RESEARCH PAPER

FEATURES OF UNIQUE LAKES DEVELOPMENT ON THE KURGALSKY PENINSULA IN THE SOUTHEAST BALTIC SEA BASED ON THE RESULTS OF INTERDISCIPLINARY RESEARCH

Tatyana V. Sapelko*, Artem E. Lapenkov, Vadim V. Guzivaty, Sergei G.Karetnikov, Tatyana V. Gazizova, Natalia V. Ignatyeva, Denis D. Kuznetsov, Alexander G. Rusanov
Institute of Limnology of the Russian Academy of Sciences, SPC RAS, St. Petersburg
***Corresponding author:** tsapelko@mail.ru
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ABSTRACT. The increased number of extreme marine events is one of the most serious hazards to coastal areas around the world. The study of the impacts of marine events on coastal lakes has enabled us to gain important insights into the coastal ecosystem's response to these events. On the Baltic Sea southeast coast as a result of studying Lake Lipovskoye and Lake Beloye on the Kurgalsky Peninsula obtained data on hydrology and hydrochemistry of the lakes, structure of lakes' sediments, the distribution of macrophytes and features of the vegetation reflection in the lakes' surface sediments based on pollen data. Bathymetric maps of lakes and their watersheds were constructed. Our complex studies confirmed the lakes' uniqueness. According to hydrochemical data, Lake Lipovskoye has mesotrophic status and is classified as brackish water, whereas Lake Beloye is oligotrophic and freshwater. It was found that the lakes are characterized by small values of specific catchments – 10.3 for Lake Lipovskoye and 2.7 for Lake Beloye. Subrecent pollen spectra of lake surface samples quite adequately reflect modern aquatic vegetation, especially the communities of submerged hydrophytes in Lake Lipovskoye and floating hydrophytes in both lakes. *Potamogeton (P. pectinatus L., P. perfoliatus L.)* and *Myriophyllum sp.* are dominants in the pollen spectra and modern aquatic plant communities in the lakes. Over a short-term period, there are substantive differences in the species composition and dynamics of macrophyte pollen for both lakes. The study of lake sediments found a link between the Holocene sedimentation in Lipovskoye and Beloye lakes and the Baltic's transgressive and regressive stages (Ancylus, Littorina, and Baltic Ice Lake stages).

KEYWORDS: lakes, Baltic Sea coast, modern status, bathymetry, hydrochemistry, macrophytes, pollen, lake sediments, sea level

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INTRODUCTION

Extreme events such as marine level changes or extreme wind events affect coastal areas of seas around the world. Disastrous consequences for people also usually have impacts on lakes and other coastal ecosystems. When saltwater gets into coastal lakes, it mostly affects the plants and organisms that live there. This is especially true if the communities are mostly made up of species with limited osmoregulatory abilities (Cunillera-Montcusí et al. 2022). Impacts of extreme winds mainly come from their influence on water turbidity. These events are critical for the function and state of coastal lake ecosystems, often accompanying widespread coastal erosion and landscape transformation as well (Mallin and Corbett 2006). Predicting ecosystem responses to marine extreme events is challenging due to a limited understanding of the attributes that drive the resilience of lakes (Pleskot et al., 2024). All these extreme events were characteristic of the lakes of the Kurgalsky Peninsula during the Holocene period and for Lake Lipovskoye - even at present.

The first studies of the lakes on the Kurgalsky Peninsula were conducted in the mid-19th century by the hydrographic party of the maritime department for the production of the Baltic survey. The measurements of Lake Lipovskoye bottom were taken at 31 points. The measured maximum depth was then about 15 m. In connection with the design of the port in the 1920s, Lake Lipovskoye, after a long break, again became the subject of research, during which depth measurements were made. The lake department of the Russian Hydrological Institute clarified the maximum depth of the lake, which was 16.25 m and the average depth was 9.6 m (Arnold-Alyabyev, 1924). In 1922 the Main Hydrographic Directorate near the rapper near the bridge over the channel connecting Lake Lipovskoye to the Baltic Sea, a water gauge was installed. Observations of the water levels are made along this gauge. It was then established that the level of water fluctuations in the channel was determined not by the spring flood but by changes in the sea level. The wind from the sea led to an increase in the water level in the channel. Lake Beloye was of interest to researchers of those periods only due to its proximity to Lake Lipovskoye; practically no research was carried out on it. It was assumed that the two lakes were connected by a channel. A.A. Sokolov has a small mention of the lakes of the Kurgalsky Peninsula (Sokolov, 1952). He clarified the areas of Lake Lipovskoye (5.6 km^2) and Beloye (3.6 km^2).

The next largest study of lakes of the Kurgalsky Peninsula was started by the Institute of Limnology of the Russian Academy of Sciences in 2019. The modern algae developments in lakes have been studied (Stanislavskaya et al., 2021). He studies concluded that the ecological status of both lakes, based on trophic conditions and algae species compositions (II–III classes of water quality), is satisfactory. The modern Flora underwent the most comprehensive research on the Kurgalsky Peninsula. The research revealed the coastal, aquatic, semiaquatic biotopes, rare plant communities, and rare vascular plant species (Glazkova & Bubyreva, 1997; Glazkova et al., 2020). Thanks to these studies, we chose Lipovskoye and Beloye lakes for their history study using macrophytes.

In the 1920s, K.K. Markov (1927, 1931) began geomorphological and paleogeographical studies of the Kurgalsky Peninsula that were continued by S.A. Yakovlev, I.I. Krasnov, O.M. Znamenskaja, D.D. Kvasov, D.B. Malakhovsky, and others (State geological map, 2021). Paleolimnological studies on the Kurgalsky Peninsula have not previously been carried out.

This work aims to investigate the effects of marine extreme events on coastal lakes located in the Kurgalsky Peninsula.

STUDY AREA

The Kurgalsky Peninsula was deglaciated about 12,700 calibrated years before the present and was subsequently flooded by waters of Baltic Ice Lake, the Yoldia Sea, Ancylus Lake, and the Littorina Sea (Rosentau, 2013; 2021). The Kurgalsky Peninsula is on the lower terrace of the southern coast of the Gulf of Finland (Fig. 1). The Paleozoic clays overlain by marine Pleistocene sediments - boulder loams of moraines reworked by the sea, as well as clays and sands.

The climate is temperate and maritime. The average temperature in July is +15°C, in January it is -5°C. The Atlantic cyclones, which occur 200 days a year, determine the weather. The annual precipitation is approximately 700 mm; most of it falls in the summer. The average snow cover lasts 120 days; its thickness is 40 cm. The active growing season with average daily temperatures above +10ºC lasts approximately 120 days. The prevailing winds are from the south, south-west, and west.

The vegetation belongs to the southern taiga subzone. Most of the Kurgalsky Peninsula is occupied by dry green moss pine forests. In the south of the peninsula, pine forests with blueberries and lingonberries predominate (Glazkova & Bubyreva, 1997). There are areas with broad-leaved and spruce-deciduous forests, raised sphagnum bogs, black alder coastal swamps with oak, upland, steppe, and floodplain meadows with a variety of plants, coastal marshes and meadow communities, and reed communities in the coastal zone.

The zonal soils are characterized by varying degrees of podzolic sodality. However, due to the widespread occurrence of swamps on the peninsula, boggy gley soils predominate here.

MATERIALS AND METHODS

Investigations included hydrological, hydrochemical and paleolimnological studies. Bathymetric surveys allowed obtaining depth maps. We also determined the area of the lakes' watersheds.

Field work

Using a Russian corer with a 5 cm chamber diameter and 1 m length, sediment cores were taken from Lipovskoye and Beloye lakes' ice in March 2023 (Sapelko et al., 2023). Additionally, we collected 16 surface samples from lakes using the Voronkov sampler (Fig. 2). We collected surface sediment samples from the lakes on the Kurgalsky Peninsula in 2019 and 2023.

Morphometry

To describe the distribution of depths and identify bottom features, measurements were made according to

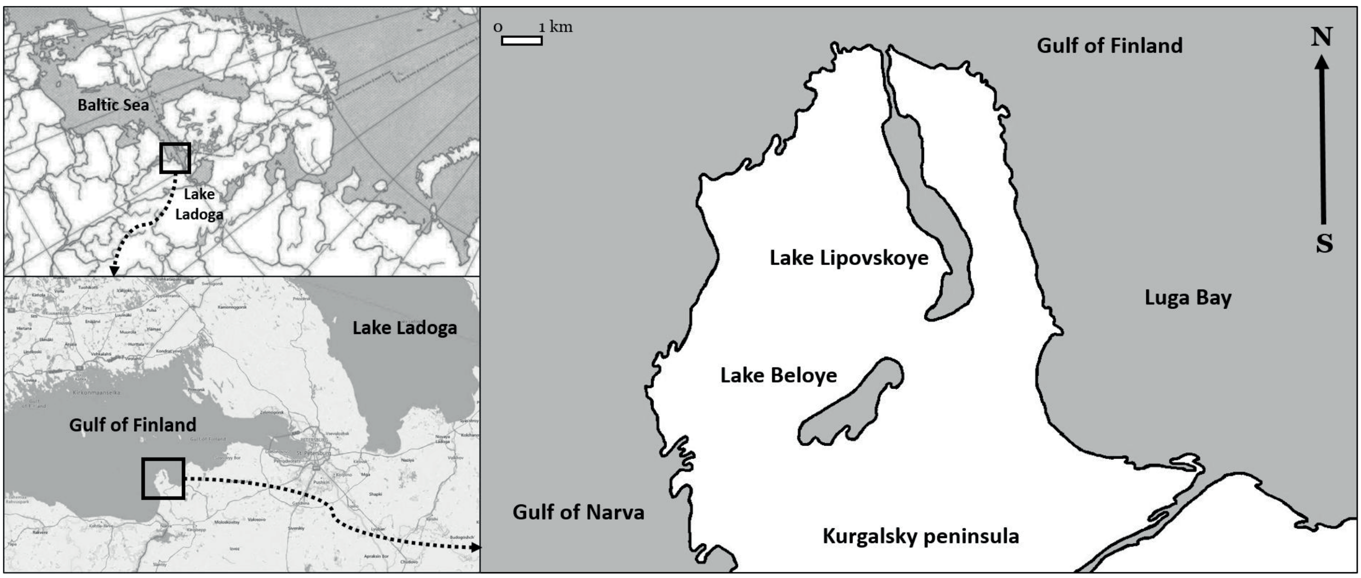

Fig. 1. Location map

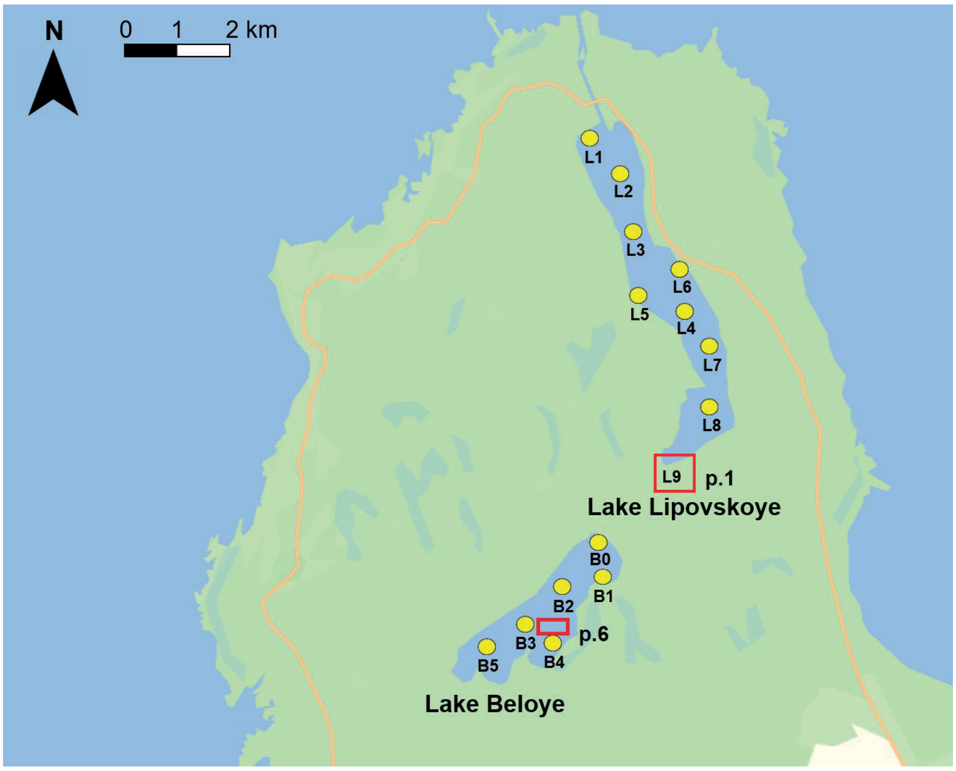

Fig. 2. Map with surface sampling points (yellow circles) and points of cores (p.1 and p.6)

the instructions (Instructions for creation, 1985; Manual for hydrometeorological stations, 1972), with 100 m between each tack. To measure the depth of reservoirs, a LOWRANCE HDS-7 echo sounder was used, featuring a double-beam emitter, a maximum echolocation depth of 300 m (at 800 KHz), an output power of 500 (RMS) / 4000 (peak), and an operating frequency of 200, 455. The power supply range was 9.5 - 32 V. The device allows you to synchronously record depth with resolution up to 1.0 cm and the location of the vessel with an accuracy of ±2.0 m. Work was carried out from an inflatable boat with a draft of 0.2 m to reduce errors. The echo sounder emitter was installed on a special extension at the side of the boat, which made it possible to control the depth of its immersion and bring it as close as possible to the water's edge when moving to new tacks. Before carrying out the measuring work, a temporary water-measuring station and maps of lakes with planned tacks were prepared. To obtain the absolute level of water in Lake Lipovskoye on the date of measurement work, the average level of the Baltic Sea was taken according to data in Narva and Sosnovy Bor. To obtain the absolute water level in Lake Beloye, a leveling course was carried out with a length of 4.5 km with a mark of 23 m from the Baltic Sea level. During the measurement work in the water area of Lake Lipovskoye, 33,767 depth measurements were made, and on Lake Beloye, 27,645 depth measurements were taken. In the water area of Lake Lipovskoye, 80 tack intersection points were selected, and in Lake Beloye, 87 tack intersection points. Lake Lipovskoye has mean square errors of 10 cm for depths at the points where tacks meet, and Lake Beloye has them at 9 cm. These are less than the allowed standard deviations (Manual for hydrometeorological stations, 1972). To better construct diagrams of the depths of lakes, data on the elevations of the territories adjacent to them, taken from topographic maps, was added to the data on bottom marks.

Watershed area calculation

In our research, we used data from TessaDEM for calculations of the watershed area. TessaDEM is a global digital elevation model with a resolution of 30 m. We employed TessaDEM to obtain accurate terrain elevation data. We utilized vector layers that contained the boundaries of Lake Lipovskoye and Lake Beloye. We conducted bathymetry measurements to gather information about the lake depths. During the processing of the Digital Elevation Model (DEM) using the SAGA (System for Automated Geoscientific, 2006 Analyses) software, the "Fill Sinks" module (Wang & Liu) was applied prior to the watershed calculation. The "Fill Sinks" module, available within SAGA, is utilized to fill sinks or depressions in the digital elevation model. Sinks can occur in the DEM due to measurement errors or missing data. By employing the "Fill Sinks" module, we eliminated these sinks and smoothed the terrain to obtain more accurate and continuous data. Following the application of the "Fill Sinks" module to the DEM, we obtained an amended digital elevation model, which was subsequently used for the calculation of the watershed of the lakes. To calculate the watershed for each lake, we employed the "Upslope Area" module from the SAGA software. The "Upslope Area" module provides functionality for determining watersheds based on the digital elevation model.

Hydrochemistry

In order to compile the hydrochemical characteristics of the lakes and study the seasonal dynamics of hydrochemical variables, water samples were taken in March, May, July and September 2019 in different parts of Lake Lipovskoye (at 7 points) and Lake Beloye (at 5 points). Additionally, Lake Lipovskoye was sampled at 2 stations in August 2023. Water samples were taken from the surface and bottom layers using a 2L Limnos sampler.

Chemical analyses were performed in two laboratories: the Laboratory of Hydrochemistry of the Institute of Limnology RAS and the Ecological and Analytical Laboratory of the State Hydrometeorological University. The conventional methods were used: dissolved oxygen content was determined by the Winkler titration (iodometric method); specific electrical conductivity (SEC) – conductometrically; pH –

potentiometrically with a glass electrode; color – by visual colorimetry; chemical oxygen demand (COD_{Cr}) – oxidation with $K_2Cr_2O_7$ and H_2SO_4 followed by titration with Mohr salt; HCO_3^- – potentiometrically; SO_4^{2-} – turbidimetrically; Cl^- – mercurimetrically; Ca^{2+} and Mg^{2+} – titration with EDTA; $\Sigma(Na^+ + K^+)$ and CO_2 – by calculation methods; ions content (dry residue) – gravimetrically, inorganic phosphorus (IP) – by molybdate method; total phosphorus (TP) – in the same manner following oxidation with $K_2S_2O_8$ and H_2SO_4; ammonium-ions – colorimetric method with hypochlorite and phenol; nitrite-ions – colorimetric method with Griess reagent; nitrate-ions – reduction of NO_3^- to NO_2^- (Cu-Cd) followed by determination of NO_2^-; total nitrogen (TN) – by alkaline persulfate oxidation followed by determination of $\Sigma(NO_3^- + NO_2^-)$; Fe_{total} – by photometric method with sulfosalicylic acid.

Pollen

Samples for pollen analysis were prepared using the separation technique by V.P. Grichuk (1940) modified at the Institute of Limnology RAS with K-CdI_2 heavy liquid. Pollen identification refers to guides (Kupriyanova and Aleshina, 1972; 1978), electronic pollen databases, and the collection of the Institute of Limnology RAS. Pollen percentages were calculated based on the sum of trees, herbs, and spores pollen grains. Pollen diagrams were generated using Tilia, TiliaGraph, and TGView software (Grimm, 2004).

RESULTS AND DISCUSSION

Morphometric data of Lipovskoye and Beloye lakes

As a result of the watershed area calculations, the following values were determined for the lakes: the watershed of Lake Lipovskoye is 58.12 km^2 and the watershed of Lake Beloye is 8.9 km^2 (Fig. 3).

Lake Beloye

Fig. 4(a) presents the distribution of lake depths. A special feature of the lake is the small area of its watershed and the lack of surface runoff from it. Currently, the level of the lake varies little by season, however, in Fig. 4(b), which represents a diagram of the distribution of slopes of the lake bottom, one can see the presence of an underwater terrace at a depth of 1.5 - 2 m, indicating a long-term standing of the lake's water level below the present level in the past. Below the underwater terrace, there is a coastal slope, highlighted in gray, with bottom slopes ranging from 2 to 17°. With an interpolation step of 10 m, the average slope of the bottom of Lake Beloye is 1.5°. The central part of the lake, occupying more than 70% of the lake's area, has a flat bottom with slopes of up to 2° and a small depression of up to 13.1 m.

Lake Lipovskoye

Fig. 5(a) presents the distribution of lake depths. The level regime of Lake Lipovskoye depends on the level of the Baltic Sea, which varies little over time; therefore, the coastal slope with bottom slopes from 2 to 24°is formed along the shores, without underwater terraces. In Fig. 5(b), the zone of the lake with maximum bottom slopes, which occupies less than 30% of the lake area, is shaded in gray. With an interpolation step of 10 m, the average slope of the bottom of Lake Lipovskoye is 2°. The rest of the lake has a flat bottom with a gradual decline toward the central part with maximum depth.

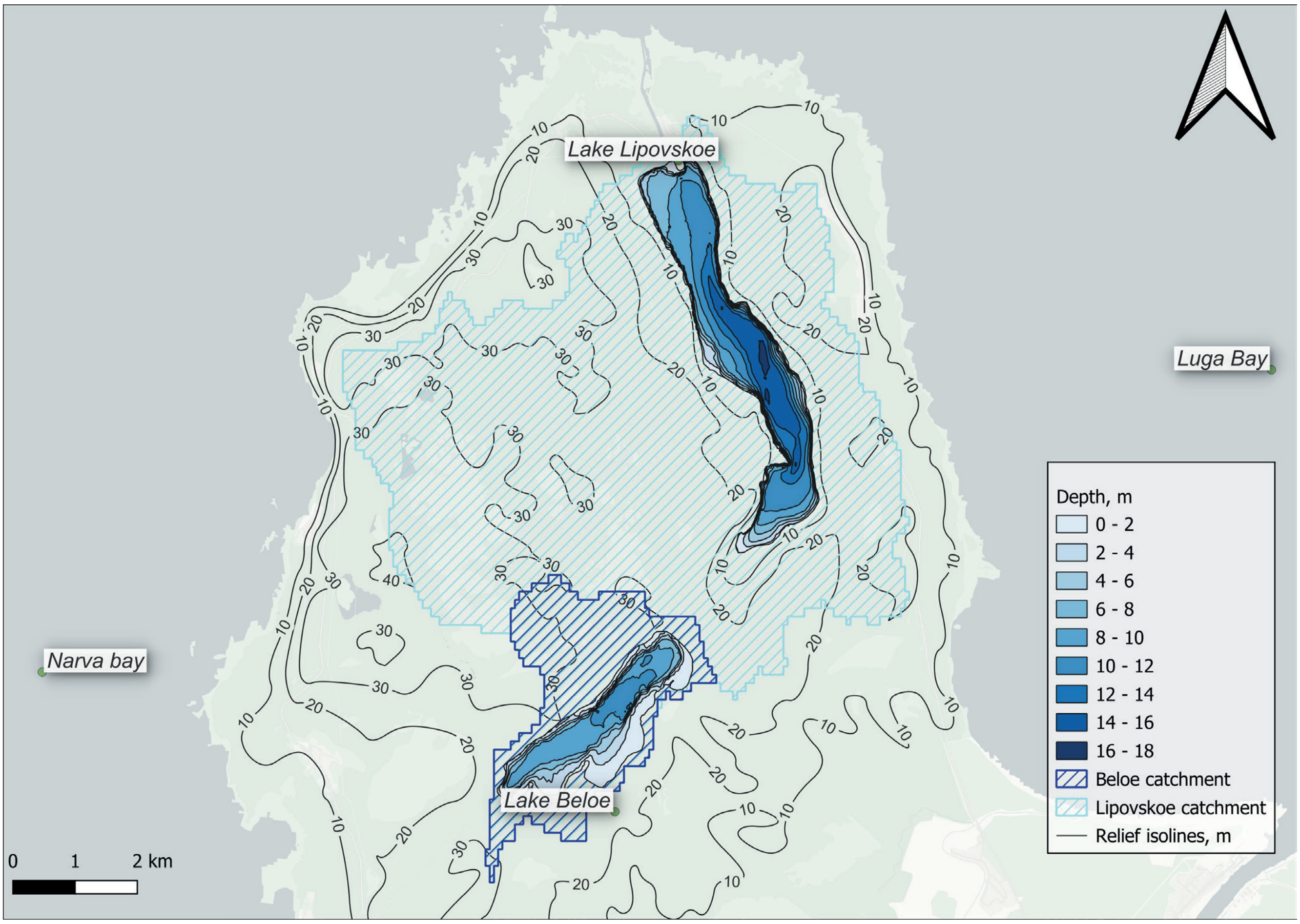

Fig. 3. The watersheds of Lake Lipovskoye and Lake Beloye

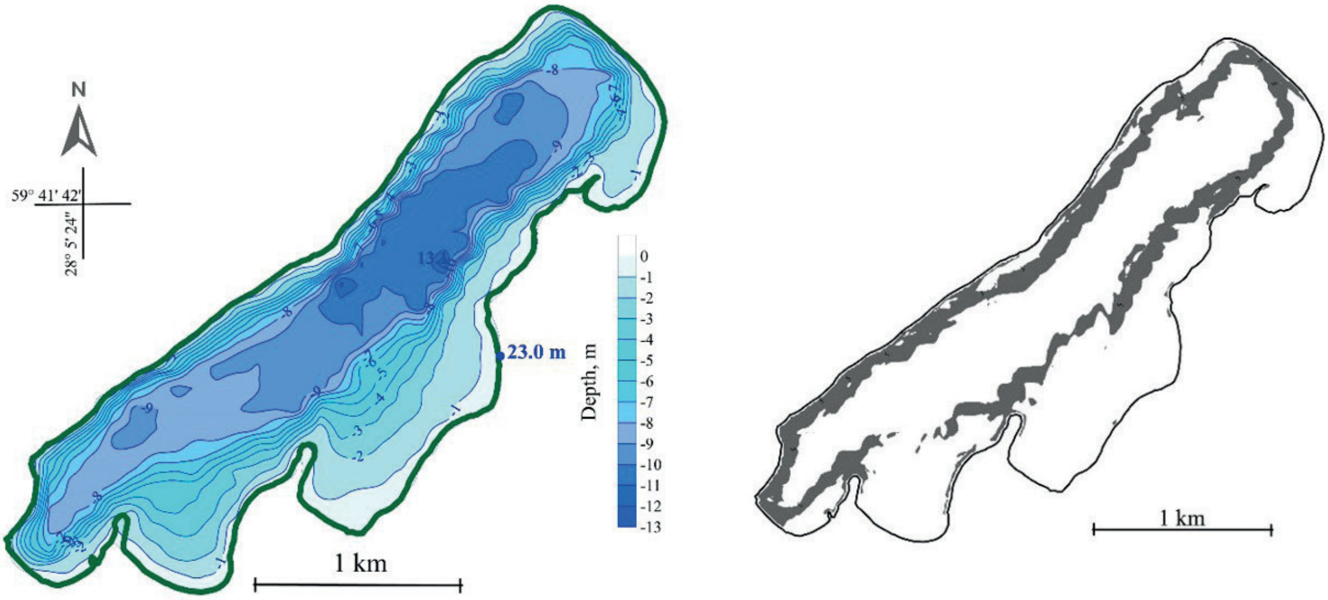

Fig. 4. Morphometry (a) and the zone of Lake Beloye with bottom slopes from 2 to 17 degrees (b)

Fig. 6 presents the distribution of lake bottom slopes as a percentage of their area. Both distributions are exponential in nature, but Lake Beloye is characterized by a greater differentiation of bottom slopes compared to Lake Lipovskoye. Table 1 provides the comparative statistical characteristics of the bottom slopes of the two lakes.

The shape of the bathymetric curve of Lake Lipovskoye displays three sections of its basin. Up to a depth of 6 m there is a coastal slope with an area of 1.3 km^2, which starts directly from the water's edge without shallow waters of significant area, below to a depth of 12 m the bottom flattens out, the area of this area is 2.8 km^2, deep-sea depressions occupy the bottom with an area of 1.5 km^2. For Lake Beloye, three sections can also be distinguished: up to 3 km^2 of shallow water with depths of up to 2 m; a steep coastal slope is noted to depths of 8 m; below there is a bottom with a gentle slope to a depression with an area of 1.2 km^2.

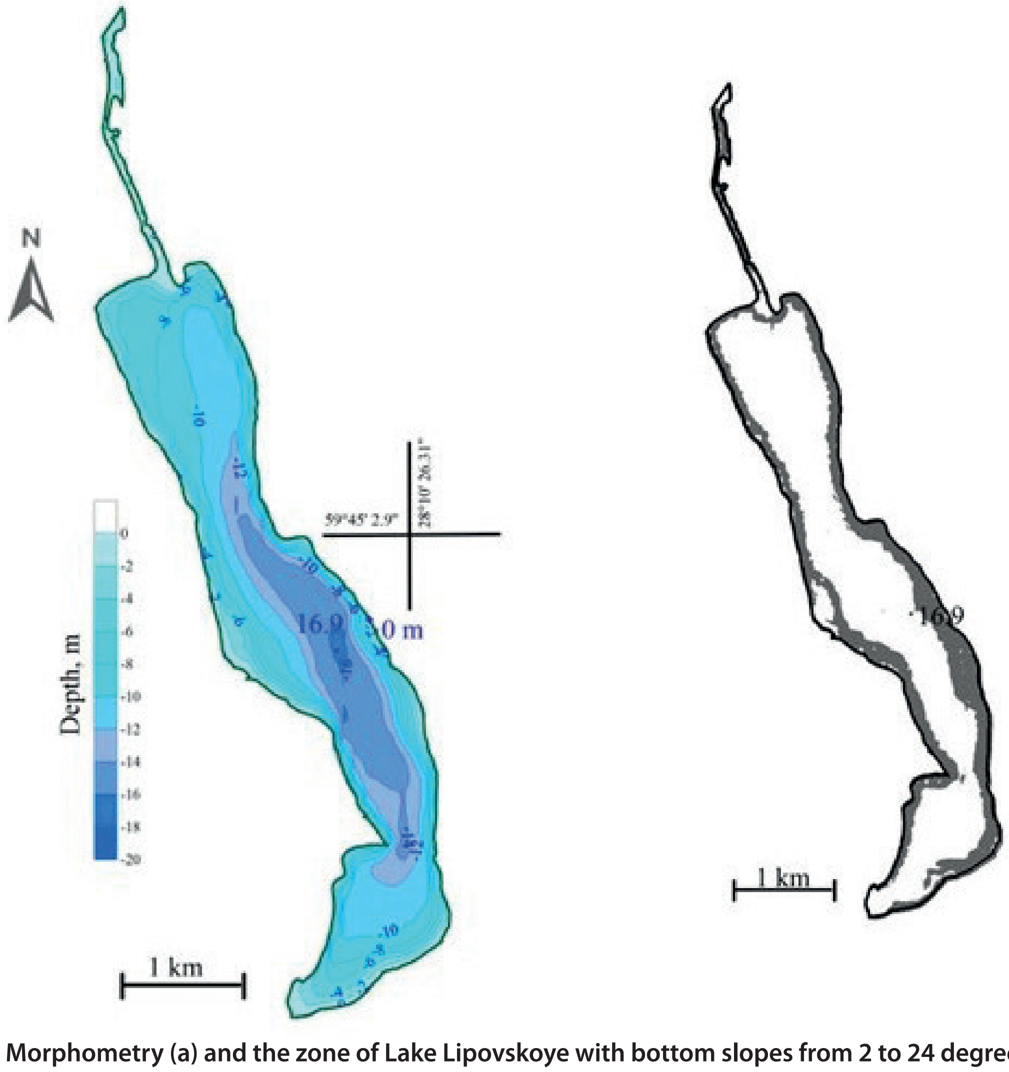

Fig. 5. Morphometry (a) and the zone of Lake Lipovskoye with bottom slopes from 2 to 24 degrees (b)

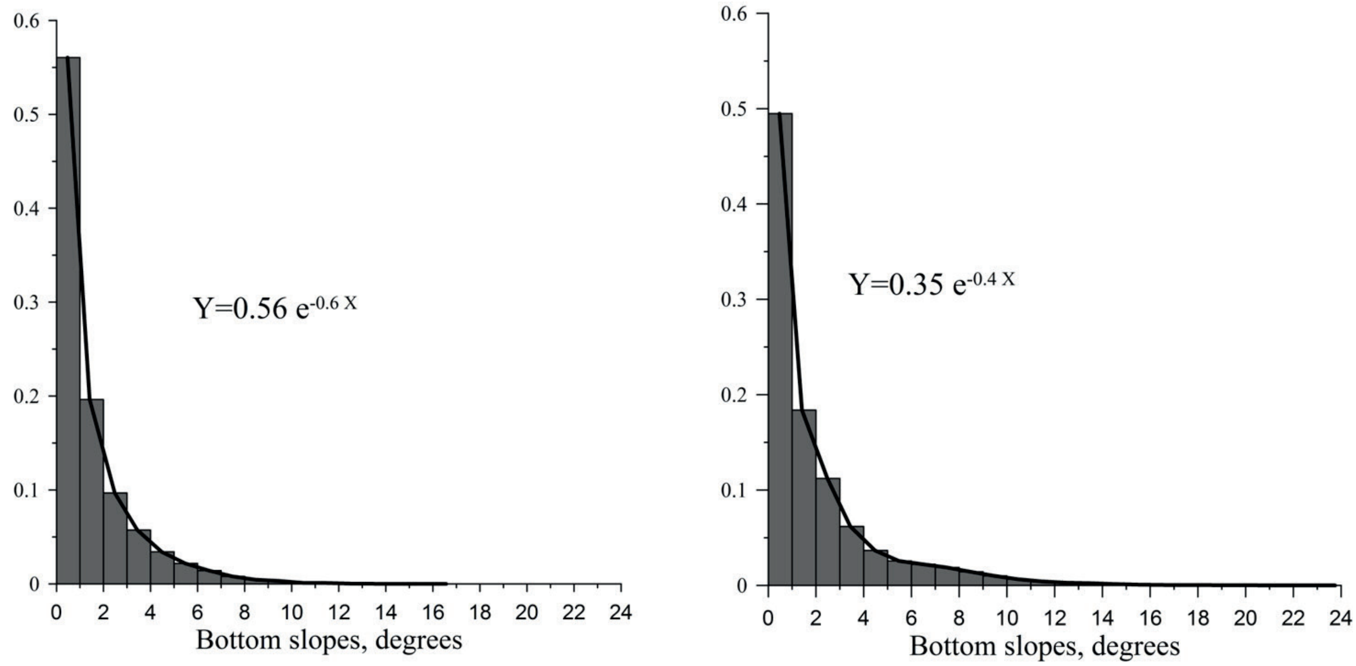

Fig. 6. Histograms of the relative distribution of bottom slopes of lakes Beloye (a) and Lipovskoye (b)

Table 1. Comparative characteristics of lake bottom slopes

Lake	Beloye	Lipovskoye
Average slope	1.491724	2.032837
Standard error	0.009596	0.010709
Median	0.839381	1.016122
Standard deviation	1.729976	2.527355
Sample variance	2.992816	6.387521
Excess	6.568455	6.857175
Asymmetry	2.283405	2.375512
Maximum, deg.	16.96576	23.74195
Number of cells	32503	55694

Hydrochemistry

According to Table 2, Lake Lipovskoye is salty by the average value of ions content (dry residue). The reason for this is the hydraulic connection of the lake with the Gulf of Finland. Extreme values were recorded at the end of the ice-covered period: the highest – in the near-bottom layer, the lowest – in the surface layer, directly under the ice. In the ice-free period, the water mass of the lake is more homogeneous, and ion content varies in a rather narrow range of values 4.07 – 4.89 g l^{-1} (average 4.47 g l^{-1}), while the difference of values between the surface and near-bottom layers does not exceed 0.6 g l^{-1}. According to the classification of O.A. Alekin (Alekin, 1970) the lake water belongs to the chloride class, sodium group, third type. This type is typical for strongly mineralized waters. In spite of the fact that the lake is stretched in a meridional direction, with saline waters inflowing to its northern end, and in the ice-covered period the ion content in the surface and bottom layers differs by an order of magnitude, the ratio of main ions is practically not subjected to spatial and temporal changes. The average relative contents of major ions in the anionic composition are the following (eq. %): Cl^- – 90, HCO_3^- – 2, SO_4^{2-} – 8; in the cationic composition (eq. %): $\Sigma(Na^+ + K^+)$ – 76, Ca^{2+} – 5, Mg^{2+} – 19.

The fact that Lake Beloye, located on the Kurgalsky Peninsula at a distance of 1.8 km south of Lake Lipovskoye, has no direct connection with the Gulf of Finland determines significant differences in the chemical composition of the water in the two lakes. As can be seen from Table 2, the ion content in Lake Beloye for the same observation period is about 80 times lower than in Lake Lipovskoye, which allows us to classify it as an ultra-freshwater lake. At the same time, the ratio of major ions also differs significantly. In contrast to Lake Lipovskoye, sulfates dominate the anionic composition of Lake Beloye, while calcium dominates the cationic composition. The average content of major anions is the following (eq. %): SO_4^{2-} – 47, HCO_3^- – 28, Cl^- – 25; major cations (eq. %): Ca^{2+} – 48, Mg^{2+} – 27, $\Sigma(Na^+ + K^+)$ – 24. According to the classification of O.A. Alekin, the lake water belongs to the sulfate class, calcium group, second, or third type.

The values of chemical oxygen demand (COD_{Cr}), indirectly characterizing the content of organic matter, in the water of Lake Lipovskoye are twice as high as in Lake Beloye, while the average value of the watercolor in the ice-free period in both lakes is the same (Table 2). The highest COD_{Cr} values refer to the surface layer in the deep-water zone of the southern half of the lake at the end of winter. The same waters are also characterized by the highest

Table 2. Average and extreme (in parentheses) values of chemical variables of lakes Lipovskoye and Beloye in March – September 2019*

Chemical variable	Lipovskoye	Beloye
O_2, %	74 (0 ÷ 124)	92 (73 ÷ 100)
SEC, µS cm^{-1}	6320 (948 ÷ 8230)	40 (34 ÷ 47)
pH, unit pH	7.58 (6.00 ÷ 8.38)	7.34 (5.90 ÷ 8.25)
Color, degree Pt-Co	31 (13 ÷ 172)	15 (10 ÷ 19)
COD_{Cr}, mg O l^{-1}	34.1 (11.3 ÷ 74.1)	16.8 (5.5 ÷ 35.1)
HCO_3^-, mg l^{-1}	84.1 (9.2 ÷ 273)	5.95 (2.75 ÷ 9.15)
SO_4^{2-}, mg l^{-1}	202 (64 ÷ 332)	7.70 (3.99 ÷ 9.52)
Cl^-, mg l^{-1}	1791 (208 ÷ 2260)	3.01 (2.02 ÷ 4.77)
Ca^{2+}, mg l^{-1}	53.9 (9.3 ÷ 66.0)	3.34 (3.13 ÷ 3.69)
Mg^{2+}, mg l^{-1}	132 (15.0 ÷ 167)	1.14 (0.57 ÷ 1.73)
$\Sigma(Na^+ + K^+)$, mg l^{-1}	1062 (142 ÷ 1405)	2.10 (0.12 ÷ 4.57)
Ions content, g l^{-1}	4.03 (0.46 ÷ 5.05)	0.052 (0.018 ÷ 0.078)
CO_2, mg l^{-1}	3.3 (0.4 ÷ 16.0)	0.5 (0.1 ÷ 1.3)
IP, mg P l^{-1}	0.038 (0.003 ÷ 0.299)	0.003 (0.001 ÷ 0.007)
TP, mg P l^{-1}	0.064 (0.020 ÷ 0.355)	0.010 (0.007 ÷ 0.017)
NH_4^+, mg N l^{-1}	0.183 (0.011 ÷ 0.914)	0.067 (0.033 ÷ 0.130)
NO_2^-, mg N l^{-1}	0.001 (0.000 ÷ 0.003)	0.001 (0.000 ÷ 0.011)
NO_3^-, mg N l^{-1}	0.076 (0.000 ÷ 0.930)	0.026 (0.004 ÷ 0.074)
TN, mg N l^{-1}	0.53 (0.17 ÷ 1.56)	0.27 (0.14 ÷ 0.46)
Fe_{total}, mg l^{-1}	0.30 (0.02 ÷ 1.49)	0.12 (0.01 ÷ 0.54)

** The hydrochemical variables' values at two Lake Lipovskoye sampling stations that were sampled on August 10, 2023, were within the ranges of values found in 2019.*

color values due to both the presence of colored forms of organic matter (humus) and high iron content, which is a peculiarity of this geochemical province. Probably, it is connected with sub-ice flooding of water coming with slope runoff during the period of snow melting and the appearance of edges on the lake.

Lake Beloye is characterized by a favorable oxygen regime, whereas in the hypolimnion of Lake Lipovskoye, a decrease in the concentration of O_2 until its complete disappearance and the formation of H_2S was observed from the end of the ice-covered period until mid-summer. The anaerobic situation in the near-bottom water layer persisted at least until the end of September. The value of pH varied in the range from slightly acidic to slightly alkaline waters and was approximately the same for both lakes.

According to the value of the average annual total phosphorus content (TP) in the water, Lake Lipovskoye is classified as eutrophic, Lake Beloye is oligotrophic (upper limit). The seasonal dynamics of the TP content in Lake Beloye are practically absent. In Lake Lipovskoye, there was a progressive increase in the phosphorus reserve in the lake water from the end of the ice-covered period to autumn. During this period, bottom sediments serve as the primary source of phosphorus, and the establishment of anaerobic conditions significantly increases their phosphorus release. Similarly to phosphorus, the nitrogen content in Lake Lipovskoye is higher than in Lake Beloye (Table 2). Despite the good aeration of the water mass, the reduced ammonium form dominates among the inorganic forms of nitrogen in both lakes. In Lake Lipovskoye, the N/P ratio (w/w) in the annual cycle averages 13, while during the open water period, it averages 9. This means that during the vegetation period, the ratio of the main nutrient content in the lake water is close to the optimal value for phytoplankton growth. In Lake Beloye, the N/P ratio in the annual cycle averages 28, varying in different seasons from 21 to 35. Thus, Lake Beloye's water has a significant excess of nitrogen, and the phosphorus content limits primary production.

Hence, it was found that two lakes located in close proximity to each other in the same climatic and landscape conditions differ significantly in hydrochemical characteristics. The main differences are the presence of a hydraulic connection between Lake Lipovskoye and the Gulf of Finland, which is most noticeable in winter (during the ice-covered period), whereas Lake Beloye does not, and the differences in the external load on the lakes due to the differing specific catchments.

Lake sediments

Lake sediments are represented by grey clayey-layered silt with black layers of hydrotroilite and gyttja. The lower part of the sediments is possibly associated with the Baltic Ice Lake (BIL). Layered clay sediments of the BIL were noted in the studied region in cores located at sea level, like Lake Lipovskoye (Markov, 1931), as well as in the lower part of the lake sediment sequence of the Narva-Luga Lowland (Subetto et al., 2002; Sandgren et al., 2004).

On Lake Beloye, cores were taken at two points in the lake's central part. However, it was not possible to obtain long cores here. At one point a core of fine-grained sand with a thickness of 10 cm was taken from a depth of 6 m, and at another point a core of 35 cm was taken from a depth of 8.1 m (Fig. 7). At the second point, the sediments are represented by silt, fine-grained sand, and gyttja. The lower part of the sediments may have been formed during the Ancylus Lake period. Sediments of this type, represented by clays and clayey silts, are described in the region under consideration as sediments of Ancylus Lake (Rosentau et al., 2013; Spiridonov et al., 2010).

Modern vegetation from surface pollen

We have collected pollen data from subrecent lake sediments, specifically from Lipovskoye and Beloye lakes (Fig. 8). The pollen analysis was carried out in order to identify the reflection features of macrophyte pollen in lake sediments. Further pollen analysis of lake sediment sequences requires these results (Fig. 7). In Lake Lipovskoye, there is no specific dominant aquatic vegetation, and the presence of macrophyte pollen varies during the entire period. Pollen of the genus *Potamogeton (P. pectinatus* L., *P. perfoliatus* L.), which is the dominant according to the studies of modern aquatic vegetation, are predominated in the surface sample from the

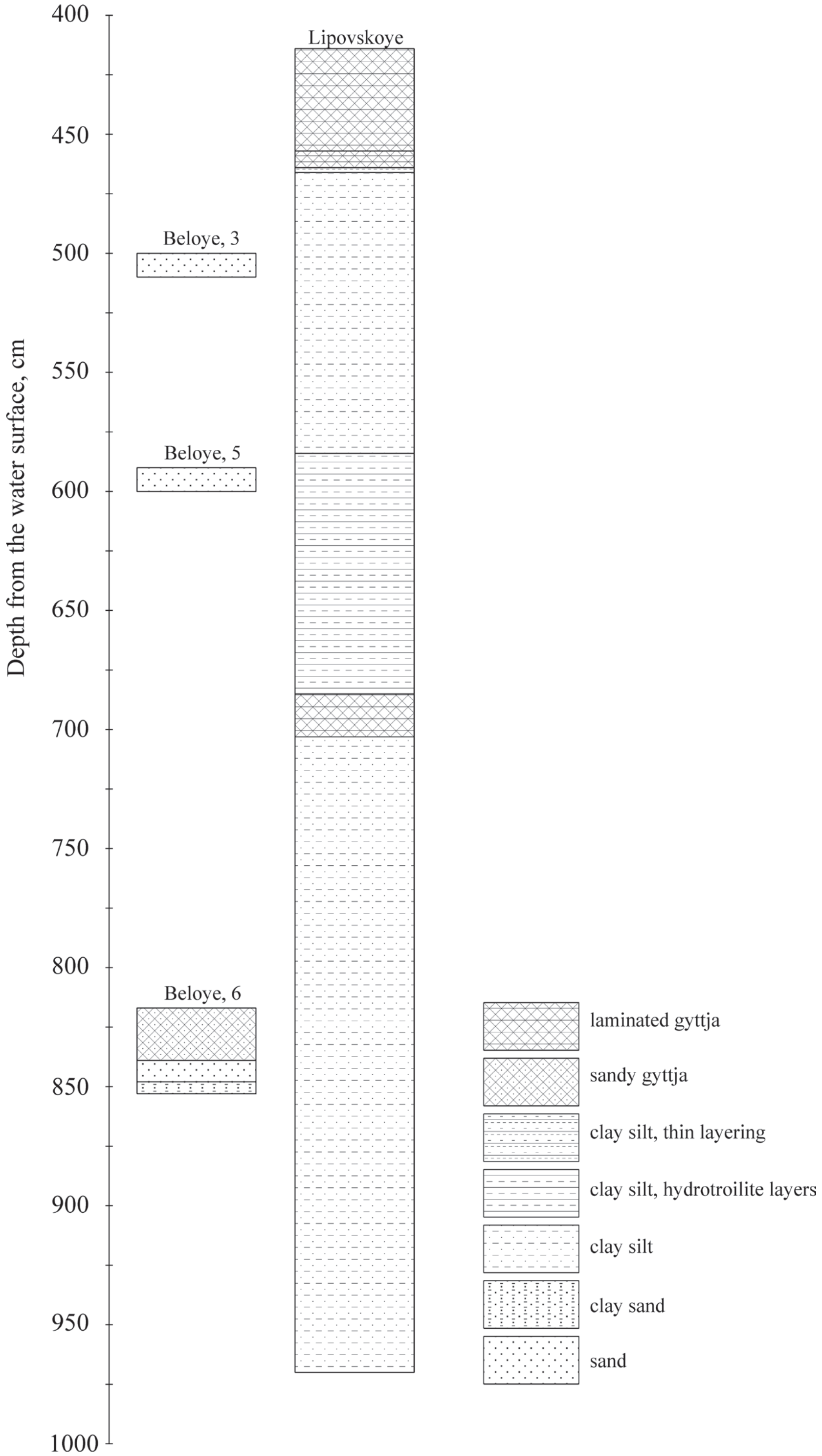

Fig. 7. Lithology of Beloye and Lipovskoye lakes sediments

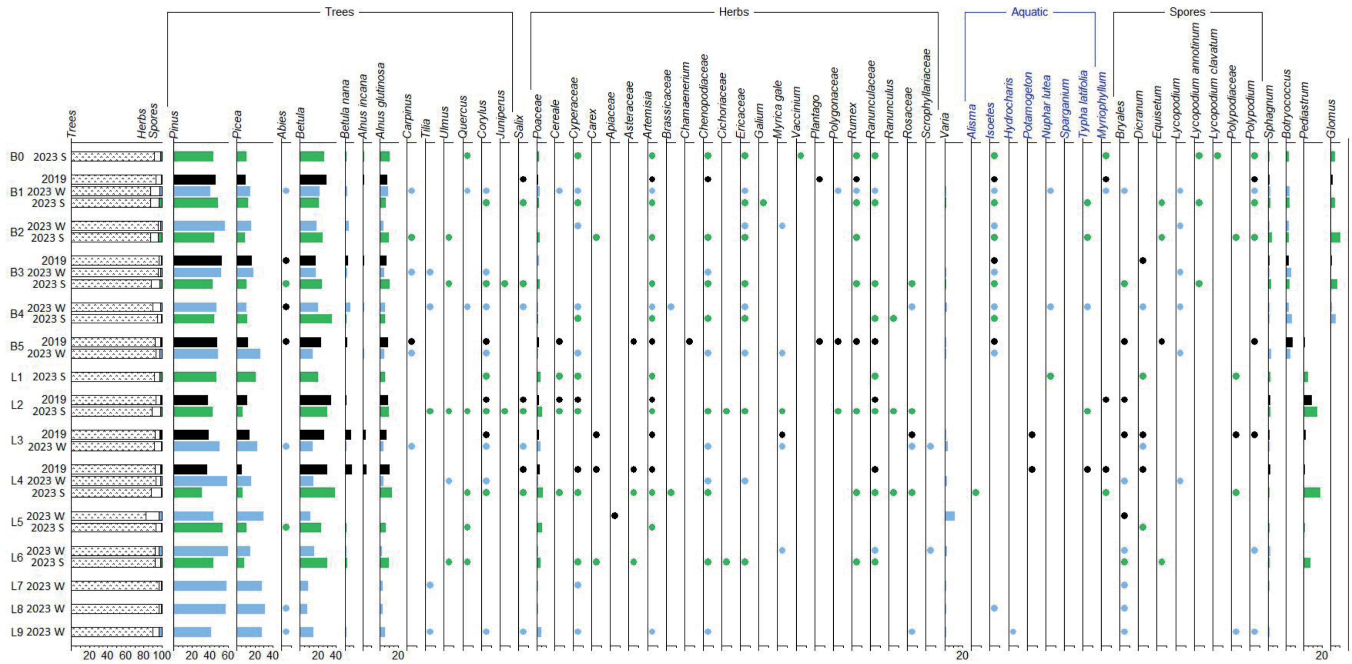

Fig. 8. Pollen diagram of surface samples from Beloye (B 0-5) and Lipovskoye (L 1-9) lakes. S-summer, W- winter

northern part of the lake. Pollen of the genus *Myriophyllum (M.alterniflorum DC., M.sibiricum Kom.)* can be found in samples from the central and northern parts in 2019. In both winter and summer samples in 2023, the diversity of macrophyte pollen differs significantly; however, the species composition in the summer samples in 2023 is similar to that in 2019 *(Myriophyllum sp., Potamogeton sp., Typha latifolia* L.).

In Lake Beloye, pollen of the main dominant, the rare species *Lobelia dortmanna* L., are not represented in SPS, although it takes an important place in submerged plant communities. *Isoetes echinospora* Durieu and *I. lacustris* L. spores are also dominant and can be found in all samples over a short period of time. Meanwhile, its quantity is higher in summer samples than in winter samples in 2023. Pollen of *Myriophyllum alterniflorumalterniflorum* is present in samples from the northern part of the lake in 2019 and in the winter in 2023, but not in the summer samples in 2023, although the plant has been described during the studies of modern aquatic vegetation (Rusanov et al., 2024). In addition to the vegetation typical of freshwater lakes, in Lake Lipovskoye, we described *Najas marina L.*, which is found in sea waters (Rusanov et al., 2024).

CONCLUSION

By looking at how the extreme coastal events affected the ecosystems of brackish Lake Lipovskoye and freshwater Lake Beloye, we reconstructed how lake ecosystems responded to these events. The morphometric characteristics of the lakes were obtained, the areas of their watersheds were calculated, and maps of lakes and bottom slopes were constructed. As a result, we received a conclusion that lakes have big areas but small watersheds (Lake Lipovskoye - 5,65/58.12 km^2; Lake Beloye - 3,28/8.9 km^2).

- Most of the hydrochemical variables of Lake Lipovskoye are characterized by pronounced seasonal dynamics. The periodic inflow of saline water from the Gulf of Finland into the northern end of Lake Lipovskoye largely determines its chemical composition and hydrochemical regime, which is evident when comparing it with Lake Beloye, located a little south, but has not hydraulic connections to the Gulf of Finland. Hydrochemical data on the current state of the lakes show the eutrophic status (by phosphorus) of Lake Lipovskoye, and allow it to be classified as brackish water. Lake Beloye is oligotrophic and freshwater.

- Subrecent pollen spectra of lake surfaces sediments on the Kurgalsky Peninsula quite adequately reflect modern aquatic vegetation, especially the communities of submerged hydrophytes in Lake Lipovskoye and floating hydrophyte (Nuphar lutea (L.) Smith) in both lakes. *Potamogeton (P. pectinatus L., P. perfoliatus L.)* and *Myriophyllum* sp. are the dominant in the pollen spectra and modern aquatic plant communities in the lakes. Over a short-term period, there are substantive differences in the species composition and dynamics of macrophyte pollen for both lakes.

- The first results from the lake sediments cores showed a between the Holocene sedimentation in Lipovskoye and Beloye lakes and the transgressive-regressive phases of the Baltic, the Ancylus and Littorina stages, and the stage of the Baltic Ice Lake.

- The sediments of both lakes showed us lithological changes associated with extreme changes (sharp lithological boundaries) during the Holocene. The obtained hydrological, hydrochemical results and the study of the dynamics of modern vegetation have shown that now the influence of extreme marine events on Lake Beloye has ended but is still affecting Lake Lipovskoye.

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