normality test and Levene’s test were used to confirm normality and homogeneity of variance of the data, respectively.

3. Results

The protein and lipid levels in the muscle tissue of axillary seabream either harvested from the copper alloy mesh pen or captured from wild populations aggregated around the cage system were slightly higher but not significantly different \((p > 0.05)\) in the LF group than the SF group. The ash contents followed the same trend, with higher levels of ash in muscle tissue of LF compared to those of the SF groups of both cage-farmed or cage-aggregated fish. Fish body indices of fish harvested from copper alloy mesh pens or captured wild fish representatives around the cage were similar in both fish size groups and did not present any significant differences \((p > 0.05)\). The only remarkable finding in terms of body indices was the detectable GSI in the cage farmed fish with a harvest weight of 251.2 g, whereas no GSIs were detectable in the other fish groups (Table 1).

The concentrations of Zn, Fe, and Mn in fish muscle tissues were significantly lower \((p < 0.05)\) than those accumulated in the liver, gills and skin for all investigated fish groups. The Cu contents in the gills of all fish groups were slightly lower but not significantly different \((p > 0.05)\) than the Cu levels in the muscle tissues. In fish harvested from copper alloy mesh pen, all trace metals investigated (Cu, Zn, Fe, Mn) in the liver, gills, skin and muscle tissues were similar in both SF and LF groups, with slightly elevated levels without significance \((p > 0.05)\) in the LF group. In cage-aggregated wild fish populations however, the LF group showed similar trace metals \((p > 0.05)\) with the copper cage farmed fish of both size groups, whereas the SF of cage-aggregated wild populations, presented significantly lower \((p < 0.05)\) metal contents in all the tissues compared to those of the other fish groups, with some small exceptions in Zn and Mn levels (Table 2).

The DRIs of trace metals and EDIs for humans consuming fish harvested from copper mesh or wild fish aggregated around the cage system are given in Table 3. The ADILs and AIRs, the THQs and THIs of total trace metals via consumption of copper cage farmed fish or cage-aggregated wild individuals are given in Table 4.

<table>
<thead>
<tr>
<th>Fish weight (g)</th>
<th>Moisture</th>
<th>Lipid</th>
<th>Protein</th>
<th>Ash</th>
<th>VSI</th>
<th>HIS</th>
<th>MFI</th>
<th>SSI</th>
<th>GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small fish</td>
<td>196.4 ± 17.4</td>
<td>251.2 ± 15.3</td>
<td>82.0 ± 6.0</td>
<td>102.20 ± 18.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large fish</td>
<td>70.16 ± 2.41</td>
<td>71.13 ± 2.89</td>
<td>71.11 ± 2.75</td>
<td>71.56 ± 1.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small fish</td>
<td>20.31 ± 1.96</td>
<td>21.45 ± 2.47</td>
<td>21.19 ± 2.91</td>
<td>21.62 ± 2.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large fish</td>
<td>70.12 ± 3.16</td>
<td>70.40 ± 2.88</td>
<td>62.84 ± 4.52</td>
<td>70.36 ± 2.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSI</td>
<td>10.99 ± 1.22</td>
<td>11.01 ± 1.30</td>
<td>11.13 ± 1.04</td>
<td>10.92 ± 1.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIS</td>
<td>1.79 ± 0.28</td>
<td>1.82 ± 0.41</td>
<td>1.56 ± 0.31</td>
<td>1.81 ± 0.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFI</td>
<td>1.65 ± 0.99</td>
<td>1.98 ± 1.05</td>
<td>2.99 ± 1.61</td>
<td>1.55 ± 0.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSI</td>
<td>0.03 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.00</td>
<td>0.02 ± 0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSI</td>
<td>N/d</td>
<td>0.13 ± 0.02</td>
<td>N/d</td>
<td>N/d</td>
<td>N/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VSI = Viscerosomatic index, HIS = Hepatosomatic index, MFI = Mesenteric fat index, SSI = Spleen somatic index, GSI = Gonado somatic index, N/d = not detectable.

4. Discussion

Trace metals such as Cu, Zn, Mn, Fe, Na, K, Ca, and Se are natural trace elements, essential for life, and required for the growth of microorganisms, plants, animals and humans, and necessary for the regulation of biochemical and enzymatic reactions of all life forms [25]. However, excessive levels may cause bioaccumulation and significant detrimental and toxic effects on the marine environment [26]. In both size groups, the concentrations of Cu, Zn, Fe and Mn in muscle tissues, considered as the edible part of fish, harvested from and captured around the copper alloy cage \((0.25-0.62 \text{ mg kg}^{-1}, 2.64-3.58 \text{ mg kg}^{-1}, 1.95-5.79 \text{ mg kg}^{-1},\) and \(0.09-0.28 \text{ mg kg}^{-1},\) respectively) were 3 to 80-fold lower than the permissible upper limits \((\text{Cu}: 20-30, \text{Zn}: 30-100, \text{Fe} < 100, \text{Mn} < 1)\) of international standards [27]. Only in the gills and skin tissues of copper alloy-harvested fish of both size groups (SF and LF) and the LF aggregated around the pens were high in Mn content, slightly below-or exceeding permissible upper limits.

Regarding metal content in tissues of axillary seabream, there is only one published report [13] to our knowledge so far. Therefore, tissue concentrations of similar marine finfish species from copper alloy cage farming activities are discussed here. In the present study, the trace metal levels found in the edible part of copper cage harvested or cage aggregated wild fish were in close agreement with earlier reports in cage farmed gilthead seabream in the Mediterranean Sea, Greece [12,28], and axillary seabream from a copper alloy mesh pen in the Northern Aegean Sea, Turkey [13], in salmon grown in antifouling coated or non-treated nylon nettings in Norway [6], cage farmed salmon from Port Bheachan, UK [29] and Rio de Janeiro, Brazil [30], and in Atlantic cod cultured in a copper alloy mesh cage in New Hampshire, USA [7]. However, higher levels of trace metals compared to our findings and earlier reports were found in wild and farmed seabream and seabass in the Adriatic Sea [31]. Our results, consistent with earlier reports, show that copper alloy nets presented no adverse effects on metal levels of the edible part of fish, nor has the copper cage farm influenced cage-aggregated wild populations. These results suggest that the apparent slow leaching of metals from the copper alloy mesh into the surrounding marine environment and adequately fast water circulation ensure that ambient metals concentrations do not overload the natural metals homeostatic mechanisms and detoxification processes of the fish as was also suggested by [6,32].

In the present study, the TULs for Cu, Zn, Fe, and Mn were used to evaluate highest exposure limits for human risks, since TULs are the highest average daily intake level likely to have no risk of adverse effects on health [33]. The EDIs found for Cu, Zn, Fe, and Mn in fish
Table 2
Trace metals in body tissues of copper cage-farmed and cage-aggregated wild axillary seabream. Values (mg kg$^{-1}$, means ± SD, dry weight, n= 6) with different superscript letters in the same line are significantly different at 5% levels. Values in parenthesis represent wet basis data.

<table>
<thead>
<tr>
<th>Metal</th>
<th>TUL (mg day$^{-1}$)</th>
<th>SF</th>
<th>LF</th>
<th>SF</th>
<th>LF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>344.5, 239.5, 1217.1 meal week$^{-1}$ person</td>
<td>0.37</td>
<td>0.38</td>
<td>0.39</td>
<td>0.40</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.59 ± 0.21</td>
<td>0.60</td>
<td>0.61</td>
<td>0.62</td>
<td>0.63</td>
</tr>
<tr>
<td>Iron</td>
<td>11.49 ± 2.24</td>
<td>11.50</td>
<td>11.51</td>
<td>11.52</td>
<td>11.53</td>
</tr>
<tr>
<td>Manganese</td>
<td>5.70 ± 1.17</td>
<td>5.71</td>
<td>5.72</td>
<td>5.73</td>
<td>5.74</td>
</tr>
</tbody>
</table>

Table 3
Dietary reference intakes (DRI) of trace metals and estimated daily intake (EDI), and the compensation of minimum daily requirements (CMDR) upon consumption of axillary seabream harvested from -or around the copper cage farm system.

<table>
<thead>
<tr>
<th>Metal</th>
<th>EAR (mg day$^{-1}$ person)</th>
<th>RDA (mg day$^{-1}$ person)</th>
<th>TUL (mg day$^{-1}$ person)</th>
<th>CMDR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
<td>4.157</td>
</tr>
<tr>
<td>Zn</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
<td>1.964</td>
</tr>
<tr>
<td>Fe</td>
<td>4.0</td>
<td>6.0</td>
<td>8.0</td>
<td>2.369</td>
</tr>
<tr>
<td>Mn</td>
<td>1.2</td>
<td>1.8</td>
<td>2.4</td>
<td>0.351</td>
</tr>
</tbody>
</table>


Table 4
In regards to the TUL and trace element levels in fish meat, highest rates of ADILs or AIRs were recorded for the SF groups of the wild populations aggregated around the copper alloy cage, which was followed by the SF and LF harvested from copper cage and LF aggregated around the copper pen, respectively. Even though, the ADILs or AIRs for fish harvested from the cage or the cage aggregated wild were reasonably high, with no consumers’ health risks up to 16.04, 11.17, 7.77, and 39.45 kg fish consumed day$^{-1}$ per person, or 494.5, 344.5, 239.5, and 1217.1 meal week$^{-1}$ person for Cu, Zn, Fe and Mn by eating the most affected fish in -or around the copper cage farm.
around a copper alloy cage system, with no adverse effects on human health.

Our findings in the present study regarding THQs, and total THIs for metals were far beyond the threshold for unacceptable risk of “1” (THQ < 1; THI < 1) and all trace metals investigated in the present study resulted in safe limits with no health risks through consumption of copper cage farmed fish or cage aggregated wild fish populations, under the conditions tested in this study. Our results for the estimated potential health risks from fish consumption are in close agreement with an earlier report [16] on the assessment of potential human risks via consuming Mediterranean mussels collected from a copper alloy cage site, where the authors commented THQs and THIs as THQ < 1, and THI < 1, respectively, for an adult human, underlining the food safety of marine resources around a copper alloy cage system.

Considering the compensation of the requirements for the investigated essential trace elements via fish consumption, an adult human might only meet about 1.74 to 4.37% of the minimum daily requirement level for Cu, 1.51 to 2.05% for Zn, 1.54 to 4.56% for Fe, and 0.24 to 0.76% for Mn by consuming cage farmed or -aggregated wild axillary seabream in the copper-alloy cage system. Furthermore, in the present study, the EDIs were compared with TULs in order to assess any potential risks for human when consuming fish at excessive levels. Our findings show that an adult human might consume only 0.16 to 0.39%, 0.42 to 0.56%, 0.27 to 0.81%, and 0.05 to 0.16% of the health risk threshold limits for the investigated trace elements of Cu, Zn, Fe, and Mn, respectively, when consuming fish at excessive levels. Similar to our finding in the present study, Yigit et al. [16] reported that an individual would compensate only 0.013% to 0.94% of the minimum daily requirement level for Cu, Zn, Fe, or Mn via consumption of Mediterranean mussels (M. galloprovincialis) grown near a cage farm with copper alloy mesh pen. Our results in terms of excessive exposure of human to trace metals at TUL levels were also in close agreement with the findings of Yigit et al. [16], who estimated that an individual could consume only 0.006% to 0.259% of the upper limit of health risks from trace metals via consumption of extremely high amounts of mussels from a copper alloy cage site.

Conflicts of interest

The authors declare no conflicts of interest.

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Table 4

<table>
<thead>
<tr>
<th>Metal</th>
<th>CAM - farmed SF</th>
<th>CAM - farmed LF</th>
<th>CA - wild SF</th>
<th>CA - wild LF</th>
<th>CAM - farmed SF</th>
<th>CAM - farmed LF</th>
<th>CA - wild SF</th>
<th>CA - wild LF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>16.84</td>
<td>16.04</td>
<td>40.25</td>
<td>17.15</td>
<td>519.3</td>
<td>494.5</td>
<td>1241.2</td>
<td>528.9</td>
</tr>
<tr>
<td>Zn</td>
<td>11.67</td>
<td>12.05</td>
<td>15.15</td>
<td>11.17</td>
<td>359.8</td>
<td>371.5</td>
<td>467.1</td>
<td>344.5</td>
</tr>
<tr>
<td>Fe</td>
<td>14.96</td>
<td>11.79</td>
<td>23.04</td>
<td>7.77</td>
<td>461.3</td>
<td>363.6</td>
<td>710.5</td>
<td>239.5</td>
</tr>
<tr>
<td>Mn</td>
<td>85.73</td>
<td>64.58</td>
<td>126.9</td>
<td>39.45</td>
<td>2643.6</td>
<td>1991.4</td>
<td>3913.8</td>
<td>1217.1</td>
</tr>
<tr>
<td>Target Hazard Index (THI)</td>
<td>0.0141</td>
<td>0.0155</td>
<td>0.0090</td>
<td>0.0190</td>
<td>0.0007</td>
<td>0.0010</td>
<td>0.0005</td>
<td>0.0016</td>
</tr>
</tbody>
</table>

CAM-farmed: copper-alloy mesh farmed fish; CA-wild: cage-aggregated wild fish; SF: small fish size group; LF: large fish size group.

5. Conclusion

In conclusion, trace metals in the edible part of Axillary Seabream harvested from the copper cage or the fish caught from wild populations near the copper cage were below permissible upper limit for metals without any risks to human when consuming these fish. Hence, these findings may indicate that fish cultured in copper alloy mesh or their wild representatives aggregating around these pens would not cause any likely risks for human via consumption. Further, regular consumption of these fish would contribute to meeting the minimum daily requirement levels for these trace metals.

The authors declare no conflicts of interest.


