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Article

Composition, structure of ichthyofauna and biological characteristics of fish populations of Lake Bolshoe Krasnoe (Solovetsky Archipelago, the White Sea)

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Abstract. The data of long-term studies (1965–2023) of the ichthyofauna of Lake Bolshoe Krasnoe have been summarized and systematized. Lake occupies a key position in the main lake-canal system of Bolshoy Solovetsky Island. The fish community of the lake is represented by six species, five native ones (the northern pike, burbot, the European perch, common roach, and the Eurasian ruffe) and one acclimatized (vendace). The formation of the lake ichthyofauna was influenced by abiotic and trophic characteristics of the reservoir, primarily the temperature regime, availability and amount of food. Specific responses of different fish populations to environmental factors are noted, manifested in a decrease/increase in growth rate. No fundamental differences have been found since 1965 for the fish population characteristics in Lake Bolshoe Krasnoe, which indicates the resilience of this island freshwater ecosystem to observed environmental factors.

Keywords: Bolshoy Solovetsky Island, freshwater ichthyofauna, species diversity, ecology and biology of fish

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Научная статья

Состав, структура ихтиофауны и биологические особенности популяций рыб озера Большое Красное (Соловецкий архипелаг, Белое море)

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Аннотация. Обобщены и систематизированы данные результатов многолетних (1965–2023 гг.) исследований ихтиофауны оз. Большое Красное, занимающего ключевое положение в главной озерно-канальной системе Большого Соловецкого острова. Рыбная часть сообщества водоема представлена 6 видами, 5 из которых являются аборигенными и 1 – акклиматизированным (европейская ряпушка). На формирование ихтиофауны озера повлияли абиотические и трофические характеристики водоема, в первую очередь температурный режим, доступность и количество пищи. Отмечена индивидуальная реакция разных популяций рыб на факторы среды обитания, которая проявляется в снижении или, наоборот, увеличении темпов роста. Анализ изменений популяционных характеристик рыб оз. Большого Красного за последние 60 лет не выявил принципиальных отличий, что свидетельствует об устойчивости этой островной пресноводной экосистемы к факторам внешней среды.

Ключевые слова: Большой Соловецкий остров, пресноводная ихтиофауна, видовое разнообразие, экология и биология рыб

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Introduction

Lake systems are one of the most important natural components of the Solovetsky Archipelago, they largely determine its uniqueness. According to various authors, the number of lakes on the islands ranges from 376 to 500, or even more; most of them are located on Bolshoy Solovetsky Island. In terms of the saturation of the territory with water bodies (more than 11% of the entire territory), it surpasses other regions of the North-West of Russia (Grigoryev and Gritsevskaya, 1959). Lakes of Bolshoy Solovetsky Island are united into a unique lake-canal system, but the water differ in a number of hydrological, hydrochemical and hydrobiological characteristics in different areas of this system (Dvoryankin and Novoselov, 2005; Gritsevskaya et al., 1972; Prirodnaya sreda..., 2007). The lakes of the western group are the largest bodies of water, characterized by the population size and species diversity of ichthyofauna; that is why they have been chosen for ichthyological research.

Lake Bolshoe Krasnoe is the most important element of the freshwater ecosystem of the archipelago. It is the main water body of the lake-canal system of Bolshoy Solovetsky Island, which includes dozens of lakes (including the largest on the archipelago); it is also most susceptible to anthropogenic impact. In mid-1960s, it was assigned as the main reservoir for ichthyological monitoring of lakes due to its dominant position in the main lake-canal system of the island and due to the specifics of its hydrological and hydrochemical characteristics, the level of anthropogenic load, and the characteristics of the species composition of fish. In addition, ichthyological studies conducted at this lake from 1965 to the present day allow us to perform a comparative analysis and to determine the nature of possible changes in the ichthyofauna of the reservoir and the biology of the inhabiting fish species.

The study aims to analyze the composition, population structure, and biological characteristics of fish of Lake Bolshoe Krasnoe, located on the Solovetsky Archipelago of the White Sea.

Materials and methods

Ichthyological studies at Lake Bolshoe Krasnoe (Fig. 1) were performed in the summer period of 2004, 2015 and 2021–2023. Hook tackle and fixed nets (mesh size of 20–70 mm) were used to obtain representative data on the species composition of ichthyofauna, relative abundance and size-age structure of fish populations. Fishing gear was set up in different parts of the lake from the water's edge down to a depth of 15–16 m. Despite the selectivity of net fishing gear, their comprehensive use allowed us to obtain reliable data on the fish population structure in this reservoir (Shibaev, 2007).

The ichthyological samples were processed immediately using freshly obtained material by the method of I.F. Pravdin (1966), taking into account the recommendations of Yu.S. Reshetnikov (1980) as applied to vendace. The fish were measured for their commercial length (AD, cm), Smith's length (AC, cm), and absolute body length (AB, cm). The fish age was determined using scales, gill covers, or otoliths, depending on the species, under an MBS-10 stereomicroscope (LOMO, Russia). The nomenclature of species is given according to the Atlas of Freshwater Fishes of Russia (2003a, b). For comparative analysis, data on the lake ichthyofauna, collected by other researchers in 1965–1966, were used (Anukhina, 1972). The obtained data was processed statistically using standard programs; for 1965–1966 and 2004, statistical processing of archival data for some species is incomplete due to the lack of the necessary information.

In total, 284 specimens of fish belonging to 6 species underwent full biological analysis, including 164 specimens of the European perch, 43 specimens of common roach, 56 specimens of the Eurasian ruffe, 19 specimens of vendace, one specimen of the northern pike and burbot each.

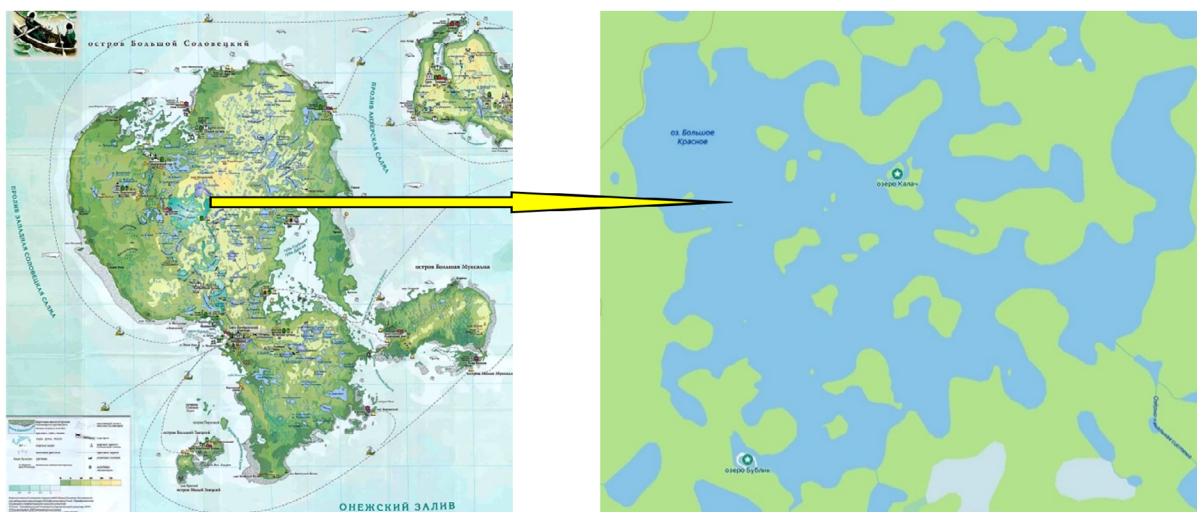


Fig. 1. Schematic map of Lake Bolshoe Krasnoe, the Solovetsky Archipelago, the White Sea.

Results and discussion

Fish habitat

Lake Bolshoe Krasnoe, located in the northwestern part of Bolshoy Solovetsky Island, is the largest body of water in the Solovetsky Archipelago (Fig. 1). The lake area is 2.74 km², it has a lobate shape with many peninsulas and bays, and one of the most developed coastlines among the water bodies of the archipelago. Lake has 21 small islands with a total area of about 0.1 km². The complex geological relief makes lake basin structure complex also, the latter includes five depressions with a depth of 10 to 31 m. These depressions are separated by rapids, in some cases they rise above the lake level. The maximum depth of the lake is 31 m, the bottom mark here is several meters below sea level. Until recently, the greatest registered depth of the reservoir was 25 m; during our studies, we have found even deeper part. Lake Bolshoe Krasnoe is a typical oligotrophic reservoir with a low organic content in the water. The water has a low colour (12–14°) and high transparency (7–8 m), permanganate oxidizability does not exceed 4.4. The water pH is neutral (7.2–7.4), the oxygen saturation of surface waters is high (95–110%). In mid-July, the surface water temperature fluctuates within 17–22 °C, in the near-bottom layers, as 6–8 °C (Gritsevskaya et al., 1972).

Ichthyofauna

Species diversity and habitat ecology

The ichthyofauna of the lake is quite diverse despite its island location on the archipelago. Six species of fish live in the lake, five of them are native: the northern pike *Esox lucius* Linnaeus, 1758, burbot *Lota lota* (Linnaeus, 1758), the European perch *Perca fluviatilis* Linnaeus, 1758, common roach *Rutilus rutilus* (Linnaeus, 1758), and the Eurasian ruffe *Gymnocephalus cernuus* (Linnaeus, 1758); one species is acclimatized (vendace *Coregonus albula* (Linnaeus, 1758)). According to the classification of G.V. Nikolsky (1980), the species living in the lake belong to two faunal complexes. The boreal plain complex includes the northern pike, the European perch, common roach, and the Eurasian ruffe (66.7%); the arctic freshwater complex includes vendace and burbot (33.3%). All fish inhabiting the lake are represented by freshwater non-migratory species; their life cycles are entirely confined to this reservoir.

The northern pike and burbot are typical predators. The European perch has a mixed diet: during the first years of life, it consumes benthic organisms like the Eurasian ruffe; as its linear size increases, young fish become increasingly important in the diet of the European perch. Common roach is an euryphagous species, feeding on both animal and plant organisms. Zooplankton organisms dominate in the vendace diet.

Population characteristics and species status

The European perch is found in almost all lakes of the Solovetsky Archipelago, except for dystrophic small lakes of peat bogs (Zakhvatkin, 1925). In Lake Bolshoe Krasnoe, this species is the most numerous in fish community; it is a part the so-called core of the lake ichthyocoenosis (Zhakov, 1984). Data on the biological characteristics of the local perch population have been obtained since 1965 during targeted studies of the lake ichthyofauna (Anukhina, 1972). This makes it possible to trace changes in the perch population for almost 60 years.

In 2004 and 2021–2023, 164 specimens of the European perch were caught and undergone full biological analysis. Data on the sample size of perch in 1965–1966 are absent. Our catches included perch of ten age groups (2+ to 11+) with a length (AD) of 10 to 31 cm and a weight of 16 to 652 g (Table 1). In Lake Bolshoe Krasnoe, the European perch apparently forms two ecological groups: fast-growing perch, a predator of open lake areas, and slow-growing benthophagous specimens, living in overgrown shallows. This conclusion is supported by significant differences in the length and weight of perch of the same age. The ratio of males and females in the perch population is close to 1:1, with a slight predominance of females (Table 1). Also, local perch population is characterized by sexual dimorphism, when females are larger than males of the same age. Spawning of perch in Lake Bolshoe Krasnoe takes place unusually late: at the end of June, most of males were at the V stage of maturity, and females were actively spawning. It is worth saying that the spawning of the European perch in this climate zone on the mainland usually takes place in the second half of May.

In general, the size and age parameters of the European perch of Lake Bolshoe Krasnoe correspond to similar characteristics of representatives of this species from continental waters of the northern part of the Arkhangelsk Oblast (Dvoryankin, 2021; Sterligova et al., 2016). At the same time, the analysis of long-term changes in size and age indicators of the local perch population indicates a small but stable trend of increasing of its growth rates (Table 1). We assume global climate change or still unnoticeable processes of eutrophication of the reservoir as the main factors of this phenomenon. The lake also experiences increasing anthropogenic load for several decades; since the 1960s, the number of tourists and pilgrims to the Solovetsky Archipelago has increased manifold. This assumption, of course, requires additional research. Being the most numerous fish of Lake Bolshoe Krasnoe, the European perch has a certain fishery value, being the most widespread and favorite object of amateur fishing for the local population.

Common roach is found in most lakes of Bolshoy Solovetsky Island (except for its north-eastern part (Zakhvatkin, 1925)), including the main lake-canal system and Lake Bolshoe Krasnoe. Unfortunately, small sample sizes during observation period do not allow us to draw reliable conclusions about the dynamics of changes in the local roach population. However, our data obtained recently indicate favorable habitat conditions for this species in the lake. A number of authors pay attention to the unusually large size of roach at the Solovetsky Archipelago; the fish length may reach 35 cm, weight, 1 kg or even more (Anukhina, 1972; Pravdin, 1951). Our studies confirm this information. In 2023, common roach with a length (AD) exceeding 33 cm and a weight of about 800 g was caught in Lake Bolshoe Krasnoe (Table 2).

In Lake Bolshoe Krasnoe, size and age of the studied individuals of common roach are noticeably higher than that of roach in reservoirs inhabiting the southern part of the Arkhangelsk Oblast (Dvoryankin, 2018; Ilmast et al., 2019). At the same time, the lake is an oligotrophic reservoir, belonging to the low-food category for benthophagous fish (Pidgayko et al., 1968). Currently, there are no reliable hypotheses about the reasons for this phenomenon. According to some scientists, the growth rate of common roach at the Solovetsky Archipelago is beneficially influenced by special geographical and hydrological regimes of islands' reservoirs (Anukhina, 1972; Pravdin, 1951).

Vendace of the Solovetsky Archipelago is of particular interest. This species inhabits the western lakes of Bolshoy Solovetsky Island; it is the most valuable fish here, having commercial significance. Most researchers believe that vendace was brought to the islands by monks in the XIX century (Alekseeva et al., 2014). According to our data, vendace has formed two ecological forms on the archipelago (small and large), which differ significantly from each other in growth rates. The population of this species in Lake Bolshoe Krasnoe belongs to the small form, reaching a length (AC) of 18–20 cm and a weight of 50–80 g at the age of 4+ years (Table 3). No significant differences were revealed when comparing the vendace population characteristics for different years.

Table 2. Size-age characteristics of common roach of Lake Bolshoe Krasnoe in 2004, 2015, and 2023 (original data).

Indicator	Age, years							Total	Proportion of males, %	
	4+	5+	6+	7+	8+	13+	Average			
2004										
Average length AD, cm	17.9	20.6	22.6	26.7	28.3	–	23.1	–	–	
Average weight, g	60	86	126	232	254	–	147	–	–	
Number of specimens	1	1	2	1	1	–	–	6	0	
% of composition	16.7	16.7	33.2	16.7	16.7	–	–	100	–	
Average age	6.0							6.0	–	–
2015										
Average length AD, cm	15.6 ± 0.5	–	–	–	–	–	15.6	–	–	
Average weight, g	63 ± 4.5	–	–	–	–	–	63	–	–	
Number of specimens	3	–	–	–	–	–	–	3	100	
% of composition	100	–	–	–	–	–	–	100	–	
Average age	4.0							4.0	–	–
2023										
Average length AD, cm	–	19.6 ± 0.1	–	25.1	–	33.1	20.2	–	–	
Average weight, g	–	143 ± 13.3	–	295	–	764	166	–	–	
Number of specimens	–	32	–	1	–	1	–	34	47.1	
% of composition	–	94.2	–	2.9	–	2.9	–	100	–	
Average age	5.3							5.3	–	–

Table 3. Size-age characteristics of vendace of Lake Bolshoe Krasnoe in 2004, 2015, and 2022 (original data).

Indicator	Age, years			Average	Total	Proportion of males, %
	2+	3+	4+			
2004						
Average length AD, cm	–	16.5	19.3	17.4	–	–
Average weight, g	–	44	72	53	–	–
Number of specimens	–	2	1	–	3	33.3
% of composition	–	66.7	33.3	–	100	–
Average age	–	3.3	–	3.3	–	–
2015						
Average length AD, cm	–	16.0 ± 0.3	18.3 ± 1.0	17.0	–	–
Average weight, g	–	33 ± 3.1	52 ± 4.9	41	–	–
Number of specimens	–	7	5	–	12	66.7
% of composition	–	58.3	41.7	–	100	–
Average age	–	3.4	–	3.4	–	–
2022						
Average length AD, cm	15.4 ± 0.3	–	–	15.4	–	–
Average weight, g	41 ± 4.9	–	–	41	–	–
Number of specimens	4	–	–	–	4	75
% of composition	100	–	–	–	100	–
Average age	–	2	–	2	–	–

Table 4. Size-age characteristics of the Eurasian ruffe of Lake Bolshoe Krasnoe in 1965–1966 (Anukhina, 1972), 2004, 2015, and 2023 (original data).

Indicator	Age, years									Average	Total	Proportion of males, %
	3+	4+	5+	6+	7+	8+	9+					
1965–1966												
Average length AD, cm	–	–	–	–	13.5	15.0	–	–	–	–	–	–
Average weight, g	–	–	–	–	40	55	–	–	–	–	–	–
2004												
Average length AD, cm	–	–	–	–	14.8 ± 0.3	16.9 ± 0.1	18.2 ± 0.1	–	–	–	–	–
Average weight, g	–	–	–	–	39 ± 1.9	55 ± 1.2	67 ± 1.8	–	–	–	–	–
Number of specimens	–	–	–	–	7	24	7	–	–	–	38	7.9
% of composition	–	–	–	–	18.4	63.2	18.4	–	–	–	100	–
Average age	8									8.0	–	–
2015												
Average length AD, cm	–	–	12.2 ± 0.4	13 ± 0.2	13.3 ± 0.4	14.2	14.6	–	–	–	–	–
Average weight, g	–	–	35 ± 3.5	44 ± 1.0	44 ± 4.0	58	55	–	–	–	–	–
Number of specimens	–	–	4	3	5	1	1	–	–	–	14	7.1
% of composition	–	–	28.6	21.4	35.7	7.1	7.1	–	–	–	100	–
Average age	6.4									6.4	–	–
2023												
Average length AD, cm	9.4	–	13.0	13.4	14.7	–	–	–	–	–	–	–
Average weight, g	18	–	32	41	49	–	–	–	–	–	–	–
Number of specimens	1	–	1	1	1	–	–	–	–	–	4	5.3
% of composition	25	–	25	25	25	–	–	–	–	–	100	–
Average age	5.3									5.3	–	–

The Eurasian ruffe is found in most lakes of the Solovetsky Archipelago, including its main lake-canal system; this species has a significant population (Anukhina, 1972). In Lake Bolshoe Krasnoe, the collected samples of ruffe cover the period from 1965 to 2023. At the same time, small volume of material studied do not allow us to draw reliable conclusions about the dynamics of changes in the biological characteristics of ruffe population in this lake. However, in general, we may indicate relatively large sizes of the local ruffe specimens: its length (AD) may reach 18.2 cm, weight, 67 g, at the age of 9+ years (Table 4).

In Lake Bolshoe Krasnoe, the studied individuals of ruffe had higher linear-weight indicators than ruffe of the same age groups from lakes in the southern Arkhangelsk Oblast, including large ones such as Lekshmozero and Kenozero (Dvoryankin, 2016). Probably, larger size of the local ruffe is due to its specific habitat at the Solovetsky Archipelago, which has been mentioned also by I.F. Pravdin (1951).

Similar to the European perch, spawning of the Eurasian ruffe in Lake Bolshoe Krasnoe takes place quite late: only half of the ruffe had spawned in late June – early July. Females dominate in the catches (92%).

The northern pike and burbot are not numerous in Lake Bolshoe Krasnoe; they are caught occasionally by fishing gear. The northern pike was represented in the catches by only one specimen: a female of 3+ years, maturity stage II, length (AD) of 31 cm, weight of 184 g. Burbot was also represented by a single specimen: a female of 4+ years, length (AD) of 23.9 cm, weight of 76 g. These size-age indicators are noticeably smaller than those of representatives of this species from continental waters (Dvoryankin, 2016, 2017).

Conclusions

The abiotic characteristics of the reservoir precondition the composition of its ichthyofauna. Except acclimatized vendace, only native species live here: the northern pike, burbot, the European perch, common roach, and the Eurasian ruffe. They belong to two faunal complexes: boreal plain complex (the northern pike, the European perch, common roach, the Eurasian ruffe) and arctic freshwater complex (burbot and vendace). The northern pike and burbot are typical predators, common roach and the European perch are euryphagous, vendace feeds on zooplankton, ruff is a benthophage. The European perch is the most numerous fish species in the lake, common roach is the subdominant species, other species have an insignificant share. The size and age characteristics of the fish inhabiting this lake are obviously predetermined by abiotic and biotic factors that formed in the lakes of the Solovetsky Archipelago during their isolation. At the same time, each fish species responds to these factors individually. The biological indicators of the European perch correspond to that for the populations inhabiting continental waters of the northern Arkhangelsk Oblast. The Eurasian ruffe has larger body size; size and age characteristics of common roach significantly exceed that of representatives of mainland populations. The northern pike and burbot are characterized by low size-age indices. Obviously, the oligotrophic nature of the reservoir affects the body size of local vendace significantly, since it differs greatly from the fast-growing vendace from other lakes of the archipelago.

No significant changes in size and age characteristics of fish have been traced since 1965 in Lake Bolshoe Krasnoe, indicating the resilience of this island freshwater ecosystem. A small but consistent trend of increasing growth rates of European perch requires further studies. This may be explained by global climate change, as well as the still unnoticeable processes of eutrophication of the reservoir, which has been under increasing anthropogenic load for several decades.

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