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HEAVY METALS AND RADIONUCLIDES IN MUSCLES OF FISH SPECIES IN THE SOUTH ADRIATIC – MONTENEGRO

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Abstract. *This paper deals with the concentration of Pb, Cd, Cu, Fe, Mn, Ni, Cr and Zn, and activity concentrations of ^{137}Cs, ^{40}K, as well as levels of ^{226}Ra and ^{232}Th through their daughters ^{214}Bi and ^{228}Ac, in muscles of six fish species from the South Adriatic Sea adjacent to Montenegro. Specimens of three mullet species from the Liza genus – Liza aurata (golden grey mullet), Liza saliens (leaping mullet) and Liza ramada (thinlip grey mullet), were caught by a trawl net in the area of Tivat – Boka Kotorska Bay, as well as Merluccius merluccius (European hake), Dicentrarchus labrax (European seabass), Sparus aurata (gilt-head sea bream). Element concentrations were determined in a standard procedure using iCAP 6000 ICP-OES and atomic absorption spectrophotometer AA-6800, whilst radionuclide activity concentrations – in a standard HPGe ORTEC gamma spectrometry. The results showed a level of ^{137}Cs somewhat lower than in the muscles of previously analyzed the other (mullet) species from the South Adriatic, in contrast to ^{214}Bi level which is mostly found to be slightly higher than its parent (^{226}Ra) level in the other previously analyzed species. Committed effective dose from the annual intake of radionuclides due to an adult fish consumption is found to be highest for M. merluccius (13.8 μSv), showing all the radionuclides above minimum detectable activity. In muscle of L. aurata element concentrations were found to be ordered as: Fe>Zn>Cr>Mn>Ni>Cu>Pb>Cd. This species showed a concentration of each element higher than the other species (particularly Pb, Fe, Mn, Ni, and Cr). The concentration of Zn only could be considered as more or less comparable in all the muscles. No one muscle showed a concentration of toxic trace elements Pb and Cd exceeding the limits from the EU regulations. A potential health risk associated with Pb and Cd intake due to consumption of analyzed fish species is estimated using the target hazard quotient found to be ≤0.055.*

Keywords: *Fish, radionuclides, essential elements, toxic metals, health risks, South Adriatic*

1. INTRODUCTION

It is well known that nowadays the contamination of the aquatic environment with heavy metals increases due to various artificial sources. An aquatic environment can also be contaminated by radioactivity originating from natural radioisotopes, the fallout from the atmosphere, and from radioactive effluents from various facilities (medical, industrial, nuclear).

The considerable ability for fish to accumulate heavy metals and radioisotopes even when their concentrations in water are small, pathways to fish tissues – important for understanding dynamics of the isotope in the aquatic environment, and known bioaccumulation, could be used in an aquatic environment monitoring. At the same time, metal bioaccumulation and distribution in fish organs were found to be highly inter-specific (e.g. [1, 2]).

Some of the heavy metals naturally occurring in the environment play an essential role in the metabolism and growth, and are not harmful to the organism except for high concentrations when they could produce toxic effects. On the other hand, some of them are toxic even in trace amounts, and the determination of metal concentrations in fish and its different organs is of considerable interest.

The essential trace elements, such as Zn and Cu, are significant since "deficiency in human organism leads to several disorders, but an excessive Zn intake can cause acute adverse effects" and Cu "deficiency in adults can result in blood and nervous system disorders" as said in [1]. Furthermore, Mn is significant "for normal immune function, for regulation of blood sugar and cellular energy, reproduction, digestion, bone growth…" but also "may have toxic effects for human beings" [1].

International recommendations, standards and regulations from Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO), European Union (EU) etc., usually deal with toxic trace elements (such as Pb, Cd – that can generally be toxic to animals, plants, and humans).

So, FAO and WHO 1972 [3] in the evaluation of some food contaminants and additives, gave provisional tolerable weekly intake (for adults) of 3 and 0.4-0.5 mg per person, for Pb and Cd, respectively, i.e. 0.05 and 0.0067-0.0083 mg/kg of body weight, respectively. In the compilation of legal limits for

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hazardous substances in fish and fishery products, FAO 1983 [4], permissible limits in many countries for Zn and Cu are given together with the limits for toxic trace elements (Pb, Cd). Given limits for Cu in different countries were 10 (mostly), 20, 30 and 100 mg/kg; for Zn – 40, 50, 100 and 150 mg/kg. Permissible limits for Pb in different countries ranged from 0.05 to 10 mg/kg, for Cd – from 0.05 to 5.5 mg/kg. One limit for Cr was also given (1 mg/kg (Hong Kong) [4]). In addition, the WHO 1989 technical report 776 [5] gave provisional tolerable weekly intake of Cd in an amount 0.007 mg/kg of body weight.

The European Commission regulation 78 [6], for example for grey mullet, set the maximum level of Cd "in the muscle meat of fish" of 0.1 mg/kg (wet weight), and Pb – 0.4 mg/kg. The national Montenegro regulations previously contained the same limits for Cd and Pb in fresh fish [7]. However, new regulations set 0.3 mg/kg as the maximum level of Pb in fish muscles (wet weight), and 0.05 mg/kg of Cd, except for some fish species including grey mullet (0.1 mg/kg), but also *Auxis species* (0.2 mg/kg), *Engraulis species* and *Xiphias gladius* (0.3 mg/kg) [8].

Heavy metal concentrations and radioactivity in Montenegro beach sands were previously analyzed [9], and this study deals with the concentration of Pb, Cd, Cu, Fe, Mn, Ni, Cr, and Zn, together with activity concentrations of ^{137}Cs and ^{40}K in eatable portions (muscles) of six commercially important fish species. It also deals with the levels of ^{226}Ra and ^{232}Th (through their daughters ^{214}Bi and ^{228}Ac, respectively) in the same samples.

Considered fish species are European hake (*Merluccius merluccius* Linnaeus, 1758), European seabass (*Dicentrarchus labrax* Linnaeus, 1758), gilt-head sea bream (*Sparus aurata* Linnaeus, 1758), and three mullet (*Liza*) species – golden grey mullet (*Liza aurata* Risso, 1810), leaping mullet (*Liza saliens* Risso, 1810) and thinlip grey mullet (*Liza ramada* Risso, 1826). It should be noted that the names of these *Liza* species are still under taxonomic discussion. For example, the World Register of Marine Species presently gives 'accepted names' *Chelon auratus*, *Chelon saliens* and *Chelon ramada*, respectively. They were collected from the South Adriatic Sea and measured in the Centre for Ecotoxicological Research in Podgorica, mostly in the frame of the research project supported by the Ministry of Science of Montenegro (01-571). One muscle of each species is selected for the analysis in the present study.

Among all (6) the Euro-Mediterranean mullet species occurring in the South Adriatic Sea (*L. aurata*, *L. ramada* and *L. saliens*, *Mugil cephalus* Linnaeus, 1758, *Chelon labrosus* Risso, 1826, *Oedalechilus labeo* Cuvier, 1829), three are from the *Liza* genus. As Thomson found [10], general distributions of these *Liza* species are: *L. aurata* – Black Sea, Mediterranean, Eastern Atlantic from Scotland to Cape Verde Islands (introduced into the Caspian Sea, as well), *L. ramada* – Black Sea, Mediterranean, eastern Atlantic northern from Cape Verde Islands to North Sea and Baltic, *L. saliens* – Black Sea, Mediterranean, and introduced into the Caspian Sea.

Furthermore, *M. merluccius* is distributed along the Atlantic Coast (Europe and western North Africa), the Mediterranean and the Black Sea, as well as *D. labrax* (the North Atlantic, the Mediterranean and the Black Sea...), while *S. aurata* (Mediterranean, Atlantic – to Cape Verde and around the Canaries) is rare in the Black Sea [11].

Some of the abovementioned mullets were previously investigated radioecologically (e.g. [12, 13]). A study on activity concentration of the cosmogenic radionuclide ^{7}Be in fish species from the South Adriatic Sea has also been performed recently [14].

2. Materials and Methods

In order to complete the ecological and environmental picture, the present study has been conducted to analyze the muscles of the mentioned fish species and seawater for metal and radioactive isotopes. It is aimed to provide baselines for both further research and future comparison, and evaluation of potential risk for the fish themselves and their human consumers. The specimens were caught by a trawl net in the area of Tivat – Boka Kotorska Bay, Coast of Montenegro, in 2013-14 (mullets, including seawater from the same area), and in 2018 (the other species).

Total lengths and wet weights of whole individuals whose muscles are analyzed in this study were: European hake – 25.5 cm and 108 g, gilt-head sea bream – 24.2 and 200 g, European seabass – 32.2 cm and 338 g – adult and 24.7 and 158 g – juvenile, golden grey mullet – 29.3 cm and 224 g, leaping mullet – 32.4 cm and 247 g, and thinlip grey mullet – 37.4 cm and 338 g.

Sample preparation and measurements were performed in an accredited laboratory of the Centre for Ecotoxicological Research in Podgorica. Standard preparation and measuring procedures were applied for the determination of the element concentrations, i.e., the AOAC Official Methods of Analysis (972.23, 986.15 and 999.11) and instruments – iCAP 6000 ICP-OES (Thermo Scientific, UK) and Atomic Absorption Spectrophotometer AA-6800 (Shimadzu, Japan). Validation of the method was carried out in accordance with the MEST ISO 17025 Standard, with the reference material Tuna Fish Flash Homogenate IAEA-436. All the elements were measured using the iCAP 6000, while the additional measurements of Cu, Fe, Mn, Cr, Zn, Ni were performed using AA-6800 (flame), and Pb, Cd – using AA-6800 (graphite).

A potential health risk associated with toxic trace elements intake due to consumption of analyzed fish species is estimated using the target hazard quotients (THQ) [15]

$$THQ = [(EF \cdot T_a \cdot FIR \cdot C_m)/(ROD \cdot ABW \cdot ET)] \cdot 10^{-3}, \qquad (1)$$

where:

EF is exposure frequency of 365 days per year,

T_a is an average lifetime taken to be 70 years,

FIR is the fish meat ingestion rate in an individual amount of 36 g per day (around 13 kg per year),

C_m is the metal concentration (in mg/kg wet weight),

ROD is the reference oral dose of $1 \cdot 10^{-3}$ for Cd and $4 \cdot 10^{-3}$ for Pb (in mg per kg and day),

ABW is the average adult consumer body weight taken as 67 kg, ET is the exposure time (EF·T_a).

Since the samples were also analyzed for radioactivity, seawater (20L) was evaporated (to 1L) and sealed in 1L Marinelli beaker, and fish samples were also prepared in the standard procedure, i.e., homogenized (freshly ground and mixed). The measurements were performed using the 50 mL cylindrical beakers at the coaxial HPGe spectrometers ORTEC GEM-40190 and ORTEC GEM-30185-S, which had been calibrated using the Czech Metrology Institute standards. Live measuring time ranged from 80 550 to 91 280 s.

Spectral analysis was based on peaks at the energies of 662 keV (^{137}Cs), 1461 keV (^{40}K), 609 keV (^{214}Bi) and 911 keV (^{228}Ac).

In order to estimate annual intake of radionuclides by an adult due to fish consumption, committed effective dose is calculated using

$$E=A_c(^{137}Cs)\cdot DC(^{137}Cs)+A_c(^{40}K)\cdot DC(^{40}K)+A_c(^{214}Bi)\cdot DC(^{214}Bi)+A_c(^{228}Ac)\cdot DC(^{228}Ac), \quad (2)$$

where A_c is radionuclide activity concentration in eatable portion of fish (in Bq/kg), and DC is corresponding dose coefficient given by the International Commission on Radiological Protection (ICRP) in the publication 119 [16]: $1.3\cdot10^{-8}$, $6.2\cdot10^{-9}$, $1.1\cdot10^{-10}$ and $4.3\cdot10^{-10}$ Sv/Bq for ^{137}Cs, ^{40}K, ^{214}Bi and ^{228}Ac, respectively. The annual dose is calculated assuming an intake of 13 kg of fish meat – as typical for Europe.

3. Results

The results of the fish muscle measurements are given in Table 1 (radionuclide activity concentrations) and Table 2 (element concentrations).

The samples of fish muscles for radioactivity measurements (Table 1) had a wet weight of 23, 38.3, 41.55, 48.1, 33.2 and 24.3 g, respectively. Sign "<" means below minimum detectable activity (MDA) calculated using the 3MDA method, while "≤" – on a level of MDA, taking into account measuring errors.

In regards to results in Table 2, measuring uncertainty for seawater sample was 10% (Cu, Fe, Mn and Zn), for the mullet muscles 5.18% (Pb) to 9.85% (Fe), and for the other fish muscles from 5% (Fe) to 9.2% (Cu).

The THQ (Fig. 1) due to human intake of Pb, Cd and both of them (total, THQ-Pb+THQ-Cd) by consuming considered fish species, is calculated using Eq. (1).

Table 1. Radionuclide activity concentrations (Bq/kg) in fish muscles and seawater

	^{214}Bi	^{137}Cs	^{228}Ac	^{40}K
European hake	≤4.13	1.92±0.78	≤7.05	167±11
European seabass – juv.	2.73±0.41	≤1.08	≤4.19	115±7
Gilt-head sea bream	≤2.07	≤0.95	≤4.10	145±7
Golden grey mullet	2.1±0.2	<1	<4	124±7
Leaping mullet	<2.6	<1.5	<5.9	97.6±7.2
Thinlip grey mullet	<3.6	<2	≤7.3	95.4±8.2
Seawater (in Bq/L)	0.017±0.002	≤0.004	≤0.02	8.25±0.28

Committed (annual) effective dose, representing annual intake of radionuclides due to an adult fish consumption (Eq.(2)), is shown in Fig. 2.

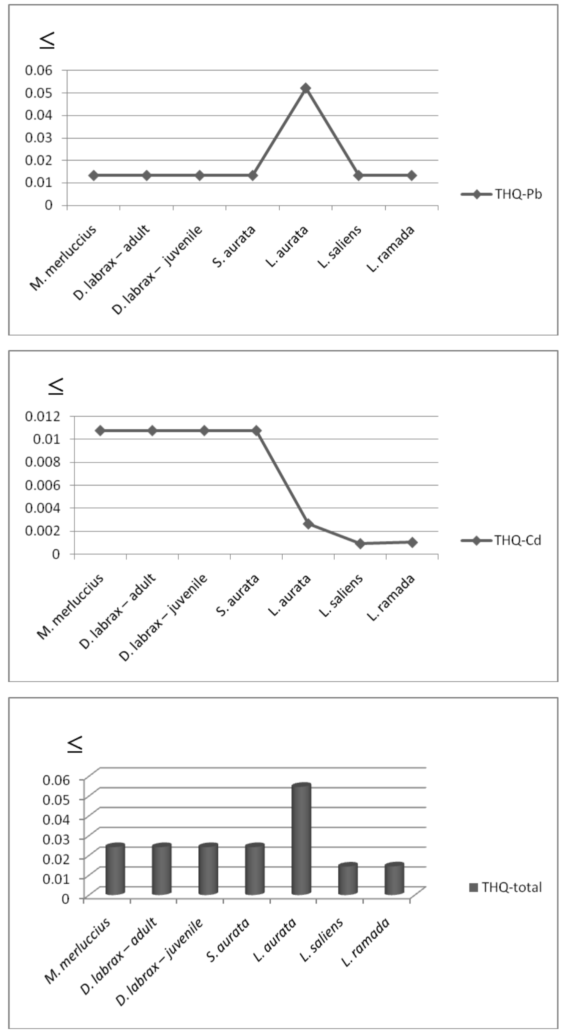

Figure 1. Target hazard quotients

Table 2. Element concentrations (in mg/kg) in fish muscles

	Pb	Cd	Cu	Fe	Mn
European hake	<0.1	<0.02	0.16	1.7	0.09
European seabass – adult	<0.1	<0.02	0.43	3.4	0.12
European seabass – juvenile	<0.1	<0.02	0.22	1.8	0.16
Gilt-head sea bream	<0.1	<0.02	0.17	1.4	0.15
Golden grey mullet	0.387	0.0049	0.82	269	4.09
Leaping mullet	<0.1	0.0017	0.45	18.53	0.22
Thinlip grey mullet	<0.1	0.0019	0.22	11.63	0.143
Seawater (mg/L)	≤0.005*	≤0.0005 *	0.002	0.03	0.007

* Level of Detection

Table 2. *Cont.*

	Ni	Cr	Zn
European hake	<0.05	0.10	3.3
European seabass – adult	<0.05	0.02	3.9
European seabass – juvenile	<0.05	0.08	4.4
Gilt-head sea bream	<0.05	0.07	4.0
Golden grey mullet	1.14	5.07	5.33
Leaping mullet	0.053	0.22	5.08
Thinlip grey mullet	0.028	0.196	4.62
Seawater (mg/L)	≤0.001*	≤0.001*	0.003

* Level of Detection

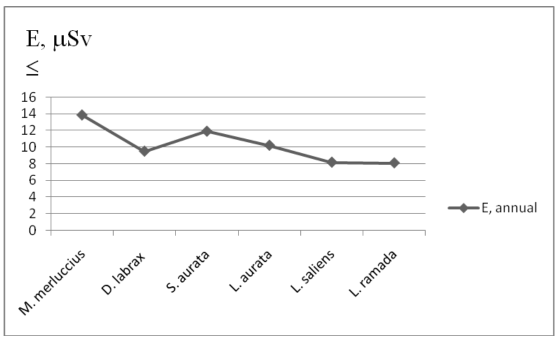

Figure 2. Effective dose due to ingestion of radionuclides in fish species

4. Discussion

4.1. Element concentrations

In literature there are publications that report metal concentrations in various fish species and their organs [17-27]. The data reported in the literature in comparison with data of the present study are given in Tables 3 and 4.

In regards to the *Liza*, *L. aurata* from the southern Atlantic coast of Spain [17], and the Caspian Sea [18], *L. ramada* from Lake Manzala, Egypt [19], *L. saliens* from the Esmoriz–Paramos coastal lagoon, Portugal [20] were investigated, as well as the other *Liza* species, but there were no data available about the *Liza* species from the South Adriatic, Coast of Montenegro.

Looking at the results reported in Table 2, in *L. aurata* muscle concentrations were ordered as: Fe>Zn>Cr>Mn>Ni>Cu>Pb>Cd, and it showed concentration of each element higher than the other two *Liza* (in particular, Pb, Fe, Mn, Ni, and Cr). The concentration of only Zn could be considered as comparable in all the *Liza* muscles.

Moreover, transfer factor, i.e., the ratio of the Pb, Cd, Cu, Fe, Mn, Ni, Cr, Zn concentrations in the *Liza* muscles and seawater, was found to be around 77, ≥9.8, 410, 8967, 584, ≥1140, ≥5070, 1777, respectively (*L. aurata*); 20, ≥3.8, 110, 388, 20, ≥28, ≥196, 1540, respectively (*L. ramada*); 20, ≥3.4, 225, 618, 31, ≥53, ≥220, 1693, respectively (*L. saliens*).

Table 3. Element concentrations (in mg/kg) reported for muscles of the same fish species

Species	Pb	Cd	Cu	Fe	Ref.
L. aurata	(0.03-0.05) 1.5 0.387	(0.013-0.03) 0.35 0.0049	(0.2-0.6) 4.54 0.82	(4.11-7.13) 67.52 269	[17] [18]* **
L. ramada	(1.43-2.43) <0.1	(0.51-1.11) 0.0019	(3.03-4.66) 0.22	- 11.63	[19]* **
L. saliens	- <0.1	- 0.0017	<2.64 0.45	- 18.53	[20]* **
D. labrax	1.58 <0.1	0.03 <0.02	0.33 0.43	11.13 3.4	[21]* **
S. aurata	1.11 <0.1	0.12 <0.02	0.55 0.17	11.12 1.4	[21]* **
M. merlucc.	- 0.001 <0.1	- - <0.02	0.258 0.077 0.16	2.584 0.307 1.7	[22] [23] **
Species	Mn	Ni	Cr	Zn	Ref.
L. aurata	(2.25-2.5) - 4.09	(0.021-0.07) 0.73 1.14	(0.029-0.038) 0.74 5.07	(3.1-8.41) 13.69 5.33	[17] [18]* **
L. ramada	- 0.143	- 0.028	- 0.196	(12.6-36.9) 4.62	[19]* **
L. saliens	- 0.22	- 0.053	- 0.22	26 5.08	[20]* **
D. labrax	- 0.12	- <0.05	- 0.02	75.38 3.9	[21]* **
S. aurata	- 0.15	- <0.05	- 0.07	76.98 4.0	[21]* **
M. merlucc.	- - 0.09	- - <0.05	- - 0.10	3.692 1.27 3.3	[22] [23] **

*Results reported for dry weight fish muscles
** Present study

Table 4. Element concentrations (in mg/kg) reported for muscles of some other fish species

Species	Pb	Cd	Cu	Fe	Ref.
Liza abu	-	-	1.36	6.88	[24]
M. cephalus	1.19 0.2	0.08 0.007	0.62 1.2	11.12 4.0	[21]* [1]
Silurus triostegus	-	-	4.27	6.38	[24]
Lepomis gibbosus	0.631	0.008	0.49	125	[25]
Arius thalassinus	- -	0.027 0.058	1.56 1.21	- -	[26]*
Johnius belangeri	- -	0.04 0.055	0.95 0.66	- -	[26]*
Species	Mn	Ni	Cr	Zn	Ref.
Liza abu	0.40	-	-	7.74	[24]
M. cephalus	- 1.0	- -	- -	60.86 3.9	[21]* [1]
Silurus triostegus	0.35	0.56	-	10.94	[24]
Lepomis gibbosus	1.07	-	-	6.54	[25]
Arius thalassinus	0.92 0.62	- -	- -	30.21 20.54	[26]*
Johnius belangeri	0.97 0.54	- -	- -	13.12 18.27	[26]*

*Results reported for dry weight fish muscles

In *M. merluccius* muscle concentrations were ordered as: Zn>Fe>Cu>Cr>Mn>Pb>Ni>Cd, in *D. labrax* adult: Zn>Fe>Cu>Mn>Pb>Ni>Cr>Cd, in *D. labrax* juvenile: Zn>Fe> Cu>Mn>Pb>Cr>Ni>Cd, while in *S. aurata*: Zn>Fe>Cu>Mn>Pb>Cr>Ni>Cd.

A literature survey generally showed that among the mullet species, regarding the number of studies and number of the considered elements, *M. cephalus* and *L. aurata* were investigated more than the other mullets. Looking at Table 3, Fe, Mn, Ni and Cr concentrations in the *L. aurata* muscles are higher than in the other species. The same species studied in [17] showed Mn concentration at least two times higher than the other species, while its Ni concentration was ten times lower than that reported in [18]. This confirms the previous findings, i.e., different species showed inter-specific variation in metal concentrations, and fish from the same species also showed significant variations. Additionally, the other researchers have already shown that seasonal variations of metal concentrations are significant, and liver or gills of various fish species accumulate metals in a higher amount than their muscles. Therefore, future research on the *Liza* from the South Adriatic should include particular element distribution (concentration) in different organs, as well as an evaluation of potential risk for the fish itself.

In particular, heavy metal concentrations revealed in the *L. aurata* muscle need further research. As mentioned above, a few heavy metals can be toxic even in trace amounts, while essential elements are not harmful to the organism except in high concentrations, which means that low intakes can result in nutritional deficiencies, while high intakes can result in toxicity.

Based on the here presented initial results and a survey of relevant literature, the comments and conclusions are as follows.

In regard to essential elements, Fe found in *L. aurata* muscle as eatable portion is generally higher than in the other species (comparable with that found in the liver of some species [2, 21]). In a literature survey given in [22], the other mullet species, *M. cephalus*, showed Fe concentrations of up to 129 mg/kg.

Related to the other essential trace elements, such as Zn and Cu, in *M. merluccius* muscle from the central Adriatic, Italy, as reported in [27], their concentrations (around 22.9 and 5.7 mg/kg, respectively) were found to be several times higher than those measured in *M. merluccius* from the South Adriatic, Montenegro (3.3 and 0.16 mg/kg). In *M. merluccius* from the Northeastern Mediterranean Sea [22] Zn, Cu, and Fe concentrations are found to be similar to those in *M. merluccius* from the South Adriatic. In the case of *L. aurata* from the South Adriatic Zn and Cu concentrations are found to be comparable with those in the same species from Spain (as given in [17]).

On the other hand, Mn concentration of 4.09 mg/kg in *L. aurata* is significantly higher than in the other fish species (Tables 3 and 4). The same can be said for *L. aurata* from the southern Atlantic coast of Spain (see [17], i.e. Table 3). As can be seen from Table 2, its concentration in the South Adriatic seawater was found to be 0.007 mg/L, while in one beach sand sample from the Coast of Montenegro, it had been 597 mg/kg, and Cr – 78.7 mg/kg [9]. Although Cr in seawater was at the level of detection, in *L. aurata* it is several times higher than that reported in [17, 18].

Considering previously mentioned international regulations [3-6], only Cr in *L. aurata* exceeded the permissible limit. Furthermore, looking at toxic trace elements, i.e. Pb and Cd concentrations, muscle of *L. aurata* showed Pb slightly above 0.3 mg/kg – a limit given in the Montenegro regulations [8].

Comparing THQs data for the analyzed fish species (Fig. 1) with the other ones, for example *Thunnus alalunga* (Bonnaterre, 1788) from the Aegean Sea, Greece [15], it can be concluded that THQ-Pb for *L. aurata* is significantly higher (around 0.052, in comparison to the maximum of 0.0075 for *T. alalunga*), while THQ-Cd is lower (a mean THQ-Cd for *T. alalunga* from two areas of the Aegean Sea is found to be 0.099 and 0.044 [15]).

4.2. Radionuclide activity concentrations

Activity concentrations of radioactive isotopes in fish muscles given in Table 1 show a level of ^{137}Cs somewhat lower than in the muscles of the other mullet species from the South Adriatic Sea, such as *C. labrosus* (2.8 Bq/kg in average, as reported in 2011 [13]), the species in which ^{226}Ra in muscles ranged from 0.88 to 1.95 Bq/kg, with an average of 1.5 Bq/kg [13]. The ^{214}Bi activity of the presently-analyzed muscles seems to be somewhat higher. At the same time, another mullet species from the South Adriatic Sea, *M. cephalus*, analyzed previously for a level of ^{232}Th [12], showed maximum activity concentrations in muscles of 1.57 Bq/kg [12].

Fish consumption by an adult brings intake of radionuclides at an annual level characterized by the committed effective dose shown in Fig. 2. The highest one (around 13.8 μSv) was found for the muscle of *M. merluccius* extensively consumed by the local and wider Montenegro population. It is important to note that activity concentrations of all the radionuclides, in this case, were equal or above the minimum detectable activity (see Table 1), as well as in the case of *D. labrax* juvenile showing a corresponding effective dose of around 9.5 μSv annually. A worldwide average committed effective doses (to adults) due to the ingestion of Ra-226 and Th-232 were estimated to be 6.3 and 0.38 μSv, respectively [28].

5. Conclusion

The muscles of six fish species from the South Adriatic Sea adjacent to Montenegro have been analyzed on metals (Pb, Cd, Cu, Fe, Mn, Ni, Cr, Zn), and radionuclides (^{137}Cs, ^{40}K, ^{214}Bi, ^{228}Ac). The main results can be summarized as:

- Fe concentration found in *L. aurata* is generally higher than in muscles of some other fish species,
- Mn concentration found in *L. aurata* is significantly higher than in muscles of some other fish species,
- Cr concentration found in *L. aurata* exceeds 1 mg/kg,

- Pb concentration found in *L. aurata* is slightly above a limit given in the Montenegro regulations,
- committed effective dose due to intake of radionuclides by fish consumption, was found to be the highest for the muscle of *M. merluccius*.

All the results presented here indicate that the marine environment of the South Adriatic should be further investigated – ecotoxicologically and radioecologically, applying an integrated approach.

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