Biological resources of Lake Kroshnozero (North-West of Russia)

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Abstract. A comprehensive analysis of plankton and benthic communities, composition, structure and quantitative characteristics indicate that the ecosystem of Lake Kroshnozero has a eutrophic status or a transitional one between the β-mesotrophic and α-eutrophic. Plankton communities are in a stable state and provide a sustainable food base for planktivores fishes. A slight decrease in the quantitative indicators of benthos is possibly due to the methodological features of sampling and the underestimation of littoral communities. The composition and structure of benthic communities have been preserved since previous studies in the 50-90s of the last century. The ichthyofauna of Kroshnozero includes 13 fish species. Whitefish, zander, and vendace are fish of commercial importance. Fish of secondary importance are bream, perch, ruff, roach, and pike. Fish such as bleak, grayling sculpin, and burbot are relatively rare and do not serve as objects of fishing. Model calculations of fish productivity of planktivores, benthophages and predatory fish, taking into account losses to 2.3 kcal/m^2 per season or 22.6 kg/ha. The average modelled ichthyomass is 4.6 kg/ha. Possible catches are one third of fish productivity equal to 7.5 kg/ha. To improve the quality and quantity of commercial stocks, recommendations are given to preserve the conditions for the reproduction and growth of valuable fish.

1 Introduction

In recent decades, the bioresources of lakes have been changing under conditions of climate fluctuations and increased anthropogenic impact on aquatic ecosystems [1-8]. Changes in bioresources occur especially rapidly in small lakes. Eutrophication due to the growth of nutrients changes the food base, and intensive fishing of valuable fish species changes the structure of ichthyocenoses. These factors lead to changes in fish stocks and structure of bioresources [4, 9, 10].

The complex relationships in the trophic web of lakes, which provide the food base for fish, make it relevant to comprehensively study aquatic ecosystems, their production properties, and the functioning of plankton and benthos. The assessment of the level of biological resources depends on the state of the entire lake ecosystem; therefore, the assessment of fish stocks should take into account the state of its planktonic and benthic organisms. An increase in the phosphorus load leads to an increase in the processes of

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eutrophication in lakes and affects all elements of the trophic chains. As a result, the production properties of the lake change, the production of zooplankton and benthos, as the main food objects, increases, and as a result, the intensity of fish production and the volume of possible catches increase [3].

Lake Kroshnozero is a small lake in the North-West of Russia. In recent decades, devastation of valuable fish stocks has been observed in this lake. The reasons for this may be changes at the level of the food supply of fish or the fish community transformation. A decrease in the share of valuable fish species may be the result of overfishing of some species and food competition from trash fish. The aquatic ecosystem of the lake is under constant anthropogenic pressure due to the functioning of the trout farm, the influx of domestic wastewater and the agricultural use of catchment areas. The high content of nutrients determines the trophic status of the lake ecosystem.

There are certain difficulties for a direct assessment of the fish productivity of a lake. Therefore, it is relevant to model estimates using the values of the food base, for example, the biomass of plankton and benthos, as well as other indicators.

It is necessary to assess the current state of the lake's ichthyocenosis, its composition, structure and food supply in order to organize a proper fish economy and increase of fish stocks.

The aim of this work is to assess the current state of the aquatic ecosystem of Lake Kroshnozero, the fish community, the level of food supply based on the indicators of plankton and benthos, as well as model calculations of fish production and possible catches.

2 Study site and methods

Lake Kroshnozero is located on the watershed of Lake Onega and belongs to the Baltic Sea basin. This lake is located on the catchment area of the River Shuya. The morphometric characteristics of the lake are given in Table 1.

Table 1. Morphometric characteristics of Lake Kroshnozero.

Center coordinates	Absolute height, m	Catchment area, km^2	Lake surface area, km^2	Lake volume, mln m^3	Depth maximal, m	Depth mean, m
61°40′ N 33°07′ E	94	173	8.9	50.5	12.6	5.7

The waters of Lake Kroshnozero are mesohumus with medium alkalinity. The average water mineralization is 37.0 mg/l. High color (67) and iron concentration (0.49 mg/l) create unfavourable conditions for fish. Water transparency averages 1.5–2.5 m, decreasing to 1 m or less in summer [11].

Lake Kroshnozero is one of the most highly eutrophic lakes in South Karelia; it is characterized by a very high content of total phosphorus (62 µg/l). The share of mineral phosphorus is 36% of the total.

To assess the current state of the lake ecosystem, an analysis was made of the indicators of summer phytoplankton, zooplankton, benthos, and fish populations.

The sampling for phyto- and zooplankton analysis was taken in July 2021 at three stations in different parts of the lake (Fig. 1). Sampling and laboratory processing were carried out by standard methods [12]. Phytoplankton samples were taken with a Rutner bathometer from the surface layers (depth of 0.5 m). Zooplankton samples were obtained by integral fishingfrom a water column with a Judy net with a pore size of 100 µm.

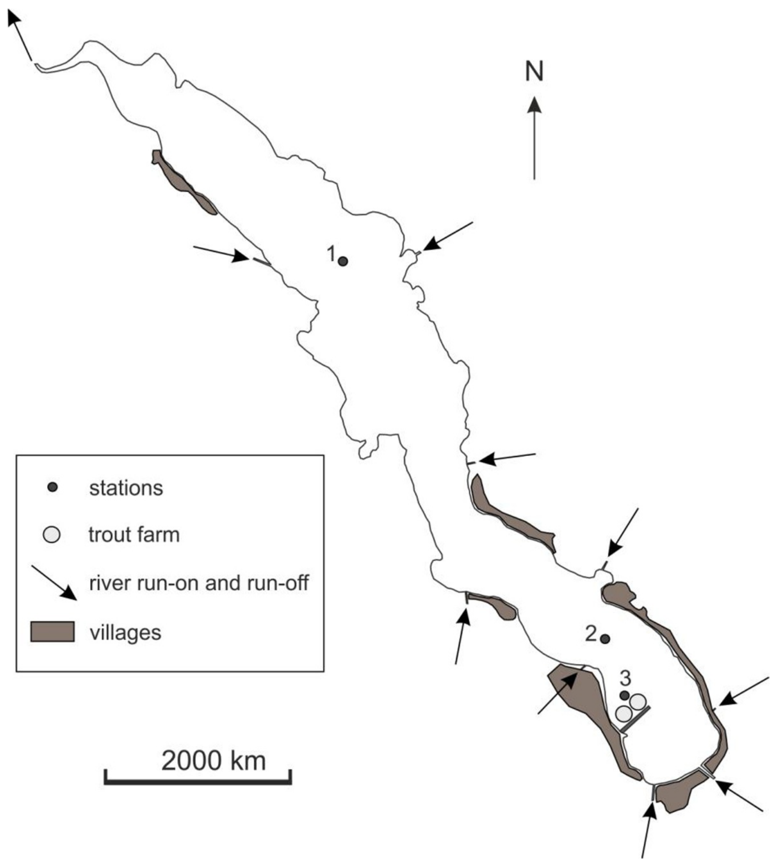

Fig. 1. Layout of hydrobiological sampling stations in Lake Kroshnozero in 2021.

Benthic samples were taken with an Ekman-Burge grab (capture area 0.023 m^2) in July 2021 and 2022 and September 2022.

For the flora and fauna of planktonic and benthic communities, an analysis was made of the species composition, biodiversity and structural indicators, as well as the dominance of indicator species. Quantitative estimates of abundance and biomass were converted to cubic meters and square meters in a column of water.

The collection of fish material (2017–2021) was carried out with a set of gillnets in the littoral and pelagial zones of Lake Kroshnozero. In total, more than 100 induviduals were caught and measured. To determine the state of fish populations, absolute annual weight gains for different ages were calculated.

To assess fish productivity, the balance model of V.V. Bouillon [13; 14], which reflects the most general regularities in the distribution of organic matter and energy in the food webs of the lake ecosystem. The patterns of this model were obtained from the analysis of data on lakes of Northern and Eastern Europe, Belarus, and the European part of Russia and are expressed in regression dependences [13; 14]. For calculations, input data were used (latitude 61.6N, average depth 6 m, maximum depth 13 m, total phosphorus content 62 µg/l, water color 67 degrees Pt). Due to the high latitude location of Lake Kroshnozero, the length of the growing season was adjusted. Its length was equated to the average duration of the ice-free period in days (168 days).

3 Results and discussion

3.1 Hydrobiological features of Lake Kroshnozero

3.1.1 Phytoplankton

The phytoplankton included 31 taxa of algae with a rank below the genus, belonging to 6 systematic divisions, were identified: Chlorophyta - 7 (22.6%), Bacillariophyta - 8 (25.8%), Chrysophyta - 3 (9.7%), Cyanophyta - 10 (32.3%), Euglenophyta - 2 (6.5%), Dinophyta - 1 (3.2%). In contrast to the data of 1959-1994, when diatoms formed the basis of phytoplankton, representatives of cyanobacteria and dinophyte algae made a significant contribution to the formation of the total biomass and abundancein the summer of 2021.

The phytoplankton biomass of the surface layer averaged 12.3 mg/l with a maximum value of 13.3 mg/l, and the abundance averaged 86.2 million cells/l, with a maximum of 92.8 million cells/l (Table 2). The average biomass in the surface layer (12.3 mg/l) allow us to characterize Lake Kroshnozero as eutrophic.

Table 2. Abundance and biomass of phytoplankton in the surface layer (0.5 m)of Lake Kroshnozero.

Station	Abundance (million cells/l)	Biomass (mg/l)
1	83.3	11.1
2	92.8	12.4
3	82.6	13.3
Mean	86.2	12.3

The depth of Secchi disk was about 1 m in July 2021, and the maximum phytoplankton biomass was noted in surface layer. The number of active algae decreased sharply deeper one meter depth. Given the average lake depth of 6 m, it can be assumed that the average biomass of algae is about 2 mg/l or 2 g/m^{3}in the water column.

3.1.2 Zooplankton

In July 2021, 45 species of zooplankton were recorded in the pelagic zone of Lake Kroshnozero: Copepodas - 10, Cladocerans - 17, Rotifers - 18. The number of species at the 1-3 stations ranged from 23 to 29 and averaged 23. For the first time, an alien species of the American rotifer *Kellicottia bostoniensis* was recorded in Lake Kroshnozero in July 2021. In terms of abundance, it reached more than 1.3 thousand ind./m^3 and almost equaled in abundance with the native species *Kellicottia longispina*.

In summer 2021, the zooplankton was dominated by large cladocerans (*Diaphanosoma brachyurum*) and copepods (*Eudiaptomus graciloides*), which form the foodbasis of the planktivores fish.

The species richness and structure of zooplankton communities of Lake Kroshnozero, taking into account their natural and seasonal variability, were typical for the lakes of this region. The list of species and the composition of mass species did not change since the 50s of XX century. Zooplankton biomass at station 1 of 4.3 g/m^{3}correspond to α-eutrophic status (Table 3). At two other stations, biomass indicators reflect the β-mesotrophic status. The structure and absolute quantitative indicators of zooplankton in the water column reflect the transitional state between the β-mesotrophic and α-eutrophic according to the "trophic scale" of lakes [15]. The average biomass during the study period was less than 3 g/m^3. The average values for the vegetation period will be even less than the maximum ones (about 2.5 g/m^3), so it can be argued that, in general, the zooplankton indicators reflect the β-mesotrophic status of the plankton system of the lake.

Table 3. Abundance and biomass of zooplankton of Lake Kroshnozero in the surface layer (0.5 m).

Station	**Abundance (th.ind. m^{-3})**	**Abundance (th.ind. m^{-2})**	**Biomass (g*m^{-3})**	**Biomass (g*m^{-2})**
1	95.7	478.7	4.3	21.2
2	135.0	1080.0	2.6	20.6
3	101.6	711.3	2.1	14.7
Mean	110.8	756.7	2.9	18.8

The transcontinental species of the American rotifer *K. bostoniensis* is currently actively expanding its habitat and spreading to the north along the lakes of Northwestern Russia, including Karelia (Lake Vygozero). Since the native rotifer *K. longispina* is not a food object for fish, the appearance of an alien species similar to it will not have a significant impact on bioresources.

3.1.3 Macrozoobenthos

According to our data, the average biomass of macrozoobenthos was 6.17 g/m^2, with an average abundance of 1.55 thousand ind./m^2. The amplitude of fluctuations in population indicators was high for both years of study. The minimum number of benthic animals was 0.09 thousand ind./m^2, the maximum was 4.30 thousand ind./m^2. The lowest biomass of macrozoobenthos was 0.2 g/m^2, the highest biomass reached 14.27 g/m^2.

The distribution of benthic fauna was characterized by a high heterogeneity. Thus, *Chaoborus* larvae reached their maximum development in terms of population indicators, especially in the southern part of the lake (st. 3) and played a dominant role in the formation of the biomass of the entire benthic community.

The quantitatively rich fauna of the bottom layers of the lake did not differ in a large variety of species. Four systematic groups of invertebrates, common for lakes of the North-West of Russia, were noted: larvae of chironomids, oligochaetes, larvae of Chaoboridae, and larvae of Ceratopogonidae. A significant role in the fauna belonged to the larvae of *Chaoborus*, which occupy the deep southern parts of the lake. The oligochaetes were represented by one eurytopic species, *Tubifex tubifex* (Müller, 1774).

In deep-water area of Lake Kroshnozero (station 2) macrozoobenthos was represented by only one group of chironomids (*Chironomus* sp. and *Procladius* sp.). Ceratopogonidae larvae were extremely rare throughout the lake.

3.1.4 Fishcommunity

The ichthyofauna of Lake Kroshnozero includes 13 species of fish.Whitefish, zander, and vendace are fish of paramount commercial importance. Fish of secondary importance in the fishery are bream, perch, ruff, roach and pike. Fish such as bleak, sculpin grayling, burbot are relatively rare and do not serve as objects of fishing. Whitefish belong to two biological groups: lake and lake-river. Lake small whitefish are of greater commercial importance, as they are more numerous. The vendace living in Lake Kroshnozero is distinguished by its small size and short life cycle, but in the northern regions there is, although small, a herd of larger vendace.

The annual growth of fish, as well as the intensity of their growth, depends on their size, biology and living conditions. Under normal fish habitat conditions, annual weight gains (dW) naturally increase with fish age (Fig. 2). On the contrary, the intensity of growth –

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relative gains (Cw) decreases with age, since juveniles grow faster than older fish. An exception is the ide, for which, apparently, unfavorable conditions for growth have developed in the lake.

Ruff turned out to be the fastest growing, the average growth rate of which was 0.0572. Bream (0.0564) and vendace (0.0534) also showed high growth rates. The growth rate of roach was somewhat lower (0.0360). The intensity of weight gain of zander (0.0255) and perch (0.0250) was approximately two times lower. Unfavorable living conditions affected the growth of ide (0.0072), the intensity of which turned out to be the lowest.

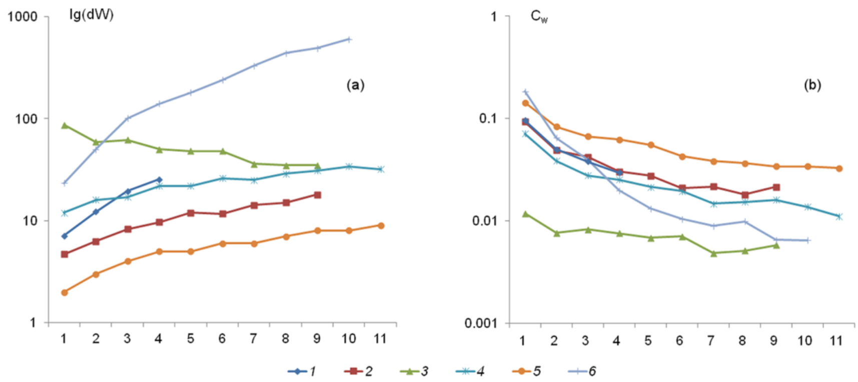

Fig. 2. Changes in annual weight gains (g) (left) and relative gains (right) depending on the age of the fish: 1 - vendace, 2 - roach, 3 - ide, 4 - perch, 5 - ruff, 6 - zander.

3.2 Temporal changes in plankton and benthic, and fish communities

The structure of the dominant complex of phytoplankton of Lake Kroshnozero in summer 2021 was similar to other eutrophic lakes of the temperate zone. In comparison with earlier studies, the species composition of blue-green algae has become more diverse, the species *Gloetrichiae chinulata* (J.E. Smithet& Sowerby) P.Richt has appeared, which usually lives in highly eutrophic lakes. Diatoms, which previously dominated Lake Kroshnozero in summer, had rather low abundance and biomass valuesin July 2021, like representatives of other divisions. The quantitative characteristics of summer 2021 are comparable with those performed in 1959-1994 [11].

During the study period (July 2021), the composition of species and the structure of zooplankton community were typical for the lakes of this region of Karelia and reflected, taking into account its natural and seasonal variability, the state between the β-mesotrophic and α-eutrophic trophic class. Modern structural and quantitative data of zooplankton do not go beyond the interannual variability of indicators and clearly expressed long-term trends are not observed.

It can be assumed that the pelagic plankton system of Lake Kroshnozero is in a balanced state and has not undergone significant changes over the previous 60 years.

The macrozoobenthos of Lake Kroshnozero has been studied since the 1940s. The average biomass for the summer period of 1947 was 15.67 g/m^2. Based on the materials of a detailed study in 1953, the average biomass was 15.78 g/m^2, with an average abundance of 2248 ind./m^2. At that time, the amphipod *Gammarus lacustris* G.O. Sars, 1863 was noted in a small amount, and was not found in summer 2021 and 2022. The data of the 1990s showed that the average biomass decreased to 5.15 g/m^2, while maintaining an average abundance of 2644 ind./m^2 [11].

The composition of benthos and its distribution in the lake differ greatly by season, which is associated with the peculiarities of the biology of its species. In addition, it was shown that in all lakes of Karelia and in Kroshnozero, there are seasonal migrations of organisms between the upper littoral and deep regions. Since benthos studies in 2021 and 2022 were carried out in July and September, they are not enough to accurately assess the current state of the benthic fauna and the existence of long-term trends, and therefore further more detailed seasonal observations are needed.

The analysis showed that the food supply of both planktivorous and benthivorous fish has not changed over the past decades. It is due to the natural level of the trophic status of the lake ecosystem. Model calculations of the total fish productivity of the lake are based on this.

3.3 Model calculation of fish productivity in terms of plankton

To calculate the fish productivity, an analysis was made of the distribution of organic matter and energy in the food webs of Lake Kroshnozero ecosystem using the balance model of V.V. Bouillon [13, 14].

Comparison of some empirical data with model calculations showed similarities (Table 4). The distribution of the biomass of plankton and benthos of Lake Kroshnozero corresponded to the general patterns of functioning of the trophic web of the aquatic ecosystem, which makes it possible to use the model for calculating fish productivity and estimating possible catches.

Model calculations of fish productivity of planktivores, benthivorous, and predatory fish, taking into account losses within the system, corresponded to 2.3 kcal/m^2 per season or 22.6 kg/ha. Possible annual catches are one third of fish productivity and equal to 7.5 kg/ha.

The ichthyomass of fish planktivores , according to the model, is 6.7 kg/ha, fish benthivorous - 3.2 kg/ha, and predatory fish - 1.2 kg/ha. Taking into account the losses on the diet of predatory fish, the average ichthyomass is 4.6 kg/ha.

Table 4. Empirical and Model Data on Lake Kroshnozero.

Station	Empirical data [11]	Model data
Transparency, m	1	1.1
Chlorophyll a,µg/l	21	21.1
Phytoplankton biomass, g/m^3	2 (1.4-2.2)	2.1
Biomass of zooplankton, g/m^3	3 (2-4)	2.0
Biomass of benthos, g/m^2	6.2 (0.2-14.3)	10.2
Fish products, kg/ha	-	22.6
Possible catches, kg/ha	-	7.2

3.4 Recommendations for increasing stocks of valuable fish in Lake Kroshnozero

Modern stocks of valuable fish species are determined by the structure of the ichthyofauna, the processes of food competition and catch. Measures to change the structure of the ichthyofauna, aimed at reducing the number of weedy fish and food competitors, as well as the protection of commercial species during their spawning period, can significantly affect the level and quality of lake bioresources.

Commercial stocks of certain valuable fish species in Lake Kroshnozero are limited. Its use as a fishing reservoir requires immediate reclamation work related to the creation of normal conditions for fish breeding and fishing. One of the most important reasons for small commercial stocks is the deterioration of the conditions for the reproduction and development of juveniles (weediness of spawning grounds, etc.). Preservation and increase of stocks of whitefish, vendace and pike perch in Lake Kroshnozero will require providing the best conditions for their natural reproduction. An important measure to increase the stocks of valuable fish should be work on the technical improvement of spawning grounds for zander and whitefish. The planting of viable young vendace and whitefish in the reservoir can have a very positive effect on the stocks of whitefish.

1. The richness of natural spawning grounds for whitefish and vendace, followed by measures to improve them, the presence of rich crustacean plankton for fattening juveniles, ensure the normal reproduction of salmon stocks. The feeding conditions of benthos and plankton are assessed as quite satisfactory for the main commercial fish.

2. Predatory fish (burbot, perch, pike) can have a negative impact on whitefish stocks. Vendace is present in the food of all these predators. In experimental catches, predatory fish accounted for about 30% by weight, with a significant share of old-aged fish, which are characterized by a lower growth rate compared to young individuals. These predators (burbot, pike, perch), eating vendace and whitefish, convert these valuable fish into a less valuable fish product. The latter negatively affects the fish productivity of the reservoir.

3. The ruff has a negative impact on the stocks of whitefish: it is known that it eats vendace and whitefish caviar. With a large number of ruff in the lake, the degree of eating away of the developing whitefish caviar by it can be very high. In addition, the ruff eats bream and whitefish food. The results of the analysis of the age structure of the spawning population of the Kroshnozero ruff indicate a relatively large number of older age groups in it. Such a herd uses the fodder resources of the lake very inefficiently. A similar picture is also observed in the herds of perch and roach.

4. A feature of the ichthyofauna of the lake is the presence in its composition of valuable species of predatory fish - zander. It is an effective biological reclamator that allows for the targeted formation of the ichthyofauna of natural reservoirs and increase their natural fish productivity by increasing the pressure on weed fish species and improving feeding conditions for valuable fast-growing fish species.

5. Currently, for a number of reasons (increased volume of capture, including illegal fishing, amateur and sport fishing; deterioration of conditions for natural spawning; low level of measures for its artificial reproduction), the volume of zander catch in the lake is decreasing annually. Significantly change the negative situation in the near future could be large-scale measures for the artificial reproduction of zander.

6. One of the priority measures for the organization of fisheries on Lake Kroshnozero should be the cleaning of the lake from overgrowths of ruff, perch, roach, burbot and other low-value fish. Such an event can help increase the growth rate of valuable commercial fish. In practice, it can be carried out by intensive catching of these fish during their spawning period, i.e., in May-June (for burbot, also in February). Along with the organization of intensive catching of low-value fish, it is expedient to introduce a temporary (for 3-4 years) ban on catching zander and whitefish. In the future, it is necessary to establish a limit on the catch of these species.

7. The planned fish catch for the next five years should be based on the catch of perch, roach, burbot. The catch of whitefish and vendace, in order to increase their stocks, should be limited to 30% of the total catch.

4 Conclusions

A comprehensive analysis of data on the state of plankton and benthic communities, their composition, structure and quantitative characteristics indicate that the aquatic ecosystem of Lake Kroshnozero has a eutrophic status or a transitional one between the β-mesotrophic and α-eutrophic according to the "trophic scale" of lakes [15]. The comparison of our results with data previous years showed that aquatic communities have not undergone noticeable changes since the 50-90s of the last century. Plankton communities are in a stable state and provide a sustainable food base for planktivorous fish. A slight decrease in the quantitative indicators of benthos is possibly due to the methodological features and the underestimation of coastal communities in the shallow water zone. The composition and structure of benthic communities have been preserved since previous studies in the 50-90s of the last century.

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To improve the quality and quantity of commercial stocks, recommendations are given to preserve the conditions for the reproduction and growth of valuable fish.

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