The presence of heavy metals in fish meat from Danube River: an overview

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Abstract. The degree of intensification, related to various human activities, such as heavy industry, agriculture, livestock and aquaculture, due to the continuous upward tendency of world population, had generated high level of pollution in different ecosystems. Hence, water pollution has become one of the most interested topics among the research communities. Danube River is an international river, which crosses 10 countries and is an important source of economic growth for all the riverine countries, especially for its consistent and valuable fish stocks. Several studies have emphasized the problems related to high environment pollution, especially with heavy metals, in the Danube ecosystems. The current paper aims to present information regarding the heavy metals accumulation in fish from the Danube River. Therefore, various databases were revised and the relevant information was centralized, in order to obtain a clear view on the concentration dynamics and accumulation tendency of several heavy metals, as follows: Cd, Pb, Hg, Cu and Fe. As a conclusion to this research, we can state that the highest concentrations of heavy metals in fish meat was encountered in case of pontic shad (*Alosa immaculata*, Bennet, 1835), followed by catfish (*Silurus glanis*, Linnaeus, 1758). Also, among all studied metals, Fe had the highest concentrations in all fish species, followed by Cu.

Key Words: Danube River, heavy metals, fish meat, pollution, pontic shad, shad.

Introduction. Danube River is considered one of the most important European rivers, being the second largest river in Europe, therefore being subjected to large amounts of wastewater inputs (Ilie et al 2014; Milanov et al 2016; Subotic et al 2013. With a total distance of 2,860 km, the Danube River represents an important transport route, but is also significant for its commercial fishing, fact that makes it permanently subjected to both natural and anthropogenic pressures (Milanov et al 2016; Gasparotti 2014).

Environmental pollution does not suddenly occur, it develops gradually and can be assessed by the use of various bioindicators. The pollution along the Danube is caused mainly by factors such as: point sources (municipal, industrial and agricultural), diffuse sources (agricultural, agglomerations), effects of modifying the flow regime through abstraction or regulation, morphological alteration (Gasparotti 2014). One of the most significant factors affecting the water quality of the Danube River basin is the hazardous substances pollution (Gasparotti 2014). River sediments can immobilize metal ions through processes such as adsorption, flocculation, and co-precipitation, hence sediments can act as hot spots of increased metal concentration (Morina et al 2016).

According to Gasparotti (2014) the lower reaches of the rivers are most affected by pollution. Most pollution point sources from the basin are found in Romania (125), followed at long distance by Bulgaria (41), Hungary (36), and Croatia (36) (Gasparotti 2014).

Concerning the causes of pollution in fluvial environments, heavy metals originate from various natural and anthropogenic sources, such as atmospheric deposition, geological weathering, agricultural activities, residential and industrial products (Webber et al 2013). Industry contributes to the Danube pollution with heavy metals (extraction and processing industry, chemical industry) (Gasparotti 2014). Paulino et al (2014) mentioned that chronic exposure to multiple contaminants in water, even at low levels, affects the resident biota, including fish. Contaminant accumulation in the tissues induces changes in the biochemistry and physiology of the cells, which may lead to histological changes in the organs (Paulino et al 2014).

Revising their impact on the environment, heavy metals have positive and negative effect on human health and surroundings (Abdulali et al 2012). When ingested in excess amounts or allowed to accumulate above tolerable limits, heavy metals can lead to random binding with cellular biomolecules such as enzymes and proteins in order to form stable bio-toxic compounds, which may compromise their structure and/or function (Duruibe et al 2007; Raheam et al 2015).

By analysing their impact on fish, heavy metals can be classified as essential: Fe, Zn, Cu, Mg, Se, Co, Vn and non-essential (potentially toxic trace elements): Al, As, Cd, Sb, Sn, Pt, Hg, Pb, Bi (Munoz-Olivas & Camara 2001). Fish are one of the reliable indicative factors in freshwater systems and accumulation levels in fish can be used for the estimation of trace metal pollution (Kalyoncu et al 2012). Monitoring heavy metal contamination in river systems by using fish tissue helps to assess the quality of aquatic ecosystems (Webber et al 2013). Metal ions dissolved in the environmental water are absorbed through the gills and other permeable body surfaces of the fish (Alvarado et al 2006). The content of toxic heavy metals in fish can counteract their beneficial effects (El-Moselhy et al 2014).

Several researches (Heath 1995; Simionov et al 2016) mentioned that heavy metals can be distributed in aquatic environment through water, organic and sediment particles.

Fish from open waters are considered "wild animals" as there is no possibility to control the composition of their growing environment (Clarkson 1998). The mechanisms of accumulation and storage of trace metals in aquatic animals are diverse, varying with the chemical form of the metal, mode of uptake and animal species (Sandor et al 2001). Multiple factors including season, physical and chemical properties of water can play a significant role in metal accumulation in different fish tissues (Romeo et al 1999). Acording to Strungaru et al (2015), the most important two water parameters that influence metal accumulation in biota are the pH and salinity. There is a strong positive correlation between these parameters and metal accumulation and it seems that acidic medium increases the metal accumulation in the biota (Strungaru et al 2015).

Metals in water environments can also result in the loss of biodiversity through toxicity effects on biota (Tao et al 2012; Podar 2010).

In fish, the toxic effects of heavy metals can affect the individual growth rates, physiological functions, mortality and reproduction. Heavy metals enters the fish bodies by three pathways: by gills, by digestive track and body surface. The gills are considered as the significant site for direct uptake of metals from the water, though the body surface is normally estimated to take minor part in uptake of heavy metals in fish. Heavy metals accumulation can also be caused by the food source, possibly leading to bio-magnification, the augmentation of toxins up the food chain.

Factors that are considered to be critical for heavy metal toxicity are as follows: size, developmental stage and water salinity in the aquatic environment. Affected organisms show response to heavy metals by accumulating in their bodies or by shifting to the next trophic level of the food chain (Afshan et al 2014).

The aim of this current study is to analyze the heavy metals uptake efficiency of various fish species found from the Danube River, between the area of 73.5 river km and 1503 river km.

Results and Discussion. In order to obtain o clear view, several databases were rivised in Table 1 (Visnjic-Jeftic et al 2010; Ionita et al 2014; Zrncic et al 2013; Milanov et al 2016; Subotic et al 2013; Miloskovic et al 2016; Jaric et al 2011). The research articles were selected by ranking the journals using their most significant publication domains as a primary criteria. Taking into consideration that the heavy metals research domain is continuously updating, papers published period ranged from 2010 to 2016, therefore ensuring the novelty degree of the current scientific paper. If two or more papers had the same topics and have been published in the same journal, the latest published one was selected for review.

Table 1

Data regarding heavy metals concentrations in different fish species according to different authors

SPECIES	**METALS µg/g d.w.**					**LOCATION**	**REFERENCE**
	Cd	**Pb**	**Hg**	**Cu**	**Fe**	(*Danube River*)	
Alosa immaculata	0.433 ±0.181	-	-	4.074 ±2.433	40.346 ±40.036	863 river km	Z.Visnjic-Jeftic et al (2010)
	0.091 ±1.5	0.65 ± 1.4	-	5.34 ± 3.5	-	257 river km	C. Ionita et al (2014)
	0.012 ± 1.8	0.45 ±2.4		3.30 ±2.3	-	73.5 river km	
Cyprinus carpio	0.016 ±0.004	0.014 ±0.005	0.234 ±0.107	-	-	1436 - 1478 - 1503 river km	S. Zrncic et al (2013)
	0.014 ±0.004	0.036 ±0.015	0.207 ±0.027			1206 river km	R. Milanov et al (2016)
	0.084 ± 2.8	0.58 ±3.1	-	5.10 ±4.1	-	257 river km	C. Ionita et al (2014)
	0.010 ± 2.5	0.38 ±3.3	-	3.22 ±1.1	-	73.5 river km	
	0.005 ±0.0005	-	0.89±0.22	1.30±0.98	19.62 ±11.38	1168-1170 river km	S. Subotic et al 2013
Silurus glanis	0.02 ±0.001	0.032 ±0.013	0.235 ±0.128	-	-	1436 - 1478 - 1503 river km	S. Zrncic et al (2013)
	0.008 ±0.003	0.014 ±0.005	0.327 ±0.110	-	-	1206 river km	R. Milanov et al (2016)
	0.09 ±0.008	0.17±0.05	0.33 ±0.1	0.07±0.03	0.95 ±0.08	1255 river km	A. Miloskovic et al (2016)
	0.01 ±0.001	0.016 ±0.023	0.2 ±0.01	0.07±0.02	1.33 ±0.24	1173 river km	
	0.004 ±0.0001	0.16 ±0.03	0.62 ±0.4	0.07±0.008	0.55 ±0.13	851 river km	
	0.01 ±0.001	-	1.63 ±0.51	1.42 ±1.79	27.06 ±36.53	1168-1170 river km	S. Subotic et al (2013)
Sander lucioperca	0.018 ±0.002	0.043 ±0.023	0.173 ±0.076	-	-	1436-1478-1503 river km	S. Zrncic et al (2013)
	0.003 ±0.0007	0.21 ±0.03	0.15 ±0.1	0.09 ±0.02	0.81 ±0.12	1255 river km	A. Miloskovic et al (2016)
	0.04 ±0.06	0.23±0.11	0.3 ±0.11	0.11±0.24	2.35±0.4	1173 river km	
	0.002 ±0.0014	0.18 ±0.1	0.28 ±0.12	0.11 ±0.023	4.63 ±4.15	851 river km	
	0.005 ±0.001	-	1.32 ±0.47	0.75±0.69	17.97 ±30.47	1168 -1170 river km	S. Subotic et al (2013)
Acipenser ruthenus	0.085 ±0.116	-	-	0.976 ±0.383	12.494 ±22.867	1319 - 1173 - 861 river km	I. Jaric et al (2011)

Data regarding heavy metals in fish meat from the Danube River (73.5-1503 river km) were reported for 5 fish species, as follows: *Alosa immaculata* (Bennet, 1835), *Cyprinus carpio* (Linnaeus, 1758), *Silurus glanis* (Linnaeus, 1758), *Sander lucioperca* (Linnaeus, 1758), *Acipenser ruthenus* (Linnaeus, 1758).

Pontic shad (*Alosa immaculata*, Bennet, 1835). Visnjic-Jeftic et al (2010) and Ionita et al (2014) reported different heavy metals concentration for pontic shad that was cached at 863 and respectively 257 and 73.5 river kilometer (Figure 1).

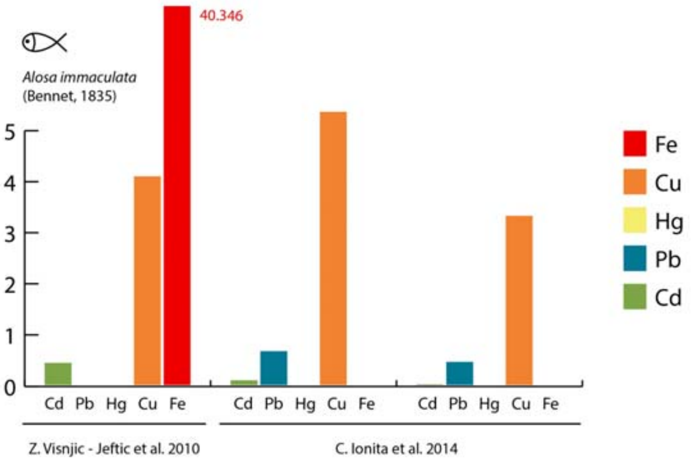

Figure 1. Heavy metals concentration in *Alosa immaculata* (Bennet, 1835) from Danube River.

Concerning the heavy metals concentrations, the highest value, which is also the only registered one, was reported for iron (40.346 μg/g d.w.) at 863 river kilometer, followed by copper (5.34 μg/g d.w.) at 257 river kilometer. Cadmium concentration appears to register the lowest values (0.012 μg/g d.w.) for pontic shad catches, recorded at 73,5 river kilometer.

Common carp (*Cyprinus carpio*, Linnaeus, 1758). Zrncic et al (2013), Milanov et al (2016), Ionita et al (2014), and Subotic et al (2013) reported different heavy metals concentration for the common carp that was cached at 1436, 1478, 1503 river kilometer, respectively 1206 river kilometer, 257 and 73.5 river kilometer, 1168 and 1170 river kilometer (Figure 2).

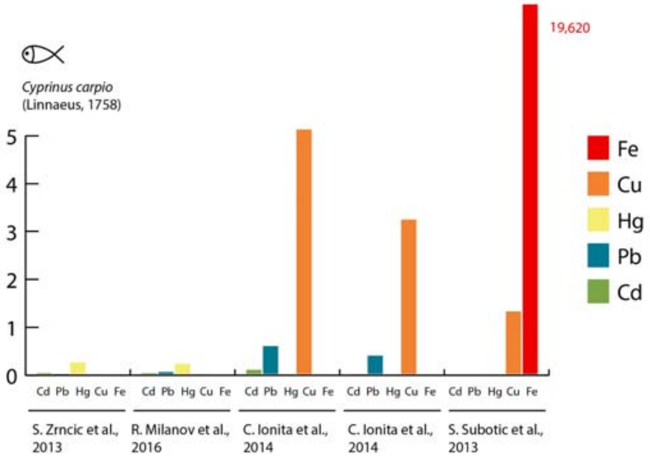

Figure 2. Heavy metals concentration in *Cyprinus carpio* (Linnaeus, 1758) from Danube River.

The highest value of heavy metals concentrations, which is also the only registered one, was reported for iron (19.620 μg/g d.w.) at 1168-1170 river kilometer, followed by copper (5.10 μg/g d.w.) at 257 river kilometer. Cadmium concentration appears to register the lowest values (0.005 μg/g d.w.) for common carp catches, recorded at 1168-1170 river kilometer.

Catfish (*Silurus glanis*, Linnaeus, 1758). Zrncic et al (2013), Milanov et al (2016), Miloskovic et al (2016), and Subotic et al (2013) reported different heavy metals concentration for the catfish that was cached at 1436, 1478, 1503 river kilometer and respectively 1206 river kilometer, 1255, 1173 and 851 river kilometer, 1168 and 1170 river kilometer (Figure 3).

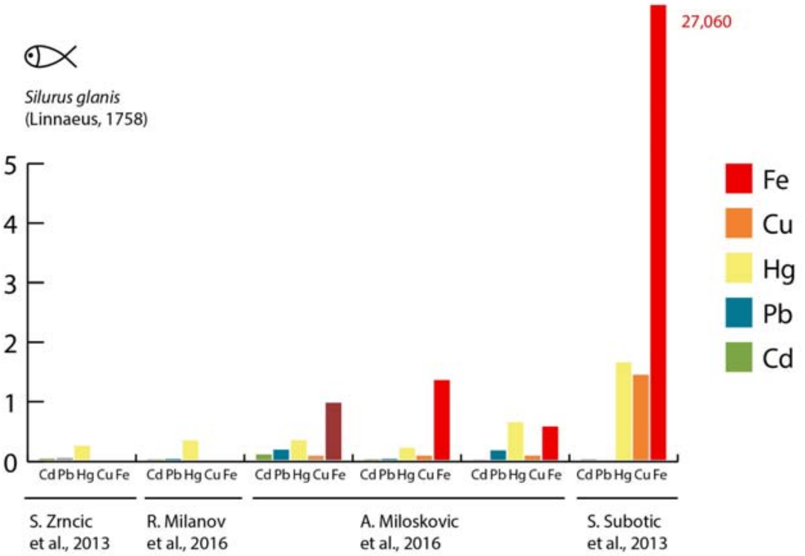

Figure 3. Heavy metals concentration in *Silurus glanis* (Linnaeus, 1758) from Danube River.

The highest value of heavy metals concentrations was reported for iron (27.060 μg/g d.w.) at 1168-1170 river kilometer, followed by mercury (1.63 μg/g d.w.) also at 1168-1170 river kilometer. Cadmium concentration appears to register the lowest values (0.008 μg/g d.w.) for the catfish catches, recorded at 1206 river kilometer.

Zander (*Sander lucioperca*, Linnaeus, 1758). Zrncic et al (2013), Miloskovic et al (2016), Subotic et al (2013) reported different heavy metals concentration for the zander that was cached at 1436, 1478, 1503 river kilometer and respectively 1255, 1173 and 851 river kilometer, 1168 and 1170 river kilometer (Figure 4).

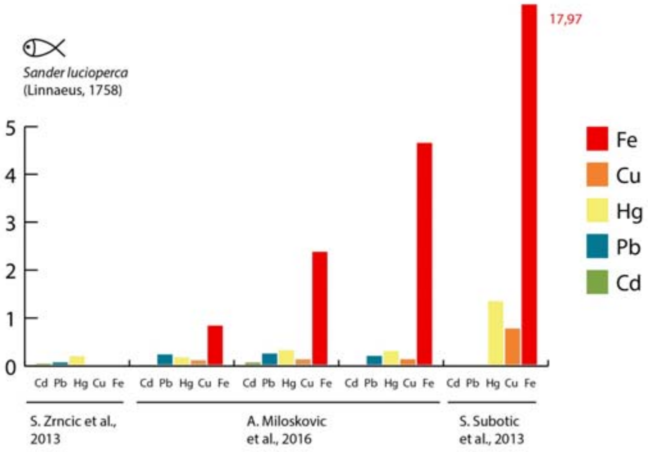

Figure 4. Heavy metals concentration in *Sander lucioperca* (Linnaeus, 1758) from Danube River.

The highest value of heavy metals concentrations was reported for iron (17.97 μg/g d.w.) at 1168-1170 river kilometer and at 851 river kilometer (4.63 μg/g d.w.). Cadmium concentration appears to register the lowest values (0.005 μg/g d.w.) for the zander catches, recorded as well at 1168-1170 river kilometer.

Sterlet sturgeon (*Acipenser ruthenus*, Linnaeus, 1758). Jaric et al (2011) reported different heavy metals concentration for the sterlet sturgeon that was cached at 1319, 1173 and 861 river kilometer (Figure 5).

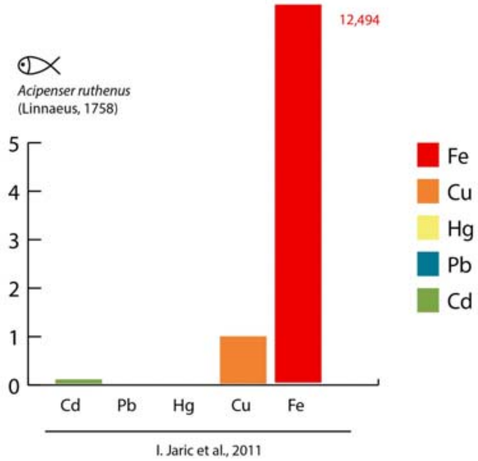

Figure 5. Heavy metals concentration in *Acipenser ruthenus* (Linnaeus, 1758) from Danube River.

The highest value of heavy metals concentrations was reported for iron (12.494 μg/g d.w.) at 1319, 1173 and 861 river kilometer. Cadmium concentration appears to register the lowest values (0.085 μg/g d.w.) for the sterlet sturgeon catches, recorded as well at 1319, 1173 and 861 river kilometer.

Cadmium. Cadmium is classified as a b-class (soft) metal and it occurs naturally in the environment, at low levels, along with other metals such as lead, copper and zinc (da Silva & Williams 1991; Strungaru et al 2016). All types of rocks and soils contain low amounts of cadmium, but as an element, it is not involved in natural biochemical processes, hence it is highly toxic because of its competition with essential metals for binding sites and also because of its interference with sulphydryl groups, which are essential for the normal functioning of enzymes and structural proteins (Strungaru et al 2016; Weber et al 2013; da Silva & Williams 1991).

Among the analysed scientific articles, the maximum cadmium concentration is reported in *Alosa pontica* – 863 river kilometer (0.433 μg/g d.w.), followed by *Cyprinus carpio* – 73.5 river kilometer (0.010 μg/g d.w.) and *Silurus glanis* – 1173, 1169 and 1170 river kilometer (0.01 μg/g d.w.).

It is assumed that fish absorb metals in the ionic form, but according to Heath (1995), along with the cadmium ion, fish can take up cadmium chloride as well. Gasparotti (2014) mentioned that cadmium registered exceeding values over the admitted targets in many locations on the Lower Danube region.

Cadmium has a biological half-life of 10-30 years (Strungaru et al 2016). Once it bio-accumulates in the fish organism, cadmium can be excreted very difficult from the liver and is positively linked to the age and size of the fish (El-Moselhy et al 2014).

Lead. Lead is a chemical element from the heavy metals category and it is one of the most ubiquitous and useful metal known to humans (Strungaru et al 2012; Stancheva et al 2014). Even though it has no essential role in the living organism, lead is detectable in practically all phases of the inert environment and in all biological systems (Strungaru et al 2012; Stancheva et al 2014).

Pb is a typical component in the long-range transported pollution aerosols in the atmosphere, so it enters the water environment primarily through atmospheric transport, besides other metals which have continental origins (Dinescu et al 2004; Mulayim & Balkis 2015).

Because of the water cycle in nature, lead reaches the soil and the aquatic ecosystems. Lead toxicity is very high because it may inactivate some enzymes, produce damage of the nervous and reproduction systems (Strungaru et al 2012).

Among the analysed scientific articles, the maximum lead concentration is reported in *Alosa immaculata* – 257 river kilometer, respectively 73.5 river kilometer (0.65 µg/g d.w. and 0.45 µg/g d.w), followed by *Cyprinus carpio* – 257 river kilometer, respectively 73.5 river kilometer (0.58 µg/g d.w. and 0.38 µg/g d.w.) and *Sander lucioperca* – 1173 river kilometer (0.23 µg/g d.w.).

Lead has a biological half-life of 5-20 years (Strungaru et al 2016). The most important anthropogenic sources of Pb are the municipal discharges, from sludge generated by wastewater treatment (Burada et al 2015).

Mercury. Mercury is a pervasive and toxic environmental contaminant, which is globally widespread in aquatic ecosystems due to atmospheric deposition (Fitzgerald et al 1998). It is a known human toxicant and the primary sources of Hg contamination in man are through eating fish (Stancheva et al 2014). Elemental Hg is a non-essential heavy metal. Mercury is lipophilic and its most toxic form is MeHg, which is transferred from inorganic Hg by microorganisms in aquatic systems (Gilmour et al 1992).

Accoring to Miloskovic et al (2016), Hg can accumulate more easily in muscle than the other organs and thus, edible muscle tissue should be analyzed.

The lipid content of tissues is an important variable affecting the concentration of metals accumulated in fish, especially for the bioaccumulation of Hg since this metal is deposited mainly in the lipid fraction of fish (as methylmercury). It is believed that Hg has a higher uptake through food than through the water component (Gati et al 2013).

Among the analysed scientific articles, the maximum mercury concentration is reported in *Silurus glanis* – 1168-1170 river kilometer (1.63 µg/g d.w.), followed by *Sander lucioperca* – 1168-1170 river kilometer, (1.32 µg/g d.w.) and *Cyprinus carpio* – 1168-1170 river kilometer (0.89 µg/g d.w.).

Mercury has a very low elimination rate, and therefore, even in slightly polluted environments, the concentration in fish continuously increases throughout the life span of the fish (Miloskovic et al 2016).

Copper. Copper, along with zinc, is generally considered an essential metal for aquatic organisms because of their wide involvement in physiological processes (enzyme-catalyzed reactions, metallothionein synthesis and lymphocyte differentiation). The small quantities of cooper required by aquatic organisms to maintain physiological and morphological normality of growth, development and reproduction, must be taken from foods and the ambiance (Simkiss & Mason 1983; Kalay & Canli 2000).

Copper accumulates in liver and brain, and its toxicity is a fundamental cause of Wilson's disease (Raheam et al 2015). There are also a number of important copper-containing proteins and enzymes, some of which are essential for the proper utilization of iron (Stancheva et al 2010). It must be mentioned that cooper naturally occurs in the environment together with other metals at low levels and is essential for biological systems such as enzymatic activities (Strungaru et al 2016; Subotic et al 2013). Metals such as copper have relatively low solubility in water, so they tend to accumulate in sediments, fact positively influenced by the clayey soil components (Webber at al 2013). Granada et al (2015) stated that some studies have also shown that high concentrations of copper can affect phytoplankton diversity.

Among the analysed scientific articles, the maximum copper concentration is reported in *Alosa immaculata* – 257 river kilometer, respectively 73.5 river kilometer (5.34 µg/g d.w. and 5.30 µg/g d.w.), followed by *Cyprinus carpio* – 257 river kilometer, respectively 73.5 river kilometer (5.10 µg/g d.w. and 3.22 µg/g d.w.) and *Silurus glanis* – 1168-1170 river kilometer (1.42 µg/g d.w.)

In the the aquatic environment, cooper has been introduced with several industries such as mining, electroplating, paint, chemical and agricultural effluents (Bat et al 2014).

The accumulation of essential metals in the liver is likely linked to their role in metabolism. High levels of Cu and Zn in hepatic tissues are usually related to natural binding proteins such as metallothioneins (MT) (El-Moselhy et al 2014).

Iron. Iron is a constituent of hemoglobin, myoglobin and a number of enzymes, therefore is an essential nutrient (Stancheva et al 2010). This metal tends to accumulate in hepatic tissue due to the physiological role of the liver in blood cells and hemoglobin synthesis (El-Moselhy et al 2014).

Among the analysed scientific articles, the maximum iron concentration is reported in *Alosa immaculata* – 863 river kilometer (40.346 µg/g d.w.), followed by *Silurus glanis* – 1168-1170 river kilometer (27.06 µg/g d.w.) and *Cyprinus carpio* as well at 1168-1170 river kilometer – (1.42 µg/g d.w.).

As an essential mineral, Fe plays an important role in the human physiology. High Fe absorption causes excessed Fe to be stored in the organs, eventually leading to Fe overload (Stancheva et al 2014).

General view. As a general view of this current study, the highest concentrations of heavy metals, found after analyzing the scientific articles (Ionita et al 2014; Visnjic-Jeftic et al 2010; Subotic et al 2013), were presented in Figure 6.

Figure 6. The geographical distribution of different heavy metals highest concentration.

Studies revealed that the need for the metals at global scale started with the Industrial Revolution and the technological development, these phenomena released important quantities of high toxic compounds in air, water and land (Strungaru et al 2016).

To avoid pollution disaster like precedent Minamata disease, in Japan, by Hg and Cd poisoning, continuous follow up and monitoring of environmental pollution is mandatory (Asefa & Beranu 2015).

In fluvial environments, heavy metals originate from various natural and anthropogenic sources, such as atmospheric deposition, geological weathering, agricultural activities, residential and industrial products (Webber et al 2013).

Metals are considered to be among the major pollutants in the Danube in Serbia, especially in the area of the cities of Belgrade and Novi Sad. The Tisa River, the second largest Danube tributary, is also contaminated through numerous industrial accidents from the Carpathian mountain region in Romania, which has a long tradition of mining, especially of gold (Au), silver (Ag), lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd), and manganese (Mn) (Miloskovic et al 2016).

Over 90% of the Cd, Pb, Mn, Ni and Zn content present in freshwater and sediments originates from human activities (Burada et al 2015).

In 2004, the amount of lead directly discharged was 138 t/year, and for the zinc, 171 t/year (Administration Basin of Water Seaside Dobrogea 2010). The transport activities appear to be important sources of oil pollution and represent the main source of lead, to the Danube and its tributaries (Gasparotti 2014). The most important anthropogenic sources of Pb are: municipal discharges, from sludge generated by wastewater treatment (Burada et al 2015).

Fishes are cold-blooded aquatic vertebrates with high tolerable capacity to environmental conditions (Strungaru et al 2015). Mainly plankton feeding fish contain much higher concentrations of some heavy metals than bottom feeding fish (Topping 1973). This fact was confirmed also by Khaled (2004), which reports that herbivore fish accumulate higher concentrations of heavy metals in their muscle, than carnivorous ones. It is known that benthic fish species are dietary exposed to heavy metals through consumption of zoobenthic biota (shellfish, worms) from contaminated sediment (Gati et al 2013).

When a metal is present in the water, depending on the concentration, fish will tend to take it up rather than excrete it (Heath 1995).

The plasma protein ceruloplasmin binds copper in mammals. Copper and zinc binding proteins have also been found in fish and there may be a different protein for each essential and non-essential metals may use one of the already existing proteins (Heath 1995). When ingested in excess amounts of heavy metals combine with body's bio-molecules, like proteins and enzymes to form stable bio-toxic compounds, thereby mutilating their structures and hindering them from the bio-reactions of their functions (Raheam et al 2015).

Differences are expected to exist among fish collected from different areas, depending on the feeding, the water quality and geographical properties of the area (Sandor et al 2001).

Conclusions. As a main conclusion of this review, it can be stated that the maximum cadmium concentration was found in *Alosa immaculata* – 863 river kilometer (0.433 μg/g dry weight), the maximum lead concentration was found in *Alosa immaculata* – 257 river kilometer (0.65 μg/g dry weight), the maximum mercury concentration was registered in *Sander lucioperca* – 1168-1170 river kilometer (1.32 μg/g dry weight), the maximum copper concentration was found in *Alosa immaculata* – 257 river kilometer (5.34 μg/g dry weight), the maximum iron concentration was found in *Alosa immaculata* – 863 river kilometer (40.36 μg/g dry weight).

Therefore, *Alosa immaculata* appears to have the highest concentration of heavy metals from the studied fish species, found in the analyzed scientific articles. However, this cannot emphasize the pollution degree of Danube River, since *Alosa immaculata* is a migratory fish that comes from the Black Sea to the Danube River, only in spring and autumn seasons. Thus, this fish species cannot be used as a pollution bio-indicator for the Danube River. There are still biosecurity issues regarding *Alosa immaculata*, considering the fact that it is a high economic species that has a strong market demand and considerable catches are recorded both on spring and autumn seasons.

The most polluted areas of those taken in the analysis resulted to be 257 and 863 river kilometer, fact justified by the intensive industrial activities and also, numerous industrial accidents.

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