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Comparative analysis of radiosensitivity of fish eggs from northern and temperate climate

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Abstract. In the radiobiological studies of aquatic organisms, fish eggs are a favorite subject for experimental work because of easy availability of embryos and the possibility of observing the development of embryos within eggs. Data from Russian/FSU publications concerning the effects of ionizing radiation on the survival and development of fish eggs were compiled within the framework of the EC Project EPIC "Environmental Protection from Ionizing Contaminants in the Arctic" (2000-2003). Comparative analysis was performed for effects on roe of two representative fish species: cold-water fish salmon (*Salmo salar*), and pike (*Esox lucius*), which is widespread predatory fish from the temperate climatic zone.

1. INTRODUCTION

The EPIC database "Radiation effects on aquatic biota" has been compiled as part of the recent EC Project EPIC (Environmental Protection from Ionizing Contaminants in the Arctic) in 2000 – 2003. The EPIC database includes Russian/FSU (Former Soviet Union) data, which are based on information from publications in Russian. The database is focused on the effects of chronic/lifetime radiation exposure; this information is of great importance for the purpose of establishing the permissible dose limits to biota [1-3]. This paper is focused on the part of the EPIC database, which is related to the studies of effects of ionizing radiation on the survival and development of fish eggs.

2. EFFECTS OF IONIZING RADIATION ON FISH EGGS

The EPIC database includes 262 records describing the effects of ionizing radiation on the survival and development of fish eggs. In the radiobiological studies of aquatic organisms, fish eggs are a favorite subject for experimental work because of easy availability of embryos and the possibility of observing the development of embryos within eggs. Radiobiological experiments with fish eggs can be divided into two main categories:

- incubation of roe in water containing radionuclide or mixtures of radionuclides at different concentrations;
- external exposure of roe (mainly acute exposure), using gamma-sources.

Investigations of radiation effects on fish embryos developed in radioactive solutions were performed mainly with radionuclides of ^{90}Sr and ^{137}Cs [4 – 16]. Some of these experiments were made with the roe from the exposed parent fish dwelling in the water bodies contaminated with these radionuclides. Few experiments were performed with other radionuclides, such as ^{60}Co, ^{54}Mn, ^{144}Ce, ^{14}C, mixture of fission products, etc. [10, 17-19]. The ranges of radionuclide activities in incubation solutions varied in different experiments within very wide ranges from a few Bq L^{-1} up to about 1E(+7) Bq L^{-1}.

In the experiments with external exposure, fish eggs were subjected to acute gamma-exposure at particular stages of the embryo's development [9, 20-22]. In different experiments, the moment of acute exposure varied from the first minutes of embryo's development till the last days before hatching. Doses of acute gamma-exposure of fish eggs were within the range 0.25 – 12 Gy.

Typically, the following parameters were studied as effects of ionizing radiation:

- death of embryos;
- amount of abnormalities in embryos and fore-larvae;
- survival of fore-larvae; time of hutching;
- chromosomal aberrations; development of blood cells;
- primary sex cells in embryos;
- changes in blood, organs and tissues of fore-larvae.

The radiobiological studies with fish eggs, despite of the simplicity of experimental technique, provide some difficulties to researchers due to a high variability and low reproducibility of results especially at low doses of radiation. Eggs of many fish species are not easily incubated under laboratory conditions, being sensitive to variations in temperature above optimal values, deficiency in oxygen, mechanical disturbances and other factors, which themselves may cause considerable increases in mortality/abnormalities of embryos. The summation of effects of incubation with effects of radiation exposure may result in considerable variability between replications of one and the same experiment. Also, the natural qualities of eggs obtained from artificial impregnation of fish may vary considerably, providing additional variations in the survival of embryos [16].

Technique associated with radiobiological experiments on fish eggs has been improved considerably since the time of early studies. Thus, more recent results are more reliable than those obtained in late 1950s-early 1960s. The early views [23-24], that the fish eggs are extremely sensitive to radiation exposure were not, in general, supported by later experiments [16, 25-26].

Roe of several fish species typical in Russian water bodies (northern/temperate climatic zones) was used in radiobiological experiments. Among fish species, the roe of pike *Esox lucius* has been a favourite test subject for radiobiological studies (116 records in the EPIC database). Pike are very widespread in water bodies of the northern/temperate climatic zones, and its roe is easily available. The development of pike roe takes only 8-10 days. The roe of pike is easily incubated under laboratory conditions.

In the EPIC database, special attention was given to radiobiological studies of roe of cold-water fish species: salmon *Salmo salar*, rainbow trout *Salmo irideus*, peled *Coregonus peled* (40 records in the EPIC database). The eggs of northern/Arctic fish develop very slowly (several months) at very low temperatures. The experiments with cold-water fish roe are much more time-consuming comparing with those with short-developed eggs of fish from temperate/warm climatic zones.

Among other fish species, experiments were conducted with roe of tench *Tinca tinca* (75 records in the EPIC database), loach *Misgurnus fossilis* (21 records), also with roe of roach *Rutilus* rutilus, perch *Perca fluviatilis*, bream *Blicca bjorkna*, bleak *Alburnus alburnus*, goldfish *Carassius carassius*, and silver carp *Hypophtlmichthys molitrix.*

3. DOSE-EFFECTS RELATIONSHIPS

3.1 Incubation of fish eggs in radioactive solutions

The threshold concentrations of radionuclides, at which negative effects on development and survival of fish eggs were revealed, are shown in Table 1. In the most of publications dealing with the incubation of fish eggs in radioactive solutions, doses to eggs were not estimated, so the authors of the EPIC database made preliminary dose estimations using appropriate dosimetric methodology [27-28].

Table 1. Threshold concentrations of different radionuclides caused negative effects on fish eggs, literature data.

Radionuclide	Activity concentration in water, Bq L^{-1}	Reference
^{60}Co, ^{54}Mn	(1-10)E+04	[17]
^{14}C	(7.4-74)E+04	[19]
^{144}Ce	5.2E+03	[10]
^{137}Cs	1.9E+04	[10]
^{90}Sr	(3.7-370)E+04	[9]

3.2 Dose-effects relationships for roe of cold-water fish (Salmonidae, Coregonus spp.)

Roe of cold-water fish, such as Salmonidae, Coregonus species are potentially vulnerable to the presence of radioactive substances in aquatic media. Development of roe of these species takes several months, whereas warm-water fish eggs are developed within few days. So, at the same level of environmental contamination, doses accumulated by fish eggs in the northern climate are considerably higher than those for fish with short-time development dwelling the warm waters.

Salmon and other cold-water fish species are known to be among the most radiosensitive species dwelling the water bodies in the temperate/northern climatic zones. The scale of radiation effects in developing eggs of salmon (*Salmo salar*), constructed on the basis of the EPIC database collection, is presented in Table 2.

Table 2. Dose-effects scale for roe of salmon (*Salmo salar*), derived from the EPIC database [1].

Dose	Effects
Chronic exposure from radionuclide in aquatic media during the whole period of fish eggs development	
Chronic < 1E(-04) Gy d^{-1}	Effects are insignificant [17], or slight stimulation of salmon's eggs development [6]
Chronic (1-2)E-04 Gy d^{-1}	First effects appeared: some cytogenetic changes in blood of fore-larvae [10, 17]; slight decrease in survival of embryos [10]
Chronic 0.001-0.005 Gy d^{-1}	Decrease in survival of eggs, appearance of dead and abnormal embryos, in some cases damaged were 30-50% of eggs [10, 17]
Chronic 0.03 Gy d^{-1}	Considerable decrease in survival of roe, mortality about 50%
Chronic 0.13-0.33 Gy d^{-1}	Practically total death of roe
Acute external gamma exposure during fish eggs development	
Acute exposure 3 Gy	LD_{50} for salmon eggs exposed at the initial period of development [20]
Acute exposure 5 Gy	Practically 100% mortality of salmon eggs exposed at the initial period of development [20]

3.3 Dose-effects relationships for roe of pike

Pike eggs are rather radioresistant among other fish species – pike is known to survive even in highly contaminated water bodies. Pike eggs are developed within 8-10 days. From the EPIC collection the following scale of dose-effects relationships can be suggested for pike eggs (Table 3).

Table 3. Dose-effects scale for roe of pike (*Esox lucius*), derived from the EPIC database [1].

Exposure	Effects
Chronic exposure from radionuclide in aquatic media during the whole period of fish eggs development	
Chronic >3E(-04) Gy d^{-1}	Increase in cytogenetic effects appeared [9]
Chronic 0.005 Gy d^{-1}	Some decrease in the time of embryo's development – hutching occurred earlier comparing with the control (eggs from non-exposed fish. Eggs obtained from exposed parent fish had increased number of abnormalities [9]
Chronic 0.03 Gy d^{-1}	Increase of chromosomal aberrations – bridges and fragments [9]
Chronic 0.30-0.47 Gy d^{-1}	Decrease of survival of pike eggs and fore-larvae [4, 9, 12, 14]
Chronic 0.94 Gy d^{-1}	Total death of pike roe [4, 14]
Acute external gamma exposure during fish eggs development	
Acute exposure 2 Gy	Survival decreased by 30%; considerable amount of embryos had abnormalities [9, 21-22]
Acute exposure 4 Gy	Practically 100% mortality of pike eggs exposed at the initial period of development [9, 21-22]

4. CONCLUSIONS

Data on dose-effects relationships for salmon and pike roe define a range of differences in radiation responses between sensitive cold-water fish and relatively radioresistant fish species from temperate climatic zone. Although the LD values are similar for both salmon and pike eggs exposed at initial stage of development; at chronic exposures, salmon eggs are more vulnerable than pike eggs. Available information from the EPIC collection show that the radiosensitivity of roe from other fish species may be considered to lie somewhere between sensitivity of salmon and pike.

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