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The Kuril Islands as a Potential Region for Aquaculture: Organochlorine Pesticides in Pink and Chum Salmon

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Abstract

The Kuril Islands region is considered promising for development of salmon aquaculture. There are 41 salmon fish hatcheries in the Sakhalin Island and the Kuril Islands, 38 of them are hatcheries of the pink and chum. Food safety of products is an important task of aquaculture. Therefore, concentrations of isomers of hexachlorocyclohexane (α-, β-, γ-HCH) and dichlorodiphenyltrichloroethane (DDT) and its metabolites (dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE) were determined in pink and chum salmon were caught in this region. The contents of toxic substances don't exceed the maximum permissible concentrations (MPC) according to the Russian sanitary standards. The average total concentration of pesticides in organs of salmon from the Kuril Islands is lower than that in salmon from the North Pacific American coast and the Atlantic Ocean. The region can be used to grow smolts, which will be later released into the ocean.

Keywords: Pesticides; Chum and pink; Kuril Islands; Salmon aquaculture

Introduction

Marine and oceanic feeding grounds of pacific salmon occupy vast expanses of subarctic waters in the North Pacific, the Bering, the Okhotsk, the Japan, and the Chukchi Seas with the total area about 15 million km^2. Within the exclusive economic zone of Russia, the feeding grounds of adult pacific salmon (age 1 and elder) include the deep-water parts of the Okhotsk and the Bering Seas and the waters eastward from the Kuril Islands and the Kamchatka with the total area 3 million km^2. To 2.0-2.5 million ton of salmon (mainly pink and chum) migrate through this region annually. The main areas of juvenile (postcatadromous) salmon feeding in summer-fall are the southern deep-water part of the Sea of Okhotsk, the waters at the western Kamchatka, and the Commander Basin in the Bering Sea with the total area about 1.5 million km^2.

At present salmon culture in the Russian Far East is an important part of Russian aquaculture. The total of 56 salmon hatcheries are operating in the Far East, which are cultivated six species of the Pacific salmon. Among them, chum and pink salmon amount to to 98%. For effective reproduction is necessary to ensure the biological optimum, i.e. a range of environmental factors, which is the most favorable for the development of salmon juveniles. An important component of the biological optimum is safety of the habitat and quality of producers.

The Kuril Islands region is considered promising for development of salmon aquaculture. There are 41 salmon fish hatcheries in the Sakhalin Island and the Kuril Islands, 34 of them are hatcheries of the chum. Rivers of the Kuril Islands are area of spawning for salmon, on which is located the salmon fish hatcheries. The total number of these hatcheries in the region should be increased in 1.5 times in the coming years. Therefore, the quality of the aquatic environment is the key factor for deployment of large-scale aquaculture industry in the Kuril Islands [1].

Organochlorine pesticides (OCPs) are chemical dangerous group of toxic substances, which has a negative impact on the environment [2]. Concentration of pesticides in fish, used as an important item in the human diet, is especially hazardous [2,4,6,8].

During their feeding season and particularly prior to the spawning migration, salmon accumulate reserves of neutral lipids, both to satisfy their energy needs and to develop gonads while migrating. Accumulation of lipophilic pollutants occurs along with the build up of lipid reserves, both in subtropical latitudes and in the temperate zone. It was shown that pink and chum salmon from the Sea of Okhotsk, as the most abundant species of Pacific salmon, perform the pesticide transfer from ocean to freshwater environments [9,10].

In this work, we provide data on OCPs concentrations in two species of Pacific salmon of the genus *Oncorhynchus* (chum and pink) from the water off the Kuril Islands and discuss the level of accumulation of the pollutants in these species compared to other "wild" salmon of the Pacific coast of North America and farmed salmon from the Atlantic Ocean.

Materials and Methods

Study sites and samples

Samples of organs from fish of two *Oncorhynchus* species – pink (*O. gorbuscha*) and chum (*O. keta*) – were analyzed. The samples were collected during expeditions organized by Pacific Research Fisheries Centre (TINRO-Center) from water off the Kuril Islands (North-Western Pacific Ocean, Russia) in June 2012 and 2013 (Table 1 and Figure 1). The fish were dissected, their organs were separated from the body, frozen at −20°C, and delivered to the laboratory for the further analysis. In pink and chum, the organs subjected to analysis were muscles, liver, male gonads, eggs, and whole fish.

Chemical analysis

Before chemical analysis, whole fish and separate organs were homogenized by mechanically. Lipids were extracted from

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homogenized tissues (20g) by means of *n*-hexane extraction, with subsequent disintegration of the fat components by concentrated sulphuric acid [11]. Detection of the concentrations of organochlorine pesticides (HCH isomers (α-, β-, γ-HCH), DDT and its metabolites (DDD, DDE)) in samples was performed on a gas chromatograph Shimadzu GC-2010 Plus with an ECD (electron capture detector) (capillary column Shimadzu HiCap CBP5). Column temperature −210^{0}C, injector −250^{0}C, and detector −280^{0}C. Carrier gas is argon, inlet pressure: 2 kg/cm^2, 1:60 flow divider, and flow rate of carrier gas through the column: 0.5 ml/min.

QA/QC and data analyses

Laboratory blank samples were extracted and analyzed on a regular basis. Retention times for the standard samples were constant and were therefore relied upon for component identification. To identify individual substances, standard working solutions of OCPs in the concentration range of 1-100 mg/ml were applied. The calibration lines showed excellent linearity in the range of the concentrations of interest. To determine the quality of the methodology, a recovery study was performed using standard addition methods. Twelve fish tissue samples were spiked with the mixture of pesticides standards. The spiked samples were extracted and analyzed as described in the method above. The results revealed that the mean recovery values ranged from 85.1 to 98.6%. This indicates that the analytical procedures outlined for the OCPs determination in this study were reliable, reproducible and efficient. Concentrations of analytes are expressed as ng/g lipid weight unless otherwise specified.

The statistical analysis of the results was performed in the software package IBM SPSS Statistics for Mac 21 OS X. Significance of the obtained data was evaluated by using the Mann-Whitney *U* test with the significance level of $p \leq 0.05$.

Results and Discussion

HCHs and DDE were found in all analyzed samples (Table 2). The total content of pollutants in various organs varied within a wide range, from 56 to 4223 ng/g lipids. In general, the pesticide concentration increased in the following order: muscles < liver < eggs < male gonads. All three HCH isomers were. The maximum concentration was recorded from sockeye male gonads (4223 ng/g lipids), where ΣHCHs constituted 3850 ng/g that was also the maximum value for the studied salmon. Of the DDT group, only DDE has been detected. The highest concentration of DDE was found in chum male gonads (373 ng/g). The total concentration of HCH isomers in all the species was generally higher than the DDE concentration.

A comparison of the total OCPs (ΣHCHs + DDE) amount in muscles and liver of two fish species showed that the median didn't differ significantly. The concentration increases in the follow: chum ≤ pink; for instance, the total concentration (median of OCPs) in muscles was 134.9 and 126.7 ng/g lipids, respectively (Table 2).

Species	Location	Range of weight, g	Organs	N	Range of lipid, %
Pink	The southern Sea of Okhotsk, off the Kuril Islands, in June 2012 and 2013	1168–1486	Muscles	6	1.9-7.9
			Liver	6	1.5-2.5
			Male gonads	3	0.2-0.4
			Eggs	3	4.1-4.9
			Whole fish	6	4.2-7.2
Chum		1564–1982	Muscles	6	1.5-6.9
			Liver	6	1.3-3.1
			Male gonads	3	0.1-0.7
			Eggs	3	4.0-5.1
			Whole fish	6	4.6-6.1

Table 1: Characteristics of study salmon's samples.

Species	Organs	α-HCHs	β-HCHs	γ-HCHs	ΣHCHs	DDE	ΣOCPs
Pink	Muscles (*n*=6)	86.4 61.4-185.9	19.5 4.4-32.0	13.4 5.2-16.8	125.2 71.0-215.2	6.4 4.4-18.3	134.9 89.3-222.8
	Liver (*n*=6)	179.3 60.9-345.8	29.6 nd*-68.4	47.4 nd-65.6	258.9 60.9-450.9	16.7 nd-49.6	275.5 60.9-500.5
	Male gonads (*n*=3)	394.2 374.1-446.8	138.5 120.3-171.0	52.9 48.8-54.7	585.6 549.1-666.6	44.5 39.3-48.6	630.1 588.4-715.2
	Eggs (*n*=3)	255.8 100.0-275.6	29.1 16.4-76.1	26.4 10.2-47.7	311.3 126.6-399.4	5.0 nd-14.0	325.3 131.5-399.4
	Whole fish (*n*=6)	171.8 132.9-214.2	38.9 22.4-49.0	25.5 16.6-34.4	234.6 179.4-295.6	41.1 30.6-49.7	276.2 211.7-344.2
Chum	Muscles (*n*=6)	64.6 27.4-90.9	42.1 9.1-76.7	nd nd-19.5	114.5 56.0-167.6	12.2 6.5-22.8	126.7 78.8-174.1
	Liver (*n*=6)	89.0 17.2-169.2	37.8 nd-71.2	36.4 nd-85.0	171.0 39.1-275.3	17.9 nd-34.5	194.0 56.0-294.1
	Male gonads (*n*=3)	1181.1 884.2-1227.9	1055.7 nd-2126.8	542.4 308.2-556.9	2840.4 1192.4-3850.3	334.0 293.0-372.7	3174.4 1485.3-4223.0
	Eggs (*n*=3)	947.7 486.8-1073.3	306.9 nd-369.0	478.9 nd-752.0	1795.6 793.7-1825.4	nd	1795.6 793.7-1825.4
	Whole fish (*n*=6)	247.1 157.0-285.9	102.7 33.5-437.7	110.7 4.7-161.6	470.7 258.2-814.6	40.1 8.8-89.8	480.0 268.3-904.4

*nd – not detected.

Table 2: Concentrations (ng/g lipids) of organochlorine pesticides (OCPs) (median and range) in organs of pink and chum salmon.

When whole body of chum and pink were compared, a significantly ($p \leq 0.05$) larger concentration was recorded from chum (Table 2) that can be related both to larger weight and fattiness of chum and to its longer period of being in the sea. Pink has a one-year cycle and comes back to spawn the following year after smolts' downstream migration to the sea; chum may feed for two to five years. The body weight range of pink and chum samples within 1168–1486 and 1564–1982 g, respectively (Table 1).

Many authors point out that salmon can accumulate pesticides already in the freshwater stage of development, due to pollution of spawning waters [13,14]. On the Russian coast of Pacific Ocean, there are no local sources of pesticide pollution, and thus, salmon are unlikely to intake toxicants during their freshwater period of growth. In this regard, the pesticide accumulation in organs of salmon inhabiting the water off the Kuril Islands probably originates from the global transport of toxicants via the atmosphere from regions where they are used, their precipitation on to the sea surface, binding with suspended particles, accumulation by planktonic organisms and, eventually, by fish.

Currently, farmed Atlantic salmon (*Salmo salar*) constitutes a significant portion of the world's salmon market [15]. Pesticides content in organs of these fish is strictly controlled; nevertheless, pollution of its habitat causes toxicants to accumulate in aquaculture objects [16]. The major attention is paid to fish muscles (fillet), as these organs are most frequently used as item of diet and in food industry (Figures 2 and 3). The total OCPs concentration in muscles of pink, chum [10], chinook and sockeye salmon does not exceed sanitary standards of the Russian Federation [17].

The total pesticide content in muscles of salmon from the study area was mainly lower than that in fish from other regions and in Atlantic salmon (Figure 2). The same was observed also for DDE. However, the ΣHCHs content in salmon from the water off the Kuril Islands was higher than that in fish from other regions. The maximum concentration was recorded from pink (215 ng/g lipids) that is higher than the value for pink from the other Pacific coast (Figure 2). In salmon, the same as in other species collected off North America, the DDE metabolite always dominates [18,19]. As we showed earlier, the total concentration of HCHs in marine organisms from the the Sea of Japan, the Sea of Okhotsk and the Bering Sea, as a rule, is higher than the DDT content [5,9,10,20-23]. The same difference was observed for salmon from the Sea of Okhotsk. ΣHCHs, as compared to DDT, are subject to atmospheric transfer to a greater degree [24]; as a result, ΣHCHs is spread northward along the Asian coast and accumulates in the Arctic region [25-27].

The air-borne transport from land can also be a source of pesticides that pollute ecosystem of marginal seas. Technical HCH, comprising over 55% α-HCH, has been used on the territories of Russia and China for quite a long period. Its residual amounts are still detected both on land and in marine organisms. Thus, HCH concentrations in bottom sediments of Lake Baikal were 3 times as high as the DDT level [28]. In salmon, high concentrations of pesticides including DDE are recorded more frequently as compared to those in other fishes of the North Pacific such as cod, flounder, greenling, and some others [18]. This difference is explained mostly by the wide range of salmon's feeding migrations, by presence of fish predominantly in the upper pelagic zone where atmospheric precipitations concentrate, as well as by high fattiness of salmon.

The main source of pesticide input to salmon is feeding. The salmon feeds mainly outside shelves, where other epipelagic fishes are relatively

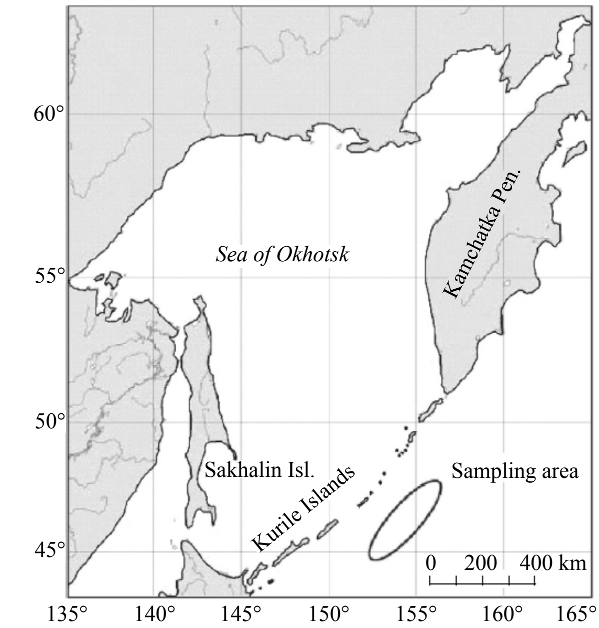

Figure 1: A schematic map of the catch area of the pink and chum salmon in water off the Kuril Islands.

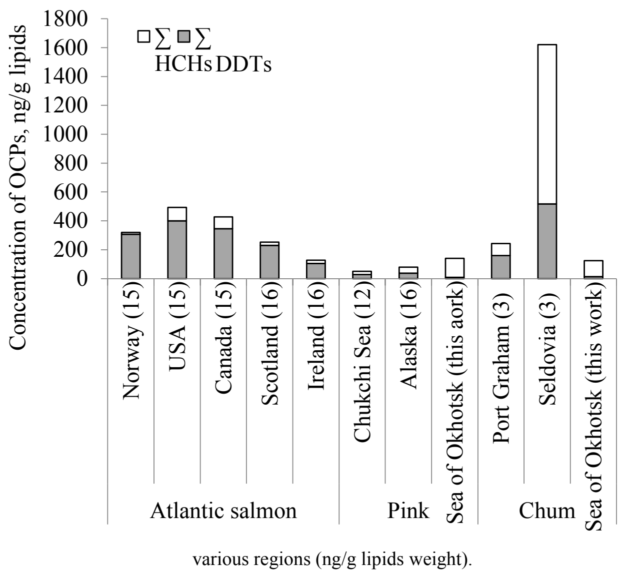

Figure 2: The average total concentration of OCPs (ΣHCH+ΣDDT) in muscles of Pacific and Atlantic salmon from various regions (ng/g lipid weight) [3,12,15,16].

low-abundant. So, pacific salmon "diverges" considerably with other epipelagic planktivores. It's unschooled life-style, dispersion over vast areas, and ability to extensive horizontal and vertical migrations reduce intraspecies and interspecies (for genus *Oncorhynchus*) food competition. The species of pacific salmon are divided on two groups by their trophic orientation: mainly planktivorous (pink, chum, and sockeye) and mainly carnivorous (coho, masu, and chinook). But all these species have high trophic plasticity that allows them to feed upon other prey. As the planktons are organisms with short life cycle, they do not have time to accumulate pesticides, and this determines the low concentrations in salmon. Availability of extensive feed resources is the base for growing salmon.

Pink diet includes amphipods, euphausiids, pteropods, and small-sized nekton. The same groups dominate in the chum salmon feeding, but sometimes its diet includes mostly gelatinous zooplankton (Appendicularia, Ctenophora, jellyfishes, and salps). Despite of high trophic plasticity, all species of pacific salmon have a well-marked feeding selectivity. They usually don't feed upon the dominant groups of zooplankton (copepods and chaetognaths), but prefer minor plankton objects (amphipods, euphausiids, and pteropods) which are not more than 1/3 of total biomass available for their feeding. Stably selective feeding on these plankton groups by the most abundant salmon species (pink, chum) indicates a high level of the pacific salmon forage base.

Based on the numerous data obtained in the Far-Eastern Seas and North-West Pacific annually in the last three decades in the surveys conducted by Pacific Fisheries Research Center (TINRO), food consumption and effect of food supply on the salmon growth was analyzed. The study results don't confirm the widespread mention on strong limitation of the pacific salmon abundance, growth and size by their forage base. Strong interspecific and intraspecific food competition is not observed. Significant dependence of the salmon growth and survival on zooplankton abundance, as well as on the salmon and related nekton species abundance, is not revealed. The food shortage that takes place sometimes during marine period of the salmon life cycle could affect on its growth rate or distribution, but there are no any authentic facts on its abundance limitation by food supply.

Therefore, the carrying capacity overflow doesn't threaten to development of the salmon industrial breeding, and number of the salmon rearing stations can be considerably increased (there are about 700 stations in the North Pacific recently). Russian continental shore of the Japan Sea, the Amur basin, and the northwestern shore of the Okhotsk Sea are the most promising areas for new salmon rearing stations founding [29]. For example, on the coast of the Sea of Japan, in the Tatar Strait, should be breeding chum and masu; in the Amur basin – masu, sockeye and pink salmon; in Kamchatka – coho, sockeye, chinook and masu. The main region of salmon breeding on the Russian coast is the island of Sakhalin, where the main objects are pink and chum salmon. In general, the salmon juvenile from hatcheries feeds in the Sea of Okhotsk, the Bering Sea and the North Pacific Ocean [7].

According to the reviewer's comments, Data of the monitoring allow correcting further plans of aquaculture development. The question about the number of salmon hatcheries in the North Pacific may be subject to international agreements.

Conclusion

Thus, concentrations of OCPs were found in salmon collected from the water off the Kuril Islands, which does not exceed sanitary standards of the Russian Federation. Accumulation of pesticides in fish organs reflects the global pesticide background that has formed both all over the planet and particularly in the World Ocean. Accumulation of these persistent highly toxic compounds can affect health of adult individuals, their reproductive success, and survival of their offspring. A continuation of the monitoring of pesticide accumulation in salmon, which is conducted immediately in fish spawning grounds, in our further studies will provide new information on this poorly known factor that can have an influence both on catches and on the total stock of this commercially valuable group of fish.

Atlantic salmon are grown on a farm before transport in market. Therefore, the only source of pollutants in organism is food. Salmon are grown on Russian fish hatcheries before sexual maturity, further it's feeding in the ocean, and follow in potential spawning area. Thus, the salmon, which feeding in the Sea of Okhotsk, did not accumulate higher concentrations. This fact is characterizing the studied areas as the safe environment of for aquaculture development.

Also, our results will be important to build a more powerful aquaculture, a larger number of hatcheries and support of natural spawning salmon.

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