Ribogospod. nauka Ukr., 2016; 3(37): 5-21
DOI: http://dx.doi.org/10.15407/fsu2016.03.005
UDC 574.64:597.08(285.2)(477)

HEAVY METALS IN ORGANS AND TISSUES OF STERLET (*ACIPENSER RUTHENUS* L.) IN THE DNIEPER-BUG ESTUARY

Yu. Sytnik, sytnik_yu@ukr.net, Institute of Hydrobiology of NAS of Ukraine, Kyiv
Yu. Pilipenko, pilipenko_eco@mail.ru, Kherson State Agrarian University, Kherson
P. Shevchenko, shevchenko.petr@edu.ua, National University of Life and Environmental Sciences of Ukraine, Kyiv
V. Plugatarev, vedorz@mail.ru, Dnieper sturgeon fish-reproductive plant named after academician S. T. Artyuschika, vill. Dneprovskoe, Belozersky district, Kherson region
N. Kolesnyk, kolesnik@if.org.ua, Institute of Fisheries NAAS, Kyiv
M. Simon, simonm@if.org.ua, Institute of Fisheries NAAS, Kyiv
A. Melnyk, melnik.kiev@mail.ru, Institute of Fisheries NAAS, Kyiv
N. Dorofey, darg@darg.gov.ua, State Agency of Fisheries of Ukraine, Kyiv

Purpose. *To iInvestigate and analyze the peculiarities of the accumulation of heavy metals (Cu, Fe, Zn, Cd, Pb, Co, Ni and Mn) in the organs (muscles, gills, liver, kidneys, fins, intestine) and tissues of sterlet (Acipenser ruthenus Linnaeus, 1758) for detecting the patterns of their accumulation and predicting the effect of their toxicological load on the organism of sturgeons as well as for evaluating the polymetallic load on this species in the Dnieper-Bug estuary.*

Methodology*. The material for the research was represented by (3+)–(4+) sterlet caught in the spring of 2016 in the Dnieper-Bug estuary. Organs and tissue samples were homogenized and then burned in a mixture of concentrated nitric (HNO_3) and hydrochloric acid (HCl). The determination of heavy metals in organs and tissues of fish were performed by flame atomic absorption spectroscopy using an atomic absorption spectrophotometer AAS-3 and AAS-3N company "Carl Zeiss" (Jena, Germany).*

Findings. *The distribution of heavy metals in organs and tissues of sterlet (Acipenser ruthenus L.) of the Dnieper-Bug estuary in the spring of 2016 was characterized by heterogeneity and depended on their physico-chemical properties and functional characteristics of organs and tissues of the investigated fish. The highest quantities copper, zinc and iron are accumulated liver, while manganese and cobalt in gills. Toxic metals (lead and cadmium) are more concentrated in gills, skin and liver. The maximum contents in the tissues and organs of sterlet were observed for iron and zinc, while the minimals ones — for cadmium and cobalt.*

Originality. *The paper describes the actual data on the contents and peculiarities of heavy metal accumulation in the body of sterlet inhabiting the Dnieper-Bug estuary.*

Practical value. *The paper contains the newest information on the accumulation and content of heavy metals in organs and tissues of sterlet in the Dnieper-Bug estuary. The results of the work will be used for future comparative and biochemical studies of sterlet populations as well as serve as a basis for further monitoring of chemical contamination of water bodies in Ukraine.*

Keywords: *sterlet (Acipenser ruthenus), Dnieper-Bug estuary, pollutants, heavy metals, Cu, Fe, Zn, Cd, Pb, Co, Ni, Mn, ecotoxicology of sturgeons.*

PROBLEM STATEMENT AND ANALYSIS OF LAST ACHIEVEMENTS AND PUBLICATIONS

The Dnieper-Bug estuary is an open freshwater estuary in the northern part of the Black Sea located on the territory of Kherson and Mykolaiv oblasts of Ukraine. It consists of the Dnieper estuary elongated in sublatitudinal direction of (length 55 km, width up to 17 km) and narrow (width from 5 to 11 km) and meandering Bug estuary, elongated in submeridional direction with a length of 47 km. The predominant depth is 6–7, the maximum is 12 m (so-called Stanislavska pit). The estuary connects with the Black Sea through a strait with a width of 3.6 km (between Ochakiv Cape and Kinburn spit). Approximately 25–30% of water flow of the Dnieper and Southern Bug are used for irrigation and industrial water supply, resulting in an increase in salinity in the estuary. This fact, in its turn, alters the biochemical effects of heavy metals and responses of aquatic organisms on them. This is due to different actions of these elements in fresh and sea waters. For example, Cd^{2+} is more toxic at lower salinity due to its transformation into the form of free ions. At the same time, the toxic effects of Pb^{2+} and Zn^{2+} are less dependent on salinity because they present in water in the form of hydroxides.

The major pollutants of water in the estuary are brought by the Dnieper, Southern Bug and Ingulets rivers [4, 5]. The emergency discharge of mine waters became a practically planned pollution for estuary waters. For example, about 12 million m^3 of mine water of Kryvbas (Kryvorizkyi Iron Ore Basin) with a salinity of up to 4000 mg/dm^3 are dumped every year into the Ingulets River [8, 9, 10]. In addition, permanent sources of pollution of estuary waters are harboring vessels and the activity of port cities as a whole. At present, estuary sediments play a role of the collector of man-made products and a kind of the natural disposal place for heavy metals. They do not biodegrade and being gradually accumulated in various ecosystem components are actively involved in the biological cycle of chemical elements, resulting in the poisoning of biotic components in hydroecosystems. Human impacts of recent years led to the fact that the majority of the bottom sediments of the estuary waters (about 70%) belong to the category of allowable pollution, while the upper parts of the estuary and the zones of the influence of municipal landfills are recognized as hazardous areas. The status of "critically dangerous zones" is assigned to the zones of the impact of shipbuilding yards and ports. The areas of the lower parts of the estuary, where sterlet (*Acipenser ruthenus*) occasionally occurs, belong to "moderately polluted zones". Being a bottom-dwelling species, it cannot but react to the fact that the majority of bottom sediments in the estuary (83%) are contaminated with Cu^{2+} at concentrations exceeding the allowable ones, 70% of waters are contaminated with Ni^{2+}, 40% with Mn^{2+}, 32% with Zn^{2+} and 22% with Pb^{2+}. The similar level of contamination characterizes the ecological state of the water body as critical and is a constant source of toxicosis for sterlet populations.

Sterlet (*Acipenser ruthenus* Linnaeus, 1758) is the most important representative of the biota of the Dnieper-Bug estuary. It belongs to the most valuable representatives of sturgeons both with economic and environmental points of view, being one of few species of sturgeons that permanently live in fresh river water forming isolated populations. The maximum length of this fish is more than 70 cm and weight of up to 4–5 kg. In fisherman catches in natural bodies of water, mainly individuals of 40–45 cm in length and weighing up to 2 kg are observed. However, in pond farms, age-1+ fish can attain more than 1 kg. Among other sturgeons, sterlet is characterized by the earliest maturation age: males spawn for the first time at the age of 4–5 years, females — 7–8 years. The fertility varies from 4 to 140 thousand eggs. Spawning occurs in May, usually in the upper reaches of rivers. Eggs are adhesive and are deposited on stony-pebble bottom; the incubation period is about 4–5 days. Changes in environmental conditions that occur under the effect of anthropogenic factors caused a sharp decline in the number of sterlet population, creating a real threat to their existence. In Ukraine, sterlet has been listed as an endangered species in the Red Book, the official state document that contains an annotated list of rare and endangered species of flora and fauna, since 2009. Also, as for 2016, this species is listed as "vulnerable" according to IUCN (International Union for Conservation of Nature and Natural Resources). "Vulnerable species" is a conservation status assigned to species that are at risk of extinction. They require monitoring of their numbers and reproduction rates, as well as measures to promote the conservation of their habitats. Even if they are actively cultivated under controlled conditions, this status is maintained because there is a threat to the wild populations of this species.

The main way of overcoming this situation is the organization of artificial reproduction of sterlet at specialized enterprises. The Pilot Production Dnieper Sturgeon Fish-Reproductive Plant named after Academician S. T. Artyushchik (PPDSFPP) was built in 1984 for this purpose. It is a budgetary organization of state funding, which is a sub-unit of the State Agency of Fisheries of Ukraine. The total area of this enterprise is 106 hectares, of which 72 hectares are reserved for ponds (30 ponds), while the remaining area is used directly for the reproduction cycle and outbuildings. The result of more than 26 years of work on artificial reproduction of the PPDSFPP, is the release of more than 50 million downstream-migrant juveniles of sturgeons (beluga, Russian sturgeon, starry sturgeon, and sterlet) into the lower reaches of the Dnieper and the Dnieper-Bug estuary. During the period of its work, more than 2500 brood sturgeons were used for reproduction, including more than 1 thousand females and 1.5 thousand males. The amounts of works in some years fluctuated in a quite broad range and, if to take the number of free embryos into account, these numbers attained 9 million individuals with a total number of more than 113 million individuals. Based on tagging and subsequent trawl catches of sturgeon juveniles on their feeding grounds, the percentage of sturgeon fingerlings produced by artificial method at the PPDSFPP varied within 40–80% that proves the efficiency and benefits of the artificial propagation of sturgeons at fish hatcheries.

At the same time, there is an issue related to the survival and quality of adult sterlet in the Dnieper-Bug estuary, since heavy metals cause strong cumulative and synergistic effects. They occupy a leading place among the pollutants contaminating aquatic ecosystems, causing disorders in the structure of populations and reducing the adaptive functions of individual fish. The changes in ichthyocenoses occurring under the effect of heavy metals indicate on the narrowing of zones with optimum environmental conditions, deep disruption in the functioning of structures to ensure the resistance of fish to infections and infestations. The problem of the sustainable development of sterlet under constant toxicosis is especially pressing in connection with improvements in the commercial return rates of sturgeons.

HIGHLIGHT OF THE EARLIER UNRESOLVED PARTS OF THE GENERAL PROBLEM. AIM OF THE STUDY

One of the priority pollutants of the Dnieper-Bug estuary are heavy metals (Cu^{2+}, Fe^{2+}, Zn^{2+}, Cd^{2+}, Pb^{2+}, Co^{2+}, Ni^{2+} and Mn^{2+}), especially in view of port operations in Kherson and Ochakov. The majority of polymetallic pollutants are brought with waters of the Ingulets River, during the discharge of highly mineralized accumulating water reservoirs of mining and processing plants of Krivoy Rog from November to March every year [8]. This "winter" contamination of water areas with heavy metals was one of the reasons for our research why we selected sterlet caught in the spring.

The monitoring of heavy metal contents in different age groups of sterlet needs to be performed regularly, as these pollutants getting into the estuary with surface runoff, stay permanently in the ecosystem redistributing among its components. The study of the process of their accumulation and their ratios in the organism of sterlet is important for the solution of theoretical and practical problems of sturgeon culture, affecting the efficiency of the processes of domestication, incubation and restoration of the natural resources of this fish species as a whole.

Apart from the fact that heavy metals are an important indicator of the hydro-ecological status of aquatic ecosystems, they play an ambiguous role in the biochemical processes of fish organism. For example, with insufficient intake of essential microelements and excess of toxic ones, the microelement homeostasis can be disrupted, therefore not only the level of heavy metals in the organism is important, but also their ratio, because, as is known, microcelements are characterized by synergistic and antagonistic linkages. The optimum content of minerals in the organism supports the normal course of metabolic processes, and therefore high quality of brood sterlet.

To monitor the chemical and biological state of hydroecosystems and quality control of fish and fish products based on standartized elements, it is necessary to determine the levels of heavy metals in the ichthyofauna of water bodies and streams [1–7]. From the ecological and physiological point of view, the study of metabolism and concentration of heavy metals in aquatic organisms, in this case — sterlet, is an extremely important aspect for understanding the processes of their migration along food chains.

Based on the abovementioned, the aim of our work was to obtain and analyze relevant data on the pecularities of heavy metal accumulation in organs and tissues of sterlet of the Dnieper-Bug estuary.

MATERIALS AND METHODS

Age-3+ – 4+ females of sterlet (*Acipenser ruthenus* L.,) caught in the Dnieper-Bug estuary in the spring of 2016 were analyzed during this study.

The performed studies involved the determination of certain metals of the fourth period of the Mendeleev's periodic table of chemical elements, namely: copper (Cu^{2+}), iron (Fe^{2+}), zinc (Zn^{2+}), cadmium (Cd^{2+}), lead (Pb^{2+}), cobalt (Co^{2+}), nickel (Ni^{2+}) and manganese (Mn^{2+}) in the organs and tissues of investigated fish.

Samples of organs (muscle, gill, liver, kidney, fins, intestine) and tissues of sterlets were homogenized, and then burned in a mixture of concentrated nitric (HNO_3) and hydrochloric acid (HCl) at a ratio of 3:1 at 3 replications [1–3, 9, 11]. The precise weighed samples of the homogenate were 2 g for each replicate.

The determination of heavy metals in organs and tissues of fish was peformed by flame atomic absorption spectroscopy using the atomic absorption spectrophotometer AAS-3 and AAS-3N "Carl Zeiss" (Jena, Germany) at the Institute of Hydrobiology of the NAS of Ukraine and spectrophotometer C-115M1 (Sumy, Ukraine), at the Institute of Fisheries NAAS of Ukraine (Kyiv) [1–3, 12].

STUDY RESULTS AND THEIR DISCUSSION

Our works on the study of heavy metal contents in organs and tissues of fish in freshwater reservoirs of Ukraine were launched in 1986 [4, 5, 11]. The study in the Dnieper-Bug estuary continues to this day. Some materials were published [13, 14]. However, this article presents the current data on the accumulation of heavy metals (Cu^{2+}, Fe^{2+}, Zn^{2+}, Cd^{2+}, Pb^{2+}, Co^{2+}, Ni^{2+} and Mn^{2+}) in the organs and tissues of sterlet as for March 2016.

The studies confirmed that the sterlet actively accumulated iron from the environment because of its high biological activity. E.g., the iron content in the organism of investigated sterlet individuals was relatively high. Its highest concentrations were recorded in liver (32.04 mg/kg), gills (29.43 mg/kg) and fins (25.33 mg/kg). The high level of iron accumulation in liver can be explained by the fact that this organ contains large amounts of blood, where excess iron is deposited. Iron in liver performs a role of a reserve, where it is contained in the form of complexes being a starting material for further synthesis. It is liver, which contains the basic iron-containing protein — ferritin. The figure below (Fig. 1) shows a diagram of iron accumulation in the tissues and organs of sterlet caught in the spring of 2016 in the Dnieper-Bug estuary.

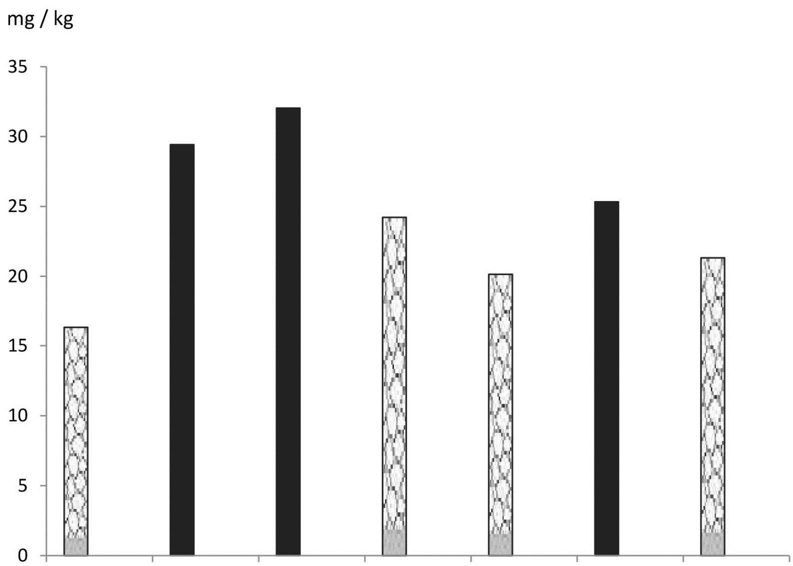

Fig. 1. **Iron accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

Thus, the lowest concentration of this metal is contained in kidneys (24.22 mg/kg), intestine (21.32 mg/kg), skin (20.14 mg/kg) and muscles (16.31 mg/kg). In ascending order of iron content in sterlet organs and tissues, they can be ranged as follows: muscles > skin > intestine > kidneys > fins > gills > liver.

According to the content level in sterlet organism, zinc is second element after iron. This is because its physiological role is polyfunctional — it is involved in the supramolecular organization of intracellular complexes, affects the activity of pituitary gonadotropic hormones, is included in the compositon of glycolysis and respiration enzymes, and required for the formation and function of intracellular membranes. The figure below (Fig. 2) shows a diagram of zinc accumulation in the tissues and organs of sterlet caught in the spring of 2016 in the Dnieper-Bug estuary.

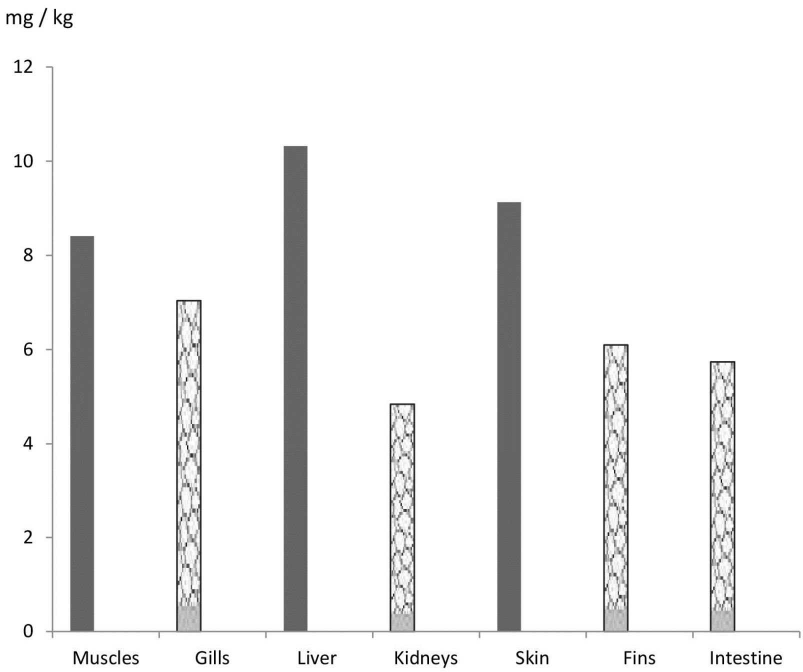

Fig. 2. **Zinc accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

As can be seen from the diagram, the largest amounts of zinc are recorded in liver (10.32 mg/kg), skin (9.13 mg/kg) and muscles (8.41 mg/kg). The lowest contents of this metal were recorded in kidneys (4.84 mg/kg), intestine (5.74 mg/kg) and fins (6.10 mg/kg). In ascending order of zinc content in sterlet organs and tissues, they can be ranged as follows: kidneys > intestine > fins > gills > muscles > skin > liver.

Copper is involved in phenol, nitrogen and nucleic metabolisms of sterlet organism. Furthermore, copper metabolism directly depends on iron content, because it affects both the absorption and the use of the latter. Thus, copper occupies the third place based on the content in sterlet organism after iron and zinc. The figure below (Fig. 4) graphically display the levels of copper accumulation in organs and tissues of investigated starlet individuals.

As can be seen from the diagram, the highest copper content is recorded in liver

(8.57 mg/kg), kidneys (1.57 mg/kg) and skin (1.30 mg/kg). The lowest levels of its content are registered in fins (0.20 mg/kg), muscles (0.53 mg/kg) and intestine (0.75 mg/kg). In ascending order of copper content in sterlet organs and tissues, they can be ranged as follows: fins > muscles > intestine > gills > skin > kidneys > liver.

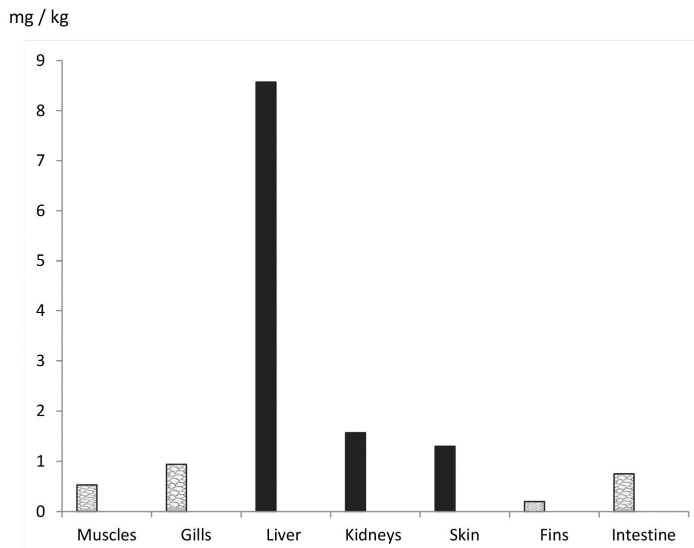

Fig. 3. **Copper accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

Lead accumulation in sterlet organism allows making a conclusion on its constant intoxication with this metal belonging to the group of priority tracking elements. It is recognized as one of the most dangerous pollutants because it is characterized by prolonged effect. As a potent inhibitor of cell metabolism, it enhances the toxicity of other metals. This metal is definitely toxic for sterlet, the symptoms of poisoning are observed at a concentration of 0.1–0.4 mg/dm^3. The diagram below (Fig. 4) shows the levels of lead accumulation in organs and tissues of the investigated sterlet.

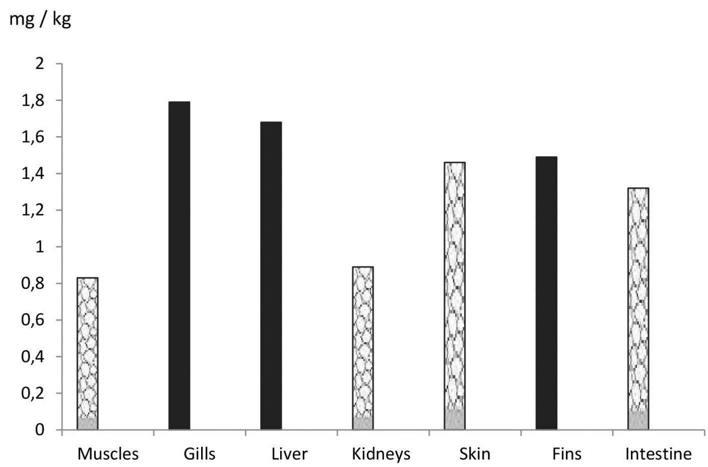

Fig. 4. **Lead accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

As can be seen from the diagram, a marked accumulation of this metal occurs in gills that is probably due to their respiratory function, ensuring the penetration of the metal into the organism. In general, the highest lead contents were recorded in fins (1.49 mg/kg), liver (1.68 mg/kg) and gills (1.79 mg/kg). The lowest concentrations of this metal were recorded in muscles (0.83 mg/kg), kidneys (0.89 mg/kg) and intestine (1.32 mg/kg). In ascending order of lead content in sterlet organs and tissues, they can be ranged as follows: muscle > kidneys > intestine > skin > fins > liver > gills.

Participating in biological catalysis and stimulating protein, carbohydrate and fat metabolisms, manganese has a significant impact on growth, reproduction and hematopoiesis in sterlet. It should be noted that the compounds of this element are the least toxic for sterlet in comparison with other heavy metals. The diagram below (Fig. 5) graphically displays the levels of manganese accumulation in organs and tissues of the investigated individuals of sterlet.

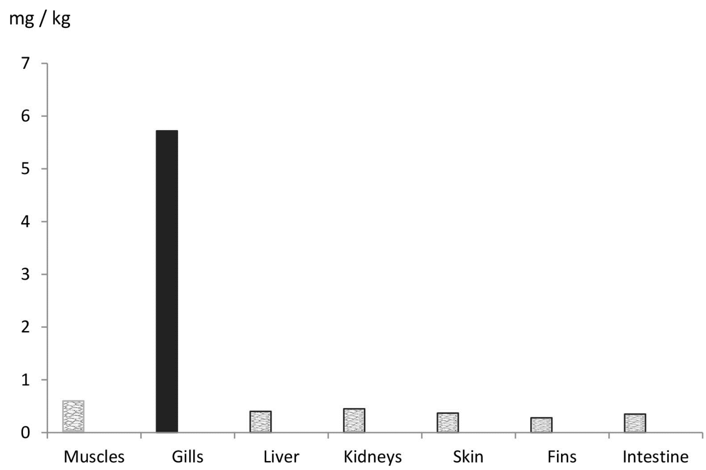

Fig. 5. **Manganese accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

As can be seen from the diagram, the highest amounts of manganese were recorded in gills (5.72 mg/kg). At the same time the lowest amounts of this metal were observed in fins (0.28 mg/kg), intestine (0.35 mg/kg) and skin (0.37 mg/kg). In ascending order of manganese content in sterlet organs and tissues, they can be ranged as follows: fins > intestine > skin > liver > kidneys > muscles > gills.

Nickel belongs to trace elements, which are necessary for normal development of multiple-age individuals of sterlet. Its compounds are catalysts of hematopoietic and enzymatic processes. At the same time, it is carcinogenic and mutagenic. The diagram below (Fig. 6) graphically displays the levels of nickel accumulation in organs and tissues of the investigated individuals of sterlet.

As can be seen from the diagram, the highest amounts of nickel are accumulated in gills (1.11 mg/kg), fins (0.91 mg/kg) and skin (0.73 mg/kg). The lowest accumulation of this metal is observed in muscles (0.33 mg/kg), intestine (0.52 mg/kg) and kidneys (0.62 mg/kg). In ascending order of nickel content in sterlet organs and tissues, they can be ranged as follows: muscles > intestine > kidneys > liver > skin > fins > gills.

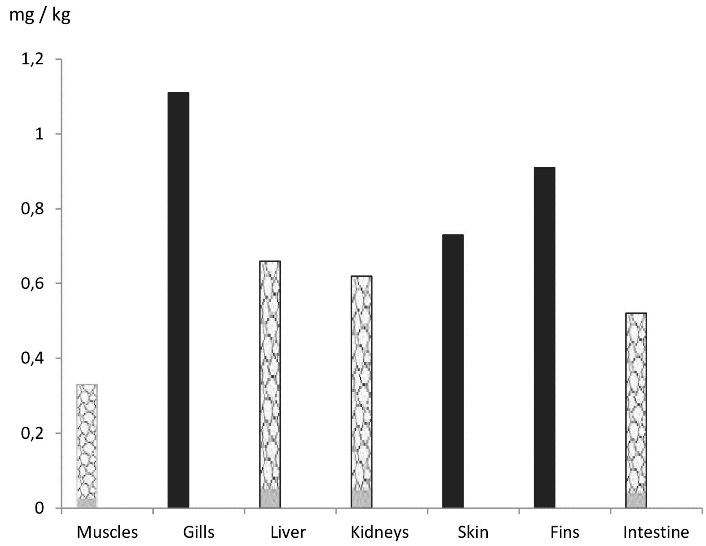

Fig. 6. **Nickel accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

The content of cadmium in the organism of sterlet was insignificant because this element is eliminated from sterlet organism with the aid of metallothioneins. While insignificant amounts of this element are required for normal function of fish organism (its low concentrations of approx. 25–100 g/dm^3 stimulate cell division), its tendency for accumulation results in metabolic disorders. The diagram below (Fig. 7) graphically displays the levels of cadmium accumulation in organs and tissues of the investigated individuals of sterlet.

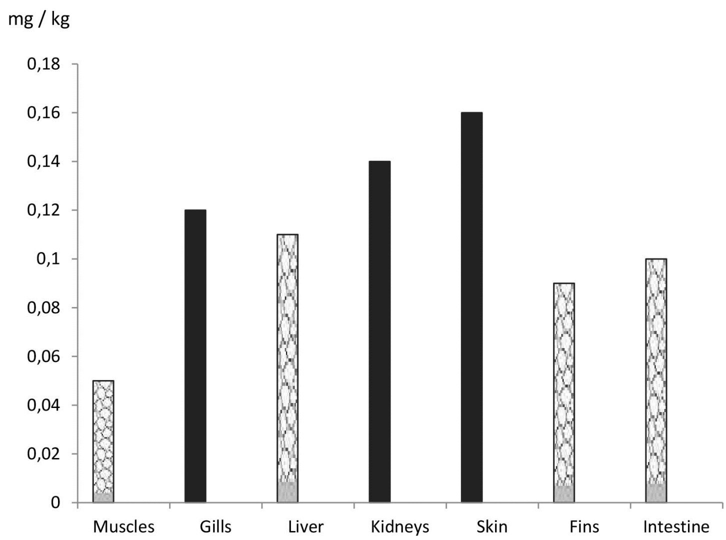

Fig. 7. **Cadmium accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

As can be seen from the diagram, the highest amounts of cadmium are accumulated in skin (0.16 mg/kg), kidneys (0.14 mg/kg) and gills (0.12 mg/kg). The lowest accumulation of this metal occurs in muscles (0.05 mg/kg), fins (0.09 mg/kg) and intestine (0.10 mg/kg). In ascending order of cadmium content in sterlet organs and tissues, they can be ranged as follows: muscle > fins > intestine > liver > gills > kidneys > skin.

Cobalt is an essential trace element for sterlet, which is constantly present in its tissues. Entering into a molecule of vitamin B_{12} (cobalamin), cobalt is necessary for hematopoiesis, normalization of nervous system and liver functioning, enzymatic reactions. At the same time, its excess causes blood pathologies and results in fish growth delay. Among the studied heavy metals (Cu, Fe, Zn, Cd, Pb, Mn, Ni), the total content of cobalt in sterlet organism is the lowest — 0.57 mg/kg of wet weight. The diagram below (Fig. 8) graphically displas the levels of cobalt accumulation in organs and tissues of the investigated individuals of sterlet.

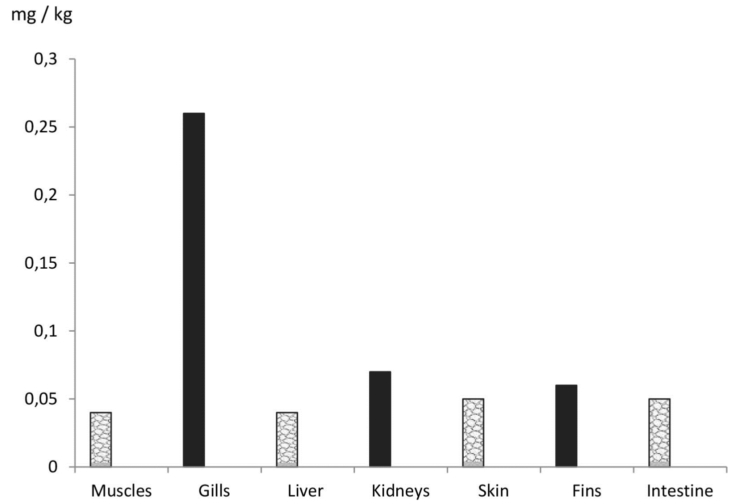

Fig. 8. **Cobalt accumulation in organs and tissues (mg/kg) of sterlet in the Dnieper-Bug estuary**

As can be seen from the diagram, the highest accumulated amounts of cobalt are observed in gills (0.26 mg/kg) and kidneys (0.07 mg/kg), while the lowest — in muscles (0.04 mg/kg). In ascending order of cobalt content in sterlet organs and tissues, they can be ranged as follows: muscles > intestine and skin > liver and kidneys > fins > gills.

The content of heavy metals in fish and fishery products is controlled by the sanitary rules, regulations and standards (SanPiN), medico-biological requirements and sanitary norms for the quality of food raw materials and food products, state standards of Ukraine. It should be noted that in Ukraine today, the content of heavy metals in edible parts of fish (muscles) is regulated according to the State standard of Ukraine 2284: 2010 "Live fish. General technical requirements". The contents of these elements should not exceed the standardized values, but they are developed only for four heavy metals: zinc, copper, lead and cadmium. Based on our data, we can say that the content of regulated heavy metals in the muscles of sterlet were significantly lower than the MAC (maximum allowable concentration): Zn — 8,41±0,63 mg/kg while MAC=40.0 mg/kg; Cu — 0,53±0,07 mg/kg while MAC=10.9 mg/kg; Pb — 0,83±0,09 mg/kg while MAC=1.0; Cd — 0.05±0.01 mg/kg while MAC=0.2 mg/kg.

The contents of heavy metals in organs and tissues of sterlet in the Dnieper-Bug estuary in the spring of 2016 are presented in Table 1.

Table 1. **The contents of heavy metals in organs and tissues of sterlet (*Acipenser ruthenus* L.) of the Dnieper-Bug estuary, mg/kg wet weight**

Organs and tissues	Heavy metals			
	Fe	Zn	Cu	Pb
Muscles	16,31±1,50	8,41±0,63	0,53±0,07	0,83±0,09
Gills	29,43±11,21	7,04±1,21	0,94±0,17	1,79±0,16
Liver	32,04±4,52	10,32±1,31	8,57±1,23	1,68±0,23
Kidneys	24,22±2,41	4,84±1,13	1,57±0,25	0,89±0,16
Skin	20,14±3,23	9,13±1,32	1,30±0,17	1,46±0,12
Fins	25,33±2,14	6,10±0,91	0,20±0,05	1,49±0,19
Intestine	21,32±1,74	5,74±0,72	0,75±0,15	1,32±0,15
Organs and tissues	**Mn**	**Ni**	**Cd**	**Co**
Muscles	0,60±0,07	0,33±0,06	0,05±0,01	0,04±0,01
Gills	5,72±0,61	1,11±0,16	0,12±0,03	0,26±0,02
Liver	0,40±0,10	0,66±0,11	0,11±0,02	0,06±0,01
Kidneys	0,45±0,09	0,62±0,13	0,14±0,03	0,07±0,02
Skin	0,37±0,11	0,73±0,05	0,16±0,03	0,05±0,01
Fins	0,28±0,05	0,91±0,17	0,09±0,03	0,06±0,02
Intestine	0,35±0,08	0,52±0,10	0,10±0,04	0,05±0,02

As the table shows, the lowest amounts of heavy metals were accumulated in muscles, kidneys and fins of sterlet. The highest levels of heavy metal accumulation were observed in gills, skin and liver. Summarizing the lowest content of heavy metals in organs and tissues of sterlet in descending order, we can form the following series: Fe (16.31 mg/kg in liver) > Zn (4.84 mg/kg in kidneys) > Pb (0.83 mg/kg in muscles) > Ni (0.33 mg/kg in muscles) > Mn (0.28 mg/kg in fins) > Cu (0.20 mg/kg in fins) > Cd (0.05 mg/kg in muscles) > Co (0.04 mg/kg in muscles). At the same time, in ascending order, the highest contents of heavy metals in organs and tissues of sterlet formed a series: Cd (0.16 mg/kg for the skin) > Co (0.26 mg/kg in gills) > Pb (1.79 mg/kg in gills) > Ni (1,11 mg/kg in gills) > Cu (8,57 mg/kg in liver) > Mn (5.72 mg/kg in gills) > Zn (10,32 mg/kg in liver) > Fe (32,04 mg/kg in liver).

The levels of heavy metal accumulation in organs and tissues of sterlet are as follows:

- muscles: Fe > Zn > Pb > Cu > Mn > Ni > Cd > Co;
- gills: Fe > Zn > Mn > Pb > Ni > Cu > Co > Cd;
- liver: Fe > Zn > Cu > Pb > Ni > Mn > Cd > Co;
- kidneys: Fe > Zn > Cu > Pb > Ni > Mn > Cd > Co;
- skin: Fe > Zn > Pb > Cu > Ni > Mn > Cd > Co;
- fins: Fe > Zn > Pb > Ni > Mn > Cu > Cd > Co;
- intestine: Fe > Zn > Pb > Cu > Ni > Mn > Cd > Co.

Thus, of all investigated sterlet organs and tissues, the highest content was recorded for iron (as in general for the entire organism, and in particular organ — liver), while the lowest content was observed for cobalt (as in general for the entire organism and a particular organ — muscles).

CONCLUSION AND PERSPECTIVES OF FURTHER DEVELOPMENT

Sterlet (*Acipenser ruthenus* L.) — is a fish with high nutritional and dietary characteristics of meat quality, which has always been a desirable object of harvest and consumption. However, under the effect of anthropogenic pressure on natural hydroecosystems, this species disappeared from commercial fishery in Ukraine and was listed as endangered.

To resolve the current situation, a technology of artificial reproduction of sterlet in specialized enterprises such as the Pilot Production Dnieper Sturgeon Fish-Reproductive Plant named after Academician S. T. Artyuschika (PPDSFPP) has been developed and continuously improved.

However, in current conditions, when downstream migrating sterlet juveniles are released in the Dnieper-Bug estuary, they are exposed to the toxic effects of heavy metals (Cu^{2+}, Fe^{2+}, Zn^{2+}, Cd^{2+}, Pb^{2+}, Co^{2+}, Ni^{2+} and Mn^{2+}) that reduces the efficiency of artificial propagation, thereby affecting the rate of its commercial return. Since all heavy metals are characterized by high ability for accumulation, this paper analyzed the peculiarities of their accumulation in adult sterlet.

The distribution of heavy metals in sterlet organs and tissues in the Dnieper-Bug estuary in the spring of 2016 is characterized by heterogeneity and depends on their physicochemical properties and functional characteristics of organs and tissues. The highest quantities of copper, zinc and iron are observed in liver, while manganese and cobalt in gills. Toxic metals (lead and cadmium) are more concentrated in gills, skin and liver. The maximum contents in sterlet tissues and organs are typical for iron and zinc, while the minimum contents — for cadmium and cobalt. Comparing the results with content levels of heavy metals in freshwater fish [1–2], it should be noted that they fall within the standard range.

The performed studies on heavy metal contents in sterlet organs and tissues provide an opportunity to assess the polymetallic load on this species in the Dnieper-Bug estuary and will serve as a basis for further monitoring of chemical contamination of reservoirs in Ukraine.

BIBLIOGRAPHY

1. Костяницын М. Н. Гидрология устьевой области Днепра и Южного Буга / Костяницын М. Н. — М. : Гидрометеоиздат, 1964. — 336 с.
2. Географічна енциклопедія України : у 3 т. / [ред. Маринич О. М. та ін.] — К. : Українська радянська енциклопедія ім. М. П. Бажана, 1989.
3. Хільчевський В. К. Основи гідрохімії / Хільчевський В. К., Осадчий В. І., Курило С. М. — К. : Ніка-Центр, 2012. — 312 с.
4. Морозов Н. П. Переходные и тяжёлые металлы в промысловой ихтиофауне океанических, морских и пресных вод / Н. П. Морозов, С. А. Петухов // Рыбное хозяйство. — 1977. — № 5. — С. 11—13.

5. Никаноров А. М. Биомониторинг тяжелых металлов в пресноводных экосистемах / Никаноров А. М., Жулидов А. В., Покаржевский А. Ф. — Л. : Гидрометеоиздат, 1985. — 144 с.
6. Никаноров А. М. Биомониторинг металлов в пресноводных экосистемах / Никаноров А. М., Жулидов А. В. — Л. : Гидрометеоиздат, 1990. — 327 с.
7. Трахтенберг И. М. Тяжелые металлы во внешней среде. Современные гигиенические и токсикологические аспекты / Трахтенберг И. М., Колесников В. С., Луковенко В. П. — Минск : Наука и техника, 1994. — 285 с.
8. Геоекологічні проблеми Криворізького басейну в умовах реструктуризації гірничодобувної галузі / [Багрій І. Д., Блінков П. В., Бєлокопитова Н. А. та ін.]. — К. : Фенікс, 2002. — 192 с.
9. Шахман И. А. Экологические аспекты химического загрязнения водных ресурсов р. Ингулец в трансформированной среде в пределах Николаевской области / И. А. Шахман, Ю. В. Пилипенко, А. Н. Быстрянцева // Таврійський науковий вісник. — 2015. — Вип. 93. — С. 265—275.
10. Условия формирования донных осадков устьевых участков рек Днепровско-Бугского лимана в условиях антропогенной нагрузки / И. Н. Малахов, Т. Н. Алехина, В. В. Иванченко [и др.] // Геология и полезные ископаемые Мирового океана. — 2010. — № 2. — С. 69—78.
11. Сосуществующие формы тяжелых металлов в поверхностных водах Украины и роль органических веществ в их миграции / П. Н. Линник, Т. А. Васильчук, Р. П. Линник [и др.] // Методы и объекты химического анализа. — 2007. — Т. 2, № 2. — С. 130—145.
12. Рыба стерлядь — фото, выращивание, биология, разведение, икра и малек [Электронный ресурс]. — Режим доступа : http://aquavitro.org/2016/05/17/sterlyad.
13. Биологический энциклопедический словарь / [гл. ред. М. С. Гиляров]. — М. : Сов. энциклопедия, 1986. — С. 59.
14. Червона книга України [Електронний ресурс]. — Режим доступу : http://redbook-ua.org.
15. IUCN, International Union for Conservation of Nature [Electronic resourse]. — Retrieved from : https://www.iucn.org.
16. Итоги работ по восстановлению численности днепровских осетровых / Ю. В. Пилипенко, В. А. Корниенко, В. А. Плугатарёв [и др.] // Вопросы рыбного хозяйства Беларуси. — 2014. — Вып. 30. — С. 180—187.
17. Петухов С. А. Распределение микроэлементов группы тяжелых и переходных металлов в органах и тканях рыб / С. А. Петухов, Н. П. Морозов, М. С. Добрусин // Экологические аспекты химического и радиоактивного загрязнения водной среды. — М. : Легкая и пищевая пром-сть, 1983. — С. 41—47.
18. Радиоактивное и химическое загрязнение Днепра и его водохранилищ после аварии на Чернобыльской АЭС / Романенко В. Д., Кузьменко М. И., Евтушенко Н. Ю. [и др.]. — К. : Наукова думка, 1992. — 195 с.
19. Евтушенко Н. Ю. Накопление тяжелых металлов в тканях и органах рыб / Н. Ю. Евтушенко, Ю. М. Сытник // Радиоактивное и химическое загрязнение

Днепра и его водохранилищ после аварии на Чернобыльской АЭС. — К. : Наукова думка, 1992. — С. 53—64.
20. Колесник Н. Л. Токсичний вплив пестицидів на біоту прісних водойм (огляд) / Н. Л. Колесник // Рибогосподарська наука України. — 2015. — № 4(34). — С. 31—53.
21. Колесник Н. Л. Розподіл важких металів серед компонентів прісноводних екосистем (огляд) / Н. Л. Колесник // Рибогосподарська наука України. — 2014. — № 3(29). — С. 35—54.
22. Техногенно-экологическая безопасность биогеосистемы Бугского лимана в условиях загрязнения тяжелыми металлами / Долин В. В., Смирнов В. Н., Ищук А. А. [и др.]. — К.; Николаев : РАЛ-поліграфія, 2011. — 200 с.
23. Морозов Н. П. Микроэлементы в промысловой ихтиофауне Мирового океана / Н. П. Морозов, С. А. Петухов. — М. : Агропромиздат, 1986. — 160 с.
24. Хавезов И. Атомно-абсорбционный анализ / И. Хавезов, Д. Цалев. — Л. : Химия, 1983. — 144 с.
25. Ситник Ю. М. Важкі метали в органах та тканинах риби Дніпровсько-Бузького лиману / Ю. М. Ситник, М. Ю. Євтушенко // Таврійський науковий вісник. — 2009. — Вип. 67. — С. 142—155.
26. Евтушенко Н. Ю. Тяжелые металлы в органах и тканях рыбы Днепровско-Бугского лимана (1987 г.) / Н. Ю. Евтушенко, Ю. М. Сытник // Тяжелые металлы и радионуклиды в окружающей среде : VI междунар. науч.-практ. конф. : матер. — Семей, 2010. — Т. II. — С. 369—376.

REFERENCES

1. Kostyanitsyn, M. N. (1964). *Gidrologiya ust'evoy oblasti Dnepra i Yuzhnogo Buga.* Moskva : Gidrometeoizdat.
2. Marynych, O. M. (Ed.). (1989). *Heohrafichna entsyklopediia Ukrainy. (Vol. 1-3).* Kyiv : Ukrainska radianska entsyklopediia im. M. P. Bazhana.
3. Khilchevskyi, V. K., Osadchyi, V. I., & Kurylo S. M. (2012). *Osnovy hidrokhimii.* Kyiv : Nika-Tsentr.
4. Morozov, N. P., & Petukhov, S. A. (1977). Perekhodnye i tyazhelye metally v promyslovoy ikhtiofaune okeanicheskikh, morskikh i presnykh vod. *Rybnoe khozyaystvo, 5,* 11-13.
5. Nikanorov, A. M., Zhulidov, A. V., & Pokarzhevskiy, A. F. (1985). *Biomonitoring tyazhelykh metallov v presnovodnykh ekosistemakh.* Leningrad : Gidrometeoizdat.
6. Nikanorov, A. M., & Zhulidov, A. V. (1990). *Biomonitoring metallov v presnovodnykh ekosistemakh.* Leningrad : Gidrometeoizdat.
7. Trakhtenberg, I. M., Kolesnikov, V. S., & Lukovenko, V. P. (1994). *Tyazhelye metaly vo vneshney srede. Sovremennye gigienicheskie i toksikologicheskie aspekty.* Minsk : Nauka i tekhnika.
8. Bahrii, I. D., Blinkov, P. V., & Bielokopytova, N. A. et al. (2002). Heoekolohichni problemy Kryvorizkoho baseinu v umovakh restrukturyzatsii hirnychodobuvnoi haluzi. Kyiv : Feniks.
9. Shakhman, I. A., Pilipenko, Yu. V., & Bystryantseva, A. N. (2015). Ekologicheskie aspekty khimicheskogo zagryazneniya vodnykh resursov r. Ingulets v transformirovannoy srede v predelakh Nikolaevskoy oblasti. *Tavriys'kiy naukoviy visnik, 93,* 265-275.

10. Malakhov, I. N., Alekhina, T. N., & Ivanchenko, V. V. et al. (2010). Usloviya formirovaniya donnykh osadkov ust'evykh uchastkov rek Dneprovsko-Bugskogo limana v usloviyakh antropogennoy nagruzki. *Geologiya i poleznye iskopaemye Mirovogo okeana, 2,* 69-78.
11. Linnik, P. N., Vasil'chuk, T. A., & Linnik, R. P. et al. (2007). Sosushchestvuyushchie formy tyazhelykh metallov v poverkhnostnykh vodakh Ukrainy i rol' organicheskikh veshchestv v ikh migratsii. *Metody i ob'ekty khimicheskogo analiza, 2, 2,* 130-145.
12. Ryba sterlyad' — foto, vyrashchivanie, biologiya, razvedenie, ikra i malek. *aquavitro.org.* Retrieved from http://aquavitro.org/2016/05/17/sterlyad.
13. Gilyarov, M. S., Baev, A. A., Vinberg, G. G., & Zavarzin, G. A. et al. (Eds.) (1986). *Biologicheskiy entsiklopedicheskiy slovar'.* Moskva : Sov. entsiklopediya.
14. Chervona knyha Ukrainy. *redbook-ua.org.* Retrieved from http://redbook-ua.org.
15. IUCN, International Union for Conservation of Nature. *iucn.org.* Retrieved from https://www.iucn.org.
16. Pilipenko, Yu. V., Kornienko, V. A., & Plugatar'ev, V. A. et al. (2014). Itogi rabot po vosstanovleniyu chislennosti dneprovskikh osetrovykh. *Voprosy rybnogo khozyaystva Belarusi, 30,* 180-187.
17. Petukhov, S. A., Morozov, N. P., & Dobrusin, M. S. (1983). Raspredelenie mikroelementov gruppy tyazhelykh i perekhodnykh metallov v organakh i tkanyakh ryb. *Ekologicheskie aspekty khimicheskogo i radioaktivnogo zagryazneniya vodnoy sredy.* Moskva : Legkaya i pishchevaya prom-st', 41-47.
18. Romanenko, V. D., Kuz'menko, M. I., & Evtushenko, N. Yu. et al. (1992). *Radioaktivnoe i khimicheskoe zagryaznenie Dnepra i ego vodokhranilishch posle avarii na Chernobyl'skoy AES*. Kiev : Naukova dumka.
19. Evtushenko, N. Yu., & Sytnik, Yu. M. (1992). Nakoplenie tyazhelykh metallov v tkanyakh i organakh ryb. *Radioaktivnoe i khimicheskoe zagryaznenie Dnepra i ego vodokhranilishch posle avarii na Chernobyl'skoy AES.* Kiev : Naukova dumka, 53-64.
20. Kolesnyk, N. L. (2015). Toksychnyi vplyv pestytsydiv na biotu prisnykh vodoim (ohliad). *Rybohospodarska nauka Ukrainy, 4(34),* 31-53.
21. Kolesnyk, N. L. (2014). Rozpodil vazhkykh metaliv sered komponentiv prisnovodnykh ekosystem (ohliad). *Rybohospodarska nauka Ukrainy, 3(29),* 35-54.
22. Dolin, V. V., Smirnov, V. N., & Ishchuk, A. A. (2011). *Tekhnogenno-ekologicheskaya bezopasnost' biogeosistemy Bugskogo limana v usloviyakh zagryazneniya tyazhelymi metallami*. Kiev-Nikolaev : RAL-poligrafiya.
23. Morozov, N. P., & Petukhov, S. A. (1986). *Mikroelementy v promyslovoy ikhtiofaune Mirovogo okeana.* Moskva : Agropromizdat.
24. Khavezov, I., & Tsalev, D. (1983). *Atomno-absorbtsionnyy analiz.* Leningrad : Khimiya.
25. Sytnyk, Iu. M., & Yevtushenko, M. Iu. (2009). Vazhki metaly v orhanakh ta tkanynakh ryby Dniprovsko-Buzkoho lymanu. *Tavriiskyi naukovyi visnyk, 67,* 142-155.
26. Evtushenko, N. Yu., & Sytnik, Yu. M. (2010). Tyazhelye metally v organakh i tkanyakh ryby Dneprovsko-Bugskogo limana (1987 g.). *Tyazhelye metally i radionuklidy v okruzhayushchey srede : VI mezhdunar. nauch.-prakt. konf. : mater. Vol. 2.* Semey, 369-376.

ВАЖКІ МЕТАЛИ В ОРГАНАХ І ТКАНИНАХ СТЕРЛЯДІ (*ACIPENSER RUTHENUS* L.) ДНІПРОВСЬКО-БУЗЬКОГО ЛИМАНУ

Ю. М. Ситник, sytnik_yu@ukr.net, Інститут гідробіології НАН, м. Київ
Ю. В. Пилипенко, pilipenko_eco@mail.ru, Херсонський державний аграрний університет, м. Херсон
П. Г. Шевченко, shevchenko.petr@edu.ua, Національний університет біоресурсів і природокористування, м. Київ
В. А. Плугатарьов, vedorz@mail.ru, Дніпровський осетровий рибовідтворювальний з-д ім. академіка С. Т. Артющика, с. Дніпровське, Білозерський р-н, Херсонська обл.
Н. Л. Колесник, kolesnik@if.org.ua, Інститут рибного господарства НААН, м. Київ
М. Ю. Симон, simonm@if.org.ua, Інститут рибного господарства НААН, м. Київ
А. П. Мельник, melnik.kiev@mail.ru, Інститут рибного господарства НААН, м. Київ
Н. А. Дорофей, darg@darg.gov.ua, Державне агентство рибного господарства України, м. Київ

Мета. *Дослідити та проаналізувати особливості накопичення важких металів (Cu, Fe, Zn, Cd, Pb, 3, Ni і Mn) в органах (м'язи, зябра, печінка, нирки, плавці, кишечник) та тканинах стерляді (Acipenser ruthenus Linnaeus, 1758) з метою виявлення закономірностей їх накопичення і прогнозування впливу токсикологічного навантаження на організм осетрових риб, а також оцінки поліметалічного навантаження на даний вид в Дніпровсько-Бузькому лимані.*

Методика. *Матеріал для досліджень був представлений (3+)–(4+) особинами стерляді, виловленої навесні 2016 року з Дніпровсько-Бузького лиману. Проби органів та тканин гомогенізували, після чого спалювали в суміші концентрованих азотної (HNO_3) і соляної кислот (HCl). Визначення вмісту важких металів в органах та тканинах риб проводили методом атомно-абсорбційної спектроскопії в полум'яному варіанті атомізації на атомно-абсорбційному спектрофотометрі AAS-3 та AAS-3N компанії «Carl Zeiss» (Йєна, Федеративна Республіка Німеччина).*

Результати. *Розподіл важких металів у органах і тканинах стерляді Дніпровсько-Бузького лиману станом на весну 2016 р. характеризується неоднорідністю і залежить від їх фізико-хімічних властивостей і функціональних особливостей органів і тканин піддослідних риб. У найбільшій кількості мідь, залізо і цинк накопичуються в печінці, марганець і кобальт — у зябрах. Токсичні метали (свинець та кадмій) більшою мірою концентруються в зябрах, шкірі і печінці. Максимальний вміст в органах і тканинах стерляді характерний для заліза і цинку, а мінімальний — для кадмію і кобальту.*

Наукова новизна. *Вперше описані актуальні дані рівнів вмісту та особливостей накопичення важких металів в організмі стерляді, що мешкає в акваторії Дніпровсько-Бузького лиману.*

Практична значимість. *Подані новітні показники накопичення та вмісту важких металів в органах та тканинах стерляді Дніпровсько-Бузького лиману. Результати роботи будуть використані для подальших порівняльних та біохімічних досліджень популяцій стерляді, а також послужать базою для подальшого моніторингу хімічного забруднення водойм України.*

Ключові слова: *стерлядь (Acipenser ruthenus), Дніпровсько-Бузький лиман, полютанти, важкі метали, Cu, Fe, Zn, Cd, Pb, Co, Ni, Mn, екотоксикологія осетрових.*

ТЯЖЕЛЫЕ МЕТАЛЛЫ В ОРГАНАХ И ТКАНЯХ СТЕРЛЯДИ (*ACIPENSER RUTHENUS* L.) ДНЕПРОВСКО-БУГСКОГО ЛИМАНА

Ю. М. Сытник, sytnik_yu@ukr.net, Институт гидробиологии НАН, г. Киев
Ю. В. Пилипенко, pilipenko_eco@mail.ru, Херсонский государственный аграрный университет, г. Херсон
П. Г. Шевченко, shevchenko.petr@edu.ua, Национальный университет биоресурсов и природопользования, г. Киев
В. А. Плугатарёв, vedorz@mail.ru, Днепровский осетровый рыбо-воспроизводительный завод им. академика С. Т. Артющика, с. Днепровское, Белозерский р-н, Херсонская обл.
Н. Л. Колесник, kolesnik@if.org.ua, Институт рыбного хозяйства НААН, г. Киев
М. Ю. Симон, simonm@if.org.ua, Институт рыбного хозяйства НААН, г. Киев
А. Ф. Мельник, melnik.kiev@mail.ru, Институт рыбного хозяйства НААН, г. Киев
Н. А. Дорофей, darg@darg.gov.ua, Государственное агентство рыбного хозяйства Украины, г. Киев

Цель. *Исследовать и проанализировать особенности накопления тяжёлых металлов (Cu, Fe, Zn, Cd, Pb, Co, Ni и Mn) в органах (мышцы, жабры, печень, почки, плавники, кишечник) и тканях стерляди (Acipenser ruthenus Linnaeus, 1758) с целью выявления закономерностей их накопления и прогнозирования влияния токсикологической нагрузки на организм осетровых рыб, а также оценки полиметаллической нагрузки на данный вид в Днепровско-Бугском лимане.*

Методика. *Материал для исследований был представлен (3+)–(4+) особями стерляди, выловленной весной 2016 года из Днепровско-Бугского лимана. Пробы органов и тканей гомогенизировали, после чего сжигали в смеси концентрированных азотной (HNO_3) и соляной кислот (HCl). Определение содержания тяжёлых металлов в органах и тканях рыб проводили методом атомно-абсорбционной спектроскопии в пламенном варианте атомизации на атомно-абсорбционном спектрофотометре AAS-3 и AAS-3N компании «Carl Zeiss» (Йена, Федеративная Республика Германия).*

Результаты. *Распределение тяжёлых металлов в органах и тканях стерляди Днепровско-Бугского лимана по состоянию на весну 2016 г. характеризуется неоднородностью и зависит от их физико-химических свойств и функциональных особенностей органов и тканей подопытных рыб. В наибольшем количестве медь, железо и цинк накапливаются в печени, марганец и кобальт — в жабрах. Токсичные металлы (свинец и кадмий) в большей степени концентрируются в жабрах, коже и печени. Максимальное содержание в органах и тканях стерляди характерно для железа и цинка, а минимальное — для кадмия и кобальта.*

Научная новизна. *Впервые описаны актуальные данные по уровням содержания и особенностям накопления тяжёлых металлов в организме стерляди, обитающей в акватории Днепровско-Бугского лимана.*

Практическая значимость. *Поданы новейшие показатели накопления и содержания тяжёлых металлов в органах и тканях стерляди Днепровско-Бугского лимана. Результаты работы будут использованы для дальнейших сравнительных и биохимических исследований популяций стерляди, а также послужат базой для дальнейшего мониторинга химического загрязнения водоемов Украины.*

Ключевые слова: *стерлядь (Acipenser ruthenus), Днепровско-Бугский лиман, поллютанты, тяжёлые металлы, Cu, Fe, Zn, Cd, Pb, Co, Ni, Mn, экотоксикология осетровых.*