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Dynamics of nitrogen group compounds in fish-farming reservoirs of the Valdai National Park in summer period

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Abstract. According to the requirements of the "Food Security Doctrine of the Russian Federation" and the accompanying "Action Plan for the implementation of the provisions of the Food Security Doctrine of the Russian Federation", as well as the order of the Ministry of Health and Social Development of the Russian Federation dated 02.08.2010 No. 593n "On approval of recommendations on rational standards of food consumption that meet modern requirements of healthy nutrition", at least 80% of fish products must be of Russian origin, and the recommended rate of consumption of fish products per capita should be 18-22 kg/year. The following indicators were measured: the concentration of ammonium ions, nitrates, and nitrites, as well as dissolved oxygen. The lack of regular control over the amount of nitrogen-containing compounds in reservoirs used for commercial fish farming does not allow timely identification of the prerequisites for such emergencies.

1 Introduction

The fishing industry is currently charged with import substitution and saturation of the domestic market with high-quality competitive products. According to the requirements of the "Food Security Doctrine of the Russian Federation" and the accompanying "Action Plan for the implementation of the provisions of the Food Security Doctrine of the Russian Federation", as well as the order of the Ministry of Health and Social Development of the Russian Federation dated 02.08.2010 No. 593n "On approval of recommendations on rational standards of food consumption that meet modern requirements of healthy nutrition", at least 80% fish products must be of Russian origin, and the recommended rate of consumption of fish products per capita should be 18-22 kg/year. Nevertheless, according to the plan for the development of the fisheries industry (FI) of Russia until 2020, the catch volumes are currently only 58% of the forecast indicators, and the volume of aquaculture (commercial fish farming) is only 24%. It is obvious that it is difficult to reach the level of forecast indicators only due to the catch and artificial reproduction of marine fish. In this regard, there has been an increased interest in the artificial reproduction of

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freshwater fish and the use of inland reservoirs for these purposes. One of the conditions for the production of high-quality commercial fish in fish farming systems using open reservoirs is water quality control, in particular, the content of nutrients in the water. First of all, this applies to nitrogen-containing substances that are formed both directly in the reservoir and enter it from the water catch area. The biochemical cycle of nitrogen is one of the most important cycles in hydroecosystems. With excessive intake into reservoirs or autochthonous synthesis of nitrites, nitrates, and ammonium ions, the system is out of balance, which leads to a deterioration in water quality, and negatively affects the health of hydrobionts. The process of oxidation of nutrients entering the reservoir together with wastewater is directly related to the oxygen regime of the reservoir and is divided in three successive stages, the last of which is the nitrification of nitrogen-containing substances with the formation of nitrates.[1]

Ammonium nitrogen is formed as a result of biochemical decomposition and ammonification of proteins, urea, and other waste products of hydrobionts and aquatic plants. Nitrites are products of incomplete oxidation of ammonia during nitrification. Unfavorable hydrochemical regime and accumulation of organic matter can lead to eutrophication and subsequent degradation of the reservoir. With a constant influx of labile organic matter, the mechanisms of natural self-purification of reservoirs do not always cope with the biogenic load.

Vital activity in the reservoir water is supported by the presence of dissolved oxygen in it. The water of uncontaminated reservoirs, depending on temperature (from 30 to about 0°C), contains 8-14 mg/l of oxygen in a saturated state at a pressure of 101.3 kn/m2 (760 mmHg). [1] Moreover, with an increase in temperature, the intensity of biochemical oxidation of organic substances increases, and the solubility of oxygen, on the contrary, decreases. When an excessive amount of organic substances enters the water and under favorable temperature conditions, there is a significant increase in the biomass of green and blue-green algae, which photosynthesize in the daytime and release oxygen. Autochthonous and allochthonous microflora and some chemicals in the process of oxidation consume oxygen dissolved in water, thereby reducing its content in water. In the dark phase of the period, oxygen consumption also increases due to the phytoplankton respiration. Thus, the consumption of oxygen in the reservoir is not compensated by its daily production, even considering the processes of reaeration from the surface. With a sharp decrease in the oxygen content in the fishery reservoir, the intensity of self-purification processes decreases, vital activity fades, “suffocations” of commercial fish are noted. [2]

In addition, nitrates, nitrites, and ammonium ions are highly toxic to fish, reduce its growth rate, and increase mortality.

Commercial fish grown in such conditions is of poor quality and does not meet food safety requirements. In particular, nitrate poisoning can cause bleeding in fish, gill discoloration, and mucus formation on the gills and skin. The content of nitrates in the muscles of fish is not acceptable. Consumption of such fish and its processed products can cause intoxication in the consumer. Lack of oxygen also has a detrimental effect on the health of fish, lowering immunity and making the hydrobiont more vulnerable to diseases, increases the risk of “suffocations”. [7] In this regard, the content of ammonium ions of nitrite and nitrate ions are included, according to the requirements of the global environmental monitoring system, in the programs of mandatory observations of the composition of natural waters, they are important indicators of the pollution degree and trophic status of natural reservoirs.

To assess the compliance of the content of nitrogen-containing substances and dissolved oxygen in the water with fishery regulations, in 2022, during the open water period, water samples were taken from the lake system "Pestovskoye Lake - fish-breeding ponds of the fish-breeding plant named after Vrassky - Velyo Lake", involved in the fishery activities of JSC "Nikolsky Fish Breeding Plant named after V.P. Vrassky".

The purpose of these studies was to establish the compliance of oxygen, ammonium ions, nitrites, and nitrates in reservoirs used in fish breeding activities with the current standards. As well as an assessment of the further suitability of the investigated water system for fish farming.

2 Materials and Methods

Water sampling was carried out in accordance with GOST 17.1.5.05-85.[2] To determine the possibility of using the reservoir for growing fish species, the requirements of the Order of the Ministry of Agriculture of the Russian Federation No. 552 of December 13, 2016 were taken as a basis. [3]

The following indicators were measured: the concentration of ammonium ions, nitrates, and nitrites, as well as dissolved oxygen.

On each of their lakes, the points experiencing the least anthropogenic load were selected as control points. To assess the impact of economic activity on the water area, points in the area of fish cages and settlement areas were selected. Sampling took place on the surface and at the bottom, as the results, the values of MPC multiplicity - the average value in water column are given.

3 Results

The content of dissolved oxygen in the water of the Pestovskoe Lake varied during the study period from 4 to 9.5 mg/l· During the period of mass phytoplankton development in July 2022, against the background of water warming up to 23°C, this value decreased to 4-5.5mg/l. At the same time, the concentration of nitrites was 0.6-1.87 MPC during the research period, in July this indicator was 1.67. The concentration of nitrates did not exceed the regulatory indicators and averaged 0.67 MPC. In July, this indicator was 0.53 MPC. The concentration of ammonium ions for the season was 0.2-1.25 MPC, in July this indicator was equal to 1.25 MPC.

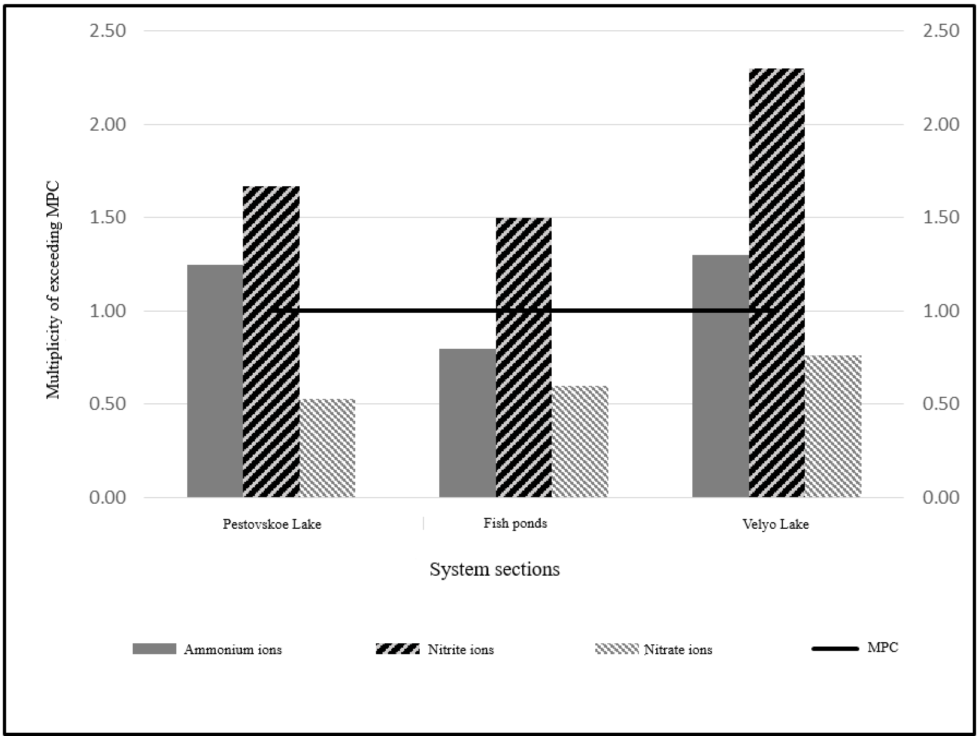

Fig. 1. The multiplicity of exceeding the MPC for nitrite, nitrate, and ammonium ions in various parts of the system in July 2022.

The concentration of dissolved oxygen in fish ponds averaged 8.7 mg/l per season. In July, this indicator was the lowest - from 5 to 6.3 mg/l. During the season, the concentration of nitrites was 0.23-1.56 MPC, in July the indicator was 1.5 MPC. At the same time, the concentration of nitrates during the study period was from 0.1 to 1.7 MPC, in July the indicator did not exceed the existing standards and amounted to 0.6 MPC. The excess concentration of ammonium ions was not observed in July, during the entire study period, the concentration varied in the range from 0.1 to 0.93 MPC.

In Velyo Lake, the dissolved oxygen content varied from 5.5 to 9.5 mg/l during the study period. Photosynthesis and reaeration did not provide sufficient dissolved oxygen in the water area sites with the greatest anthropogenic load. The oxygen concentration here varied from 5.5 to 6.3 ml/l in places where watercourses flow into the system, near cages, in areas of recreational and settlement zones. In the central part of the lake, far from the sources of pollution, the oxygen concentration did not fall below 7 mg/l. The concentration of nitrites for the season ranged from 0.2 to 2.6 MPC, in July this indicator was 2.3 MPC. The concentration of nitrates for the entire study period was 0.1–1.38 MPC, in July this indicator did not exceed the standard. Over the entire period of the study, the fluctuations of ammonium ions amounted to 0.25-1.5 MPC, in July this indicator was 1.3 MPC.

Summarizing the data obtained, it is possible to note excess concentrations of nitrites during the mass development of phytoplankton in July in all areas of the fish breeding system against the background of low concentrations of nitrates that do not exceed the MPC. The source of ammonium nitrogen can be ammonium feces of synanthropic birds and hydrobionts, and decomposing aquatic plants and phytoplankton, as well as decomposition products of non-demanded feed accumulating in the bottom horizon.

Nitrites, respectively, are formed in the process of ammonium nitrification, they can also come with effluents from residential and agricultural territories located near reservoirs. [6]

Nitrites are an intermediate step in the chain of bacterial processes of ammonium oxidation to nitrates (nitrification - only under aerobic conditions) and, conversely, the reduction of nitrates to nitrogen and ammonia (denitrophication - with a lack of oxygen). The increased content of nitrites indicates an increase in the decomposition of organic substances under conditions of slower oxidation of NO2- to NO3, which indicates contamination of a water body, i.e. it is an important sanitary indicator. It is known that seasonal fluctuations of nitrites are characterized by their absence in winter and their appearance in spring during the decomposition of inanimate organic matter, the maximum concentration of nitrites is observed in mid-summer, which is associated with increased activity of phytoplankton, in autumn the content of nitrites in water decreases again. [9], which correlates well with the results obtained. Nitrites are highly toxic to fish because they cause the oxidation of divalent iron, which is part of blood hemoglobin, into trivalent iron of methaemoglobin, which is unable to carry oxygen. The toxicity depends on the time the fish is in water with a high content of nitrites. For rainbow trout, for example, nitrite concentrations of 0.1-1 mg/l are threshold. In a fish pond, the concentration of nitrites should not exceed 0.1 mg/l for a long time and, in any case, be less than 0.2 mg/l. [10]

Normally, nitrites should not be detected in natural water. Their appearance and increase in concentration is associated with a violation of the nitrogen cycle caused by an excess of ammonium coming from wastewater, and in places of intensive fish farming, also due to feed protein. Nitrites are unstable salts, but they are oxidized to nitrates at a high content of dissolved oxygen - 80-100% saturation.

The nitrogen cycle and the concentration of oxygen in the water are directly related to the trophicity of the reservoir, the influx of a significant amount of allochthonous organic matter against the background of a low concentration of dissolved oxygen in the water, form favorable conditions for the "flowering" of reservoirs.[2] Outbreaks of the green and blue-green algae development in fish-farming reservoirs lead to a sharp decrease in oxygen concentration in reservoirs and watercourses. Thus, the rate of oxidation of nitrites to less toxic nitrates decreases and conditions unfavorable for the habitat of most hydrobionts arise. In fish hatcheries, ammonium and nitrites released by fish in large quantities are distributed throughout the reservoir through net-meshes. Thus, due to dilution, the concentration of these compounds in the cages is aligned with the concentration in other parts of the reservoir. With a small relative area occupied by cages, the concentration of ammonia and nitrites in the reservoir should not exceed the current standards. Provided that in the reservoir these substances are disposed of by nitrifying bacteria naturally in full. Nevertheless, with the slowing down of the process of self-purification of reservoirs and the accumulation of toxic intermediate products of the decay of protein compounds in them, the living conditions of hydrobionts are deteriorated significantly, especially during the period of mass development of phytoplankton. During this period, overseas phenomena may occur in the studied reservoirs and watercourses, leading to the emergence of environmental and economic risks. The lack of regular control over the amount of nitrogen-containing compounds in reservoirs used for commercial fish farming does not allow timely identification of the prerequisites for such emergencies. A decrease in water quality leads to a deterioration in the quality of commercial fish and, as a result, to economic losses. To reduce risks, it is necessary to establish a system of water quality control in fishery reservoirs and assess the effectiveness of environmental protection measures in the studied water area.

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