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COMPARATIVE CHARACTERISTICS OF THE TRACE ELEMENTAL COMPOSITION OF CHUM SALMON *ONCORHYNCHUS KETA* WALBAUM, 1792 FROM THE SEA OF JAPAN AND THE SEA OF OKHOTSK

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Content of trace elements (iron, zinc, copper, nickel, lead, and cadmium) was determined in the most popular species of Pacific salmon on the consumer market – chum salmon *Oncorhynchus keta*, which is the second largest catch in Russian waters (after pink salmon *O. gorbuscha*). Metal content in fish organs and tissues (muscle tissue, liver, and gonads) was determined by the atomic absorption method using a Shimadzu AA-6800 spectrophotometer in flame and flameless atomizers from sample extracts; the latter ones were obtained by decomposition of weighed portions of concentrated HNO_3 (high purity) in a MARS 6 complex using standard samples with known concentrations. The data was statistically processed in SPSS Statistics 21. Sexually mature individuals of chum salmon (five specimens of males and females on each spot) were sampled in autumn 2018 in storage cages of salmon hatcheries on the Firsovka River (southeastern Sakhalin, Gulf of Patience) and Reidovaya River (Iturup Island, Kuril Islands), as well as in October 2019 in breeder holding cages on the Poima River (southwestern Primorye, the Sea of Japan). Muscle tissue, liver, and gonads were sampled from every individual. The elements determined were clearly divided according to content values into two groups depending on the sampling spot: Cd and Pb prevailed in organs and tissues of chum salmon from the Sakhalin-Kuril Region of the Sea of Okhotsk, whereas Fe, Zn, Cu, and Ni prevailed in the Sea of Japan fish. The reason for heavy metal contrasting distribution in fish organs and tissues is obviously environmental geochemical conditions formed in salmon feeding areas and on migration routes. In the Sea of Japan, practically enclosed, poorly connected with the Pacific Ocean by several shallow straits, the aquatic environment is under significant anthropogenic, technogenic, and terrigenous load (household and industrial drains, surface washing from coastal areas, and combustion of hydrocarbon fuel by ships). In the Sakhalin-Kuril basin, it is affected by natural phenomena: surface and underwater volcanism and post-volcanism of the Kuril Islands, as well as upwellings, which carry from the depths of the Kuril–Kamchatka Trench into the surface layer practically the entire set of chemical elements of the Mendeleev’s periodic table. At the same time, Pb, with its unusually high sorbability, is retained on any suspended particles, both living and non-living, and enters fish organisms with food. The distribution of trace elements over chum salmon organs and tissues differs significantly. Specifically, in fish muscle tissues, the lowest metal content is observed, regardless of the catch spot. The liver is characterized by increased levels of all metals, except for Ni, with the highest Fe, Zn, and Cu content recorded in the Sea of Japan fish liver. The distribution of metals in fish gonads is characterized by its own specificity, with very clear manifestation in the Primorye salmon. Thus, in female gonads, Fe, Zn, and especially Cu predominated: Cu content in female gonads from the Poima River was the same as in liver. Female gonads of the Sea of Japan chum salmon had the highest Ni concentration, although male gonads were characterized by a high, albeit very variable, content of this element as well. As for Pb and Cd, the most toxic elements monitored by sanitary services (for technical reasons, we determined their amount in the Sea of Okhotsk fish only), a well-known pattern was observed in their distribution in organs and tissues: maximum content was found in fish liver. Pb content exceeded the sanitary standard only in some individuals that came to spawn in the Firsovka River in the southeastern Sakhalin. Cd concentration in Sakhalin fish liver was 2.5–4.0 times higher than threshold limit value, and in Kuril fish liver, 2.1–5.0 times higher.

Keywords: Pacific salmon, chum salmon, Sakhalin-Kuril Region, Sea of Okhotsk, Primorsky Krai, Sea of Japan, trace elements

Chum salmon is one of six Pacific salmon species of the genus *Oncorhynchus*. It inhabits both coasts of the Pacific Ocean and is one of the most abundant salmon species. In the present work, mature chum salmon individuals were studied, that came to spawn and were caught in the rivers of the southeastern Sakhalin, Iturup Island, and southern Primorye. In chum salmon soft organs and tissues, the content of six chemical elements was investigated: iron, zinc, copper, nickel, lead, and cadmium.

Out of six trace elements analyzed, three – Cu, Zn, and Fe – are essential (necessary), or true ones, and other three – Ni, Cd, and Pb – are non-essential, but almost constantly present in organs and tissues. In addition to their biological significance, these trace elements differ in geoecological peculiarities. Cu and Zn, if they do not enter the environment from copper-zinc industries or spots where these metals, their alloys, and compounds are used in technology (mining, enrichment, smelting, work with electroplated and anti-corrosion coatings, *etc.*), are the tracers of technogenic load on the environment and are present in all household drains; Ni contamination occurs mainly during the combustion of hydrocarbon fuel, wood, and waste, as well as because of nickel production and use (Khristoforova et al., 2018b ; Kobzar & Khristoforova, 2015).

Iron enters the environment due to widespread use of a variety of surface and underwater steel structures and their rusting, as well as due to river, terrigenous, and surface runoff, stirring up of loose bottom sediments in coastal waters, and decomposition of dead hydrobionts, in which Fe is an obligatory component (macroelement) (Khristoforova, 1989).

In the 1960s and 1970s, Pb and Cd were, along with Hg, at the top of all the blacklists of heavy metals in organisms due to their toxic effect. Now, they are considered as the tracers of technogenic load on the environment (Khristoforova, 1989).

Chum salmon *Oncorhynchus keta* (Walbaum, 1792) is the species in demand and the most numerous species of Pacific salmon in the food markets of Russia and other countries. Due to its high commercial quality and a distinct homing, chum salmon currently accounts for the overwhelming part of all artificially reproduced salmon along both the Asian and American coast of the North Pacific. In Russia, in particular in Sakhalin, high chum salmon catches are mainly due to the work of the hatcheries. In our country, artificial reproduction of chum salmon is carried out in Primorsky Krai, Kamchatka, Khabarovsk, Magadan, and Sakhalin regions.

The Sakhalin Region has exceptionally favorable environmental conditions for a large-scale development of aquaculture. In 2019–2020, over 60 fish hatcheries of different forms of ownership were engaged in artificial reproduction of Pacific salmon in the Sakhalin-Kuril Region. Due to their stable and systematic work, salmon hatcheries release more than 800 million ind. of juveniles every year, ensuring the sustainable development of the fishing industry in the region. In 2019, more than 1 billion ind. of juveniles were released there, *inter alia* 263.2 million ind. of pink salmon and 863.6 million ind. of chum salmon (Ofitsial'naya informatsiya o rybovodnykh predpriyatiyakh, 2020b).

The main species of Pacific salmon reproduced in the Sakhalin Region are autumn chum salmon and pink salmon. Most chum salmons from the Sakhalin-Kuril basin are of artificial origin. Due to the operation of fish hatcheries, more than 20 thousand tons of salmon enter the coastal area of the Iturup Island alone annually, while before the start of the fish farming program in the Kuril Islands, the comebacks of wild fish were, at best, 500–700 tons (Ofitsial'naya informatsiya o rybovodnykh predpriyatiyakh, 2020b).

The large-scale work of the salmon hatcheries, as well as natural reproduction, annually ensure stable approaches of salmon to the rivers of Sakhalin and the Kuril Islands. In 2018, in the Sakhalin-Kuril Region, according to official data of the Sakhalin Government, 126 thousand tons of Pacific salmon were caught by commercial fishing; out of them, there were 85 thousand tons of pink salmon and more than 40 thousand tons of chum salmon. In 2019 – the less productive year – salmon caught in the Sakhalin-Kuril waters amounted to 75.5 thousand tons; out of them, there were more than 28 thousand tons of pink salmon and 45.5 thousand tons of chum salmon.

The Primorye chum salmon is characterized by a southern distribution within the species range. The very fact of fish entering local rivers, although in small abundance, indicates the passage of chum salmon through the southern Sea of Japan (Goryainov et al., 2007 ; Shuntov et al., 2004).

In the Primorsky Krai, there are several fish hatcheries of different forms of ownership engaged in the Pacific salmon reproduction. Out of them, there are two state enterprises: Ryazanovka Experimental Commercial Fish Hatchery and Barabashevka Fish Hatchery. Both are located in the Khasansky District, have been operating since the mid-1980s, and are structural subdivisions of the Federal State Budgetary Institution "Glavrybvod". For the hatcheries, the main farming object is autumn chum salmon. Its basic watercourses are the Ryazanovka and Barabashevka rivers. Eggs for laying are mostly obtained on the Ryazanovka River. Eggs are collected on the Poima River as well, which flows into the Baklan Bay of the Peter the Great Gulf of the Sea of Japan (the Khasansky District, near the Slavyanka urban-type settlement).

In the Khasansky District, hatchery chum salmon schools are of mixed origin since in different years, fertilized eggs were delivered to the Primorye hatcheries not only from Primorsky Krai (Olginsky District), but also from the southwestern Sakhalin.

Over the past 20 years, stable approaches of chum salmon have been observed in the areas where the hatcheries operate. The annual release is 25–30 million ind. of juveniles. During the 2019 season, more than 39 million chum salmon eggs were collected and incubated at the Primorsky Krai hatcheries (Ofitsial'naya informatsiya o rybovodnykh predpriyatiyakh, 2020a). According to V. G. Markovtsev (2006), it is the operation of these two fish hatcheries that ensures salmon fishing in the Primorye.

The aim of the study is to compare the content of trace elements in chum salmon that came to spawn in the rivers of the Sakhalin-Kuril Region and Primorsky Krai, which was collected from the storage cages of three salmon hatcheries (on the Iturup Island, in Sakhalin, and in the southwestern Primorye).

MATERIAL AND METHODS

The material for research was sampled during the period of spawner accumulating and egg laying for incubation in the spots of egg collecting – on the basic watercourses of Sakhalin fish hatcheries: in October 2018, on the Firsovka River (Firsovka Salmon Hatchery, Gulf of Patience, southeastern Sakhalin) and Reidovaya River (Reidovaya Salmon Hatchery, Iturup Island, Greater Kuril Chain); in October 2019, on the Poima River of the Khasansky Dictrict, Primorsky Krai (the basic watercourse of the Ryazanovka Experimental Commercial Fish Hatchery) (Fig. 1).

Fig. 1. Chum salmon sampling areas

In total, five chum salmon males and five chum salmon females were sampled (randomly) at each hatchery from breeder holding cages. Muscle tissue, liver, and gonads were sampled from every individual.

The time required for chum salmon spawners to mature directly depends on the feeding efficiency in the marine life period, especially at its early stage, and can range for this species 2 to 5 years. According to official information from the Sakhalin branch of VNIRO, chum salmon from the Reidovaya River in most cases (54.5 %) comes back to spawn at the age of 3+. Based on our data, 80 % of the studied spawners of the Primorye chum salmon are individuals aged 5+, *i. e.* feeding areas for the Sea of Japan chum salmon are likely to be less forage (according to information of the Primorsky branch of "Glavrybvod", 53 % of mature individuals come back at the age of 4+; 44 %, at the age of 3+). We determined the age of chum salmon from the Firsovka River as 3+.

All spawners were at the 4^{th}–5^{th} stage of maturity. In Table 1, fish length and mean weight values are given.

As can be seen, the Poima River fish is of maximum weight, whereas the Firsovka River individuals are of minimum one. At the same time, salmon of average weight from the Reidovaya River are the longest ones, especially males.

All the elements were determined from sample extracts according to the State Standard 26929-94 (2010) using a Shimadzu AA-6800 spectrophotometer (Cd and Pb, by graphite furnace atomic absorption; the other trace elements, by flame atomization). The work was carried out at the "Center for Landscape Diagnostics and GIS Technologies" core facility at the Pacific Geographical Institute FEB RAS. Sample extracts were obtained by decomposition of weighed portions of fish organs and tissues with concentrated HNO_3 (high purity) by microwave mineralization in a MARS 6 complex.

Table 1. Morphometric characteristics of *Oncorhynchus keta* from the Firsovka, Reidovaya, and Poima rivers (2018–2019)

Sampling date	Sampling spot, sex of fish	Mean body weight of fish, g (min–max)	Mean length of fish, cm (min–max)	
			SL	SCL
October 2018	Reidovaya River, ♀	2423 (2232–2774)	67.0 (65–69)	63.0 (61–65)
	Reidovaya River, ♂	3115 (4834–2154)	71.0 (66–82)	67.0 (62–78)
October 2018	Firsovka River, ♀	2096 (1626–2402)	56.6 (53–59)	53.4 (50–56)
	Firsovka River, ♂	3008 (2086–3008)	60.8 (53–60)	56.8 (53–60)
October 2019	Poima River, ♀	3220 (2350–4250)	66.6 (60–71)	61.6 (55–66)
	Poima River, ♂	3330 (3000–3800)	68.6 (67–70)	64.6 (63–67)

Note: SL denotes length according to Smith (up to middle rays of caudal fin); SCL, length up to end of scale cover.

The accuracy of the element determination and possible contamination of the samples during the analysis were controlled by comparison with calibration solutions, *inter alia* with a "blank" (zero) one (concentrated HNO_3, 10 mL after heating in a microwave mineralizer, evaporated and diluted in the same ratio with 0.1 M solution).

The accuracy and precision of the method used were confirmed by regular analysis of the standard reference material (SRM) 1566a (NIST, oyster tissue) for each element determined in the samples (Table 2). The mean value, standard deviation (*SD*), and significance of the compared differences (applying the Mann–Whitney *U* test) were calculated in SPSS Statistics 21 for macOS. The detection limits were quantified as 3×*SD* of 10 fish samples mixed with a known minimum amount of the elements analyzed. For analytes that could not be determined in mixed samples, the detection limits were found as the amount of substance in the sample in accordance with the minimum concentration of the calibration standard. The minimum amount of the calibration standard was determined based on the State Standard 30178-96 (2010).

Total concentrations (mean ± *SD*) for Fe, Zn, Cu, Ni, Cd, and Pb were quantified in $\mu g \cdot g^{-1}$ wet weight.

Table 2. Comparison of the results of trace metal determination ($\mu g \cdot g^{-1}$ dry weight) in certified material [SRM 1566a (oyster tissue)] with passport data; limit of detection (LOD)

	Fe	Zn	Cu	Pb	Ni	Cd
Certified value	539 ± 15	830 ± 57	66.30 ± 4.3	0.371 ± 0.014	2.25 ± 0.44	4.15 ± 0.38
Present study	554 ± 16	821 ± 51	61.09 ± 3.2	0.358 ± 0.012	2.52 ± 0.48	4.19 ± 0.37
Limit of detection	0.2	0.01	0.02	0.01	0.05	0.01

As seen, the results of the control determination of the trace elements in the certified sample are comparable with the passport data of the reference material.

RESULTS

The trace element concentration in organs and tissues of chum salmon that came back to spawn in the rivers of the southeastern Sakhalin, Iturup Island, and southern Primorye differs significantly (Table 3).

Table 3. Trace elements content in *Oncorhynchus keta* organs and tissues from the Firsovka, Reidovaya, and Poima rivers (μg·g^{-1} wet weight)

Organs and tissues	Fe	Zn	Cu	Pb	Ni	Cd
Sakhalin Island, Firsovka River (October 2018)						
Muscle	7.6 ± 2.5	1.66 ± 0.23	0.52 ± 0.15	0.40 ± 0.15	0.29 ± 0.10	0.06 ± 0.02
Liver	*60.2 ± 34.6*	3.48 ± 1.24	0.54 ± 0.22	**1.18 ± 0.36**	0.23 ± 0.10	**0.66 ± 0.15**
Male gonads	13.0 ± 6.2	1.74 ± 0.23	0.39 ± 0.12	0.48 ± 0.17	0.19 ± 0.05	0.12 ± 0.03
Female gonads (eggs)	15.6 ± 2.4	1.92 ± 0.09	0.33 ± 0.05	0.45 ± 0.14	0.26 ± 0.04	0.04 ± 0.01
Iturup Island, Reidovaya River (October 2018)						
Muscle	11.4 ± 3.9	1.74 ± 0.29	0.49 ± 0.12	0.45 ± 0.07	0.26 ± 0.11	0.05 ± 0.02
Liver	*48.1 ± 19.1*	3.35 ± 1.22	0.55 ± 0.315	0.87 ± 0.19	0.31 ± 0.07	**0.72 ± 0.3**
Male gonads	10.4 ± 4.0	2.18 ± 0.23	0.38 ± 0.14	0.64 ± 0.09	0.23 ± 0.05	0.09 ± 0.03
Female gonads (eggs)	16.2 ± 4.3	2.60 ± 0.41	0.46 ± 0.01	0.57 ± 0.05	0.20 ± 0.06	0.07 ± 0.00
Southern Primorye, Poima River (October 2019)						
Muscle	10.5 ± 3.0	*5.20 ± 0.65*	0.76 ± 0.28	N. d.	*0.48 ± 0.14*	N. d.
Liver	121.9 ± 95.2	33.463 ± 14.83	5.49 ± 3.36	N. d.	*0.51 ± 0.21*	N. d.
Male gonads	*20.0 ± 10.2*	*7.17 ± 1.18*	0.76 ± 0.28	N. d.	0.97 ± 0.93	N. d.
Female gonads (eggs)	*23.4 ± 5.5*	20.67 ± 0.82	5.68 ± 0.40	N. d.	0.75 ± 0.38	N. d.

Note. N. d. denotes "were not detected"; in italic, increased concentrations for each of trace elements are highlighted; in bold, their highest values. According to sanitary rules and regulations, threshold limit values (μg·g^{-1} wet weight) for seafood are as follows: Pb, 1.0; Cd, 0.2 (SanPiN 2.3.2.1078-01, 2002).

Specifically, the trace elements are ranked according to their content as follows: Fe opens the row; Zn follows it; Cu and Pb share the 3rd and 4th places; Ni is noticeably behind them; and Cd closes the row.

The Sea of Japan chum salmon was characterized by higher concentrations of all elements determined (p = 0.012…0.048). Particularly noteworthy is Fe content in liver of the Poima River fish: it was 2 times higher than in the Firsovka River chum salmon and almost 3 times higher than in the Reidovaya River fish. At the same time, in muscles of chum salmon from any river, approximately equal or similar values were recorded. Zn clearly predominated in the Primorye chum salmon, with its high content not only in liver (p = 0.03), but also in female gonads (eggs) (p = 0.032). Cu concentrations both in liver and eggs of the Sea of Japan chum salmon females were an order of magnitude higher than those in the Kuril (p = 0.02) and Sakhalin fish (p = 0.029). Ni content in all organs and tissues of the Sea of Japan chum salmon was higher as well (p = 0.018…0.045) than in the Sakhalin and Kuril fish; however, male and female gonads were characterized by both higher Ni concentration and its higher variability.

While Ni was almost evenly distributed between organs and tissues of the Sea of Okhotsk chum salmon, Cd clearly (by an order of magnitude or more) predominated in liver. Primorye salmons were characterized by both higher Ni content in general and its different distribution. Specifically, the difference in Ni concentrations in the Sea of Japan chum salmon in muscles and liver reached

2 times ($p = 0.019$), whereas in both female and male gonads the content was 3–4 times higher ($p = 0.012$) than in muscles. The highest Ni concentration was observed in male gonads (its content in male gonads was 1.3 times higher than in female gonads, although it was very variable).

DISCUSSION

Increased Fe concentration in male and female gonads of the Sea of Japan chum salmon and the highest Fe content in fish liver clearly indicate a higher terrigenous load on the water area of the almost enclosed Sea of Japan and on its inhabitants, as well as the detoxification of the trace element excess by liver.

Besides Fe, other trace elements enter the coastal waters of the Sea of Japan with terrigenous and surface runoff as well (Khristoforova & Chernova, 2005). The presence of Zn (the second highest concentration trace element in fish organs and tissues) confirms a much higher anthropogenic load on the water area of the Sea of Japan than on the water area of the Sea of Okhotsk. Another trace element indicating anthropogenic load on the environment and organisms is Cu. Its concentration neither in liver nor in male and female gonads of the Sea of Okhotsk salmon did not differ significantly from the trace element content in fish muscles. However, in chum salmon that came to spawn in the Poima River, Cu concentration in liver was in sharp contrast to its value in muscles; this indicates the detoxification of its excess by liver. Moreover, there was a strong difference between Cu concentration in female gonads and male gonads in the Sea of Japan chum salmon, which was not observed in the Sea of Okhotsk fish. Since copper is both biophilic and biocidic trace element, much higher Cu content in female gonads is likely to indicate a stronger physiological control over the trace element concentration in tissues of females and excretion of its excess from the organism both with gonads and because of liver detoxification. When studying in detail the behavior of metals in commercial molluscs in the Peter the Great Bay (Khristoforova et al., 1994) and paying attention to species peculiarities, seasonal variability in the distribution of the trace elements in organs and tissues, and age differences in their content, we repeatedly observed sex differences in toxic metal concentrations (Cu, Pb, and Cd), registered the ability of molluscs to limit copper bioaccumulation, and noted, as well as other authors, that this ability is higher in females under conditions of increased Cu content in the environment. Excess of Zn (really biophilic trace element, unlike Cu) is also excreted from the organism and in the same ways, if taking into account its significant predominance in liver and female gonads.

Nickel predominance in fish liver was not revealed in the Kuril, Sakhalin, or even Primorye individuals. However, there was a clear excess of its concentration in gonads of the Sea of Japan fish, especially in females; this seems to result from gonad excretion into the environment (Khristoforova et al., 1994).

On the example of the Sea of Japan fish, it can be seen as follows: only a small amount of the trace element entering the organism is assimilated and redistributed in the organs and tissues; most of it is transported to the excretion system; as well as other authors, we have previously observed it when studying bivalves (Khristoforova et al., 1994).

As known, within the same species, older or larger individuals, weighing much more than younger ones, have higher trace element concentrations (Kelly et al., 2008 ; Khristoforova et al., 2019b). It seems likely that older age (5+) and, consequently, longer feeding period and larger mass of the Sea of Japan chum salmon than of the Sakhalin and Iturup fish result in higher trace element concentrations in the Sea of Japan chum salmon.

After a release, juveniles from the salmon hatcheries in the southeastern Sakhalin and Iturup Island of the Kuril Chain enter the coastal area of the southwestern Sea of Okhotsk; juveniles from the Primorye hatcheries enter the Peter the Great Bay of the Sea of Japan.

Quite recently, the Sea of Japan was not even considered as a feeding and wintering area for chum salmon. However, not all juveniles from the Sea of Japan basin go to the Sea of Okhotsk and the Pacific Ocean in the first year of life (Shuntov & Temnykh, 2011 ; Salo, 1991). A. I. Smirnov (1975) pointed out that the Primorye chum salmon and part of the Amur, Sakhalin, and Hokkaidō chum salmons winter and feed in the Sea of Japan, to the east and southeast of the Korean Peninsula. It was proved in the late 1990s that some chum salmons winter in the Sea of Japan (Semenchenko et al., 1997). Several authors believe that all underyearlings of the Primorye chum salmon winter in the Sea of Japan and only the next year partially leave it (Goryainov et al., 2006).

The role of the Sea of Japan as a feeding area for chum salmon, especially in the first – the marine one – year of life, is not known in detail. Unlike pink salmon and masu salmon, chum salmon have not been caught in winter and winter to spring periods within the Russian economic zone in the Sea of Japan (Atlas rasprostraneniya, 2002 ; Shuntov et al., 2004). It has not also been mentioned in the works on drifter salmon cruises to the central and southern Sea of Japan. There is no actual data on chum salmon specific wintering areas and conditions in the Sea of Japan. However, there is the point of view that some chum salmons, living side by side with pink salmons, winter in the Sea of Japan (Goryainov et al., 2007). It is evidenced by their joint occurrence in catches in wintering areas and on the routes of anadromous migrations confirmed by long-term studies. In winter, in the Sea of Japan, aggregations of pink salmon, and, consequently, chum salmon, are distributed from the Korea Bay to the Noto Peninsula, in two wintering areas. The first one is in the latitudinal direction from the Korea Bay to the island of Honshu; the second one is to the north – along the shores of the island of Hokkaidō. The second wintering area is characterized by lower temperatures; in terms of wintering conditions, it is like an ocean one. Analyzing the migration of the Primorye pink salmon in the Sea of Japan in winter, I. B. Birman (1986) noted as follows: during winter, "pink salmon, that came from the north to the waters of Korea, migrates eastward to the Noto Peninsula area" – at the confluence of the southern and northern branches of the Tsushima current. Undoubtedly, the currents supply fish with food. In April, fish migrates back to the west, and when reaching the Korea Bay, it comes to the north along the coast of Primorye. This seems to be associated with a water warming and increase in plankton abundance.

During the northern summer salmon migrations, chum salmon can be found in small quantities in the open waters of Primorye. It was established in a large series of TINRO summer trawl surveys (Atlas rasprostraneniya, 2002 ; Shuntov et al., 2004), as well as during drifter cruises in May and June in the 1990s and early 2000s (Dudarev et al., 2004 ; Semenchenko et al., 1997). These facts allow suggesting as follows: a small part of chum salmon at the age of 3+ and 4+ does not go to the ocean for feeding at all (Shuntov & Temnykh, 2011). Migrations of chum salmon of all ages, breeding in the western Sea of Japan, *inter alia* the Korean Peninsula, have not actually been traced (Shuntov & Temnykh, 2008).

The main feeding areas for chum salmon in Asian waters are the western Bering Sea, Sea of Okhotsk, and Kamchatka and Kuril waters of the northwestern Pacific Ocean (Shuntov & Temnykh, 2011). In early winter, juveniles of the Sakhalin and Kuril pink salmon and chum salmon, along with other juvenile schools, go to feed in a wide front through the northern Kuril straits to the open areas of the Pacific Ocean (N40° to N45°). For the first time in its life, salmon crosses the geochemically impact and at the same time high-feeding zone: the Kuril Chain and Kuril–Kamchatka Trench. For the second time, the pink salmon crosses the impact zone the next year, during anadromous migration, when going in the opposite direction, to the spawning areas (Khristoforova et al., 2019b). As for chum salmon, according to data of Shuntov and Temnykh (2011), during its marine life period (usually, 3–4 years), it can go several times along the Kuril Islands, with the trace element concentration in tissues increasing. Possessing a powerful growth potential, which is characteristic of all Pacific salmon, chum salmons significantly increase in length and body weight during the months spent in the sea.

Making extensive migrations, chum salmon goes after wintering to the Commander–Aleutian Trench, enters the deep-water western Bering Sea, and, after feeding in this area, goes along the Kamchatka, gradually moving to the polar front for wintering. Having completed at least three cycles of passage to the Bering Sea and back, it finally descends the feeding route along the Kamchatka, Kuril Islands, and Kuril–Kamchatka Trench; through the southern Kuril straits, the fish goes to the rivers on the Asian coast of the mainland, Sakhalin, and Kuril Islands (Shuntov & Temnykh, 2008, 2011).

On its way to feeding and back, to native rivers, the Primorye chum salmon goes through the Sea of Japan. The fish passes this sea twice in its life, following migratory routes to feeding areas and back – to spawn in the Primorye rivers. The Peter the Great Bay of the Sea of Japan and its bays, *inter alia* Amur and Posyet ones, where chum salmon juveniles migrate primarily, are characterized by high anthropogenic and terrigenous load on the environment and biota (Khristoforova et al., 1994 ; Kobzar & Khristoforova, 2015). Thus, different feeding conditions and migration routes of chum salmon of “Primorye” and “Sakhalin” or “Kuril” origin result in different trace element composition of its organs and tissues. Estimating heavy metal content in pink salmon and masu salmon in our previous studies (Khristoforova et al., 2015, 2018a, 2018b, 2019a, 2019b), we also noted that pink salmon from the Sea of Okhotsk and Sea of Japan had significant differences in the trace element concentration in organs and tissues. Specifically, the Sea of Japan pink salmon was characterized by Zn predominance; salmon from the Sakhalin-Kuril Region, which went to feed in the Pacific Ocean and twice crossed the geochemically impact and at the same time high-feeding zone (the Kuril Islands and Kuril–Kamchatka Trench), was characterized by Pb and Cd predominance.

Conclusions:

1. Kuril and East Sakhalin chum salmon, which winters in the ocean and feeds along the high-feeding zone, accumulates increased amounts of Pb and Cd in its organs and tissues. This results from volcanism and upwellings, which carry nutrients from the depths into the surface layer and cause rapid plankton development, as well as from geochemical impact of the region related to a high sorbability of these trace elements on nutrient suspension particles.
2. Chum salmon wintering and feeding in the enclosed Sea of Japan, which is poorly connected with the ocean and subject to terrigenous, anthropogenic, and technogenic load, are accompanied by Fe, Zn, Cu, and Ni accumulation in fish organs and tissues. The elements are tracers of this load and indicate intense shipping, household and industrial drains, and almost complete surrounding by land.
3. A predominant metal accumulation in liver, typical for fish of the areas studied (except for Ni, which is almost evenly distributed between organs and tissues of Kuril and East Sakhalin fish), and an increase in the element concentrations in female gonads, especially noticeable in the Sea of Japan chum salmon, where Ni clearly predominates, indicate the regulatory capabilities of salmon organisms and the entry (redistribution) of element excess into the excretion system.

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СРАВНЕНИЕ МИКРОЭЛЕМЕНТНОГО СОСТАВА КЕТЫ *ONCORHYNCHUS KETA* WALBAUM, 1792 ИЗ ЯПОНСКОГО И ОХОТСКОГО МОРЕЙ

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Определено содержание микроэлементов (железа, цинка, меди, никеля, свинца и кадмия) в наиболее востребованном на потребительском рынке виде тихоокеанских лососей — кете *Oncorhynchus keta*, являющейся в российских водах вторым по объёму вылова объектом (после горбуши *O. gorbuscha*). Концентрации металлов в органах и тканях рыб (мышечная ткань, печень, гонады) определены атомно-абсорбционным методом на спектрофотометре Shimadzu AA-6800 на пламенном и беспламенном атомизаторах из минерализатов проб, полученных при разложении навесок концентрированной HNO_3 марки ОСЧ в комплексе MARS 6, с использованием стандартных образцов с известными концентрациями. Статистическая обработка данных выполнена в программе SPSS Statistics 21. Половозрелые особи кеты (по 5 экз. самцов и самок в каждом месте сбора) отобраны осенью 2018 г. в садках-накопителях лососевых рыбоводных заводов на реках Фирсовка (юго-восток Сахалина, зал. Терпения) и Рейдовая (о-в Итуруп, Курильские острова), а также в октябре 2019 г. в садках для выдерживания производителей на р. Пойма (юго-запад Приморья, Японское море). От всех особей отдельно взяты пробы мышечной ткани, печени и гонад. Определяемые элементы чётко разделились по величинам концентраций на две группы в зависимости от места сбора проб: Cd и Pb преобладали в органах и тканях кеты из Сахалино-Курильского региона Охотского моря, а Fe, Zn, Cu и Ni — в япономорских рыбах. Причиной контрастного распределения тяжёлых металлов в органах и тканях рыб являются, очевидно, геохимические условия среды, формируемые в акваториях нагула и миграционных путей лососей. Если в практически замкнутом Японском море, слабо связанном с Тихим океаном малочисленными мелководными проливами, водная среда находится под сильным воздействием антропогенных, техногенных и терригенных факторов (хозяйственно-бытовых и промышленных стоков, поверхностных смывов с прибрежных территорий, сжигания судами углеводородного топлива), то в Сахалино-Курильском бассейне она испытывает влияние природных явлений — надводного и подводного вулканизма и поствулканизма Курильских островов, а также апвеллингов, выносящих из глубин Курило-Камчатской впадины в поверхностный слой практически весь набор химических элементов периодической системы Д. И. Менделеева. При этом Pb, обладающий высокой способностью к сорбции, задерживается на любых взвешенных частицах (как живых, так и неживых) и поступает в организмы рыб с пищей. Распределение микроэлементов по органам и тканям кеты существенно различается: в мышечной ткани зарегистрированы наименьшие концентрации металлов независимо от ме́ста вылова, а печень характеризуется повышенными уровнями всех, кроме Ni, металлов, причём в печени япономорских рыб определены самые высокие концентрации Fe, Zn и Cu. Для распределения металлов в гонадах рыб характерна своя специфика, особенно ярко проявившаяся в приморских лососях. Так, в гонадах самок преобладали как Fe, так и Zn, но особенно Cu: концентрация меди в гонадах самок кеты из р. Пойма была такой же, как в печени.

Гонады самок япономорской кеты имели наибольшие концентрации Ni, хотя гонады самцов тоже отличались высоким, пусть и очень изменчивым, содержанием этого элемента. Что касается Pb и Cd, наиболее токсичных и контролируемых санитарными службами элементов (их количество по техническим причинам нам удалось определить только в охотоморских рыбах), то в их распределении по органам и тканям отмечена хорошо известная картина: максимальная концентрация выявлена в печени рыб. При этом содержание Pb превосходило санитарную норму лишь в отдельных особях, пришедших на нерест в р. Фирсовка на юго-востоке Сахалина; по Cd превышение ПДК в печени всех сахалинских рыб составляло 2,5–4,0 раза, а для всех курильских рыб — 2,1–5,0 раз.

Ключевые слова: тихоокеанские лососи, кета, Сахалино-Курильский регион, Охотское море, Приморский край, Японское море, микроэлементы