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HEAVY METALS AND ARSENIC IN COMMERCIAL FISH OF THE SEA OF JAPAN, SEA OF OKHOTSK, AND BERING SEA: CURRENT STATUS (LITERATURE REVIEW)

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The paper summarizes literature data on the concentrations of toxic elements – As, Pb, Cd, and Hg – in commercial fish of the Far Eastern seas – the Sea of Japan, Sea of Okhotsk, and Bering Sea. According to the analysis carried out, main commercial facilities and fishery basins meet the sanitary and hygienic standards. However, the existence of impact natural areas in fish ranges and on the routes of their migration contributes to an increase in concentrations of toxic elements in fishery objects. In some cases, the values exceed the maximum permissible levels. In this regard, it is necessary to continue monitoring of toxic microelements in commercial facilities and fishery basins of the Far Eastern seas.

Keywords: heavy metals, toxic elements, Far Eastern seas

The content of pollutants in marine ecosystems increases (Donets & Tsygankov, 2019), and this prioritizes food safety of seafood. Therefore, it is necessary to carry out chemical assessment of the quality of fish raw materials, in particular, from the standpoint of its pollution with heavy metals (Steblevskaya et al., 2016).

Heavy metals are characterized by high density and toxic effects even at very low concentrations (Duffus, 2002). Their intake into natural ecosystems occurs due to both natural processes and anthropogenic activities (Li et al., 2019). Heavy metals are considered hazardous because of their toxic and cumulative effects on living organisms and persistence in the environment.

Cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), and zinc (Zn) are essential trace elements; those are important for various biochemical and physiological functions (Dökmeci et al., 2014). Other metals – cadmium (Cd), mercury (Hg), and lead (Pb) – negatively affect living organisms even at relatively low concentrations (Bashkin & Kasimov, 2004 ; Hassan & Aarts, 2011).

Arsenic (As) is a carcinogenic chemical element with some properties of metals. In aquatic ecosystems, it can exist in both organic and inorganic (more toxic) forms (Soloduhina, 2014). Prolonged consumption of food containing As compounds can cause dangerous diseases (*e. g.*, coronary heart disease and neurological pathologies). Moreover, there may be physical and mental retardations in children and adolescents. Exposure to arsenic can cause diseases of the mucous membrane of the upper respiratory tract and emphysema, which increase the risk of lung cancer. Skin, liver, and bladder cancer may develop as well (Makarov, 2012).

Basically, cadmium, lead, mercury, and arsenic are accumulated in liver. This organ intensively accumulates metals, is a functional depot of these trace elements, and simultaneously participates in detoxification. A secondary position in terms of accumulation of toxic elements (Pb, As, and Cd) is occupied by muscle tissue. It can be attributed to accumulating organs as well, given that muscles make up a high percentage of body weight. Mostly, increased content of arsenic is recorded in gonads (Glazunova, 2007). Cadmium actively replaces calcium in cellular mechanisms regulating Ca concentration (through calcium channels). This toxicant enters the body mainly from the aquatic environment through gills which are actively involved in water–salt metabolism – regulate both absorption and excretion of water and salts (Chemagin et al., 2019). Lead is accumulated mainly in fish gills, liver, kidneys, and bones. In water bodies, Pb can be adsorbed by particles of bottom sediments; therefore, it will enter a body mostly through gills or with food. In the aquatic environment, under the effect of microorganisms, mercury is transformed into methylmercury which is taken up by a fish *via* the alimentary route and through gills during respiration, is intensively absorbed by tissues, and is accumulated in lipocytes. Moreover, methylation of inorganic Hg can occur in fish liver and intestines. Dissolved arsenic exists in trivalent and pentavalent forms. Fish absorb As from water through gills and intestines (Hrytsyniak et al., 2015). Analyzed organs and tissues accumulate various metals to varying degrees. The distribution of metals in fish is characterized by unevenness and depends on functional characteristics of organs, their cumulative activity, and chemical properties of a metal itself (Glazunova, 2007).

The issue of natural ecosystem pollution with heavy metals became especially acute in the mid-1960s – due to poisoning of people with mercury and cadmium compounds. They consumed food grown or caught in the environment polluted with Hg and Cd (Langston, 1990). Such cases confirm the need for monitoring water bodies aimed at detecting toxic elements and preventing dangerous situations.

In Russian Federation, the permissible level of heavy metals and arsenic is determined by the following regulatory documents controlling food safety: Sanitary Rules and Regulations 2.3.2.1078-01 (2002) and Technical Regulation of the Customs Union 021/2011 (2011).

Currently, in the Far Eastern fishery basin, about 99 % of all salmon are caught (out of the total catch in Russia), 100 % of crabs, over 90 % of flounders, over 40 % of herring, and about 60 % of molluscs. In terms of the volume of aquatic biological resources harvested by Russian fishermen, the Far Eastern basin ranks first (Pavlova et al., 2020). Therefore, annual studies of marine hydrobionts are required – in order to control commercial fishing areas.

To date, a large number of publications is focused on determining the trace element composition of hydrobionts in the Far Eastern seas (Chusovitina et al., 2020 ; Khristoforova & Kobzar, 2017, 2018 ; Khristoforova et al., 2015b ; Lebedev & Polyakova, 2019; *etc.*). Thereby, the aim of this work was to summarize the literature data on the content of toxic elements (cadmium, lead, arsenic, and mercury) in commercial fish of the Far Eastern seas of Russia.

Analytical techniques for determining heavy metals and arsenic

When determining the trace element concentration, the researchers used measuring instruments that differ in the way they work.

Predominantly, the atomic absorption was used which is based on the absorption of electromagnetic radiation of a certain wavelength by free atoms of the analyzed element. This technique involves using either electrothermal or flame atomizer. The electrothermal atomization is more sensitive to trace concentrations in the sample (from thousandths to tenths of μg·L^{-1}) compared to the flame atomization (its sensitivity is much lower to concentrations from tenths to tens and hundreds of μg·L^{-1}). At the same time, its detection limit is higher (from 10^{-1} to 10^{5} ng) than in the electrothermal variation (from 10^{-5} to 10 ng) (Burger et al., 2007 ; Khristoforova et al., 2015a, 2016 ; Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2016).

When determining mercury, the researchers carried out the stripping voltammetry and cold vapor atomic absorption. The core of the first technique is the isolation of the analyzed element from a dilute solution by electrolysis on a stationary indicator electrode, subsequent anodic dissolution of the obtained amalgam, and registration of the current–voltage curve. It allows determining the content at the level of tenths and hundredths of μg·L^{-1} (Khristoforova et al., 2015a, 2016). The cold vapor atomic absorption is based on the property of mercury to exist in the form of free atoms in the gas phase under normal conditions. The detection limit for this technique is 0.001–0.5 μg·mL^{-1} (Burger et al., 2007 ; Hwang et al., 2019 ; Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2016).

The core of the X-ray fluorescence is obtaining the spectrum of the studied material under X-rays. The detection limit is from 0.0001 % to 100 % (Chusovitina et al., 2020 ; Steblevskaya et al., 2013, 2016).

Toxic elements in commercial fish of the Sea of Okhotsk

The Sea of Okhotsk is one of the largest and deepest seas in Russia. Its area is 1,603 thousand km^2; volume, 1,318 thousand km^3; mean depth, 821 m; and maximum depth, 3,916 m (Dobrovolsky & Zalogin, 1982). It is characterized by impact geochemical conditions; those are formed by surface and underwater volcanism and postvolcanism of the Kuril Islands, as well as by upwellings delivering many chemical elements from the depths of the Kuril–Kamchatka Trench to the surface layer (Khristoforova et al., 2019b). The runoff of the Amur River carrying a large number of pollutants into the Sea of Okhotsk, active navigation, and oil production on the shelf are the factors which can negatively affect the trace element composition of marine ecosystems in this sea (Isakov & Kasperovich, 2007).

Pacific salmon (*Oncorhynchus* Suckley, 1861). It is the most valuable commercial fish: in terms of catch in the current century, Pacific salmon ranks the second–third (after pollock and herring). Its catches are 90 % provided by three species – the chum, pink, and sockeye salmon (Khristoforova et al., 2015b). These species are a suitable object for monitoring environmental pollution with trace elements due to their nutritional value, high abundance, and specificity of biological cycles and life strategies. While feeding in the ocean, fish make long seasonal migrations; as a result, trace elements can be accumulated in them in large amounts (Khristoforova et al., 2015b).

In 2013–2016, carcasses of the chum and pink salmon were investigated (Fig. 1). The content of toxic elements did not exceed the maximum permissible levels (hereinafter MPL) (TR TS 021/2011, 2011). Importantly, lead concentrations in carcass of the chum salmon sampled in 2013 (0.98 mg·kg^{-1} wet weight) approached the MPL (1.0 mg·kg^{-1} wet weight).

In the chum salmon tissues, trace element concentrations were higher than in the pink salmon tissues. This may be due to a longer life span and higher weight of the chum salmon (Zelenikhina et al., 2015).

In the chum salmon liver, high concentrations of lead were recorded: the values exceeded the MPL (TR TS 021/2011, 2011) (Fig. 2). Apparently, this is due to accumulating function of liver (Khristoforova et al., 2016). The content of mercury did not exceed the MPL.

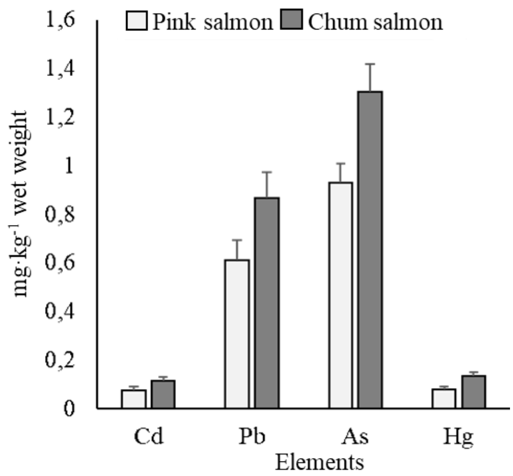

Fig. 1. Mean concentrations of heavy metals and arsenic in the pink and chum salmon carcasses, the Sea of Okhotsk (Khristoforova et al., 2015a)*

Such levels of accumulation are likely to be related to a long life span of the Pacific salmon and the fact that its feeding areas are located near spots characterized by abnormally high trace element concentrations (Khristoforova et al., 2016).

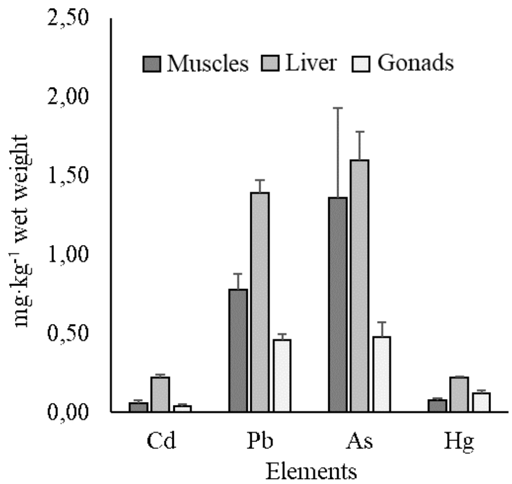

Fig. 2. Maximum mean concentrations of heavy metals and arsenic in the chum salmon organs, the Sea of Okhotsk (Khristoforova et al., 2016)

Sculpin (Cottidae Bonaparte, 1831). This family is one of the most typical and diverse in the northern Pacific Ocean. Cottidae lead benthic lifestyle and can make seasonal migrations (Matveev & Terentiev, 2016).

In 2013, representatives of the genus *Myoxocephalus* Tilesius, 1811 were sampled (Kovekovdova et al., 2013). When studying the trace element composition, a significant excess of the MPL was registered for cadmium in liver. Specifically, a value of 4.52 mg·kg^{-1} wet weight was recorded while the threshold is 0.7 mg·kg^{-1} wet weight. Moreover, arsenic, lead, and mercury were found in liver (Table 1). It can be concluded that liver is the main accumulating organ (Glazunova, 2007).

*Note. Maximum permissible levels (TR TS 021/2011, 2011) of toxic elements in fresh, chilled, and frozen sea fish: Pb, 1.0; Cd, 0.20; As, 5.0; Hg, 0.50 mg·kg^{-1} wet weight. In fish caviar and milt: As, 1.0; Cd, 1.0; Hg, 0.2 mg·kg^{-1} wet weight. In fish liver: Cd, 0.7; Hg, 0.2 mg·kg^{-1} wet weight.

Arsenic is accumulated mainly in muscles and gonads. The values registered during the research (see Table 1) may indicate the effect of terrigenous and anthropogenic pollution since *Myoxocephalus* fish feed in coastal areas during their migration (Wheeler, 1983).

Table 1. Maximum concentrations of heavy metals and arsenic in organs of *Myoxocephalus* fish, the Sea of Okhotsk, 2013, mg·kg^{-1} wet weight (Kovekovdova et al., 2013)

Organ	Cd	Pb	As	Hg
Liver	4.52	0.05	0.84	0.09
Muscles	0.05	0.02	1.88	0.02
Gonads	0.60	0.02	1.42	0.01

Righteye flounder (Pleuronectidae G. Cuvier 1816). This family is characterized by a rather wide species diversity in the World Ocean. Mostly, Pleuronectidae representatives are found in coastal shallow water, intertidal zones, and shelf areas. Fish can make seasonal migrations. The righteye flounders can be predators (benthivorous) or fish with a mixed feeding type (Wheeler, 1983). When reaching high abundance, some Pleuronectidae representatives become economically valuable. However, those are currently considered as a minor commercial species encountered as by-catch (Datsky & Maznikova, 2017).

In 2013, Schrenk flounder *Pseudopleuronectes schrenki* (Schmidt, 1904) was sampled for the trace element analysis (Kovekovdova et al., 2013). In liver, an increased concentration of cadmium was registered (1.7 mg·kg^{-1} wet weight): the MPL (0.7 mg·kg^{-1} wet weight) was exceeded by 2.4 times. The content of arsenic in gonads (1.2 mg·kg^{-1} wet weight) also exceeded the MPL (1.0 mg·kg^{-1} wet weight) (Fig. 3). Such a high concentration of cadmium in Schrenk flounder liver is explained by its metabolic–accumulating function, as well as by possible fish feeding in the area of wastewater of mining enterprises.

In general, it is arsenic that is most actively accumulated in all the studied organs. Apparently, this is due to physiological peculiarities of the Schrenk flounder.

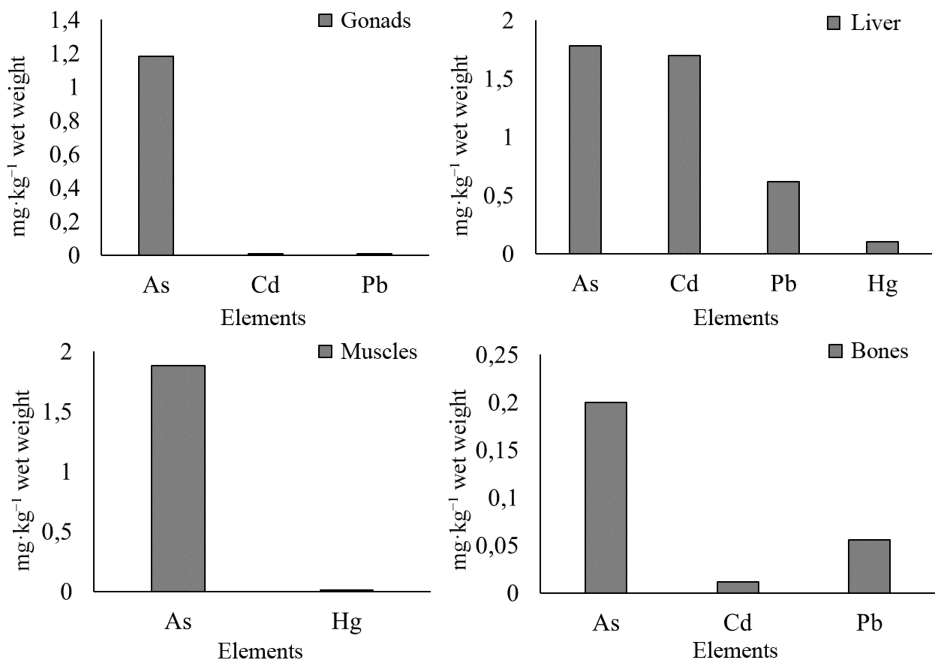

Fig. 3. Maximum concentrations of heavy metals and arsenic in organs of the Schrenk flounder *Pseudopleuronectes schrenki*, the Sea of Okhotsk (Kovekovdova et al., 2013)

Toxic elements in commercial fish of the Bering Sea

The Bering Sea is the largest of the Far Eastern seas washing the shores of Russia. Its area is 2,315 thousand km^2; volume, 3,796 thousand km^3; mean depth, 1,640 m; and maximum depth, 5,500 m. It is located in the northern Pacific Ocean and separated from it by the Aleutian and Commander islands; the Bering Strait connects it with the Chukchi Sea and Arctic Ocean (Shlyamin, 1958).

Anthropogenic load on the Bering Sea is exerted by rather active navigation causing local oil pollution. Coastal areas – the Anadyr Estuary, Ugolnaya Bay, and Kamchatka Peninsula shelf (Kamchatka Bay) – are subjected to the most intense load. The most polluted waters are those off the coast of Alaska (Balykin, 2006). Also, the trace element composition of waters can be affected by underwater volcanism – in particular, by activity of the Piip Volcano which is one of the largest (Astakhov et al., 2011). Importantly, near Anadyr, there is Ugolnye Kopi urban locality, with its mines and polluted industrial and domestic wastewaters. In some years, those brought to the Anadyr Estuary oil; petroleum products; sulfurous and hydrogen sulfide–containing gases; drill cuttings; mineralized formation water and wastewater from oil industry and well drilling; *etc.* (Poddubny, 2002).

Codfish (Gadidae Rafinesque, 1810). These pelagic fish are characterized by a wide species diversity and are widely spread in the oceans and seas of the Northern Hemisphere. Codfish are of high commercial importance. Gadidae representatives grow in size as long as they live, and fish life span averages 25 years. Codfish can be predators or plankton feeders (Orlov & Afanasiev, 2013).

The Pacific cod do not make long migrations; fish inhabit water areas of the Sea of Japan, Sea of Okhotsk, and Bering Sea keeping to the shore. The cod life span averages 10–12 years (Orlov & Afanasiev, 2013). For these reasons, codfish can act as bioindicators.

In order to study the trace element composition, the Pacific cod *Gadus macrocephalus* Tilesius, 1810 was sampled in the Aleutian Islands area in 2004 (Burger et al., 2007). The maximum values were recorded in liver (Fig. 4). The relatively high concentration of Cd in liver can be explained by high content of specific low molecular weight proteins – metallothioneins which have the capacity to bind cadmium (Alexeyeva & Tyunev, 2017).

In liver, the concentration of arsenic approaches the threshold of 5.0 mg·kg^{-1} wet weight. In muscles, lead and mercury prevail.

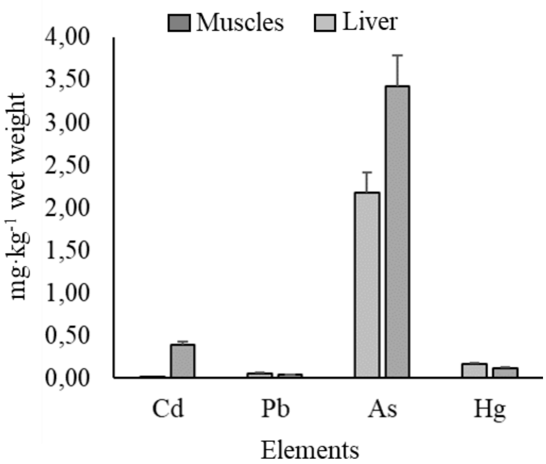

Fig. 4. Mean concentrations of heavy metals and arsenic in organs of the Pacific cod *Gadus macrocephalus*, the Bering Sea (Burger et al., 2007)

Righteye flounder (Pleuronectidae). Fish were sampled in the Aleutian Islands area in 2004 (Burger et al., 2007). In kidneys, the highest concentrations of lead and arsenic were recorded. Pb content (1.2 mg·kg^{-1} wet weight) exceeded the MPL (1.00 mg·kg^{-1} wet weight) (Fig. 5). In liver, cadmium, arsenic, and mercury prevailed. Cd concentration in liver (4.96 mg·kg^{-1} wet weight) was almost 7 times higher than the MPL (0.7 mg·kg^{-1} wet weight). In muscle tissue, Hg concentration was the highest since most of the mercury–binding proteins are there (Petukhov & Morozov, 1983).

In all analyzed organs, arsenic levels exceeded its threshold (MPL for sea fish is 5.00 mg·kg^{-1} wet weight, see note to Fig. 1). Specifically, in flounder kidneys, the value was 32.38 mg·kg^{-1} wet weight; in liver, 18.95; and in muscles, 19.45. The threshold was exceeded by almost 6.5, 4, and 6.5 times, respectively.

Fish were sampled on the Aleutian Islands – the islands of Adak, Kyska, and Amchitka. During World War II, military vehicles and weapons were tested there. As a result, lead, mercury, cadmium, and arsenic entered the water area, as well as petrochemicals, polyaromatic hydrocarbons, pesticides, and radioactive materials (Public Health Assessment, 2002).

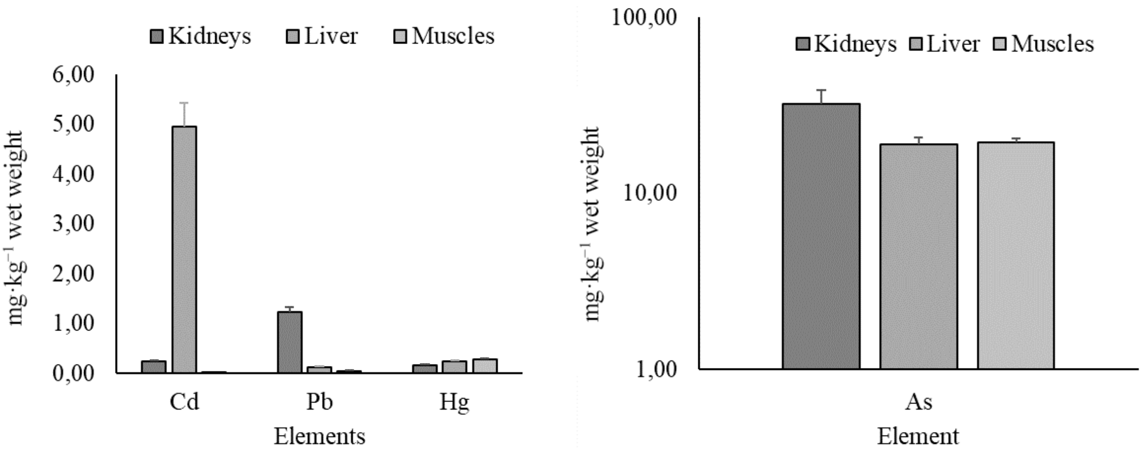

Fig. 5. Mean concentrations of trace elements in flounder, the Bering Sea (Burger et al., 2007)

Sculpin (Cottidae). In 2004, representatives of the genus *Myoxocephalus* were sampled in the Aleutian Islands area (Burger et al., 2007). The highest concentrations in fish liver were those of arsenic and cadmium. Importantly, the value for Cd (1.26 mg·kg^{-1} wet weight) exceeded the MPL (0.7 mg·kg^{-1} wet weight) (Fig. 6). Apparently, this is due to the fact that liver is involved in detoxification.

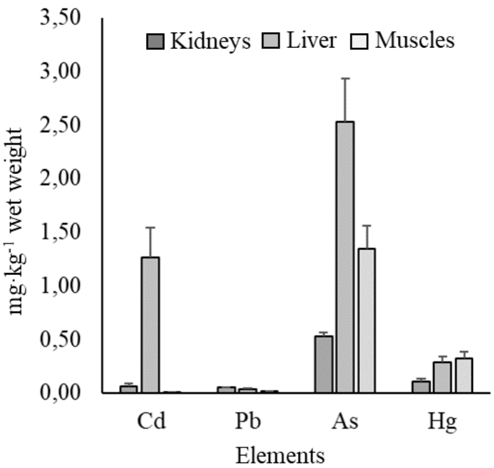

Fig. 6. Maximum mean concentrations of heavy metals and arsenic in organs of *Myoxocephalus* fish, the Bering Sea, 2004 (Burger et al., 2007)

Mercury is accumulated mostly in muscles; lead, in kidneys. In general, in *Myoxocephalus* fish, as in righteye flounders, increased concentrations may originate from the military activity on the Adak Island (Burger et al., 2007).

Toxic elements in commercial fish of the Sea of Japan

The Sea of Japan is a semi-enclosed sea of the Pacific Ocean. Its area is 1,062 thousand km^2; volume, 1,715 thousand km^3; mean depth, 1,750 m; and maximum depth, 3,720 m. From the neighboring Sea of Okhotsk, it is separated by the Sakhalin Island; from the Yellow Sea, by the Korean Peninsula. It washes the coasts of Russia, Japan, South Korea, and North Korea (Shuntov, 2001).

Due to a weak connection with the Pacific Ocean by several shallow straits, the Sea of Japan is under strong anthropogenic, technogenic, and terrigenous load. The affecting factors are domestic and industrial wastewaters, surface runoff from coastal areas, and consequences of burning fuel oil due to active navigation (Khristoforova, 1989).

Pacific salmon (*Oncorhynchus*). In 2013–2015, the pink salmon *Oncorhynchus gorbuscha* (Walbaum, 1792) was sampled (Kovekovdova et al., 2013, 2016). Its trace element composition complied with the thresholds; there was no noticeable excess of the MPL (Fig. 7). Apparently, this is due to a too short life span of the pink salmon – about 1.5 years (Khristoforova et al., 2019a).

Trace elements are mainly accumulated in liver, especially cadmium and arsenic. This is due to its metabolic–accumulating function.

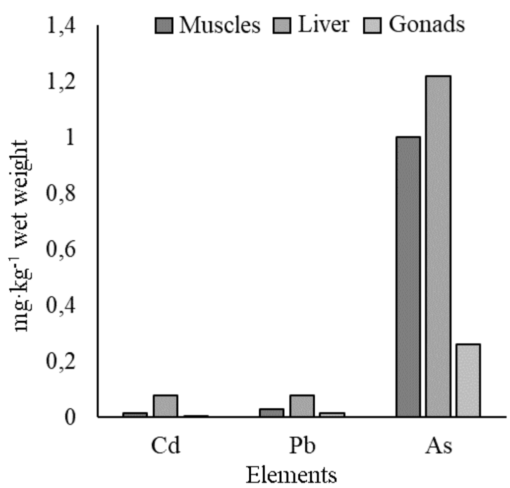

Fig. 7. Maximum concentrations of trace elements in organs and tissues of the pink salmon *Oncorhynchus gorbuscha*, the Sea of Japan, 2013–2015 (Kovekovdova et al., 2013, 2016)

Greenling (Hexagrammidae Gill, 1889). Representatives of this family lead predominantly benthic and coastal lifestyle. Fish are objects of both recreational and commercial fishing. Mostly, greenlings feed on benthos and plankton (Antonenko & Pushchina, 2002).

In 2004–2013, Hexagrammidae fish were sampled for the trace element analysis (Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2013). The excess of the MPL for cadmium (0.7 mg·kg^{-1} wet weight) was recorded in liver alone: the value was of 0.79 mg·kg^{-1} wet weight. In muscles, active accumulation of arsenic was registered (Fig. 8). Cadmium, lead, and mercury are accumulated predominantly in liver.

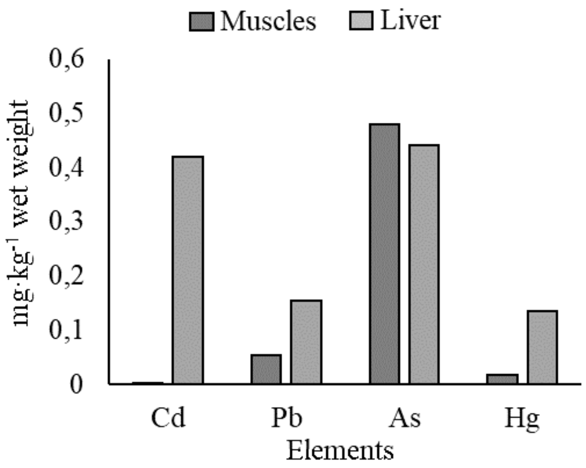

Fig. 8. Maximum concentrations of heavy metals and arsenic in organs and tissues of Hexagrammidae fish, the Sea of Japan, 2004–2013 (Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2013)

Herring (Clupeidae G. Cuvier, 1817). Fish are widely spread from the Subantarctic to Arctic. A typical representative of this family is the Pacific herring *Clupea pallasii* Valenciennes, 1847 having three ecological forms – marine, coastal, and lagoon–lake. Along the continent of Asia, herring is spread continuously from the Yellow Sea to the Bering Strait, *inter alia* in the Sea of Japan, Sea of Okhotsk, and Bering Sea. Fish feed mainly on zooplankton. The life span is up to 19 years (Naumenko, 2007).

The values for the trace element content in herring sampled in 2004–2013 generally complied with the MPL (Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2013). Importantly, cadmium concentrations in fish liver were rather high: the value was of 0.96 mg·kg^{-1} wet weight while the MPL is 0.7 mg·kg^{-1} wet weight (Fig. 9).

Interestingly, all the studied trace elements were localized in muscles (see Fig. 9). This can be explained by fish feeding in the areas of terrigenous and anthropogenic runoff.

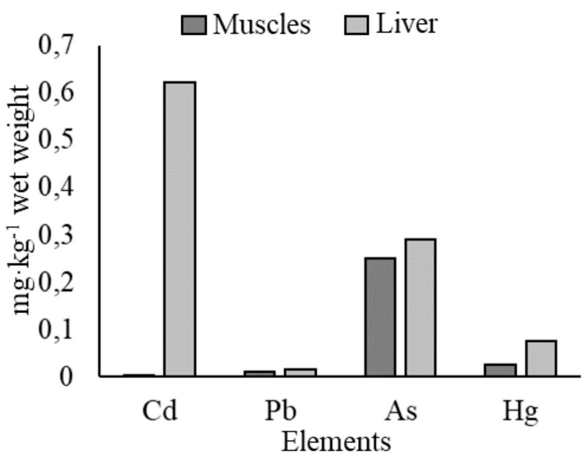

Fig. 9. Maximum concentrations of trace elements in organs and tissues of the Pacific herring *Clupea pallasii*, the Sea of Japan, 2004–2013 (Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2013)

Codfish (Gadidae). In 2013–2014, representatives of this family were studied – the Alaska pollock *Gadus chalcogrammus* Pallas, 1814 and saffron cod *Eleginus gracilis* (Tilesius, 1810) (Hwang et al., 2019 ; Kovekovdova et al., 2013).

Codfish are characterized by a wide species diversity. Those inhabit mainly the pelagic zone; some fish lead benthic lifestyle. By the feeding type, codfish are mainly predators (Napazakov et al., 2001).

As can be seen in Fig. 10, trace element concentrations in liver significantly exceed those in other organs. The MPL for arsenic was exceeded by almost 4 times. Mercury was accumulated predominantly in gonads. Muscles accumulated cadmium (the value was almost 45 times higher than the MPL) and lead (see Fig. 10). Such an active intake of trace elements and their subsequent accumulation in fish organs can originate from surface and river runoff, resuspension, and bioturbation of bottom sediments (Khristoforova, 1989).

Such values may result from rapidly developing industry of the Republic of Korea as well (some Gadidae representatives were sampled in its territorial waters) (Hwang et al., 2019). This country is quite rich in deposits located on its coast. Mainly, coal, iron, molybdenum, and lead–zinc ores are mined (Hwang et al., 2019). Apparently, these industries are the reason for the intake of polluted waters into the Sea of Japan.

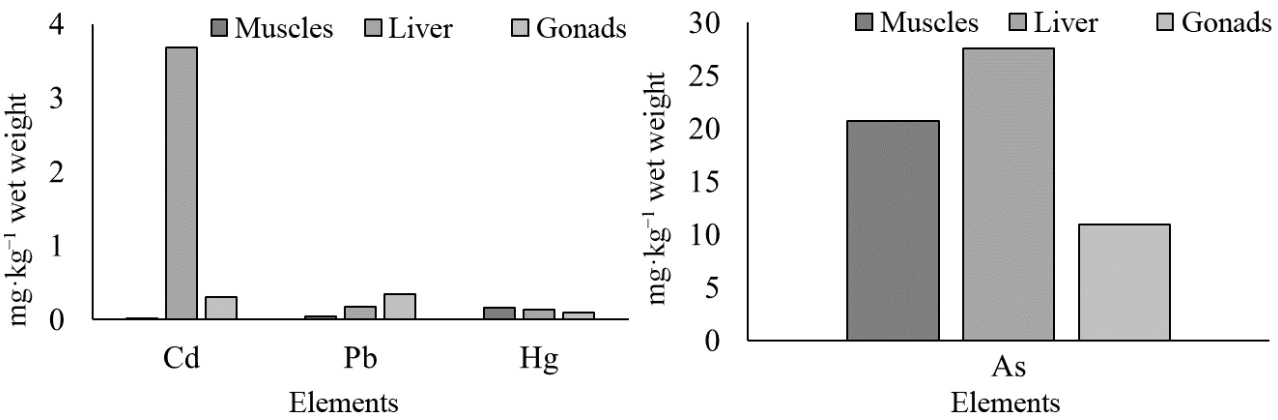

Fig. 10. Maximum concentrations of heavy metals and arsenic in organs and tissues of Gadidae fish, the Sea of Japan, 2013–2014 (Hwang et al., 2019)

Righteye flounder (Pleuronectidae). Representatives of this family were sampled in the Sea of Japan in 2004–2020 (Chusovitina et al., 2020 ; Kovekovdova & Simokon, 2004 ; Steblevskaya et al., 2013, 2016).

Based on the analyzed data, there was no excess of the MPL in righteye flounder organs. Cadmium and mercury were accumulated most actively in liver; arsenic, in muscles; and lead, in gills (Fig. 11).

Recorded concentrations of trace elements may indicate their accumulation in soils. Specifically, studies carried out by L. Kovekovdova *et al.* (2002, 2010) revealed an increase in arsenic content in organs and tissues of molluscs and fish in the Amur Bay due to its high concentration in soils.

The generalized data on the excess of the MPL for toxic trace elements in fish sampled in the Far Eastern seas are given in Fig. 12.

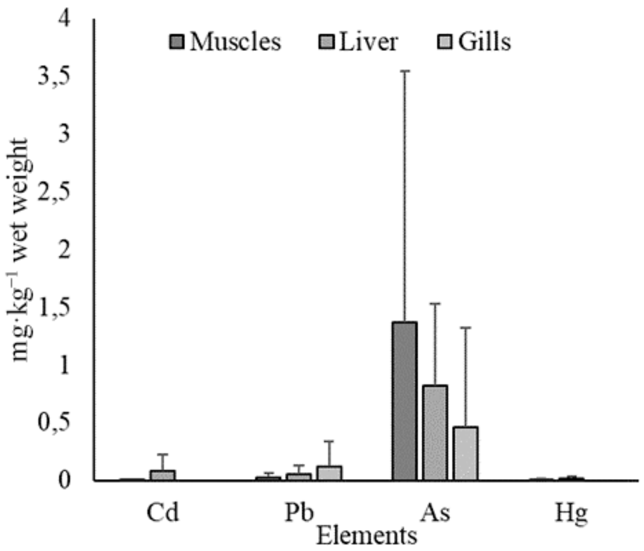

Fig. 11. Maximum mean concentrations of heavy metals and arsenic in organs of Pleuronectidae fish, the Sea of Japan, 2004–2020 (Chusovitina et al., 2020 ; Kovekovdova & Simokon, 2004 ; Steblevskaya et al., 2013, 2016)

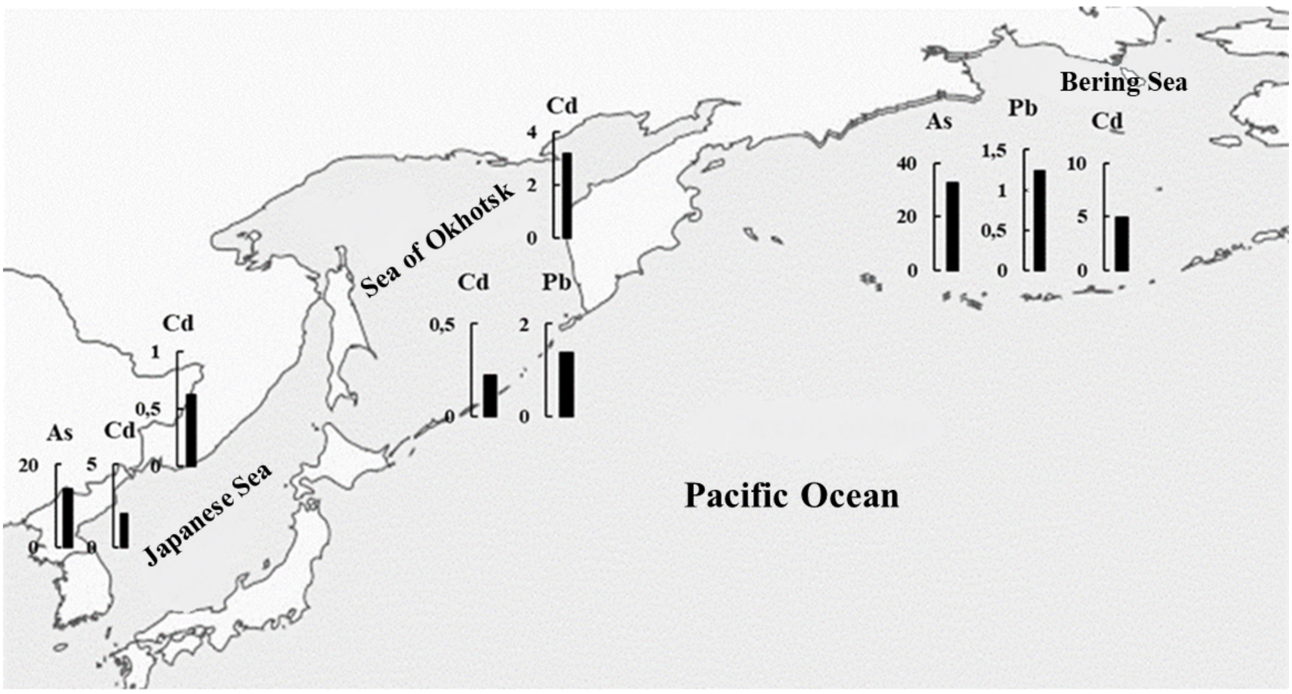

Fig. 12. Excess of the maximum permissible level (see note to Fig. 1) of toxic elements in fish of the Far Eastern seas: 1, maximum concentration; 2, maximum mean concentration; 3, mean concentration; 4, muscles; 5, gonads; 6, liver; 7, kidneys (Burger et al., 2007 ; Hwang et al., 2019 ; Khristoforova et al., 2016 ; Kovekovdova & Simokon, 2004 ; Kovekovdova et al., 2013)

Conclusion. In almost all studied fish, excess concentrations of such extremely toxic elements, as cadmium, lead, and arsenic, were revealed.

The highest cadmium content was recorded in organs of fish sampled in the Sea of Japan. Specifically, Cd concentration in muscles of codfish was 45 times higher than the maximum permissible level. Apparently, this is due to the fact that muscles make up a high percentage of body weight. Moreover, muscles are an accumulating organ; therefore, muscles are capable of accumulating significant concentrations of trace elements. Lead content in liver of the righteye flounder from the Sea of Okhotsk exceeded the MPL by 1.2 times. These fish are benthivorous; when feeding, they can accumulate adsorbed Pb from bottom sediments. High concentrations of arsenic were recorded in kidneys of the righteye flounder sampled in the Bering Sea (the MPL was exceeded by 6.5 times) and in liver of codfish from the Sea of Japan (the MPL was exceeded by 5.5 times). In the Far Eastern seas, there are areas with anomalous hydrochemical and geochemical conditions which can affect the trace element composition of hydrobionts. Food safety largely depends on the frequency of consumption of a particular product. This is especially relevant for trace elements which are capable of biomagnification and therefore can be accumulated over a lifetime.

Thus, consuming products from fish caught in the Far Eastern seas may be unsafe for human health. Regular monitoring is required to control the quality of seafood. In this regard, studies of the trace element composition of fish remain extremely relevant.

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ТЯЖЁЛЫЕ МЕТАЛЛЫ И МЫШЬЯК В ПРОМЫСЛОВЫХ РЫБАХ ЯПОНСКОГО, ОХОТСКОГО И БЕРИНГОВА МОРЕЙ: СОВРЕМЕННОЕ СОСТОЯНИЕ (ОБЗОР ЛИТЕРАТУРЫ)

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В работе обобщены сведения о концентрациях токсичных элементов As, Pb, Cd и Hg в промысловых рыбах дальневосточных морей — Японского, Охотского и Берингова — на основе анализа литературных данных. Изучение показало, что в целом основные промысловые объекты и рыбохозяйственные бассейны соответствуют санитарно-гигиеническим нормативам, однако наличие импактных природных зон в ареалах и на пути миграции рыб способствует увеличению концентраций токсичных элементов в рыбных объектах промысла, а в некоторых случаях уровни превышают предельно допустимые концентрации. Необходимо продолжать мониторинг токсичных микроэлементов в промысловых объектах и рыбохозяйственных бассейнах дальневосточных морей.

Ключевые слова: тяжёлые металлы, токсичные элементы, дальневосточные моря