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On the hygienic safety of commercial fish species in the Azov-Black Sea basin

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ABSTRACT

Introduction. In the modern period, the reservoirs of the Azov-Black Sea basin continue to be sources of commercial fish species. In this regard, monitoring for the levels of accumulation of toxicants is the main task in assessing the physiological and biochemical state of fish in terms of reproduction and their use as food.

The purpose. To assess the safety of commercial fish species in the Azov-Black Sea basin.

Materials and methods. Based on studies conducted during 2024, there were determined the levels of accumulation of polychlorinated biphenyls (PCBs), pesticides, toxic elements, and specific activity of radionuclides in the muscles of tulka, anchovy, pilengas, crucian carp, atherina, gobies, gloss's flounder, whiting, sprat, loofah, horse mackerel, and perch, caught in the Azov and Black Seas.

Results. The results obtained during 2024 for toxicants in fish are correlated with the current fish as food standard. The results obtained over 2024 were compared with the retrospective data (2020–2023). The analyses were carried out in accordance with certified methods included in the scope of accreditation of the Analytical Testing Center of the Azov-Black Sea branch of the Scientific Research Center of the Russian Federation VNIRO Federal State Budgetary Scientific Institution.

Limitations. The limitations are related to the specifics of sampling: the study was limited to the maximum possible selection of biological resources.

Conclusion. Low concentrations of pesticides and toxic elements (lead, cadmium, mercury, arsenic), and PCBs were detected, the specific activity of caesium-137 and strontium-90 was recorded at a low level. Therefore, tulka, hamsa, pelengas, crucian carp, atherina, gobies, Gloss flounder, whiting, sprat, lufari, horse mackerel are suitable for food in terms of pollution and radiation safety in accordance with the requirements of TR CU 021/2011.

Keywords: Azov Sea; Black Sea; limans; hydrobionts; heavy metals; arsenic; pesticides; PCB; specific activity of radio nuclides

Compliance with ethical standards. The study does not require the submission of the conclusion of the biomedical ethics committee or other documents.

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О гигиенической безопасности промысловых видов рыб Азово-Черноморского бассейна

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РЕЗЮМЕ

Введение. Водоёмы Азово-Черноморского бассейна — значимый источник промысловых видов рыб, поэтому мониторинг накопления токсикантов остаётся главной задачей при оценке физиолого-биохимического состояния рыб в плане воспроизводства и при использовании в качестве продуктов питания.

Цель работы — оценить безопасность промысловых видов рыб Азово-Черноморского бассейна.

Материалы и методы. На основании проведённых в 2024 г. исследований определены уровни накопления полихлорированных бифенилов (ПХБ), пестицидов, токсичных элементов, удельной активности радионуклидов в мышцах тюльки, хамсы, пиленгаса, карася, атерины, бычка, камбалы Глосса, мерланга, шпрота, лufари, ставриды, окуня, выловленных в Азовском и Чёрном морях.

Результаты. Полученные в 2024 г. данные о содержании токсикантов в рыбах соотнесены с действующим нормативом качества рыбы как продукта питания. Проведено сравнение результатов 2024 г. с ретроспективными данными (2020–2023 гг.). Анализы проводились в соответствии с аттестованными методиками, входящими в область аккредитации аналитического испытательного центра Азово-Черноморского филиала ГНЦ РФ ФГБНУ «ВНИРО» («АзНИИРХ»).

Ограничения исследования связаны со спецификой отбора проб: исследование ограничивалось максимально возможной выборкой биологических ресурсов.

Заключение. Установлены низкие концентрации пестицидов и токсичных элементов (свинца, кадмия, ртути, мышьяка) и незначительные уровни ПХБ, удельной активности цезия-137 и стронция-90. Следовательно, тюлька, хамса, пиленгас, карась, атерина, бычки, камбала Глосса, мерланг, шпрот, лufарь, ставрида по показателям загрязнения и радиационной безопасности в соответствии с требованиями ТР ТС 021/2011 пригодны для пищевых целей.

Ключевые слова: Азовское море; Чёрное море; лиманы; гидробионты; тяжёлые металлы; мышьяк; пестициды; ПХБ; удельная активность радионуклидов

Соблюдение этических стандартов. Исследование не требует предоставления заключения комитета по биомедицинской этике и иных документов.

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Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов в связи с публикацией данной статьи.

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Introduction

The Azov-Black Sea Basin includes the Black Sea and the Azov Sea, along with the river basins flowing therein, as well as watersheds in certain regions of Russia that are of significance for fisheries (Order of the Ministry of Agriculture of Russia No. 1 dated January 9, 2020)¹. The seaports of Rostov-on-Don, Azov, Taganrog, Yeisk, Temryuk, Kavkaz, Taman, Anapa, Novorossiysk, Gelendzhik, Tuapse, and Sochi have a significant anthropogenic impact on the ecosystem of the Azov-Black Sea Basin [1]. Intensive economic activity affects environmental quality through discharges into the water area and via river runoff. Other types of pollution in the water bodies of the Azov-Black Sea basin include:

- petroleum products (intensified transportation of oil and petroleum products, hydrocarbon production on the shelves of the Azov and Black Seas, accidental and unauthorized spills of fuels and lubricants);
- heavy metals (the waters of the Feodosia Gulf, Sevastopol Bay, and gas production areas in the northwestern Black Sea are particularly susceptible to pollution) [2];
- persistent organochlorine pesticides (in certain years, the concentration of DDT metabolites in the water increased compared to background levels, which may be a result of the erosion of pesticide burial sites located in southern Ukraine) [3, 4].

The majority of the Azov-Black Sea basin is an area of intensive agricultural productivity, hence the significant threat of runoff from fields and livestock pastures contaminating surface waters. Anthropogenic factors cannot be excluded, such as the construction of locks on the Don River and the salinization of the Sea of Azov, which affects the lower reaches of the Don [5].

Pollution of waters in the Azov-Black Sea basin is negatively affecting aquatic organisms. Deteriorating water quality and heavy recreational pressure have already led to a significant decline in fish stocks. Many pollutants can accumulate in the tissues of aquatic organisms, causing poisoning, developmental disorders and reproductive system disorders, which leads to a decline in population numbers and even the extinction of some species [6]. Toxic substances move up the food chain, from microscopic organisms to large predators, resulting in the accumulation of harmful compounds in the body, which can have a negative impact at all levels of the ecosystem. Fish eggs and larvae are considered the most vulnerable to pollution, as their defense systems are not yet fully developed and they are unable to leave polluted areas [7]. Nevertheless, the basins' water areas still possess a rich feeding supply, hydrological, and hydrochemical features satisfactory for the commercial fish species' feeding [8].

The species considered most sensitive to pollution in the Azov-Black Sea basin are:

- demersal fish species (mercury and arsenic accumulate to a greater extent in their tissues, due to their diet and lifestyle, which are influenced by the accumulation processes and the rate of transformation of pollutants in the seabed);
- sturgeon;
- gobies (a numerous species characterized by a sedentary lifestyle and, consequently, vulnerability in the event of adverse situations related to pollution, hypoxia and hyperthermia in their habitats);
- pelagic horse mackerel (its tissues often contain elevated levels of zinc and copper) [9].

The degree of fish vulnerability depends on the season, the biological characteristics of the fish and the level of habitat pollution. Fish sensitivity to the effects of toxicants is also influenced by species, age and physiological condition. Adverse environmental conditions, starvation, overcrowding, parasite infestation and other factors reduce fish resistance to pollutants. Among medium and large fish species, large specimens are now becoming increasingly rare [10].

Materials and methods

The aim of the study was to assess the levels of toxicants in commercial fish species caught in the waters of the Azov-Black Sea basin in 2024. Muscle samples were analyzed from sprat, anchovy, pilengas, crucian carp, sand smelt, crucian carp, goby, glossy flounder, whiting, sprat, blue whiting and horse mackerel caught in the Azov and Black Seas.

Sampling of aquatic biological resources was carried out in accordance with the requirements of GOST 31339–2006². The sample included females and males with similar intraspecific morphometric parameters and gonadal maturity stages. In total, more than 100 samples of aquatic biological resources were collected and processed. The data presented in the article correspond to the analysis of an average sample of each fish species ($n = 10$).

The reliability of differences between samples for determining the statistical significance of differences in mean values was assessed using Student's t -test: if the probability (p) was below the significance level ($p < 0.05$), the samples were considered to belong to two different populations, i.e. the differences were statistically significant provided that the data were normally distributed and the variances of the compared groups were equal. Excesses of the obtained values relative to the standard were assessed using a binary test (a simple test where the acceptance limit coincides with the tolerance limit), taking into account methodological error (uncertainty). The research results were statistically analyzed using Excel, and figures were also constructed within the programme.

When monitoring the accumulation levels of priority toxicants in fish muscle, methods adopted and approved at federal level for environmental monitoring studies were used. For the determination of pesticides in fish muscle, gas chromatography with an electron capture detector was used (NDI 05.05–2013)³. PCBs were determined by gas chromatography–mass spectrometry using a gas chromatograph and a high-resolution mass spectrometric detector, allowing the detection of individual ions with specified masses (NDI 05.23.2012)⁴. To determine toxic elements, atomic absorption was used in two variants: with electrothermal atomisation and the cold vapour method (NDI 05.14–2007⁵; NDI 05.35–2021⁶; NDI 05.26–2014⁷). The specific activity of radionuclides was determined using the MKS-01A 'MULTIRAD' spectrometric

² NDI 05.05–2013 'Mass fractions of pesticides in soils and bottom sediments of freshwater and marine water bodies. Methodology for measurement by gas-liquid chromatography'. <https://docs.cntd.ru/document/902320560> (accessed on April 4, 2025).

³ NDI 05.23–2012 'Method for the determination of mass fractions of individual polychlorinated biphenyl congeners in soil and sediment samples from freshwater and marine water bodies by gas-chromatography-mass spectrometry'.

⁴ NDI 05.14–2007 'Method for the determination of mass fractions of cadmium, lead and zinc in samples of aquatic organisms by atomic absorption with electrothermal atomisation'.

⁵ NDI 05.35–2021 'Method for the determination of the mass fractions of aluminium, barium, cadmium, cobalt, lithium, arsenic, silver, strontium and thallium in samples of aquatic organisms by atomic absorption with electrothermal atomisation'.

⁶ NDI 05.26–2014 'Mass fraction of total mercury in aquatic organisms samples. Method for measurement by flame-less atomic absorption'.

⁷ Method for measuring the activity of radionuclides using a scintillation gamma spectrometer with 'Progress' software.

¹ Order of the Ministry of Agriculture of Russia No. 1 of January 9, 2020, "On the Approval of Fishing Regulations for the Azov-Black Sea Fisheries Basin"; <https://docs.cntd.ru/document/564189244> (accessed April 4, 2025).

Table 1 / Таблица 1

Average concentrations of toxicants in the muscles of commercial fish species caught in the Crimean region of the Black Sea in 2024, per wet weight

Средние концентрации токсикантов в мышцах промысловых видов рыб, выловленных в Крымском районе Чёрного моря в 2024 г., на сырую массу

Показатель Indicator		Вид рыб, размерность / Type of fish, dimension				Допустимый уровень, не более Acceptable level, no more than
		Хамса длина 10–12 см, масса 0.010–0.013 кг Anchovy length of 10–12 cm, weight of 0.010–0.013 kg <i>n</i> = 10 (♂ + ♀)	Шпрот длина 7–8 см, масса 0.003–0.004 кг Sprat length of 7–8 cm, weight of 0.003–0.004 kg <i>n</i> = 10 (♂ + ♀)	Мерланг длина 11–17 см, масса 0.010–0.038 кг Whiting length of 11–17 cm, weight of 0.010–0.038 kg <i>n</i> = 10 (♂ + ♀)	Ставрида длина 12–13 см, масса 0.014–0.021 кг Horse mackerel length of 12–13 cm, weight of 0.014–0.021 kg <i>n</i> = 10 (♂ + ♀)	
ПХБ, мг/кг PCB, mg/kg		< 0.007	< 0.007	< 0.007	< 0.007	2.0
Пестициды Pesticides	ГХЦГ (α-, β -, γ-изомеры), мг/кг HCH (α-, β -, γ-isomers), mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
	ДДТ и его метаболиты, мг/кг DDT and its metabolites, mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
Токсичные элементы Toxic elements	Кадмий, мг/кг Cadmium, mg/kg	< 0.005	0.055 ± 0.020	< 0.005	0.006 ± 0.002	0.2
	Ртуть, мг/кг Mercury, mg/kg	0.017 ± 0.004*	0.056 ± 0.015	0.068 ± 0.018	< 0.005	0.5
	Свинец, мг/кг Lead, mg/kg	0.05 ± 0.03	< 0.05	< 0.05	< 0.05	1.0
	Мышьяк, мг/кг Arsenic, mg/kg	0.54 ± 0.16	0.18 ± 0.05	0.13 ± 0.04	0.17 ± 0.05	5.0
Удельная активность радионуклидов Specific activity of radionuclides	Цезий-137, Бк/кг Cesium-137, Bq/kg	< 2.28	3.15 ± 2.71	< 2.39	< 3.53	130
	Стронций-90, Бк/кг Strontium-90, Bq/kg	< 36.50	< 15.50	< 31.50	< 20.50	100

Примечание. Здесь и в табл. 2: * — методическая погрешность (неопределённость) измерений.
Note: Here and in Table 2: * — methodological error (measurement) uncertainty.

system on the ‘MULTIRAD-gamma’ scintillation gamma spectrometer (measurement methodology, 2003)⁸. The safety of toxicant accumulation levels, as well as the specific activity of caesium-137 and strontium-90 in the muscle tissue of fish caught in 2024 in the Don River, the Black Sea and the Sea of Azov, was assessed for compliance with the standards set out in TR TS 021/2011⁹ ‘On the safety of food products’.

Results

Five commercial fish species caught during the summer and autumn periods were analysed in 2024 in the Caucasian and Crimean regions of the Black Sea: anchovy, whiting, sprat, blue whiting, and horse mackerel. No PCBs or pesticides were detected in any of the biological samples. The specific activity of strontium-90 was recorded at a low level only in the muscle tissue of horse mackerel caught in the autumn in the Caucasian region of the sea, whilst no specific activity of caesium-137 was detected (Tables 1, 2).

Five species of commercial fish (sprat, anchovy, pilengas, crucian carp, and sand smelt) caught in the spring and summer

in Taganrog Bay and the Azov Sea itself were researched in 2024. PCBs weren’t found in any of the samples. In the muscle tissue of anchovies caught in the Sea of Azov, p’p-DDD (a metabolite of DDT) was detected in trace amounts (0.0005 mg/kg wet weight). No specific activity of caesium-137 was recorded in the fish muscle tissue. Low specific activity of strontium-90 was noted in the muscles of sand smelt; it was absent in the other fish species studied. Of the regulated toxic elements, mercury, arsenic, and cadmium were found in the muscles of sand smelt at concentrations below the permissible level; in crucian carp, mercury, cadmium, and lead were also below the permissible level. In the muscles of the pilengas, only mercury was found in concentrations below the permissible level; cadmium, lead, and arsenic were not detected in significant quantities. In the muscle tissue of anchovies caught in the Taganrog Gulf and in the open sea, the toxic elements found were mercury and arsenic in comparable concentrations below the permissible level; no significant amounts of cadmium or lead were detected (Table 3).

During the spring of 2024, two species of commercial fish caught in the Akhtaro-Grivensky estuaries (Azov estuaries in the Krasnodar Krai) were analysed. Of the regulated toxic elements, only mercury was detected in the muscles of perch (at concentrations significantly below the permissible limit). Cadmium, arsenic, lead, PCBs, and pesticides were not detected in

⁸ Method for measuring the activity of radionuclides using a scintillation gamma spectrometer with the Progress software.
⁹ Technical Regulation of the Customs Union ‘On the Safety of Food Products’ (as amended on 22 April 2024). Approved by Decision No. 880 of the Customs Union Commission dated 9 December 2011. TR CU 021/2011

Table 2 / Таблица 2

Average concentrations of toxicants in the muscles of commercial fish species caught in the Caucasian region of the Black Sea in 2024, per wet weight
Средние концентрации токсикантов в мышцах промысловых видов рыб, выловленных в Кавказском районе Чёрного моря в 2024 г., на сырую массу

Показатель Indicator	Весна / Spring		Лето / Summer		Осень / Autumn			Допустимый уровень, не более Acceptable level, no more than
	Вид рыб, размерность / Type of fish, dimension							
	Хамса Anchovy длина 11–13 см, масса 0.010–0.012 кг length of 11–13 cm, weight of 0.01–0.012 kg <i>n</i> = 10 (♂ + ♀)	Шпрот Sprat длина 7–8 см, масса 0.002–0.004 кг length of 7–8 cm, weight of 0.002–0.004 kg <i>n</i> = 10 (♂ + ♀)	Мерланг Whiting длина 12–14 см, масса 0.017–0.024 кг length of 12–14 cm, weight of 0.017–0.024 kg <i>n</i> = 10 (♂ + ♀)	Ставрида Horse mackerel длина 10–11 см, масса 0.010–0.012 кг length of 10–11 cm, weight of 0.010–0.012 kg <i>n</i> = 10 (♂ + ♀)	Шпрот Sprat длина 7–9 см, масса 0.002–0.004 кг length of 7–9 cm, weight of 0.002–0.004 kg <i>n</i> = 10 (♂ + ♀)	Луфарь Loofah длина 16–19 см, масса 0.043–0.059 кг length of 16–19 cm, weight of 0.043–0.059 kg <i>n</i> = 10 (♂ + ♀)	Ставрида Horse mackerel длина 10–14 см, масса 0.009–0.022 кг length of 10–14 cm, weight of 0.009–0.022 kg <i>n</i> = 10 (♂ + ♀)	
ПХБ, мг/кг PCB, mg/kg	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	2.0
Пестициды Pesticides								
ГХЦГ (α-, β -, γ-изомеры), мг/кг HCH (α-, β -, γ-isomers), mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
ДДТ и его метаболиты, мг/кг DDT and its metabolites, mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
Токсичные элементы Toxic elements								
Кадмий, мг/кг Cadmium, mg/kg	< 0.005	0.008 ± 0.003	< 0.005	0.009 ± 0.003	0.065 ± 0.025	< 0.005	< 0.005	0.2
Ртуть, мг/кг Mercury, mg/kg	0.018 ± 0.005*	0.103 ± 0.027	0.150 ± 0.039	0.093 ± 0.024	0.006 ± 0.002	< 0.005	0.005 ± 0.001	0.5
Свинец, мг/кг Lead, mg/kg	0.15 ± 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	1.0
Мышьяк, мг/кг Arsenic, mg/kg	0.25 ± 0.07	0.07 ± 0.02	0.09 ± 0.03	0.09 ± 0.03	0.19 ± 0.05	0.51 ± 0.15	0.05 ± 0.01	5.0
Удельная активность радионуклидов Specific activity of radionuclides								
Цезий-137, Бк/кг Cesium-137, Bq/kg	< 2.28	< 3.76	< 3.38	< 4.34	< 4.39	< 3.84	< 5.33	130
Стронций-90, Бк/кг Strontium-90, Bq/kg	< 36.50	< 45.80	< 14.30	< 29.40	< 26.80	< 32.70	27.60 ± 18.50	100

Table 3 / Таблица 3

Average concentrations of toxicants in the muscles of commercial fish species caught in Sea of Azov in 2024, per wet weight

Средние концентрации токсикантов в мышцах промысловых видов рыб, выловленных в Азовском море в 2024 г., на сырую массу

Показатель Indicator	Таганрогский залив / Taganrog Bay				Собственно Азовское море / Sea of Azov itself					Допустимый уровень, не более Acceptable level, no more than	
	Весна / Spring		Лето / Summer		Лето / Summer						
	Вид рыб, размерность / Type of fish, dimension										
	Пилентас длина 39–43 см, масса 1.6–2.4 кг Pilengas length of 39–43 cm, weight of 1.6–2.4 kg <i>n</i> = 10 (♂ + ♀)	Тюлька длина 6–8 см, масса 0.007–0.01 кг Tulka length of 6–8 cm, weight of 0.007–0.01 kg <i>n</i> = 10 (♂ + ♀)	Хамса длина 9–12 см, масса 0.005–0.012 кг Anchovy length of 9–12 cm, weight of 0.005–0.012 kg <i>n</i> = 10 (♂ + ♀)	Тюлька длина 6–9 см, масса 0.001–0.006 кг Tulka length of 6–9 cm, weight of 0.001–0.006 kg <i>n</i> = 10 (♂ + ♀)	Карась длина 15–18 см, масса 0.182–0.209 кг Crucian carp length of 15–18 cm, weight of 0.182–0.209 kg <i>n</i> = 10 (♂ + ♀)	Хамса длина 5–12 см, масса 0.006–0.012 кг Anchovy length of 5–12 cm, weight of 0.006–0.012 kg <i>n</i> = 10 (♂ + ♀)	Тюлька длина 8–9 см, масса 0.005–0.006 кг Tulka length of 8–9 cm, weight of 0.005–0.006 kg <i>n</i> = 10 (♂ + ♀)	Атерина длина 8–9 см, масса 0.003–0.007 кг Atherina length of 8–9 cm, weight of 0.003–0.007 kg <i>n</i> = 10 (♂ + ♀)			
ПХБ, мг/кг PCB, mg/kg	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	2.0	
ГХПГ (α-, β -, γ-изомеры), мг/кг HCH (α-, β -, γ-isomers), mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	Пестициды / Pesticides					0.2	
ДДТ и его метаболиты, мг/кг DDT and its metabolites, mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0005 ± 0.002	0.0008 ± 0.002	< 0.0002	0.2	
Кадмий, мг/кг Cadmium, mg/kg	< 0.005	< 0.005	< 0.005	< 0.005	Токсичные элементы / Toxic elements					0.2	
Ртуть, мг/кг Mercury, mg/kg	0.018 ± 0.005**	0.013 ± 0.003	0.021 ± 0.005	0.017 ± 0.004	0.012 ± 0.003	0.017 ± 0.004	0.014 ± 0.004	0.021 ± 0.005	0.021 ± 0.005	0.5	
Свинец, мг/кг Lead, mg/kg	< 0.05	0.05 ± 0.03	< 0.05	0.05 ± 0.03	< 0.05	< 0.05	< 0.05	0.06 ± 0.02	< 0.05	1.0	
Мышьяк, мг/кг Arsenic, mg/kg	< 0.05	0.05 ± 0.01	0.25 ± 0.07	0.14 ± 0.004	< 0.05	0.05 ± 0.01	0.36 ± 0.10	0.06 ± 0.02	0.06 ± 0.02	1.0	
Удельная активность радионуклидов / Specific activity of radionuclides											
Цезий-137, Бк/кг Cesium-137, Bq/kg	< 3.80	—*	< 7.62	< 3.86	—	< 5.01	< 3.61	< 4.00	< 4.00	130	
Стронций-90, Бк/кг Strontium-90, Bq/kg	< 30.90	—	< 33.90	32.00 ± 20.20	—	< 22.50	< 31.30	39.10 ± 19.90	39.10 ± 19.90	100	

Примечание. Здесь и в табл. 4: * — нет данных, ** — методическая погрешность (неопределённость) измерений.
Note: Here and in Table 4: * — no data available; ** — methodological error (measurement) uncertainty.

Table 4 / Таблица 4

Average concentrations of toxicants in the muscles of commercial fish species caught in the estuaries of Azov Sea in 2024, per wet weight

Средние концентрации токсикантов в мышцах промысловых видов рыб, выловленных в лиманах Азовского моря в 2024 г., на сырую массу

Показатель Indicator	Ахтаро-Гривенские лиманы Akhtaro-Grivensky estuaries		Лиман Молочный / Molochny estuary				Допустимый уровень, не более Acceptable level, no more than
	Вид рыб, размерность / Type of fish, dimension						
	Окунь длина 11–15 см, масса 0.13–0.35 кг Perch length of 11–15 cm, weight of 0.13–0.35 kg <i>n</i> = 10 (♂ + ♀)	Карась длина 13–19 см, масса 0.12–0.16 кг Crucian carp length of 13–19 cm, weight of 0.12–0.16 kg <i>n</i> = 10 (♂ + ♀)	Пиленгас длина 25–28 см, масса 0.146–0.203 кг Pilengas length of 25–28 cm, weight of 0.146–0.203 kg <i>n</i> = 10 (♂ + ♀)	Бычки длина 16–19 см, масса 0.067–0.08 кг Gobies length of 16–19 cm, weight of 0.067–0.08 kg <i>n</i> = 10 (♂ + ♀)			
ПХБ, мкг/кг PCB, mg/kg	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	2.0
Пестициды Pesticides	ГХЦГ (α-, β -, γ-изомеры), мг/кг HCN (α-, β -, γ-isomers), mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
	ДДТ и его метаболиты, мг/кг DDT and its metabolites, mg/kg	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.2
Токсичные элементы Toxic elements	Кадмий, мг/кг Cadmium, mg/kg	< 0.005	0.006 ± 0.002	< 0.005	< 0.005	< 0.005	0.2
	Ртуть, мг/кг Mercury, mg/kg	0.010 ± 0.003*	0.032 ± 0.008	< 0.005	0.021 ± 0.005	0.032 ± 0.008	0.5
	Свинец, мг/кг Lead, mg/kg	< 0.05	0.07 ± 0.04	< 0.05	< 0.05	< 0.05	1.0
	Мышьяк, мг/кг Arsenic, mg/kg	< 0.05	< 0.05	0.29 ± 0.08	1.2 ± 0.19	3.1 ± 0.50	1.0
Удельная активность радионуклидов Specific activity of radionuclides	Цезий-137, Бк/кг Caesium-137, Bq/kg	–	–	< 3.21	< 3.06	< 3.34	130
	Стронций-90, Бк/кг Strontium-90, Bq/kg	–	–	32.00 ± 16.80	< 45.00	< 38.90	100

significant concentrations. In crucian carp muscle, mercury, cadmium, and lead were detected among the regulated toxic elements (concentrations were significantly below permissible levels). Arsenic, PCBs, and pesticides were not found in crucian carp muscle. During the autumn period, the accumulation of toxicants was assessed in three species of commercial fish caught in the Molochny Estuary (an estuary of the Sea of Azov, Zaporizhzhia Oblast). No PCBs or pesticides were detected in significant concentrations in the muscles of pilengas, gobies, and glossy flounder; no specific activity of caesium-137 was recorded, and strontium-90 was detected only in pilengas at levels below the permissible limit (48.8 Bq/kg). Of the regulated toxic elements, arsenic and mercury were recorded in fish muscle at concentrations below the permissible limits; cadmium and lead were not found (Table 4).

Discussion

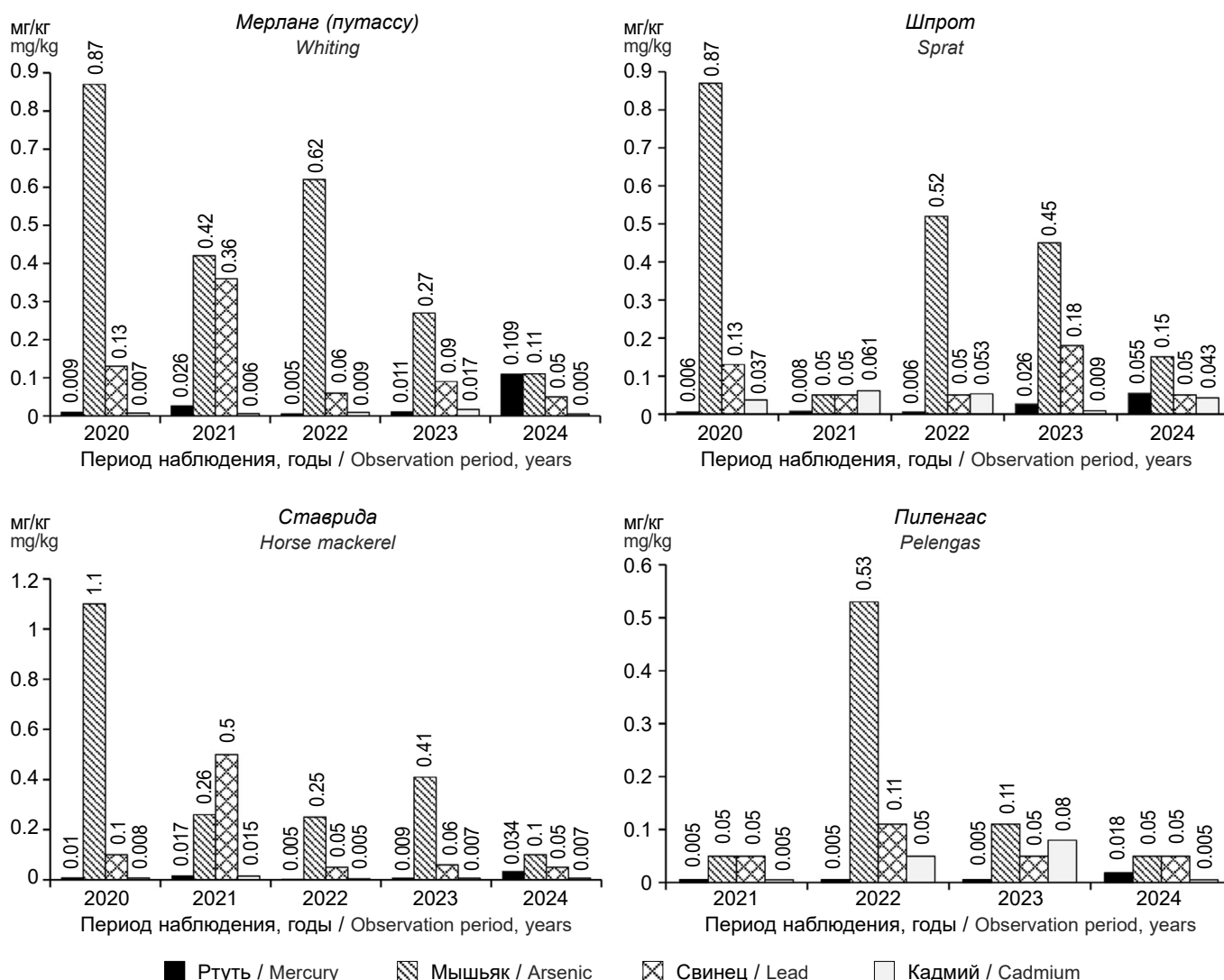
Adequate assessment levels of toxin accumulation in fish requires an awareness regarding the content of these substances in the components of the aquatic ecosystem [9]. The concentrations of all monitored elements and substances detected in the water and bottom sediments of water bodies, with some fluctuations, corresponded to the long-term average (2020–2023) values (at $p < 0.05$) [11–15].

Over the last five years of observations, the mercury content in the muscles of Black Sea whiting has increased more than tenfold (remaining within acceptable limits), the arsenic and lead contents have decreased by more than sevenfold and twofold respectively, and the cadmium content has remained at a similar level with some fluctuations (Figure).

Over the same period, the mercury content in sprat muscle increased ninefold, whilst the arsenic content decreased fivefold; cadmium and lead concentrations remain low and relatively similar (see Figure).

The mercury content in the muscles of horse mackerel had increased threefold by 2024, whilst the arsenic and lead contents had decreased by more than 10-fold and 2-fold respectively; cadmium levels changed only slightly (see Figure).

Between 2021 and 2024, the mercury content in the muscles of the



Trend in accumulation of toxic elements (mg/kg of crude weight) in the muscles of whiting, sprats, horse mackerel, pelengas caught in the Black Sea in 2020–2024.

Динамика накопления токсичных элементов (мг/кг сырой массы) в мышцах мерланга, шпрота, ставриды и пиленгаса, выловленных в акватории Чёрного моря в 2020–2024 гг.

Azov pilengas increased 3.6-fold, whilst the arsenic and lead contents, after peaking in 2022, returned to the 2021 levels (see Figure).

Conclusion

Chemical and radiological data were gathered and analyzed on the health of commercial fish species in the Azov–Black Sea basin, caught in the Azov and Black Seas during the spring, summer, and autumn of 2024. The low concentrations of pesticides and toxic elements (lead, cadmium, mercury, arsenic) detected

indicate the high physiological health and nutritional quality of the fish. No PCBs were found in significant concentrations in the aquatic biological resources studied, and the specific activity of caesium-137 and strontium-90 was found to be at an extremely low level. Tulka, anchovy, pilengas, crucian carp, sand smelt, crucian carp, gobies, glossy flounder (from the Sea of Azov, including the estuaries), as well as anchovy, whiting, sprat, blue whiting and horse mackerel (from the Black Sea) meet regulatory requirements in terms of pollution and radiation safety and are fit for human consumption.

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