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Comparative Analysis of Marine Fish for the Content of Pollutants in the Eurasian Region

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Abstract. The aim of the work was to measure the concentration of organochlorine insecticides, heavy metals, and hydrocarbons from the oil series in samples of marine fish from diverse oceans in the region. To achieve the goal, the methods of high-performance liquid chromatography and atomic absorption spectrometry, as well as the statistical method, were used. A total of 250 marine fish samples collected from the Caspian, Black, Baltic, Azov, and Okhotsk seas were analysed. The results of the study showed significant concentrations of organochlorine pesticides, including isomers of hexachlorocyclohexane (HCH), in fish living in the Caspian, Black and Baltic Seas. Specifically, the Caspian Sea is found to have the highest HCH content of 0.2123 mg/kg, while the Black Sea and Baltic Sea show 0.2031 mg/kg and 0.0187 mg/kg respectively. Heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) have also been found in fish samples. A comparative analysis of the content of pollutants in marine fish of the Eurasian region allows to draw the following conclusions: in fish living in the Caspian, Black and Baltic seas, there is a high concentration of organochlorine pesticides, heavy metals and petroleum hydrocarbons. This indicates significant pollution of the marine ecosystem by these substances. These studies highlight the need to control pollution of marine fish with pollutants and monitor the state of marine ecosystems to ensure the safety of fish consumption and public health.

Keywords: stellate sturgeon; pollution; heavy metals; hydrocarbons of the oil series; bioaccumulation.

1. Introduction

In recent decades, the global community has increasingly paid attention to the problem of environmental pollution and its consequences. Particular attention is paid to aquatic ecosystems, which, as a result of human industrial and agricultural activities, are negatively affected by various pollutants. The relevance of the study of the content of pollutants in marine fish in the Eurasian region is due to several key factors: the increased content of pollutants in marine fish can be an indicator of the general state of the marine ecosystem, the study of this topic will help to better understand the scale and consequences of environmental pollution. Also, seafood, including fish, is an important part of the diet of many people. The state and development trends of the fishing industry, alongside the impact of pollutants on this sector and the economy, are of paramount importance, especially in the Eurasian region where fishing is a key industry[1)]. The decline in fish quality due to pollution can lead to a decrease in demand and, consequently, to losses for the industry. The final factor in the relevance of the study is international cooperation. The problem of pollution of the oceans and seas extends beyond the borders of individual countries and requires international cooperation to solve it. This study could be an important part of such cooperation and help shape international environmental policy.

According to the Water Framework Directive (WFD)[2)], pollutants, which are widespread, are prioritized. The WFD is a key piece of European environmental legislation that aims to improve and protect the water quality of rivers, lakes, groundwater, estuaries, and coastal waters. It focuses on ensuring good qualitative and quantitative health by reducing and removing pollution and ensuring that there is enough water to support wildlife. The directive requires EU member states to achieve good status in terms of ecological and chemical status of surface waters, chemical status of groundwaters, and quantitative status of groundwaters. It also aims to prevent deterioration and enhance the status of aquatic ecosystems, promote sustainable water use, reduce pollution, and contribute to the mitigation of floods and droughts.

A. Buck's et al.[3)] findings underscore the pervasive nature of pollutants, which pose significant risks to the

environment and human health. They are highly persistent and can be carcinogenic, mutagenic, and teratogenic, posing a risk to the environment and human health. The main sources of pollutants are oil seeps and spills, maritime transport, sewage and industrial emissions, and precipitation. The presence of pollutants in the environment is becoming a serious problem, as they can accumulate in marine organisms and negatively affect the ecosystem and biodiversity. At the same time, I.A. Nemirovskaya[4] points out that in order to protect the marine environment and preserve human health, it is necessary to systematically monitor the content of pollutants in sea waters and biological organisms. This will help to assess the level of pollution and take appropriate measures to manage and reduce the risks associated with pollutants. Further research in this area is needed to expand the understanding of the effects of pollutants on the marine ecosystem and human health. They will also help develop effective pollution management and prevention strategies to ensure a safe marine environment and human health.

The research paper by N.V. Aladin et al.[5] is an extensive study of marine fish contamination with plastic waste. The authors of the study analysed the content of microplastic particles in the tissues of fish collected from various marine ecosystems. They have identified a significant accumulation of microplastics in fish organisms, which can lead to potential negative consequences for human health. A recent study by V. Sinyashchyk et al.[6] confirms the findings that microplastics pose an environmental risk to aquatic ecosystems. J.I. Namin and M.F. Vajargah[7] analysed the accumulation of heavy metals such as Pb, Cd, and mercury (Hg) in marine fish. The authors used chemical analysis methods to determine the content of these metals in fish samples collected from different marine regions. The results of the study showed that fish from some marine ecosystems contain significant levels of heavy metals that exceed the recommended safety limits for human consumption. Both of these studies highlight the importance of marine fish pollution and contribute to the understanding of the magnitude of the problem. They provide important data on the content of various harmful substances in the bodies of fish, which helps to understand the risks associated with the consumption of contaminated marine fish and requires appropriate measures to be taken to minimise marine pollution and protect human health.

An analysis of the Eurasian region, which includes many seas with unique ecosystems, is of considerable interest. In this context, several studies have been carried out that contribute to the understanding of water pollution and its consequences for human health. For example, G.I. Ruban and R.P. Khodorevskaya[8] conducted a study on heavy metal concentrations in fish from the Bay of Bengal, while A.E. Fathabad et al.[9], A. Pathak et al.[10] studied the bioaccumulation of heavy metals in marine organisms and assessed potential risks to human health. The article by O. Tuts[11] highlights the significant environmental impacts caused by accidents at main gas pipelines, including pollution to soil, surface, and underground water due to pipeline depressurization. These works provide a better understanding of the state of the marine environment and its impact on fisheries and industry in the region. However, despite the important contribution of these studies to understanding the problem, a comparative analysis covering all the seas of the Eurasian region has not yet been carried out, which determined the purpose of this study. In addition, most studies have focused on the study of the accumulation of certain groups of pollutants, while the range of potentially hazardous substances that can accumulate in fish organisms is much wider.

As a result of research by L. Duedahl-Olesen et al.[12], T.T. Tran-Lam et al.[13] found that the proportion of carcinogenic polycyclic aromatic hydrocarbons (PAHs) in the total amount of detected PAHs is a significant proportion, namely 29.5%. The most common of these is naphthalene, which belongs to IARC group 2B and is recognised as a possible human carcinogen. The data obtained allow to more fully characterise the distribution of PAHs in the Gulf of Catania and assess the potential risk to human health associated with the consumption of *Mullus surmuletus* in this region. An analysis of the calculation of the risk index for the development of cancer (ILCR), which shows the level of health risk associated with the consumption of fish, showed that it is well below the "maximum acceptable risk level".

R. Apiratikul et al.[14], S. Kanao and T. Sato[15] add that the observed concentrations of Cd and Pb in the marine fish *Engraulis encrasicolus* were found to be lower than in other studies conducted in the Eastern Mediterranean region. The average concentrations of Cd and Pb in the muscle tissue of this species are 2.04 and 3.22 (μg/g wet weight). However, the average Cr concentration was below the detection limit. A similar trend was found in *Sardina muscles pilchardus* from the northeastern Mediterranean Sea, where the mean concentrations of Cd, Cr, and Pb are 0.49, 1.98, and 4.74 (μg/g dry wt). In contrast, *the Engraulis study encrasicolus* in the Adriatic Sea showed Cd, Cr, and Pb values of 0.02, 0.083 and 0.046 (μg/g ww) respectively, which are lower than the concentrations observed in the SR group for all three metals, in the Pb group, in the Sa and Ma for Cd and Cr. This is also comparable to the results of the above study.

In this regard, in the study of a comparative analysis of marine fish for the content of pollutants in the Eurasian region, several tasks were set: determination of the concentration of heavy metals (for example, Pb, Cd, Cr) in samples of marine fish from different seas of the Eurasian region; comparative analysis of the level of pollution by pollutants (including organochlorine pesticides and petroleum hydrocarbons) in fish from the Caspian, Azov, Okhotsk, Black and Baltic seas; assessment of bioaccumulation and potential risks to human health associated with the presence of heavy metals and other contaminants in marine fish in the region.

2. Materials and methods

This empirical research project involves the collection and analysis of data on the content of pollutants in various

types of marine fish living in the seas of the Eurasian region. Fish samples were collected at strategically important points in each of the seas, including the Baltic, Black, Azov, Caspian, and Okhotsk Seas. These locations were chosen based on an extensive body of prior research, encompassing contributions from numerous researchers listed above as well as the established known distribution of fish populations.

Table 1. Eurasian regions for comparative analysis of fish samples.

Sea	Location Description	Types of Samples	Number of Samples	Seasonal Considerations	Method of Capture	Immediate Chilling
Baltic Sea	Off the coast of Latvia, near Ventspils. Approximate coordinates are 57.3891°N, 21.5449°E	Flounder	50	Sampling was conducted at different times of the year	Fish captured using nets to minimise stress	Promptly chilled
Black Sea	Off the coast of Turkey, near Sinop. Approximate coordinates are 42.0265°N, 35.1487°E	Raja clavata	50	Sampling was conducted at different times of the year	Fish captured using nets to minimise stress	Promptly chilled
Sea of Azov	Off the coast of Ukraine, near Mariupol. Approximate coordinates are 47.1167°N, 37.5561°E	Cyprinus vimba	50	Sampling was conducted at different times of the year	Fish captured using nets to minimise stress	Promptly chilled
Caspian Sea	Off the coast of Kazakhstan, near Atyrau. Approximate coordinates are 47.1223°N, 51.8317°E	Abramis brama	50	Sampling was conducted at different times of the year	Fish captured using nets to minimise stress	Promptly chilled
Sea of Okhotsk	Off the coast of Japan, near Monbetsu. Approximate coordinates are 43.8514°N, 144.1681°E	Teleostei	50	Sampling was conducted at different times of the year	Fish captured using nets to minimise stress	Promptly chilled

The specified coordinates are approximate and may differ slightly depending on the specific point of capture. In each of these regions, the capture was carried out within a radius of about 20 km from the specified coordinate in order to ensure the representativeness of the sample. In each sea, 50 stellate sturgeon samples were taken. As a common species for all the studied seas, this provided a sufficient sample for statistically significant analysis and made it possible to make an accurate comparison between seas and estimate pollution levels. Fish were caught at different times of the year to account for possible seasonal fluctuations in pollution levels. Sampling was carried out using nets, and it is important that the fish be alive at the time of capture to avoid the possible introduction of additional contamination after the death of the fish. After capture, fish samples were immediately chilled on ice to prevent decomposition and changes in pollutant levels. All specimens collected were labelled and documented, including the date and location of capture, size, and weight of the fish. This made it possible to trace possible correlations between these variables and pollution levels. Fish samples were processed to extract tissues that would be used for pollutant analysis. This involved removing the skin and internal organs, after which the samples were frozen until analysis.

The content of organochlorine pesticides was measured by gas chromatography on an Agilent 6890 apparatus (USA) using an electron capture detector and an Agilent HP-5 capillary column (25 m*0.3 mm) with a film thickness of 0.79 μm. The temperature of the column was

from 170℃ to 330℃ with a gradient of 5℃/min, and the detector temperature was set to 355℃. The carrier flow rate was 35 ml/min.

The collected data on the content of contaminants in fish samples will be subjected to statistical analysis. One set of analyses of the concentration of total petroleum hydrocarbons (C8-C40) for matrices used the method EPA 8015B, which detects semi-volatile and volatile petroleum products in the C8 to C40 range, using gas chromatography with a flame ionisation detector. In addition, percentage solids in sediment and marine biota samples were determined using the SM 2540G method, which provides a measure of organic and inorganic matter content by drying samples at 103 to 105°C. Alkylated PAHs were extracted from the samples prior to analysis. EPA method 3550 was used for the extraction. This method uses an ultrasonic extraction technique with an organic solvent to extract semi-volatile organic compounds from solids such as soils, sludges and tissues. EPA method 3540 was also used. This is an automated soxhlet extraction method that isolates organic compounds from solids by efficiently extracting them. The extracts were then analysed using EPA method 8270. This analytical method determines semi-volatile organic compounds in various environmental matrices, including water, soil, and air, using gas chromatography with a mass spectrometry detector. It utilises selected ion monitoring modes to detect target analytes even at low concentrations. The concentrations of PAHs are presented as a sum, usually expressed in mg/kg of sample.

For data analysis, descriptive statistics were performed, including the calculation of the mean, standard deviation, 95% confidence intervals, range, and minimum and maximum values of oil concentrations in the environment. To normalize the data, the percentile values were transformed using the arcsine function. This transformation was necessary because this type of data usually does not have a normal distribution, and the use of the arcsine transformation makes it easier to calculate descriptive statistics. The results of this transformation will be presented along with the raw means and other descriptive data. For laboratory research on heavy metals, a microwave unit from Milestone S. r. l. was used for mineralization of fish muscle tissue samples. The tissues were digested with strong acids. The decomposition solution consisted of nitric acid and hydrogen peroxide prepared according to the protocol. After mineralization, the samples were supplemented with high purity water to a predetermined volume and then divided into two aliquots: one for measuring Hg and another for measuring other metals.

For the analysis of Hg, the author used the method of oxidation and neutralisation, followed by measurement using a cold vapour analyser. An atomic absorption spectrophotometer was used to quantify the content of Cd, Cr, and Pb. Blank analyses were performed to check the accuracy and calibration of the instruments. Standard solutions prepared from certified reference solutions were used to calibrate instruments and control measurement accuracy. The potential risk to human health was assessed based on data on contaminant levels and levels of fish consumption. For this, a standard approach to health risk assessment was used, which includes an assessment of the exposure and toxicity of contaminants. Various factors, such as dose, duration of exposure, and human sensitivity, were taken into account. It is important to note that to ensure the quality and reliability of the results, all stages of the study were carried out in accordance with established protocols and standards. All selections samples were held in accordance with the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes[16] and Universal Declaration on Animal Welfare[17,18].

3. Results

This study analysed the content of petroleum hydrocarbons, organochlorine pesticides, and heavy metals in marine fish living in the seas of the Eurasian region. The data were obtained from measurements and analyses in accordance with the methods described. The results of the study of the amount of organochlorine pesticides in stellate sturgeon living in the pollutant seas of the Eurasian region showed the presence of significant concentrations of these substances. A detailed analysis revealed the presence of several types of organochlorine pesticides, including pesticides such as a, ß and y-HCH, as well as dichlorodiphenyltrichloroethane (DDT). This indicates a wide range of uses of pesticides in agriculture and other industries, which can lead to their accumulation in the ecosystem. Significant variability in pesticide concentrations in different stellate sturgeon samples was also shown, indicating different sources of contamination and spatial variability in concentrations (Table 2).

Table 2. Concentration of pesticides of organochlorine origin in muscle tissue of stellate sturgeon (mg/kg).

Location	Amount of DDT	The sum of isomers a, ß and y-HCH
Caspian Sea	0.2123	0.1256
Black Sea	0.2031	0.1897
Baltic Sea	0.0187	0.0345
Sea of Azov	0.2789	0.0198
Sea of Okhotsk	0.08147	0.1123
Maximum allowable levels	0.15	0.15

Source: compiled by the authors.

As a result of the analysis, it was revealed that the Caspian Sea has the highest content of a, ß, y-isomers of HCH with a level of 0.2123 mg/kg. The Black Sea also shows a significant content of these isomers, amounting to 0.2031 mg/kg. The lowest content of HCH was found in the Baltic Sea – 0.0187 mg/kg. Regarding the content of DDT, the highest value (0.1256 mg/kg) was recorded in the Caspian Sea, while in the Black Sea the content was 0.1897 mg/kg. The Baltic Sea and the Sea of Azov showed lower levels of DDT (0.0345 mg/kg and 0.0198 mg/kg, respectively). The Sea of Okhotsk showed the content of HCH in the amount of 0.08147 mg/kg and DDT in the amount of 0.1123 mg/kg. All values for the content of organochlorine pesticides were compared with the maximum allowable levels established for both groups of pesticides (0.15 mg/kg). Analysis of the data allows to conclude that in fish living in the Caspian Sea, the Black Sea and the Sea of Okhotsk, there is an excess of the maximum allowable levels of HCH and DDT. At the same time, the Baltic Sea and the Sea of Azov have a pesticide content that does not exceed the established limits. On average, stellate sturgeon samples collected on the coast of the Caspian Sea show high values of total petroleum hydrocarbon (TPH), reaching an average of 4.013 parts per trillion (n=50). However, the average concentration of total PAHs in these samples is much lower at 137 ppb, varying from the lower limit of detection (0) to 3.028 ppb. In turn, the average concentrations of all other sets of compounds are at a similar level, ranging from 18 to 32 ppb (Table 3).

Table 3. Kazakhstan region of the Caspian Sea: Average concentrations of total PAHs, TPH and four classes of petroleum hydrocarbon compounds in the muscle mass of stellate sturgeon.

Format	Indicators	C2 Dibenzothiafenes	C3 Dibenzothiophenes	C2 Naphthalene	C3 Naphthalene	C3 Fluorenes	C1 Phenantrenes/Anthracenes	Total PAH	TPH
Simple data	Values	0.019	0.018	0.031	0.019	0.023	0.032	0.137	4013.726
	Art. off	0	0	0.0204	0.0123	0	0.0198	0.5112	5124.9336
	n	50	50	50	50	50	50	50	50
	95% higher	0.018	0.019	0.029	0.031	0.024	0.042	0.297	5552.798
	95% inferior	0.017	0.018	0.02	0.02	0.018	0.021	-0.053	1987.421
	Max.	0.024	0.021	0.082	0.069	0.025	0.088	3.02	22686.12
	Min.	0.016	0.017	0.002	0.019	0.017	0.019	0	0.006
Formatted data Log $_{10}$ (Y +1)	Values	0.008	0.008	0.013	0.009	0.008	0.013	0.036	3.699
	Art. off	0	0	0.0068	0.0053	0	0.0091	0.0904	1.3915
	n	50	50	50	50	50	50	50	50
	95% higher	0.008	0.01	0.016	0.009	0.007	0.017	0.084	3.247
	95% inferior	0.007	0.01	0.009	0.007	0.007	0.009	-0.002	1.988
	Max.	0.009	0.01	0.028	0.028	0.007	0.045	0.636	5.118
	Min.	0.007	0.01	0.002	0.008	0.007	0.007	0	0.003

Note: the primary data concerning pollutant concentration in stellate sturgeon muscle mass include the following: mean, maximum observed concentration, sample size (n), standard deviation, $Log_{10(Y+1)}$ transformed data, and 95% confidence intervals converted data. Also shown are the data converted for normalization.

Source: compiled by the authors.

Analysis of the concentration of phenanthrenes/anthracenes (n=50) in this group showed an average value of 32 ppb, while the average concentration of dibenzothiophene (C2) was 19 ppb. Naphthalene (C3) also averaged 19 ppb (n=50) and dibenzothiophenes (C3) averaged 18 ppb. These results

indicate a rather high level of pollution in the area of the city of Atyrau in the Caspian Sea, which may adversely affect the quality of life of the population of Kazakhstan. The authors of the study attribute this to the presence of industrial complexes near the study area. Compounds derived from crude oil were found in various concentrations in all fish samples taken from the seas of the Eurasian region. In particular, the levels observed in some individuals in areas sampled during the study period were high (Fig. 1).

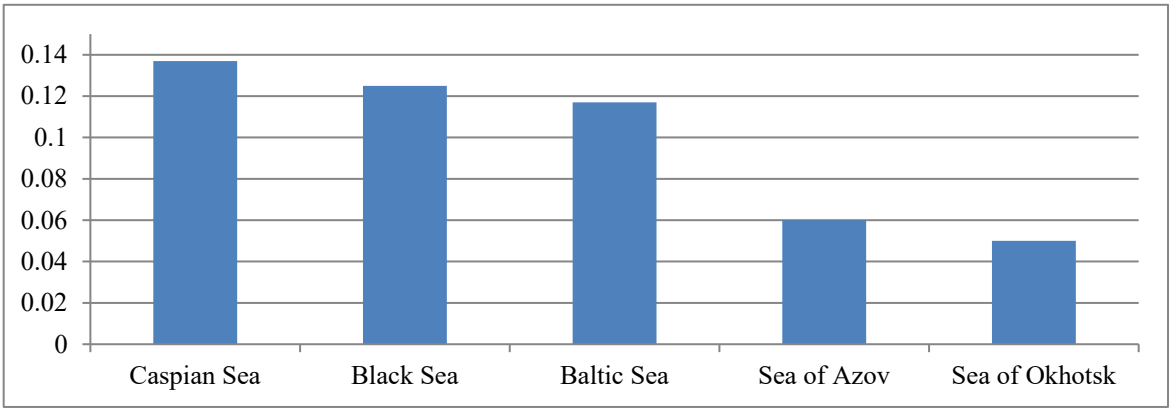

Fig. 1: Indicators of the total amount of PAHs in the seas of the Eurasian region

Source: compiled by the authors.

The data obtained indicate significant hydrocarbon pollution of the oil series of the Caspian, Black and Baltic seas. At the same time, concentration indicators in the Sea of Azov and the Sea of Okhotsk practically do not exceed the norm. This is due to the lower congestion of enterprises and vehicles in these regions. Sample analysis shows traces of Hg in all fish samples. Cd and Cr were found in all samples, except for samples from the Black Sea. Pb was found only in samples from the Azov and Black Seas (Tables 4 and 5).

Table 4. Mean Pb and Cd values, standard deviations (µg/g) for stellate sturgeon accessions, estimated weekly intake (ECI) (µg/kg live weight), and target hazard factor (TFR).

Place	Pb	RNP, Pb	CKO, Pb	CD	RNP, CD	CKO, CD
Black Sea	0.21±0.18	0.032	$3*10^{-6}$	<0.001	-	$104*10^{-6}$
Caspian Sea	0.12±0.1	0.044	$15*10^{-6}$	<0.001	-	$59*10^{-6}$
Sea of Azov	0.29±0.24	0.236	$22*10^{-6}$	0.358±0.087	0.321	0.044
Baltic Sea	<0.001	-	$21*10^{-6}$	0.298±0.097	0.244	0.026
Sea of Okhotsk	<0.001	-	$22*10^{-6}$	0354±0.149	0.275	0.044

Source: compiled by the authors.

Table 5. Mean Cr and Hg values, standard deviations (µg/g) for stellate sturgeon accessions, estimated weekly intake (ECI) (µg/kg live weight) and target hazard ratio (TCV).

Place	Cr	RNP, Cr	CKO, Cr	Hg	RNP, Hg	CKO, Hg
Black Sea	<0.001	-	$0.2*10^{-5}$	0.05±0.04	0.019	$31*10^{-5}$
Caspian Sea	<0.001	-	$0.2*10^{-5}$	0.28±0.24	0.086	$204*10^{-6}$
Sea of Azov	0.65±0.47	0.499	$19*10^{-6}$	0.05±0.04	0.038	$63*10^{-6}$
Baltic Sea	0.1±0.08	0.074	$0.4*10^{-5}$	0.14±0.13	0.095	$133*10^{-6}$
Sea of Okhotsk	0.51±0.42	0.411	$16*10^{-6}$	0.14±0.18	0.091	$122*10^{-6}$

Source: compiled by the authors.

As a result of the analysis of stellate sturgeon samples, it was found that the Pb content exceeded the limit value set by the Commission Regulation (EC)[19] (0.2 parts per million), in 71.6% of fish analysed in the Black Sea, and in 13.7% of fish, analysed in the Sea of Azov. Thus, the average value of Pb content in stellate sturgeon exceeded the limit value established by the Commission Regulation (EC)[19] only in the Black Sea. In addition, samples from the Black Sea and the Sea of Okhotsk had higher average Cr levels than samples from other sites. Overall, only 5% of the samples were found to contain Hg above the limit set by the Commission Regulation (EC)[19]. This distinguishes Hg from other metals, and its concentration in fish has a special structure. However, it is interesting to note that stellate sturgeon samples taken in the control area of the Caspian Sea are distinguished

by significantly higher values than samples from other regions.

The results of the study clearly indicate contamination of samples taken in Atyrau, a city located 15 km north of a major industrial complex. This industrial complex is well known for its high bioavailability of contaminants such as heavy metals, PCBs, and PAHs. The Caspian Sea receives a large amount of water containing pollutants from this industrial complex. Of all the surveyed sites, only in three seas – the Caspian, Baltic, and Okhotsk – significant Cd contamination caused by industrial and intensive agricultural activities found. The reference area selected in the Caspian Sea showed higher levels of bioaccumulation than expected, especially when compared to the sampling area in the Sea of Azov, which, despite greater anthropogenic impact, was found to be generally less polluted. Especially noticeable is the high content of Hg in the samples from the control zone. This may seem unusual for an area that appears to be uncontaminated. These results indicate the need for more detailed study and monitoring of pollution in the control zone of the Caspian Sea in order to understand the causes and possible consequences of high concentrations of pollutants in this area. The results obtained in the Sea of Azov region are satisfactory, as they do not differ significantly from the results in the control region of the Baltic Sea, except for the content of Pb. This indicates a similar degree of pollution in these areas and may be indicative of similar sources of pollution or similar environmental conditions.

The European Food Safety Authority[20] has developed regulatory guidelines for dietary intake of Hg, Cd and Pb. They recommend a preliminary tolerable weekly intake of 1.8 mcg/kg for Hg, 9 mcg/kg for Cd, and 28 mcg/kg for Pb. In addition, the provisional weekly allowable intake value for Cr is 712 µg/kg body weight, which is the minimum requirement to meet the needs of the human body. As can be seen from Table 4, the estimated weekly intake calculated from the collected data is below the EFSA's provisional allowable weekly intake limits. This means that even if the concentration of Cd in fish muscles is higher than European standards, this does not pose a risk to human health[21]. However, the level of contamination requires constant monitoring to ensure the safety of fish consumption and to keep the level of contamination under control. The results of the calculation of the target hazard coefficient show that there is no carcinogenic risk. CEC values below 1 indicate that the exposure level is below the reference dose, and therefore it can be assumed that the daily intake reflected in the results does not cause any adverse health effects in people during their lifetime. This suggests that the current level of pollution of fish with pollutants is not significant in terms of potential harm to human health[22].

The data obtained by the authors reflect well the expected level of pollution in the areas where the samples were taken, including both natural sources and the impact of human activity. The analysed fish showed potentially toxic concentrations of some metals that could enter the food chain. However, the level of their toxicity to humans depends on the rate at which they are taken. The results obtained through calculations indicate that the metal concentrations found in fish samples do not pose a risk to human health. This suggests that, at the moment, the level of pollution of fish with pollutants is not significant in terms of potential harm to human health.

4. Discussion

The results of this study on the levels of pollutants in marine fish samples taken from the Eurasian region's oceans show considerable regional variation in pollutant concentrations. There is also evidence of heavy metal bioaccumulation in certain areas. To evaluate the implications for marine biodiversity, food safety, and ecosystem health, the interpretation of these findings in the context of possible environmental and health repercussions involves comparing them to existing literature and regulatory requirements.

R.O. Bua et al.[23] and S. Kourdali et al.[24] in their studies on the Adriatic Sea note the absence of detection of benzofluoranthene, dibenzoanthracene, benzoperylene, and indenopyrene, while seven of the sixteen targeted PAHs were detected in all muscle tissue samples. Benzoanthracene and chrysene were detected in more than 30% of the samples, while benzofluoranthene and benzpyrene, recognised by the International Agency for Research on Cancer as the most carcinogenic PAH, were detected in only 3 samples out of 8 analysed, and their concentrations were close to the limit of quantitative determinations (0.2 µg/kg). Similar observations were made in studies of PAHs in the Caspian Sea. This indicates similarities in the distribution and concentration of PAHs in different marine regions. The detection of certain PAHs in fish confirms their presence in the marine ecosystem and possible accumulation in fish organisms[25)-28)].

In the results of the study by S. Ayele et al.[29], C. Fang et al.[30] it was found that the concentration of the total a, ß and y isomers of HCH in fish muscle tissue samples collected during the 2nd expedition exceeded the maximum permissible level. The level of excess in the roach was 9.2 times the level of the maximum allowable concentration. Also, at this point, a high content of DDT and its metabolites was found, which exceeded the maximum allowable concentration (MAC) by 270 times. In the bream at this point, an excess of the MPC for this indicator by 1.7 times was also noted. In the catfish at point 3, the excess of the MPC was 2.2 times. In other cases, the total content of a, ß and y isomers of HCH and DDT and its metabolites was within the normal range or was not detected. In the study cited above, an excess of organochlorine pesticides was also observed in fish samples.

P.W. Sammarco et al.[31], M. Rovira et al.[32] found that high molecular weight petroleum hydrocarbons settle to the bottom, so that both sediment and sediment-associated organisms have significantly higher concentrations than in the water column. They are most likely transported into the sediments along with other settling substances, organic or inorganic[33]. Due to their physicochemical properties, the concentrations of TPH in the sediments and organisms taken for this study are significantly higher than those observed in the water column. Sixty percent of the sediment samples from the Atchafalya swamps had concentrations of up to 19 PAHs that exceeded the maximum allowable values for marine sediments. This confirms the correctness of the choice of the studied samples for the comparative analysis of marine fish for the content of pollutants in the Eurasian region.

N.M. Bautista et al.[34] noted that high concentrations of C1-benzo(a)anthracene/chrysene were found in Caribbean seafood samples above the US Environmental threshold Protection Agency (US-EPA) for human consumption of seafood more than 4300 times ($1.65*10^{-5}$ ppm)[35]. This indicates significant pollution and may have negative consequences for the environment and economy of the region given its significant role in fisheries (including oysters, shrimp, blue crabs, and fish)[36]. It is possible to observe a rather similar situation in some seas of the Eurasian region and, accordingly, draw parallels with work.

Italian researchers N. Interino et al.[37] note that the main sources of pollution in Sicily are associated with the three largest industrial sites: Augusta on the central east coast (Ionian Sea), Gela on the south coast (Sicilian Canal) and Milazzo on the northeast coast (Tyrrhenian Sea). These areas produce pollutants from oil refining, wastewater, and toxic heavy metal dust emissions. At the same time, in the Palermo region (northwest of Sicily), various industrial and commercial activities, such as oil and electricity production, as well as engineering, shipbuilding, and manufacturing companies, are the main sources of air and water pollution[38]. In addition, agricultural and domestic effluents contribute significantly to pollution, making this region one of the most polluted on the Mediterranean coast. The Caspian Sea is also subject to various anthropogenic influences, which makes the situation very similar[39),40].

J.E. Balmer et al.[41], A. Kupsco et al.[42] found that in a study of heavy metal bioaccumulation in *Mullus barbatus* in the Capo Passero region (located in the Strait of Sicily with low levels of anthropogenic impact), significant scientific findings have been obtained. One of the key findings is the discovery of high Hg concentrations in fish, exceeding levels recorded at other anthropogenic contaminated sites[43]. The average concentration of Hg was 0.29 mg/kg wet weight. These results are in line with previous studies conducted in the eastern Aegean, where Hg was also observed in *Mullus. barbatus* in the range of 0.015 to 0.18 mg/kg, with an average value of 0.09 mg/kg. Additionally, a study on samples from Pantelleria showed a variety of Hg concentrations in *Mullus. barbatus* and *sardina pilchardus.* Mean values ranged from 0.061 to 0.077 mg/kg ww in *Mullus barbatus* and from 0.088 to 0.359 mg/kg wet weight in *Sardinia pilchardus*. These results indicate serious problems of Hg pollution in marine ecosystems, which are comparable to some seas in the Eurasian region[44)-46]. This suggests that, at current exposure levels, *Mullus surmuletus* poses no significant potential risk to human health. This means that in the seas of the Eurasian region, even in the presence of certain types of carcinogens, the danger can only be on paper.

5. Conclusions

The results of this study provide strong evidence of concerning levels of various pollutants, including organochlorine pesticides, heavy metals, and petroleum hydrocarbons, accumulating in marine fish across seas in the Eurasian region. An analysis of 250 marine fish samples from across the Eurasian seas demonstrates concerning pollution levels in certain regions, posing risks to ecosystems and human health. Specifically, organochlorine pesticides exceeded guidelines of 0.15 mg/kg in the Caspian, Black, and Okhotsk Seas. The presence of banned pesticides like DDT and HCH indicates a significant impact of agrochemicals, which were widely used in agriculture in the past, on the marine ecosystem. High levels of these pesticides can pose a potential risk to human health, as they can accumulate in the body and have toxic effects.

Heavy metals such as Pb, Cd, and Cr have also been found in fish from the studied seas. Pb content in the Black Sea fish exceeded the permissible limits, indicating the influence of industrial and other anthropogenic sources of pollution. Cd has been found in fish from the Caspian and Baltic Seas, likely associated with industrial emissions and ship activities. Elevated levels of Cr have been found in fish from the Black Sea and the Sea of Okhotsk, which may be related to industrial processes and emissions from industries and ships. Though immediate health risks seem low, persistent chemicals and metals can impair neurological development, reproduction, and other functions in species, including humans, indicating a need for exposure reduction. Additionally, high concentrations of PAHs were found in fish from all the studied seas. These PAHs are products of petroleum emissions and can accumulate in fish tissues. Consumption of fish high in PAHs can pose a health risk, as some PAHs are known to be carcinogens.

Findings establish that Eurasian seas are facing pressure from pollution, which may intensify with coastal development. Regional cooperation should form integrated monitoring programmes, emissions control strategies, and science-based decision-making to minimise contamination threats to ecosystems, food chains, biodiversity, fisheries, economies, and public health. It is also important to develop and implement

strategies for regulating industrial processes and the use of agrochemicals to minimise health risks and maintain the environmental sustainability of marine ecosystems. Further sampling could detail pollution pathways and impacts while tracing source-proximity relationships. In conclusion, concerted efforts balancing economic growth and environmental protection are required to curb persistent marine pollution.

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