

# Chemical elements in the muscle tissues of European eel (*Anguilla anguilla*) from selected lakes in Latvia

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**Abstract** Fish is a significant source of essential nutrients, as well as toxic elements in the human diet. Concentration of 17 elements was determined in muscles of eels (*Anguilla anguilla*) collected from five fishing lakes in the territory of Latvia. The concentration of main elements determined in muscle tissues varied within the following ranges: for Pb, 0.019–0.047; Cd, 0.0051–0.011; Hg, 0.13–0.36; Cu, 0.76–0.92; Zn, 28–42; and As, 0.13–0.23 mg kg<sup>-1</sup> wet weight. A positive correlation was revealed between the concentration of Hg in muscles and fish length in inland lakes. Concentration of metals in muscle tissues of eels from brackish coastal and inland lakes was without statistically significant difference. This research demonstrated that the elemental content of Cd and Pb in muscles of the examined fish was lower than the maximum allowed threshold set by the European Union legislation. Mercury content was over the threshold limit for all the analyzed eels if to compare with the Water Framework Directive Environmental Quality Standards. On other side, only 7 % of analyzed fish have indicated values that are over threshold limits for mercury established by the European Union food legislation. The current study contributes to the

implementation of Water Framework Directive in Latvia by collection of information necessary for the further protection measures of waters. To our knowledge, this study provides the first data on multielemental bioaccumulation in muscle tissues of European eels collected from fishing lakes of Latvia.

**Keywords** *Anguilla anguilla* · Silver eel · Multielemental bioaccumulation · Fish muscle · Lakes in Latvia

## Introduction

The European eel (*Anguilla anguilla*) from Anguillidae family is a snake-like, catadromous fish species spread over a relatively vast geographical area from the North Africa to Northern Scandinavia and from the Azores in the west to the Eastern Mediterranean region in south-east (Lelek 1987; Belpaire and Goemans 2007a). The life cycle of eels starts by hatching in salt waters of Sargasso Sea in the Atlantic Ocean, followed by growth in fresh, brackish, and coastal waters of Europe and later return to the ocean in order to spawn and die. Silver (juvenile) stage eels of *A. anguilla* live in tributaries along the European coast (Tsukamoto et al. 1998; Ringuet et al. 2002).

The aim of the chemical monitoring of eels in Europe can be subdivided in three main tasks: (1) development of a biomonitoring tool for ecological quality for local and international significance, (2) participation in the international eel restoration plan in order to develop a

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further strategy for the recovery of the eel population, and (3) surveillance of fish product safety for human consumption (Barak and Mason 1990; Belpaire and Goemans 2007a, b).

According to the European Union Water Frame Directive (EU WFD 2000), various biological quality indicative elements (phytoplankton, phytobenthos, benthic invertebrates, and fish fauna) are to be selected for biomonitoring of the ecological water quality in European countries.

European eels are widespread in most waters of European countries, and fish can be used as one of watershed monitoring tools for determination of ecological quality. Eels are benthic species that eat insect larvae, crustaceans, snails, worms, mussels, and fish, in particular small bottom-dwelling species (Deelder 1970; Sinha and Jones 1975; Belpaire and Goemans 2007b). Such a diverse feeding pattern defines the high bioaccumulation capacity of toxic residues reflecting the fluctuations of the environmental pollution over time. In some reports (Batty et al. 1996; Usero et al. 2003; Durrieu et al. 2005; Maes et al. 2008), metal content in European eels has been used as an indicator of environmental quality.

Health status of eels can be affected by the chemical composition of their habitat. As the population of eels is declining over recent decades (Dekker 2003; ICES/EIFAC 2004), groups of researchers decided to create the International European Eel Quality Database. Scientists are collecting data on diseases of eel that may correlate with the presence of harmful organic substances and metals (Belpaire et al. 2011). One of the possible reasons is the decreased viability of the silver eels (spawners) (Castonguay et al. 1994; Robinet and Feunteun 2002; Haenen et al. 2010).

Various elements are released in the aquatic environment by anthropogenic sources through atmospheric fallout and industrial, domestic, and agricultural effluents. Precautionary measures are important as many contaminants including metals and metalloids that are toxic and tend to accumulate in food chains (Al-Yousufa et al. 2000). Some elements, e.g., arsenic, cadmium, mercury, and lead, can be toxic even at low concentrations while others such as cobalt, copper, zinc, manganese, and magnesium are known as essential elements at low concentrations and play an important role in metabolism. As a top predator, eel may accumulate these metals through the food chain, with concentrations exceeding the

metabolic tolerance and resulting in toxic effects (Le et al. 2009).

Since eels at juvenile and adult stages are relatively long-living animals, they can accumulate high concentrations of pollutants and become dangerous for human consumption (Bruslé 1990).

Our research was focused on the investigation of the chemical quality of European eel from brackish coastal and inland lakes in Latvia in order to evaluate ecological trends regarding metals and metalloids.

Implementation of national eel management plans at river-basin level requires continuous monitoring that allows the control of water quality and successful performance of restocking actions. A set of measures can be applied if the monitoring results show possible influence of toxic elements by inhibition of metabolic processes in eels, thus decreasing the biological quality of the population.

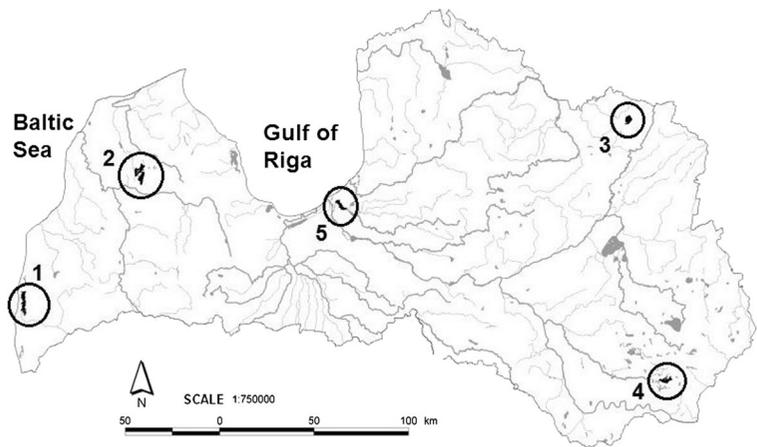
Latvia had made several efforts to reverse the decline of eel population. Glass eel restocking was practiced intensively already in early 1920s–1930s of the twentieth century; later in 1960s–1980s, it was done in several lakes of Latvia, but after 1990, restocking of glass eels has been mostly funded and performed sporadically by private companies and fisheries. Another reason for the rapid decline of eel stock is the fact that approximately 60 % of the territory and majority of lakes and rivers are not accessible for the natural migration of eels for decades due to hydroelectric dams. The Ministry of Agriculture of the Republic of Latvia coordinated the implementation of the Eel Management Plan from 2009 to 2013, and 1,386,200 glass eels were introduced in several lakes and rivers in a total of 39 locations.

This research included typical examples of three major eel stocked production inland lakes and two natural eel habitats brackish coastal lakes.

## Materials and methods

The major lakes of Latvia—Usma, Sīvers, and Alūksnes—are of glacial origin. Glacial and late glacial lakes in Latvia were formed in lowlands when larger relief depressions were filled with the Baltic Ice Lake waters (Usma), or in local upland depressions (Alūksnes, Sīvers) that were washed out by water flowing beneath and from retreating ice masses in lobes of glaciers (Fig. 1). Post glacial lakes such as ancient Baltic Sea Littorina stage lakes Ķīsezers and Liepāja

**Fig. 1** Sampling locations in Latvia for European eels used in the current study for analysis of chemical elements. 1 Lake Liepāja, 2 Lake Usma, 3 Lake Alūksnes, 4 Lake Sivers, 5 Lake Ķīšezers



(Fig. 1) are located close to the seacoast and are connected with the Riga Gulf and the open Baltic Sea through a river outlet and trade channel, respectively. Both freshwater lakes are former Littorina Sea lagoons, although nowadays due to prevailing winds brackish water occasionally flows through outlets into lakes for shorter or longer periods of time. These freshwater systems are thus influenced by the sea water.

These five lakes were chosen as typical examples for research, as literature sources (Eipurs 1984; Kavacs 1998) mention that eels in Latvia prefer eutrophic lakes with moderate up to high pollution with organic matter (saprobity index around 2.3–2.5). Eutrophic lakes in comparison to oligotrophic and dystrophic are rather rich with nutrients and organic matter. Organic matter in sediments on one hand can successfully bind toxic elements out from the water, but on the other hand, fish that consume these sediments are under the threat of exposures from toxic elements.

Brackish coastal surface waters have around six times higher water conductivity and two times higher total hardness values compared to inland lakes (Briede 1996). Lakes Liepāja and Ķīšezers are located close to urban areas and pollution sources from various metallurgical industries, domestic, agricultural effluents, and wastewaters that affect the quality of water and sediments in terms of heavy metal contamination (Vircavs et al. 1995; Briede 1996; Kļaviņš et al. 1998a; Kļaviņš et al. 2002) (Table 1).

Eels were sampled by hook (fyke nets) during the spring months March to April (2014) from five lakes in Latvia. In addition, eels were fished from Usma in October in order to investigate seasonal trends. According to the Regulation on Angling in Latvia

(Republic of Latvia 2001), fishermen are not allowed to catch eels shorter than 40 cm in length. Investigated fish length ranged from 40 to 90 cm (Table 2). All eels were at the silver stage of development. The lakes were located in various regions of Latvia (Fig. 1). Female eels were killed, measured, and weighted. Samples of the edible parts (skeletal muscles) were removed using stainless steel knife and were put in plastic bags and frozen (−20 °C) prior to analysis. Approximately 0.5 g of refrigerated, homogenized muscle tissues were placed in a Teflon digestion vessel and treated with 8 mL of concentrated nitric acid, 2 mL of hydrogen peroxide, and 250 μL AuCl<sub>3</sub> (γ=1000 mg L<sup>−1</sup>) (the AuCl<sub>3</sub> solution was added for Hg measurements). The chemical reagents were of analytical purity grade. Digestion procedure was performed by using microwave oven. The solutions were heated for 40 min at 150 °C and then for 40 min at 180 °C. After cooling, the solutions were diluted to 50 mL with deionized water. High purity water (Millipore Milli-Q System) was used throughout the analysis.

The accuracy of the chemical analysis was checked using the reference material available from the 20th Proficiency Test on Kidney (for Hg, Pb, Cu, Cd). The found values of elements were in a good agreement with the certified values, with the recoveries ranging from 90 to 110 %. The condition factor was estimated with Fulton’s condition factor (Bagenal and Tesch 1978) according to the following formula:  $K=100 \cdot w/l^3$ , where  $w$  is the total weight (g) and  $l$  is the fork length (cm). Elemental concentration measurements were carried out by using inductively coupled plasma mass spectrometry (ICP-MS).

**Table 1** Physical geographical parameters of lakes where several case studies were performed (Kļaviņš et al. 2002)

| Lake     | Lake surface area (km <sup>2</sup> ) | Maximum depth (m) | Average depth (m) | Water exchange rate (times per year) | Class     |
|----------|--------------------------------------|-------------------|-------------------|--------------------------------------|-----------|
| Alūksnes | 15.60                                | 15.2              | 7.1               | <1                                   | Eutrophic |
| Sīvers   | 17.59                                | 24.5              | 6.3               | <1                                   | Eutrophic |
| Usma     | 38.92                                | 27.0              | 5.4               | <1                                   | Eutrophic |
| Ķīšezers | 17.30                                | 4.2               | 3.0               | 6-20                                 | Eutrophic |
| Liepāja  | 37.15                                | 3                 | 1.5               | >20                                  | Eutrophic |

## Results and discussion

A total of 58 eels were selected for the analysis of elements in their muscle tissues. European eels as benthic species reflect the quality of the lake sediments and biota. During this investigation, older eels were sampled (the maximum length of fish was around 80–90 cm). Older eels can be potentially more contaminated with pollutants and are not recommended for human consumption. According to the Boyden (1977) report, some elements, e.g., mercury, in soft organs are bound relatively weakly (temporary store), but in flesh, more strongly (permanent store). Elements that are weakly bound in soft organs may be more affected by seasonal changes in comparison to those strongly bound in flesh.

Muscle tissues of eels were chosen for the ICP-MS analysis as eels indirectly reflect the environmental quality regarding contamination with metals in water ecosystems and potential hazards in the case of human consumption.

The calculated Fulton's condition factor varied from 0.15 to 0.18 for samples collected during the spring season. Close values of this index among the samples reflect similar interaction of biotic and abiotic factors to the physiological condition of fish in different lakes (Lizama and Ambrosio 2002; Lawal and Bichi 2014). Seasonal fluctuations of the condition factor were observed; the lowest values were recorded in April and May while higher values were found in October.

Comparison of individual concentrations of cadmium (Cd), lead (Pb), and mercury (Hg) in eels from different lakes shows that there are no significant variations among geographical locations (Table 3). The higher concentrations of these toxic elements were recorded in Lake Usma (Table 3). Bioaccumulation of elements in eels from Lake Usma was more pronounced as these specimens had a lower proportion of fat and the dissemination of contaminants in the flesh was lower. According to the arguments given by Linde et al. (1996), the failure to detect bioaccumulation of non-

**Table 2** Biometric parameters of eels from different lakes (mean length and weight with standard deviations)

| Location                   | Season        | Length (cm)    |    | Weight (g)       |     |
|----------------------------|---------------|----------------|----|------------------|-----|
|                            |               | Mean (min–max) | SD | Mean (min–max)   | SD  |
| Alūksnes<br>( <i>n</i> =9) | April, 2014   | 81 (74–95)     | 7  | 994 (760–1600)   | 262 |
| Usma<br>( <i>n</i> =8)     | October, 2013 | 55 (50–67)     | 5  | 997 (820–1555)   | 240 |
| ( <i>n</i> =10)            | April, 2014   | 69 (53–85)     | 9  | 519 (200–1000)   | 230 |
| ( <i>n</i> =9)             | May, 2014     | 62 (39–87)     | 21 | 600 (99–1243)    | 479 |
| Sīvers<br>( <i>n</i> =11)  | April, 2014   | 90 (84–99)     | 5  | 1244 (890–1538)  | 284 |
| Liepāja<br>( <i>n</i> =6)  | May, 2014     | 82 (72–95)     | 8  | 875 (550–1300)   | 268 |
| Ķīšezers<br>( <i>n</i> =5) | May, 2014     | 95 (92–101)    | 3  | 1580 (1400–1800) | 148 |

**Table 3** The mean levels of metals in the muscle tissues of eels in freshwater and brackish water ecosystems (mg kg<sup>-1</sup> wet weight)

| Element | Alūksnes      | Sīvers        | Liepāja       | Ķīšezers      | Usma, April   | Usma, May   | Usma, October |
|---------|---------------|---------------|---------------|---------------|---------------|-------------|---------------|
| Pb      | 0.024±0.015   | 0.027±0.013   | 0.0192±0.008  | 0.022±0.009   | 0.029±0.014   | 0.035±0.02  | 0.047±0.02    |
| Hg      | 0.21±0.06     | 0.17±0.08     | 0.13±0.05     | 0.18±0.07     | 0.24±0.20     | 0.36±0.17   | 0.33±0.14     |
| Cd      | 0.0054±0.0006 | 0.0059±0.0011 | 0.0057±0.0010 | 0.0051±0.0015 | 0.0071±0.0018 | 0.011±0.002 | 0.0081±0.0017 |
| As      | 0.20±0.09     | 0.15±0.08     | 0.21±0.07     | 0.23±0.10     | 0.14±0.06     | 0.13±0.03   | 0.15±0.06     |
| Mg      | 183±22        | 193±20        | 217±27        | 226±14        | 195±23        | 199±14      | 208±21        |
| Zn      | 42±5          | 37±6          | 35±7          | 28±2          | 36±9          | 37±5        | 38±2          |
| Fe      | 9.7±1.8       | 9.5±1.8       | 8.4±2.0       | 9.3±2.4       | 10.8±2.5      | 13.2±3.6    | 10.5±3.7      |
| Cu      | 0.82±0.06     | 0.83±0.12     | 0.85±0.04     | 0.77±0.04     | 0.76±0.09     | 0.92±0.25   | 0.92±0.09     |
| Mn      | 0.23±0.08     | 0.20±0.06     | 0.25±0.05     | 0.28±0.09     | 0.24±0.11     | 0.29±0.16   | 0.29±0.13     |
| Sr      | 0.09±0.03     | 0.11±0.07     | 0.25±0.09     | 0.19±0.06     | 0.12±0.06     | 0.15±0.06   | 0.13±0.07     |
| Rb      | 1.8±0.4       | 1.8±0.3       | 1.0±0.2       | 1.5±0.4       | 1.4±0.4       | 1.6±0.6     | 1.8±0.2       |
| Ba      | 0.084±0.013   | 0.07±0.03     | 0.068±0.017   | 0.050±0.012   | 0.09±0.03     | 0.14±0.04   | 0.082±0.017   |
| Se      | 0.32±0.05     | 0.44±0.11     | 0.41±0.07     | 0.37±0.06     | 0.44±0.12     | 0.46±0.06   | 0.42±0.09     |
| Cs      | 0.0068±0.0013 | 0.0056±0.0015 | 0.008±0.004   | 0.008±0.004   | 0.0033±0.0018 | 0.006±0.004 | 0.007±0.002   |
| Cr      | 0.34±0.08     | 0.34±0.09     | 0.32±0.02     | 0.30±0.05     | 0.29±0.05     | 0.35±0.10   | 0.31±0.01     |
| Al      | 1.7±0.3       | 1.9±0.3       | 1.7±0.3       | 1.7±0.3       | 1.8±0.3       | 2.1±0.4     | 2.2±0.8       |
| Ni      | 0.16±0.06     | 0.14±0.08     | 0.17±0.05     | 0.12±0.06     | 0.12±0.05     | 0.15±0.07   | 0.18±0.06     |

essential elements has two alternative explanations: (1) bioelimination is countering the deleterious effects of heavy metals and (2) the fish that accumulated high concentrations of lead and/or cadmium are subject to selective mortality, whereas metal-free fish survive, multiplying and growing preferentially.

A positive Pearson correlation was found for mercury bioaccumulation in muscles and eel length ( $r=0.49$  (Alūksnes);  $r=0.45$  (Usma);  $r=0.43$  (Sīvers)) in inland lakes. This trend might be observed since fish muscles are the main target of organic mercury (Hakanson 1984) with the higher affinity of methylmercury for binding to proteins in fish muscles.

Pierron et al. (2007) have found that contaminated with cadmium eels show a lower content of lipids comparing to control ones. This observation is extremely important since the lipid content in silver eels is crucial for reproduction (Belpaire et al. 2009). By evaluating the obtained data using the Pearson correlation coefficient, the insignificant relationship varying from  $-0.3$  to  $+0.3$  was observed between two variables (lipid and cadmium contents) in all analyzed eels originated from different lakes.

Non-essential metal accumulation in muscles is comparably lower in accordance to the following order  $Hg > Pb > Cd$ .

The main anthropogenic pollution source of non-essential element arsenic (As) is leaching from agricultural lands located close to water ecosystems (Vircavs et al. 1995). Lakes Sīvers and Usma are comparably far from actively used agricultural lands, but other lakes investigated in this study are closer. Hereby, the occurrence trend for this contaminant correlates with agricultural activities.

Essential metals such as magnesium (Mg), zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) have normal physiological regulatory functions, but also in some cases, these elements can be bioaccumulated excessively and therefore can even exceed toxic levels. Essential metal accumulation order in muscles is  $Zn > Fe > Cu > Mn$ .

The seasonal variation for the metal accumulation observed in muscles of eels from Lake Usma was insignificant.

No statistically significant differences were found for concentration of any of the metals between the brackish coastal and inland lakes; it could be dependent on the age differences of fish, lipid content fluctuations, and migrations during the silver eel stage. The literature study of previous investigations by Kļaviņš et al. (1998a) shows that concentration of Pb, Cu, and Cd in muscle tissues of pike and perch

was higher in brackish compared to inland lakes. However, our study did not approve the same conclusion for eels.

A correlation matrix for elements in the muscles of eels was calculated. Aluminum (Al) showed positive correlation with lead (Pb) and iron (Fe) ( $r \geq 0.7$ ;  $p = 0.05$ ). Manganese (Mn) displayed a relationship with strontium (Sr) ( $r \geq 0.7$ ;  $p = 0.05$ ).

Such type of correlation can appear if Al and Pb come from one emission source or due to common influencing factor (Seinfeld and Pandis 2006). Nevertheless, the correlation can appear also in cases when sources of Al and Pb are close to each other geographically as well as if different factors are influencing the concentration of both elements similarly. Lead is a known anthropogenic pollutant from air emissions caused by industry, coal-fired power plants, and traffic. Diffuse air pollution can be disseminated in wide areas with aerosols and dust and accumulate in the soil and sediments of rivers and lakes. Lead has strong binding capacity to colloidal particles and often is found accessory to Al, which is widely distributed in clay minerals (Windom 1988). Fe and Al as macroelements are distributed in soils, suspended, and benthic sediments. Significant correlation between suspended Fe and Al concentrations in the water of the Daugava River in Latvia was observed by Poikāne (2008). The major source of Mn and Sr could indicate a contribution from plants. Eels are directly influenced by the surrounding environment and geochemistry, and concentrations of metals in eels could be dependent of these conditions.

The heavy metal concentrations in fish from lakes in Latvia were investigated by Kļaviņš et al. (1998a). The following concentrations of Pb ( $0.42\text{--}1.12\text{ mg kg}^{-1}$ ), Cd ( $0.04\text{--}0.08\text{ mg kg}^{-1}$ ), Cu ( $0.32\text{--}0.87\text{ mg kg}^{-1}$ ), and Ni ( $0.21\text{--}0.69\text{ mg kg}^{-1}$ ) in muscles of Northern pike (*Esox lucius* L.) and perch (*Perca fluviatilis* L.) from inland lakes in Latvia were determined in this study. Higher concentrations were determined in fish from brackish lakes (Ķīšezers and Liepāja), with the content of lead, cadmium, copper, and nickel in the muscles of these fish varying from  $2.62\text{ to }4.12\text{ mg kg}^{-1}$ ,  $0.09\text{--}0.013\text{ mg kg}^{-1}$ ,  $0.88\text{--}0.87\text{ mg kg}^{-1}$ , and  $0.85\text{--}0.89\text{ mg kg}^{-1}$ , respectively (Kļaviņš et al. 1998a). Data obtained in our research showed a similar content of Cu and Ni in the muscles of eels, but non-essential elements such as Pb and Cd were found at lower levels. That fact could be

explained by different feeding habits, the biological life cycle, and the bioaccumulation capacity or content of muscle lipids of each species. Farkas et al. (2000) investigated elemental content in the muscles of fish with different feeding habits in Lake Balaton and observed the following trends: copper and zinc proved to be at higher concentration in the muscles of eels compared to pike and perch, while lead and cadmium were at a similar level. According to this observation, our current study revealed trends that the content of Cd, Pb, Cu, and Ni in the muscles of eels from lakes of Latvia is lower than reported before (Kļaviņš et al. 1998a).

In another report, Kļaviņš et al. (1998b) found that elemental (Cu, Pb, Ni, Cd) concentration in soft tissues of mollusk *Unio unio* (benthic biota) increased with the rise of metal concentration in water and sediments of the freshwater ecosystems in Latvia. These results indicated that Lake Liepāja and Lake Ķīšezers are more polluted from anthropogenic sources in comparison to other inland surface waters in Latvia, but such trends were not observed during our current study. Perhaps benthic organisms that are inhabiting local water basins can be influenced by heavy metals and metalloids stronger than those travelled from possibly cleaner basins and are more mobile.

The content of metals in the muscle tissues of European eels from Latvian lakes is similar to that from other European regions (Table 4). The concentration of non-essential elements and metalloids (Cd, Pb, Hg, As) obtained from the analyzed samples in Latvia was found similar to the results obtained for eels from fishery areas in France, Spain, Portugal, Belgium, and East England. There are slightly higher concentrations of essential metals (Cu, Zn) in eels from the lakes studied in this paper, compared to those studied in the countries mentioned above.

The content of Cd and Pb in muscle tissues of all eel samples was below the threshold level considering the European Union legislation (EC 2006, 2008). According to these documents, the maximum permitted level for Cd is  $0.1\text{ mg kg}^{-1}$  wet wt., and for Pb,  $0.3\text{ mg kg}^{-1}$  wet wt. Mercury content was exceeded in all analyzed eels according to Water Framework Directive Environmental Quality Standards ( $0.02\text{ mg kg}^{-1}$  wet wt.). However, only 7 % of analyzed fish have shown values that are over threshold limits in guidelines set by the European Union food legislation ( $0.5\text{ mg kg}^{-1}$  wet wt.).

**Table 4** Elements in muscle tissues of eel *Anguilla anguilla* (wet weight, mg kg<sup>-1</sup>) in different regions of Europe

| Site  | Pb          | Cu          | Cd          | Zn        | Hg          | Mn        | Fe        | Ni          | As          | Cr        | Reference                |
|---|-------------|-------------|-------------|-----------|-------------|-----------|-----------|-------------|-------------|-----------|--------------------------|
| Lakes in Latvia (min-max)                       | 0.004-0.084 | 0.58-1.27   | 0.004-0.015 | 24-47     | 0.071-0.64  | 0.11-0.60 | 6.1-17.4  | 0.04-0.27   | 0.023-0.44  | 0.23-0.55 | In our investigation     |
| Lake Albufera in Valencia (Spain)               | 0.02-0.23   | 0.18-0.33   | <0.02       | 12.7-36.7 | 0.02-0.24   | 0.10-1.5  | 3.72-17   |             |             |           | Ureña et al. (2007)      |
| River in Spain                                  | 0.001-0.11  | 0.15-0.29   | 0.006-0.060 |           | 0.15-0.53   |           |           |             |             |           | Linde et al. (2004)      |
| River basins—Scheldt, Meuse, and Yser (Belgium) | 0.005-0.10  | 0.33-1.20   | 0.001-0.02  | 17-33     | 0.06-0.24   |           |           |             |             |           | Maes et al. (2005)       |
| Odiel estuary, Bay of Cadiz (Spain)             | 0.03-0.09   | 0.5-1.50    | 0.015-0.05  | 10-13     | 0.010-0.023 | 4.7-14.1  | 4.11-5.89 | 0.015-0.020 | 0.52-2.91   |           | Usero et al. (2003)      |
| Ria de Aveiro (Portugal)                        | 0.044-0.078 | 0.64-1.04   | 0.009-0.042 | 14-23.1   |             |           |           | 0.16-0.39   |             |           | Cid et al. (2001)        |
| River Turia (Spain)                             | 0.02-0.26   | 0.22-0.98   | 0.003-0.008 | 12-17     |             |           |           |             | 0.024-0.993 |           | Bordajandi et al. (2003) |
| Lesina Lagoon (Adriatic Sea)                    |             | 0.39-1.13   | 0.02-0.04   | 17.9-24.6 | 0.13-0.24   |           |           |             |             |           | Storrelli et al. (2007)  |
| Rivers in East England                          | 0.01-0.48   |             | 0.01-0.41   |           | 0.08-1.30   |           |           |             |             |           | Barak and Mason (1990)   |
| Ria de Aveiro, (Portugal)                       | 0.008-0.096 | 0.131-0.567 | 0.001-0.011 | 8.85-21.5 | 0.055-0.285 |           |           | 0.085-0.283 | 0.387-3.069 | 0.38-1.53 | Eira (2009)              |
| Watersheds of Flanders (Belgium)                | 0.001-3.45  | 0.05-0.43   | 0.001-2.47  | 1.2-243   | 0.005-1.185 |           |           | 0.005-16    | 0.014-1.805 |           | Maes et al. (2008)       |
| Rivers in France                                | 0.001-0.159 |             | 0.001-0.071 |           | 0.050-0.589 |           |           |             | 0.026-0.647 |           | Noël et al. (2013)       |

Continuous national monitoring of water quality and fish populations helps to improve the implementation of Water Framework Directive in practice.

## Conclusion

Eels all over the Europe are used as bioindicators for a variety of chemical contaminants in aquatic systems. The obtained data show that the elemental accumulation in muscle tissues of silver eels may be characterized as comparably low and it means that the Latvian freshwater ecosystem is relatively clean, and lakes included in the study are suitable for restocking of the eel population.

The amount of heavy metals accumulated in the muscles of eels is in good agreement with the results characterizing ecological water quality in other European countries.

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