

Assessment of fish productivity of two small Karelian lakes using a balance model

*Maria Syarki*¹, *Anastasia Sidorova*^{1*}, and *Julia Slastina*¹

¹Northern water problems Institute Karelian Research Center RAS, 50, Alexander Nevsky avenue, 185030, Petrozavodsk, Russia

Abstract. There are over 60,000 lakes in the Republic of Karelia (Northwest Russia). In recent years, this region has been increasingly used for tourism and recreation. The development of amateur and sport fishing increases the relevance of rational use of the bioresources of the lakes in this region. Due to the unique features of their natural potential, lakes Kroshnozero and Urozero are a favorite vacation spot for local residents, centers of attraction for tourists, and fishing enthusiasts. To assess the fish productivity of two Karelian lakes, Kroshnozero and Urozero, the mass-balance model of V.V. Bulyon was used. This model reflects the most general patterns of distribution of organic matter and energy in trophic networks of a lake ecosystem. The model was verified using hydrochemical and hydrobiological parameters of lakes (phytoplankton, zooplankton, and macrozoobenthos biomass) obtained in field conditions over the past decade. Comparison of empirical data with model calculations showed good convergence. It was shown that the adequacy of the model in describing lake processes allows its use as a tool for assessing fish productivity in various reservoirs.

1 Introduction

The popularity of amateur and sport fishing remains consistently high in northern countries, where fishing is a traditional trade of the local population and a popular activity for outdoor enthusiasts [1,2]. In these conditions, the assessment of lake fish resources is important for the conservation of their resources and sound scientific management of fisheries [3]. The assessment of the bioresource potential of lakes is especially relevant in "lake" regions such as Fennoscandia, Siberia, and Canada.

There are more than 60 thousand lakes in the Republic of Karelia (Northwest Russia) [4]. In recent years, this region has been increasingly used for tourism and recreation. A large flow of tourists creates an additional burden on the vulnerable ecosystems of northern lakes. Active development of amateur and sport fishing increases the relevance of rational use of bioresources of Karelian lakes. Due to the unique features of their natural potential, lakes Kroshnozero and Urozero are a favorite vacation spot for local residents, centers of attraction for tourists, and fishing enthusiasts. To preserve and rationally use the water resources of the lakes, it is necessary to assess their bioresource potential [5].

*Corresponding author: bolt-nastya@yandex.ru

The transformation of matter and energy within a reservoir is subject to general laws similar to the fundamental laws of physics and chemistry. Since the 1960s, a program for studying production and destruction processes in lakes has been developed [6]. To date, a large amount of information has been accumulated on reservoir processes, which are formalized in numerous simulation and regression models [7]. One of the successful examples of such models is the mass-balance model of transformation of organic matter and energy developed by V. V. Bulyon. This model reflects the most general patterns of synthesis and distribution of organic matter and energy in trophic networks of a lake ecosystem [8-11]. The model uses patterns obtained from the analysis of data on lakes in northern and eastern Europe, Belarus and the European part of Russia, and expressed in regression equations [12].

In this work, a model version with 5 input parameters was used: lake latitude, average depth, maximum depth, total phosphorus concentration in water, and water color [9]. The point model reflects organic matter and energy flows in kcal/m²·year. Generally accepted coefficients were used to convert energy units into biomass.

The model was verified using data from complex hydrobiological and hydrochemical studies of the Kroshnozero and Urozero lakes; indicators of various links of producers and consumers were used. The lakes selected for the study belong to different types according to a number of indicators. Lake Urozero is ultraoligotrophic, light-water, and is fed by the atmosphere. Lake Kroshnozero is mesotrophic, dark-water, and is fed by several streams and rivers flowing into it [4, 5]. In addition, this lake experiences significant anthropogenic impact - a trout farm currently operates in this lake, and its catchment area is used for agricultural purposes. Both lakes are actively used for recreational fishing.

Hydrobiological and hydrochemical studies in lakes Kroshnozero and Urozero were carried out over the past ten years in different seasons by employees of the Northern water problems Institute, Karelian Scientific Center of the Russian Academy of Sciences. Water samples were collected and analyzed using standard methods [5]. In this study, correct spatial-temporal averaging of values was performed to verify the model.

The aim of this study is to assess the bioresource potential of two lakes in southern Karelia - Urozero and Kroshnozero - using data from the mass-balance model of V.V. Bulyon.

2 Study site and methods

Both lakes belong to the Baltic Sea basin, in the catchment area of the Shuya River, a tributary of Lake Onega. Lake Kroshnozero lies in the middle part of the Shuya River catchment area, and Lake Urozero lies in the lower part of the Shuya River catchment area. The morphometric characteristics of Lake Kroshnozero and the chemical characteristics of its waters are given in [5]. The morphometric characteristics of Lake Urozero and Lake Kroshnozero are given in Table 1.

Table 1. Morphometric characteristics of Lake Urozero and Lake Kroshnozero [4].

Lake	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
Urozero	61°56' N 34°06' E	42/6	12.1	13.4	161	35	12
Kroshnozero	61°40' N 33°07' E	94	173	8.9	50.5	12.6	5.7

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 $\mu\text{g/l}$). The share of mineral phosphorus is 36% of the total [5].

Comprehensive studies were conducted on Lake Urozero 2018-2019, on Lake Kroshnozero in 2021. To assess the current state of the lake ecosystems, an analysis was made of the indicators of summer phytoplankton, zooplankton, and benthos.

The sampling for phyto- and zooplankton analysis was taken in July 2021 at three stations in different parts of the lake. Sampling and laboratory processing were carried out by standard methods [13]. Phytoplankton samples were taken with a Rutner bathometer from the surface layers (depth of 0.5 m). Zooplankton was obtained by integral sampled from a water column with a Judy net with a pore size of 100 μm .

According to [4], Lake Urozero is an ultra-oligohumus, moderately alkaline, weakly acidic, neutral, hydrocarbonate class, group Ca, ultra-oligotrophic, high quality lake. The water is characterized by high transparency - 9-10 m [4]. Low phosphorus concentration is typical (total phosphorus 5 $\mu\text{g/l}$, mineral phosphorus 1 $\mu\text{g/l}$).

For calculations on Lake Kroshnozero, the following input data for the model were used: latitude 61.6°, average depth 6 m, maximum depth 13 m, total phosphorus content 62 $\mu\text{g/l}$, color 67 degrees Pt. For calculations on Lake Urozero, the following input parameters for the model were used: latitude 61.9°, average depth 12 m, maximum depth 35 m, total phosphorus concentration 6 $\mu\text{g/l}$, color 5 degrees Pt.

3 Results and Discussion

The data from field measurements and the model data showed good agreement (Table 2).

Table 2. Empirical and model indicators for Lake Kroshnozero and Lake Urozero.

Parameter	Lake Kroshnozero		Lake Urozero	
	Empirical data	Model data	Empirical data	Model data
Transparency, m	1	1.1	10	6
Chlorophyll a, $\mu\text{g/l}$	21	21.1	1.2 (1.1-2.0)	1.04
Phytoplankton production, kcal/m^2 season	-	-	252*	243
Phytoplankton biomass, g/m^3	2 (1.4-2.2)	2.1	0.28 (0.14-0.65)	0.27
Zooplankton biomass, g/m^3	3 (2-4)	2.0	0.47 (0.04-0.91)	0.26
Benthos biomass, g/m^3	6.2 (0.2-14.3)	10.2	2.26	3.35
Fish production, kg/ha	-	23.4	-	10.5
Possible catches, kg/ha	-	8.0	-	3.6

* - data from [14].

The diagram of the trophic web is shown in Figure 1 for Lake Kroshnozero and in Figure 2 for Lake Urozero.

Comparison of empirical data with model calculations showed their similarity both for Lake Krosnozzero and Lake Urozero, with special conditions for its ecosystem. It is clear that due to the specific characteristics of the lakes and differences in spatial and temporal scales, there are certain discrepancies between the natural and model values of the parameters. It can be considered that the values of the same order indicate the adequacy of the model. The model also reflects the change in the structure of the fish community and fish production with an increase trophic status. Thus, in Lake Urozero, fish production was created by planktivorous by 54%, benthivorous by 42% and predators by 7% (Figure 2). In the mesotrophic Lake Krosnozzero, the roles are somewhat reversed, so planktivorous create 39%, benthivorous 47%, and the role of predators increases to 14% (Fig.1-3).

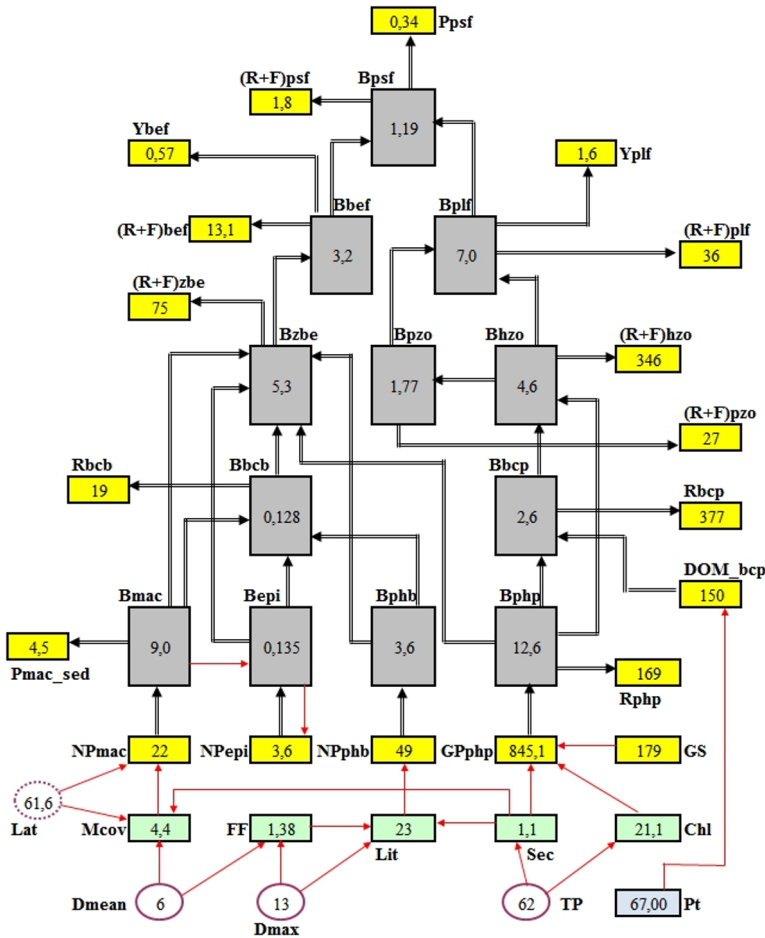


Fig. 1. Scheme of the trophic web of Lake Krosnozzero (kcal/m² year).

Model designations: GS – duration of the growing season, days; Chl – chlorophyll concentration, µg/l; Sec – water transparency (by Secchi disk); DOM – flow of dissolved organic matter assimilated by bacterioplankton;

Pools – biomass (kcal/m²): Bphp - phytoplankton, Bmac - macrophytes, Bphb - microphytobenthos, Bepi - epiphytes, Bbcp - bacterioplankton, Bbcb - bacteriobenthos, Bhzo, Bpzo - "peaceful" and predatory zooplankton, Bzbe - zoobenthos, Bplf, Bbef, Bpsf - planktivorous, benthophagous and predatory fish.

Flows ($\text{kcal}/\text{m}^2 \text{ year}$): GPp_{hp} - gross production of phytoplankton; N... - net production of macrophytes and phytobenthos;
 R, R+F - energy losses during respiration and feeding
 Yplf and Ybef - catch of planktivorous and benthophagous fish
 DOM - allochthonous dissolved organic matter assimilated by bacterioplankton.

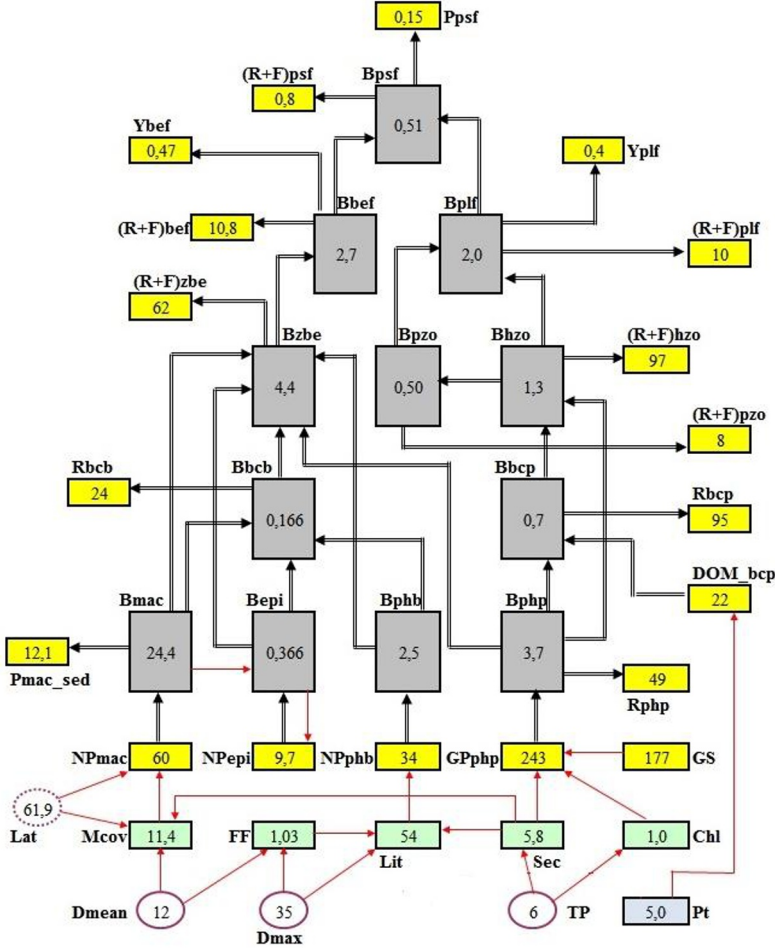


Fig. 2. Scheme of the trophic web of Lake Urozero ($\text{kcal}/\text{m}^2 \text{ year}$). Designations as in Fig. 1.

To assess the fish productivity of a reservoir, it is important to study all links of the trophic web and the interaction between them (Fig. 3).

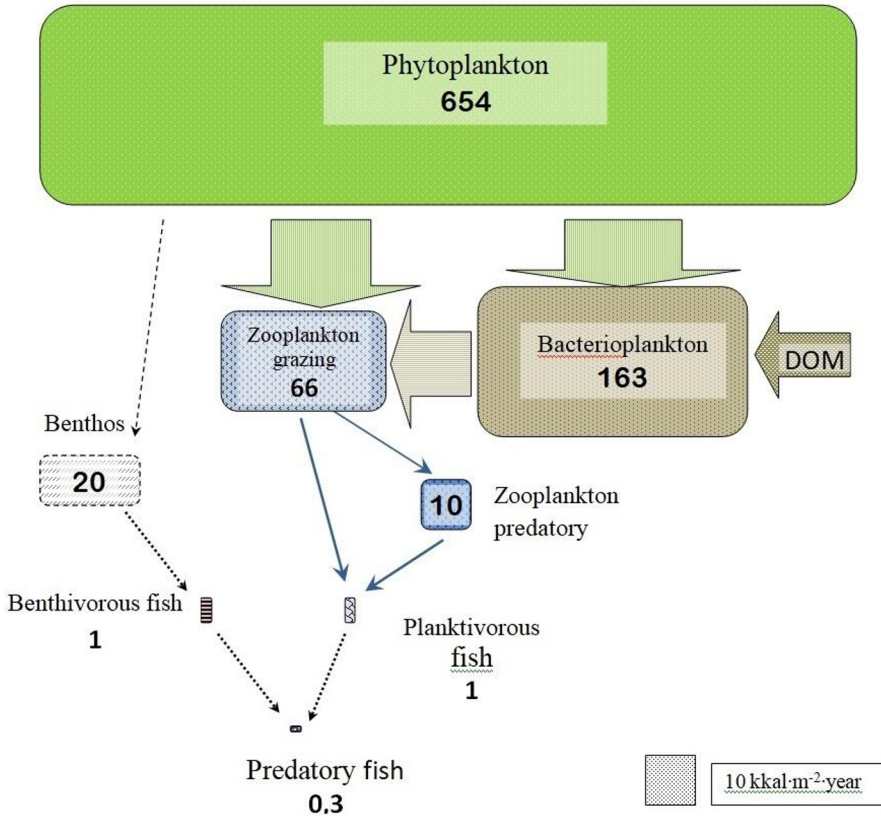


Fig. 3. Annual elements net production and energy flows in the trophic system of the pelagic zone of Lake Kroshnozero (kcal/m² year).

4 Conclusions

A comprehensive description of reservoir processes allows the model to be used in various areas: the general state of ecosystems in different types of lakes, assessment of fish productivity, eutrophication processes and the influence of allochthonic organic matter (taking into account water color), assessment of changes in the state of the ecosystem and the relationship of links in the organization of reservoirs (changes in the average and maximum depths of reservoirs and the shape of the basin), assessment of the balance, consumption and release of carbon and CO₂ in aquatic ecosystems, assessment of biotic carbon in sedimentation, etc.

Comparison of empirical data with model calculations showed good convergence. It was shown that the adequacy of the model in describing reservoir processes, taking into account various factors of the morphometrics of the basin, the properties of catchments, biogenic load, etc., allows it to be used as a tool for assessing fish production in various lakes.

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