BIO Web of Conferences **71**, 02015 (2023) https://doi.org/10.1051/bioconf/20237102015
CIBTA-II-2023

Ecological state of water bodies under the influence of natural and anthropogenic factors

K V Titova[1*], *T A* Zhibareva[1], *A A* Sloboda[1], *E A* Vakhrameeva[1], *O Yu* Moreva[1], and *N M* Kokryatskaya[1]

[1]N. Laverov Federal Center for Integrated Arctic Research Ural Branch RAS, 20, Nikolsky prospect, Arkhangelsk, 163020, Russia

Abstract. The article studies the ecological state of two neighboring lakes Sredniy and Nizhniy Pert on the Bolshoy Solovetsky Island after their separation by a dead earthen dam during the construction of the lake-channel system. The studies were carried out in July 2021. It was revealed that these anthropogenic changes led to a change in the regime of lakes, especially Nizhniy Perth, which lost its flow. Samples of water and bottom sediments were taken from the deep waters of these reservoirs. In these samples, the main hydrochemical parameters were determined, and bottom sediments were studied for the content of moisture, iron and sulfur, organic carbon and nitrogen in them. A difference was noted in the water color of the studied lakes, which is due to anthropogenic influence and the isolation of water bodies, and in their mineralization, which is associated with the location of water bodies relative to the White Sea. A greater amount of organic matter (carbon) was found in the water and bottom sediments of the lake. Sredniy Perth, therefore, in the bottom layer of the water column of this reservoir, a lower oxygen content was noted compared to the neighboring lake, while in none of them did anaerobic conditions arise in the water. The C/N ratio in the sediments indicated a greater contribution of the allochthonous pathway of organic matter inflow into both lakes, and this was slightly more pronounced in the less flowing lake Nizhniy Perth. A difference in the granulometric composition of the sediments of the studied reservoirs was revealed, which is associated with a change in hydrochemical regimes and different sedimentation conditions as a result.

1 Introduction

The Solovetsky archipelago is located in the shallowest western part of the White Sea, at the “mouth” of the Onega Bay, forming the western and eastern passages into it (Western and Eastern Solovetsky salms) [2]. Bolshoy Solovetsky Island in terms of saturation of the territory with lakes, is similar to the Karelian hydrographic region: its average lake content is 11%. The hydrographic network of the island is very peculiar: it is devoid of rivers and does not form lake-river systems. In accordance with the orography, the islands of the lakes are arranged in tiers. Due to this, a pronounced difference in heights is observed between

* Corresponding author: ksyu_sev@mail.ru

closely spaced water bodies [1]. This feature was used to create a lake-canal system for supplying water to the Solovetsky Monastery as early as the 16th century. Some lakes were connected by artificial channels (if there were no natural channels) to direct the flow of water into the lake. Sacred made boulder and earthen dams between neighboring reservoirs. So, the lakes of Sredniy and Nizhniy Perth, which had previously formed a system, were separated.

The purpose of this work was to identify the features of the functioning of these reservoirs in connection with changes in their hydrochemical regimes.

2 Materials and methods

The objects of study in this work were two lakes, Sredniy and Nizhniy Perth (Figure 1). The first reservoir belongs to the lake-canal system and is flowing. The second one does not have a clear inflow in the summer period, the flow into Lake Melnichnoye, then into the Solovetsky Bay of the White Sea. The areas of water bodies are 0.586 and 0.423 km^2, the maximum depths are 14 and 13 m, respectively. Water and sediment samples were taken in July 2021 in accordance with generally accepted methods with a horizontal bathometer and a shock tube. If necessary, samples were preserved. Bottom sediments during sampling were divided into layers of 5 cm and packed in sealed bags. Temperature and oxygen content were measured using a portable oximeter HQ30D.99. The content of the main ions was determined on a liquid chromatograph LC-20 Prominence; the content of hydrogen sulfide, iron, color, content of biogens - by photometric method, alkalinity - by potentiometric method. The granulometric composition of bottom sediments was determined according to [MI 88-16365-010-2017], the carbon content was determined from an air-dry sample on an elemental analyzer EuroVestog EA-3000. The content of sulfur, reactive iron was determined in samples of natural moisture and recalculated for an absolutely dry sample sample.

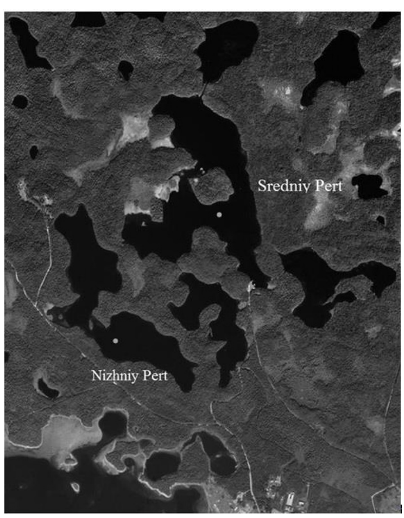

Fig. 1. Map-scheme of the studied lakes of the Bolshoy Solovetsky Island.

3 Results

In the water of the Sredniy and Nizhniy Perth lakes, direct temperature stratification was observed: a decrease in temperature from 18 to 10 ºC and from 21 to 6 ºC, respectively, was revealed. The oxygen content significantly decreased towards the bottom, but anaerobic conditions were not created (from 9.12 to 3.73 mg/L and from 9.31 to 5.31 mg/L, respectively). In the surface water layers of the lake Nizhniy Perth is marked by supersaturation of water with oxygen, in contrast to the lake Sredniy Perth.

According to the average pH values, the waters of the reservoirs we studied can be classified as slightly acidic (6.59) - Sredniy Perth and neutral (6.70) - Nizhniy Perth. This indicator decreased from the surface to the bottom of water bodies by 0.1–0.2.

The total content of the main ions (mineralization) for the studied water bodies averaged 31 mg/l in Sredniy Perth Lake, decreased from the surface layers to the bottom by 8 mg/l, and 38 mg/l in Nizhniy Perth Lake, decreased by 2 mg/l . The contribution of ions in the water of Lake Sredniy Perth was as follows (%): chlorides - 52, hydrocarbonates - 32, sulfates - 16; sodium, 49; magnesium, 25; calcium, 24; sodium - 50, calcium - 24, magnesium - 23, potassium - 3. Using the content of calcium and magnesium ions, the water hardness of the Sredniy and Nizhniy Perth lakes was determined, which differed slightly in the water column and averaged 0.27 and 0.32 mmol/l, respectively. The alkalinity used to calculate the concentration of bicarbonates also differed for the water of these water bodies: 0.13 and 0.20 mmol/L, respectively.

The chromaticity averaged 42.4 degrees for the water of the Sredniy Perth Lake and 35.4 degrees for the Nizhniy Perth Lake, increasing by several degrees towards the bottom of both reservoirs.

The content of iron was also different: it varied from the surface to the bottom in the water of Lake Sredniy Perth from 0.154 to 0.313 mg/L, in Lake Nizhniy Perth, from 0.087 to 0.139 mg/L. The concentration of organic matter in terms of carbon averaged 9.51 and 8.90 mg/l. At the same time, in the water of Lake Sredniy Perth, it decreased by 0.59 mg/l to the bottom, and in Lake Nizhniy Perth, on the contrary, an increase in this indicator by 1.18 mg/l. Hydrogen sulfide was not found in the water of both lakes.

The concentrations of forms of biogenic elements did not exceed the standards in any of the studied lakes. The content of phosphates was minimal (1-3 μg/l). Among the mineral forms of nitrogen, nitrates (140–170 μg N/l) made the largest contribution, followed by ammonium (41–45 μg N/l). The maximum values from the range are typical for the water of Lake Sredny Perth. The content of mineral forms of nitrogen and phosphorus increased from the surface to the bottom for both lakes. At the same time, the total amount of nitrogen in Lake Sredniy Perth decreased towards the bottom, while in Lake Nizhniy Perth it increased. The contribution of the organic component of nitrogen compounds in lake water changed in the opposite way: in Sredniy Perth it increased from 45 to 74% towards the bottom, in Nizhniy Perth it decreased from 56 to 47%.

The selected bottom sediments up to 30 cm thick visually represented: dark brown silty sediments without a pronounced odor in Sredniy Perth Lake, greenish-brown thick silty sediments also odorless in Nizhniy Perth Lake. According to the granulometric composition, the sediments of Lake Sredniy Perth varied from silty-pelitic (27% silt and 70% pelites) to pelitic silt (up to 80-87% pelites) in their thickness up to 25 cm, then there was again an increase in the contribution of silt (23%) and reduction of the pelitic fraction (up to 75%). The amount of the sandy fraction decreased in the sediments as compared to the upper layers of sediments. The granulometric composition of the sediments of Lake Nizhniy Perth was characterized by almost alternating layers of silt-pelitic and pelitic. The maximum contribution of the pelitic fraction reached 92% in the middle layers of sediments. A distinctive feature of the sediments of this reservoir was an increase in the proportion of the sandy fraction from the surface layers in the sediments.

The sediments of both lakes were heavily watered. Humidity decreased from 95 to 92% in the sediments of Sredniy Perth Lake and from 96 to 92% in Nizhniy Perth Lake. In contrast to this indicator, the content of organic matter (expressed in terms of the content of carbon and nitrogen) varied unevenly. With close averaged values of the content of these elements, 12.98 and 13.00%, 0.96 and 0.90%, respectively, the lowest concentrations of carbon and nitrogen are noted in the surface horizon (0-5 cm) in the sediments of both lakes: 11.91 and 0.77% (Sredniy Perth) and 10.95 and 0.74 % (Nizhniy Perth). Deeper, an increase in the carbon content was noted with a gradual decrease to 12.97 and 11.14% (25–30 cm), respectively. In the sediments of Lake Nizhniy Perth, the same tendency of the vertical distribution of organic nitrogen in sediments as carbon was observed; in the sediments of Lake Sredniy Perth, the nitrogen content did not change regularly. The average C/N ratio in the sediments of Lake Sredniy Perth was 13, and in Nizhniy Perth it was 14.

The content of reactive iron (i.e., that part of its inorganic compounds capable of transferring from the solid phase of sediments to the liquid one and vice versa when redox conditions change) in the bottom sediments of Lakes Sredniy and Nizhniy Perth averaged 3.56 and 3.76%, varied from 6.59 up to 3.82% and from 5.36 to 3.16% from the surface layer to the lower horizon. At the same time, in the sediments of Lake Nizhniy Perth, an almost uniform vertical decrease in iron was noted, and in Lake Sredniy Perth, the minimum content was detected for the horizon of 10-15 cm. The share of the reduced form of Fe^{2+} did not exceed 20% of the total content of reactive iron and was minimal in the surface layers of the sediments of both lakes.

The total sulfur content in the bottom sediments of Sredniy Perth Lake was 0.55%, and in the sediments of Nizhniy Perth Lake it was 0.35%. The concentrations of sulfate sulfur were, on average, approximately the same (0.03%), and varied vertically unevenly. For the first reservoir, the minimum content is 0.02% in the horizon (5-10 cm), the maximum is 0.06% in the surface layer; for the second, the maximum is in the 0.07% layer (5-10 cm), the minimum is also 0.02%, but in several horizons at once: in the surface (0-5 cm), middle (10-15 cm) and lower (25-31 cm). The content of elemental and sulfide forms of sulfur was minimal (less than 0.01%) in the sediments of both lakes. In sediments, the largest amount was the organic form of this element - from 85 to 90% of the total sulfur content in Lake Sredniy Perth and from 70 to 90% in Lake Nizhniy Perth. Among the sulfide forms, the pyrite content averaged 0.03 and 0.02 in sediments, which did not exceed 5% of the total sulfur. The largest amounts of this form were noted in the 20–25 cm layer for both lakes, 0.03 and 0.04%, respectively, and the smallest in the surface horizon of both lakes, less than 0.01 and 0.01%, respectively.

4 Discussion

During the period of research, the value of water temperature in the bottom water layers of the lakes of Sredniy and Nizhniy Perth depended on the depth of the sampling station, its largest gradient was noted for the second reservoir. The oxygen content in the lower layers of water is not related to depth, but is due to the amount of organic carbon, so in Sredniy Perth Lake it decreased from the surface to the bottom, and in Nizhniy Perth Lake, on the contrary, it increased, which led to the preservation of these reservoirs.

The low color of the water of Lake Nizhniy Perth, due to low concentrations of organic matter and iron compounds, contributed to supersaturation of the surface layers with oxygen and an increase in the pH value [6, 9].

A low mineralization of the waters of the studied lakes was noted [4], despite the island position of the reservoirs, which is associated with the composition of the underlying rocks and soils, as for the previously studied lakes of the Bolshoy Solovetsky Island [5]. The distribution of the main ions and the value of mineralization (and hardness) of waters indicate the influence of the sea as a source of replenishment of ions in the waters of the studied lakes, since it differs from these indicators for continental water bodies.

The difference in the alkalinity of waters and the content of bicarbonates is due to the processes of dissolution of atmospheric CO_2, the weathering of rocks, and the vital processes of respiration of all aquatic organisms [6]. The absence of hydrogen sulfide and the minimum amount of ammonium are caused by aerobic conditions in the waters of both studied reservoirs [8]. Small concentrations of other inorganic forms of nitrogen and phosphates in the summer period may indicate the absence of anthropogenic pollution, as well as their consumption during the life of various algae and phytoplankton. The accumulation of biogenic elements and organic carbon in the bottom water layers of Lake Nizhniy Perth may be due to the low flow of this reservoir, in contrast to Lake Sredniy Perth.

The bottom sediments of both studied lakes were distinguished by significant humidity, which is associated with their granulometric composition. Sediments are represented by silts with a significant pelitic fraction. At the same time, the content of organic carbon in the sediments of both lakes was significant. So in the sediments of the continental deep-water lake Baikal (Russia) [11] and the shallow lake. Taikhi (China) [10], the content of this parameter did not exceed 3.2–3.3%, and for the insular shallow lakes of Vaigach, it did not exceed 2.3% [12]. High values of the C/N ratio indicated the contribution of terrestrial higher plants to the accumulation of organic matter [10], i.e., allochthonous component.

The content of reactive iron in lake sediments is, on average, close in value to the clarke of this element in the lithosphere. The predominance of its oxidized form is due to the content of significant residual amounts of oxygen in the water. Its accumulation in the surface layer was greater in the lakes of Sredniy Perth, which is associated with greater amounts of this element in the water of this reservoir.

The concentrations of all sulfur compounds in the sediments of the studied lakes of the Bolshoy Solovetsky Island were 3–5 times higher than in the sediments of the lakes of Vaygach Island [12]. At the same time, the sediments of Sredniy Perth Lake contained more organic sulfur (more organic matter and water color) and less sulfate sulfur (due to greater remoteness from the sea) compared to Nizhniy Perth Lake.

5 Conclusion

In the course of the studies of the lakes of Sredniy and Nizhniy Perth on the Bolshoy Solovetsky Island, a low mineralization of their waters (less than 40 mg/l) was revealed, as for other lakes of this island that are not directly connected with the sea. The distribution of the main ions in the water and the differences in the salinity of the waters of these reservoirs are due to their island location.

Significant amounts of oxygen were found even in the bottom water layers of the studied lakes, which led to the presence of minimal amounts of products of anaerobic processes (sulfate reduction, ammonification).

It was established that another difference between the artificially separated lakes was the color of their waters, due to the difference in the content of organic carbon and dissolved iron.

It was revealed that in the heavily watered silty sediments of the lakes of Sredniy and Nizhniy Perth, the vertical distribution of the granulometric composition of bottom sediments was different. The largest amount of the pelitic fraction was characteristic of the sediments of the second reservoir, which is most likely due to the hydrochemical regime of the lakes and different sedimentation conditions.

It is shown that with close average values of organic carbon accumulation in the sediments of both lakes, its minimum amounts are in the surface horizons of the sediments of water bodies, but more carbon was found in the thickness of the sediments (30 cm) in the lakes of Sredniy Perth.

It was revealed that the highest content of sulfur compounds was in the sediments of Lake Sredniy Perth, due to the contribution of up to 90% of its organic component, while a slightly larger amount of sulfate and pyrite sulfur was in the sediments of Lake Nizhniy Perth.

Acknowledgement

The study was supported by a grant from the Russian Science Foundation project No. 22-27-20144 “Succession processes during the transition of a limnic ecosystem from marine to continental, taking into account the impact of natural and anthropogenic factors (on the example of water bodies of the Bolshoy Solovetsky Island)”.

References

1. G.L. Gritsevskaya, G.K. Kyabeleva, L.A. Nikolaeva, V.N. Semenov, Hydrology and hydrochemistry of the Solovetsky Lakes. Solovetsky Islands. Materials for the complex study of lakes. Proceedings of SevNIORH (Karelia Publishing House, Petrozavodsk, 1972)
2. N.N. Cherenkova, Rationale for the creation of the natural reserve "Solovki Archipelago" (Solovki, Moscow, 2014)
3. O. Rasigraf, Microbial community composition and functional potential in Bothnian Sea sediments is linked to Fe and S dynamics and the quality of organic matter, Limnology and Oceanography, **65**, 113–133 (2020)
4. C. Ferreira-Pego, N. Babio, F. Maraver, I. Vitoria, J. Salas-Salvado, Water mineralization and its importance for health, Nutri Salud, **23**, **1**, 4–18 (2016)
5. K.V. Titova, T.A. Zhibareva, O.Yu. Moreva, E.I. Sobko, A.A. Sloboda, S.S. Popov, N.S. Prilutskaya, Hydrochemical and hydrobiological studies of the lakes of the Bolshoy Solovetsky Island, Successes of modern natural science, **11**, 125–131 (2020)
6. D. Hutchinson , Limnology: Geographical, physical and chemical characteristics of lakes (Progress, Moscow, 1969)
7. M. Fakhraee, Significant role of organic sulfur in supporting sedimentary sulfate reduction in low-sulfate environments, Geochimica et Cosmochimica Acta, **213**, 502-516 (2017)
8. Y.A. Fedorov, A.V. Mikhailenko, I.V. Dotsenko, Sulfide sulfur in water objects with different mineralization, Water resources, **46**, **2**, 59–64 (2019)
9. D. He, Y. Liu, Q.L. Wu, Y. Peng, L. Ren, Humic Lake Exhibits Higher Microbial Functional Gene Diversity and Weaker Gene Interaction Efficiency than a Common Alkaline Lake, Biology **11**, **1448**, 14 (2022)
10. K. Yu, Y. Zhang, X. He, Z. Zhao, M. Zhang, Y. Chen, X. Lang, Y. Wang, Characteristics and environmental significance of organic carbon in sediments from Taihu Lake, China, Ecological Indicators, **138**, **108796**, 11 (2022)
11. J.V. Klump, D.N. Edgingtona, L. Granina, C.C. Remsen III, Estimates of the remineralization and burial of organic carbon in Lake Baikal sediments, Journal of Great lakes Research, **46**, **1**, 102-114 (2020)
12. N.M. Kokryatkaya, V.P. Shevchenko, K.V. Titova, E.A. Vakhrameeva, R.A. Aliev, V.A. Grigoriev, L.A. Savelieva, F.E. Maksimov, V.Yu. Kuznetsov, Early diagenesis of bottom sediments of freshwater lakes of the Vaygach island. Problems of the Arctic and Antarctic, Arctic and Antarctic research, **66**, **4**, 534–554 (2020)