HYDROLOGICAL AND SPECTROPHOTOMETRY RESEARCH ON KISLO–SLADKOYE LAKE

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ABSTRACT

In this work, a description of the hydrological features of the lake Kislo-Sladkoye is given. The present work is a part of complex research on bottom topography, hydrological characteristics, water light absorption spectra at different depths, benthos communities, and ecological features of macrobenthic and terrestrial organisms. Vertical profiles of coloured layers, illumination, temperature, salinity, redox potential, acidity and oxygen content were analysed in August 2014 at different positions in the lake. According to the analysis of data, the water column is divided into strata: (a) zone of wind mixing (0 - 0.5 m); (b) halocline (0.5 - 1.5 m); (c) area with high oxygen concentration (1 - 1.5 m); (d) thermocline (1.5 - 3 m); (i) hydrosulfuric zone (2.5 m to the bottom).

Phytoplankton is dominated by cryptophyte flagellates *Rhodomonas* sp. and green-coloured cocci. In the coloured layers, the following pigments were detected by spectrophotometry: chlorophyll *a*, chlorophyll *b*, bacteriochlorophyll *c* or *g*, and phycoerythrin. Therefore, the presence of cryptophytae algae (genus *Rhodomonas*), unicellular phototrophic organisms containing chlorophyll *b*, and green sulfur bacteria is shown. The distribution of the layers: 0 - 1.7 m: organisms are virtually absent; 1.7- 2.2 m: cyanobacteria; 2.2 - 2.4 m: light absorption peaks corresponding to phycoerythrin and chlorophyll *a* and *b* appear, a large number of cryptophytae algae (genus *Rhodomonas*) and unicellular green algae. 2.4 - 2.7 m: concentration of pigments decline, a small amount of cells with chlorophyll *b* and cryptophytae algae; 2.7 - 4 m: green sulfur bacteria.

For the first time, a theoretical explanation of changes in the lake Kislo-Sladkoye following a spring tide is given. Densities of seawater and lake water were calculated and the results show that seawater penetrated the lake at a depth of 1.55 m during the spring tide.

INTRODUCTION

This paper presents a description of hydrological research of the lake Kislo-Sladkoye as a part of investigations on bottom topography, hydrological characteristics, light absorption spectra of water at different depths, benthos communities and also ecological features of macrobenthos and terrestrial organisms during the period of 8-14 August 2014. Lately, collaboration with students from MSU has become a tradition at the WSBS. Students have already done quite a few studies on physical-chemical water properties and absorption spectra (1). The current work is dedicated to research of water stratification in the lake Kislo-Sladkoye and description of spring tide influence on the lake stratification. Vertical profiles of coloured layers, illumination, temperature, salinity, redox potential, acidity and oxygen content are analysed at different points in the lake. Spectrophotometry is used to identify the dominant phytoplankton groups in different water layers *via* absorption spectroscopy. Different phytoplankton taxa use varying pigments for photosynthesis. Therefore, absorption spectra analysis allows us to determine the pigment composition, which leads to taxa identification and reveals their vertical distribution.

In order to achieve this aim we set the following tasks: (a) using different gadgets and methods to get vertical profiles of illumination, temperature, salinity, redox potential, acidity and oxygen content in different points in the lake; (b) allocating water mass with contrast characteristics; (c) comparing

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the distribution of illumination in the lake and at nearest marine waters; (d) collecting samples of water from typical depths for absorption spectrum analysis; (e) detecting the most interesting layers for benthos works; (f) comparing lake stratification before and after spring tide.

METHODS

Water samples were collected from a boat using various pumps; some measurements were conducted via submergible devices. Salinity and temperature were measured with a WTW Cond 315i conductivity meter; acidity and redox potential were measured using a pH- and Eh-meter Water-Liner WMM-73 with different electrodes. Water samples were taken from different depths with the help of a portable submersible pump Whale Premium Submersible Pump GP1352. Depth was measured by means of an echo sounder FishFinder 140 Garmin. Analysis of oxygen content was performed with an oximeter (Mark 302 E) with a submersible probe for measuring *in situ*. Illumination at different depths was measured by an advanced model of a household illuminometer AR813A for submersion in water. Hydrological studies were done at four stations (Figure 1).

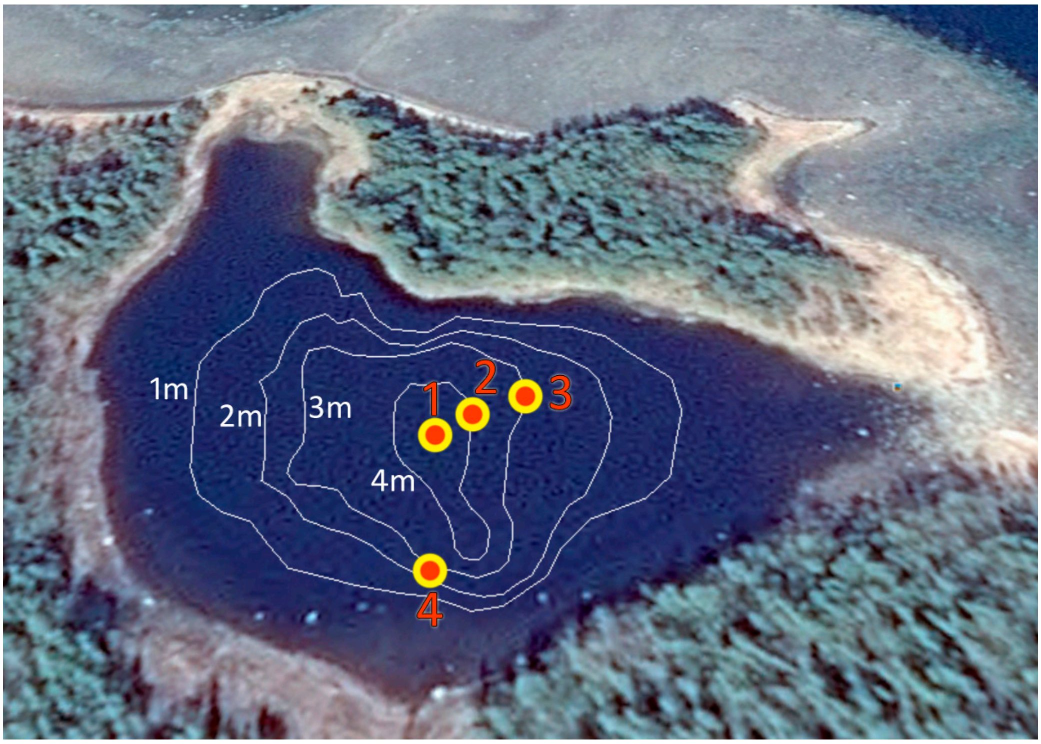

Figure 1: Allocation of hydrological stations (yellow-red dots) on the satellite map of lake Kislo-Sladkoye. Station numbers are shown in red. White lines show isobaths with corresponding depths.

According to visual examination of water coloration along the vertical column, we chose a few layers for microscopy and spectrophotometry analysis: 0 m; 1 m; 2.1 m; 2.2 m; 2.3 m; 2.4 m; 2.5 m; 2.7 m; and 4 m. The primary analyses were conducted with a light microscope LEICA DM 2500 with TRITC 515-560/580 filter at 20·10 magnification.

The samples were centrifuged for cell sedimentation, and then the water was removed. Concentrated sediments were frozen for cell destruction and pigment release. Absorbance spectra were obtained in 80% acetone using a HITACHI 220 spectrophotometer with a 0.5 nm spectral resolution. Samples from 0, 1, 2.7 and 4 m were used following particle concentration due to low phytoplankton density. Pigments were determined from the obtained absorbance spectra.

RESULTS AND DISCUSSION

Hydrology

Generalized measurement results are shown in Figure 2. After analysing the data, the water column was divided into layers:

- Zone of wind mixing (0 - 0.5 m): In this area, intensive mixing of water by wind and temperature in this zone strongly depends on weather, and consequently all the measured parameters are approximately the same at different depths;
- Halocline (0.5 - 1.5 m): In this area, salinity drastically increases with depth;
- Area with high oxygen concentration (1 - 1.5 m): Oxygen saturation in this area is at maximum and equals 13.3 mg/l;
- Thermocline (1.5 - 3 m): In this area, temperature decreases sharply with depth; water colour changes multiple times at this level, so different coloured layers can be seen. The maximum temperature is not found in the upper layer, but lower, at about one metre depth. Such phenomenons were also described in the lake Mogilnoye (2).
- Hydrosulfuric zone (2.5 m to the bottom): The layers with hydrogen sulfide smell. Such bottom layers with high H_2S content are typical of marine meromictic water reservoirs like the Black Sea (3).

The lake in general has a structure similar to that of the well-known lake Mogilnoye on Kildin island: freshened upper layer, marine salty water in the middle and hydrosulfuric zone near the bottom (4).

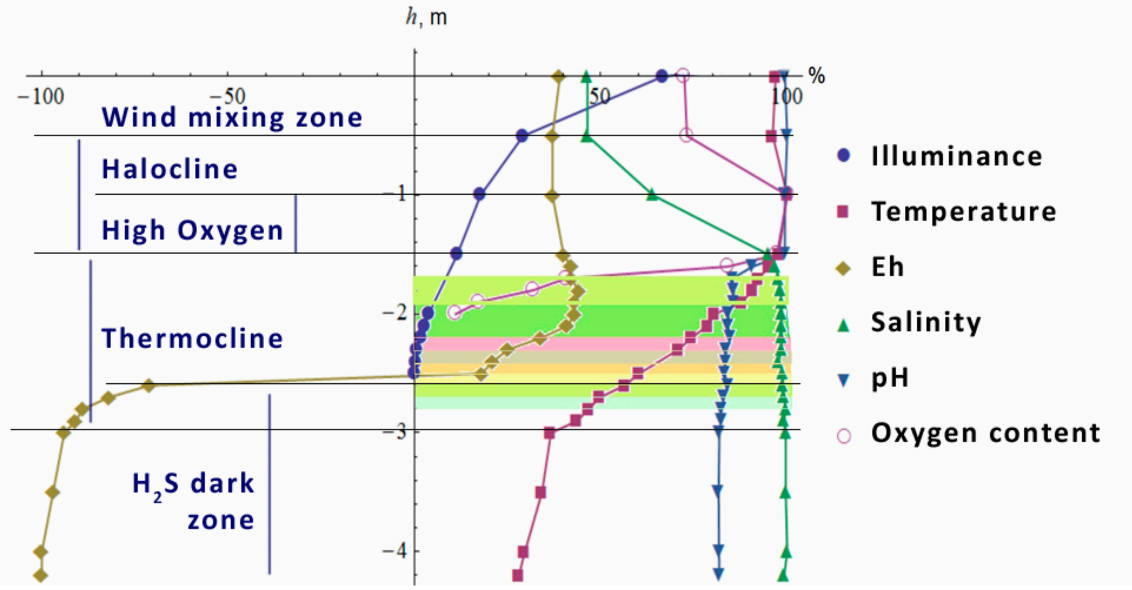

Figure 2: Illumination, temperature, salinity, redox potential, acidity and oxygen content normalized at 100%. Locations of coloured layers are shown. The vertical axis corresponds to the water depth in metres. 100% corresponds to the maximum value of each parameter: illuminance – 48000 lx (lux); temperature – 25.7°C; redox potential – 268 mV; salinity – 26,1 psu; acidity – pH 8.69; oxygen content – 13.3 mg/l.

The water is clear and transparent at depths of 0 - 1.7 m, getting greenish below; at 2.2 - 2.4 m, a bright red thin layer is located. Below the red layer, where the hydrogen sulfide concentration starts to increase, the water is yellowish-green.

Hydrological profiles of temperature, salinity and acidity measured at different stations do not differ much (Figure 3).

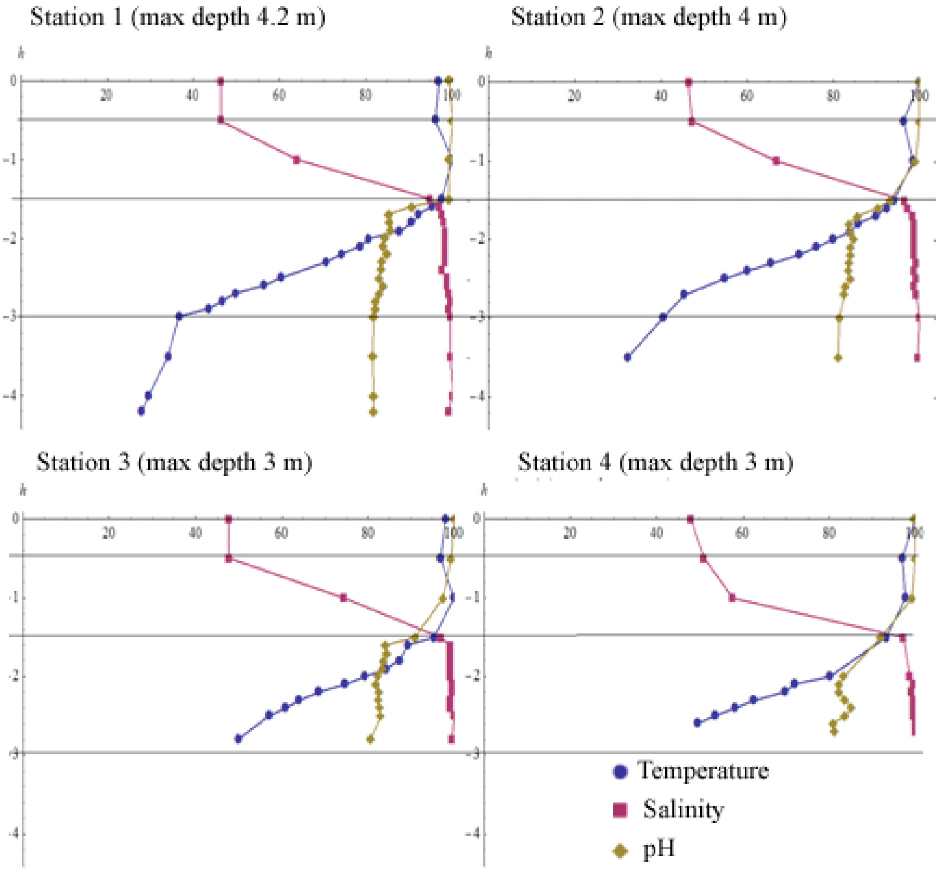

Figure 3: Temperature, salinity and acidity graphs normalized to 100% at 4 hydrological stations in the lake Kislo-Sladkoye. The vertical axis represents depth measured in metres. Horizontal lines separate stable layers which are not changing along the lake: wind mixing zone (0 - 0.5 m); halocline (0.5 - 1.5 m); thermocline (1.5 - 3 m).

Figure 4 shows the illuminance profile comparison of the lake waters and seawater at the nearest marine side. In the lake Kislo-Sladkoye, the euphotic zone ends at a depth of 2.6 m. However, in seawater, the dark zone is not revealed down to 7 m. This difference is due to the high content of suspended matter in the lake water, specifically organics and planktonic organisms.

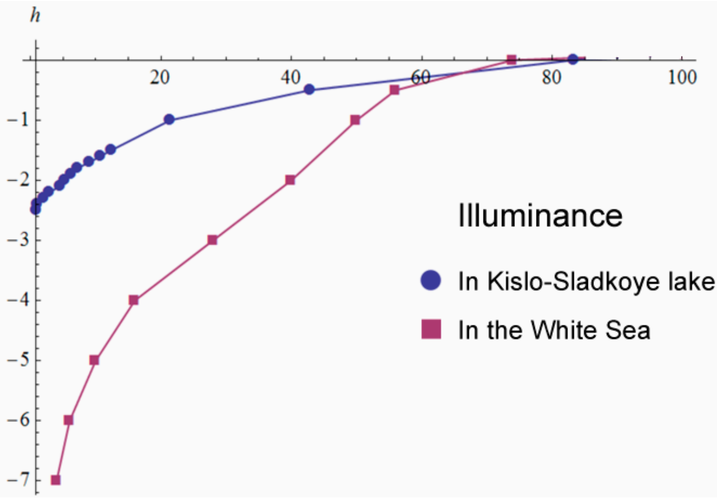

Figure 4: Illuminance profiles in the lake and in seawater normalized at 100%. Vertical axis represents depth measured in metres. 100% corresponds to a maximum value of 48.000 lx in the lake Kislo-Sladkoye and 50.000 lx in seawater.

Spectrophotometry

High amounts of unicellular algae of the genus *Rhodomonas* of crimson colour (fluorescent orange when lit with green light) and green cocci (fluorescent red when lit with green light) were detected. These two groups dominate in the lake phytoplankton. The highest number of *Rhodomonas* individuals was found at 2.2 - 2.4 m depth, i.e., in the bright red water layer. Previously in October 2012, when the redox and hydrosulfuric zones were located deeper in the lake (5), the red layer with *Rhodomonas* cells was registered at 3.5 m.

In the coloured layers, the following pigments were detected using spectrophotometry (Figure 5): Chlorophyll *a* (characterized by maximum light absorbance at 655 - 670 nm), chlorophyll *b* (characterized by a maximum light absorbance at 615 - 630 nm), bacteriochlorophyll *a* (absorbance maximum near 860 nm), bacteriochlorophyll *c* or *g* (very close absorption range near 760 nm), and phycoerythrin (characterized by maximum light absorbance at 575-580 nm).

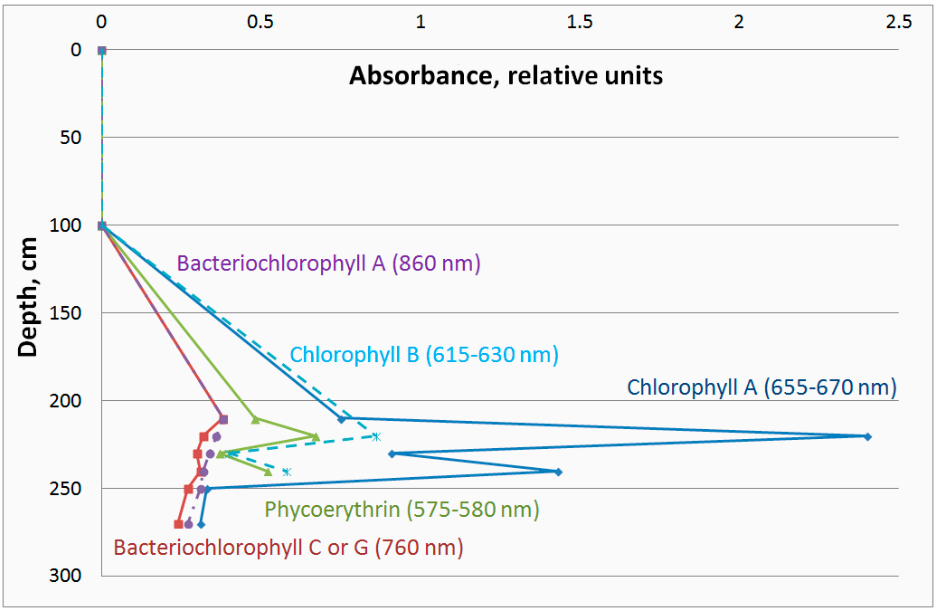

Figure 5: Absorbance peaks showing the vertical pigment distribution in the lake Kislo-Sladkoye.

Spectra from the 0 and 1 m depth samples looked pretty similar to those in clear acetone solutions of corresponding concentrations. Therefore, living organisms in these samples are very rare or absent. For most of the pigments, maximum absorbance was detected at a depth of 2.2 - 2.4 m, since this layer was the most populated (Figure 6).

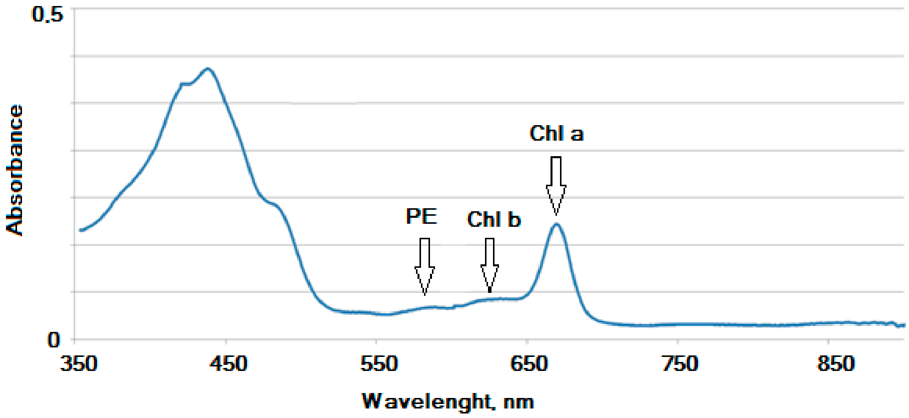

Figure 6: Light absorbance at 2.2 m depth in the lake Kislo-Sladkoye. Arrows indicate absorbance maxima of pigments: PE (phycoerythrin in Rhodomonas cryptophytes cells), Chl b (Chlorophyll b in green coloured cocci), Chl a (in all algae cells).

The pigment composition confirmed the domination of *Rhodomonas* cryptophytes and the presence of cells containing chlorophyll *b*. In the samples from 2.7 m and 4 m, the spectra had the same shape, differing only in their peaks heights. Thus, biodiversity and taxa composition are the same, and only cell density changes with depth.

Spring tide influence

For the first time, a theoretical explanation of changes in the lake Kislo-Sladkoye after spring tide has been given. In order to know the lake depth reached by water coming from the sea during spring tide, we need to know the seawater density and the profile of water density in the lake. From Archimedes' law it follows that seawater will enter the lake at a depth where the water density in the lake is equal to that of seawater. The water density at normal atmospheric pressure depends on temperature and salinity according to the following seawater equation of state:

$$\begin{aligned}\rho(T,S) = {} & 999.842594 + 6.793952\cdot10^{-2}T - 9.09529\cdot10^{-3}T^2 \\ & + 1.001685\cdot10^{-4}T^3 - 1.120083\cdot10^{-6}T^4 + 6.536332\cdot10^{-9}T^5 \\ & + \left(0.824493 - 4.0899\cdot10^{-3}T + 7.6438\cdot10^{-5}T^2 - 8.2647\cdot10^{-7}T^3 + 5.3875\cdot10^{-9}T^4\right)S \\ & - \left(5.72466\cdot10^{-3} - 1.0227\cdot10^{-4}T + 1.6546\cdot10^{-6}T^2\right)S^{3/2} + 4.8314\cdot10^{-4}S^2\end{aligned}$$

where T is the temperature in °C, S is the salinity in psu and ρ is the density in kg/m^3.

Using this equation, the densities of seawater and water from the lake were calculated and the result shows that water from the sea penetrated at a depth of 1.55 m during spring tide on 14.08.2014 (Figure 7).

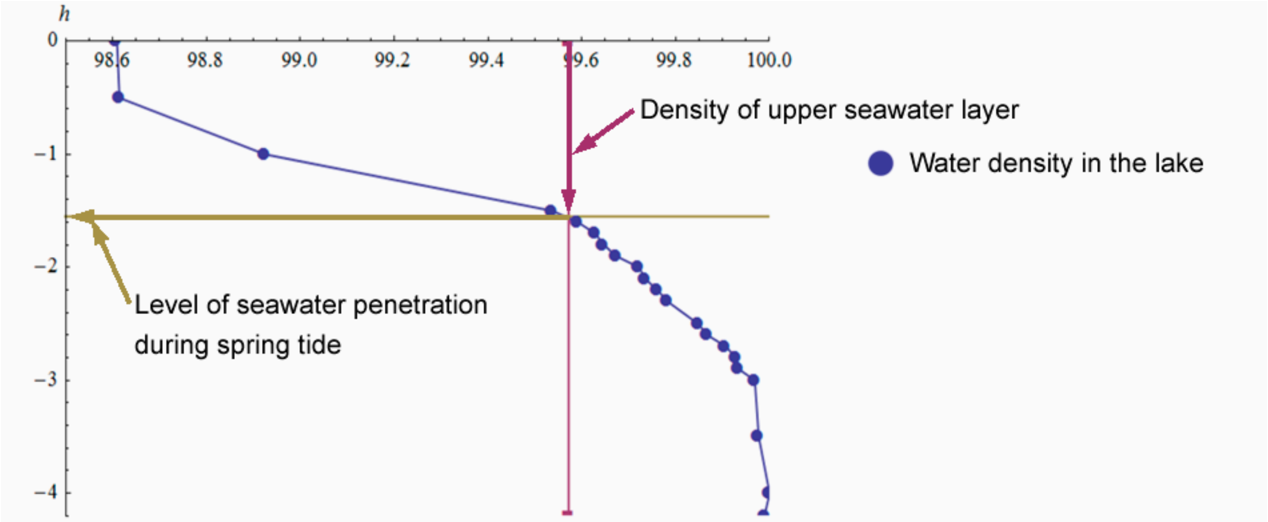

Figure 7: Lake Kislo-Sladkoye water density vertical profile graph normalized at 100% value.

Therefore, seawater cannot mix with coloured layers below 1.7 m in the lake, which has been confirmed by water samples taken after the spring tide. Moreover, Figure 6 postulates that water temperature and salinity should not change at depths below 2 m. Data measured after the high tide confirmed this concept (Figure 8).

The same calculations were done for the situation during the extremely high tide on 18.10.2012. Seawater penetrated at a depth of 3.45 m (Figure 9) and did not blur the red layer (3.5 - 4 m at that time), which was confirmed by water samples taken in the lake.

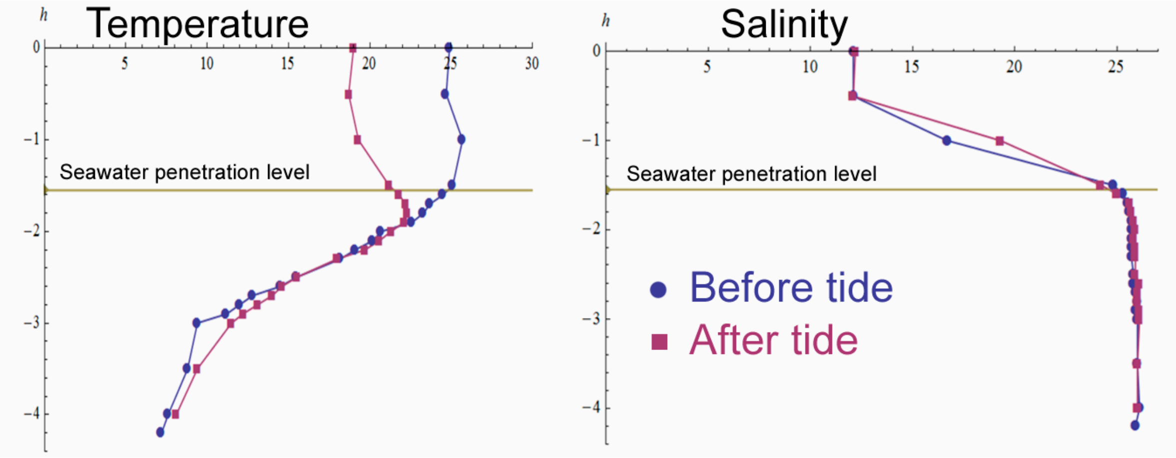

Figure 8: Temperature (°C) and salinity (psu) profiles before and after the spring tide. The horizontal line depicts the seawater penetration level. Both parameters are stable and not influenced by the tide at depths below 2 metres.

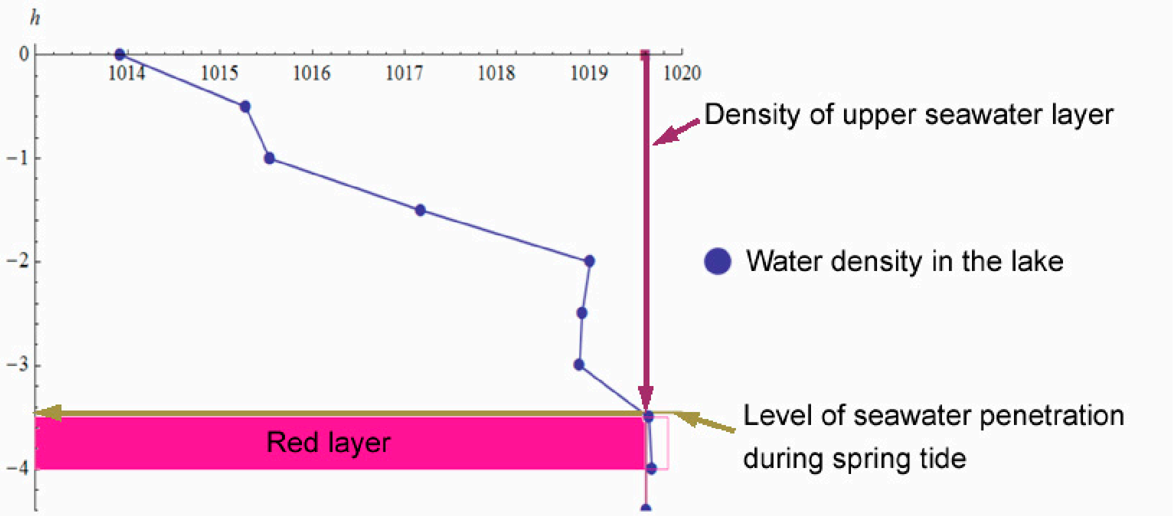

Figure 9: Density profile in the lake water in kg/m^3. The vertical arrow depicts the White Sea water density; the horizontal arrow marks the level of seawater penetration during spring tide. The red layer was located below that line, so it was not affected by seawater.

CONCLUSIONS

The measured parameters do not vary much at the same depths at different positions of the lake. Based on the vertical profile of light, temperature, salinity, redox potential, acidity and oxygen content, five vertical zones were allocated: (1) the wind mixing zone (0 - 0.5 m); (2) the halocline (0.5 - 1.5 m); (3) a layer with high oxygen concentration (1 - 1.5 m); (4) the thermocline (1.5 - 3 m); (5) the hydrosulphuric zone (2.5 m to the bottom). The lower illuminance of the lake water compared with seawater associated with more suspension in the lake might be due to planktonic organisms.

Spectrophotometry data agree with microscopy observations. At 0 and 1 m, the water is clear, phytoplanktonic organisms being scarce; they appeared near 2 m. The *Rhodomonas* maximum is at 2.2 m, slightly less at 2.4 m, and rare below 2.4 m. Below 2.7 m, only few organisms were found.

In the coloured layers, spectrophotometry detected the following pigments: chlorophyll *a* and *b*, bacteriochlorophyll *c* or *g*, and phycoerythrin. Therefore, cryptophyte algae (genus *Rhodomonas*), blue-green algae, and green sulfur bacteria are present. These data correspond with previous results (1). The vertical distribution: at 0 - 1.7 m organisms are scarce; at 1.7 - 2.2 m green cocci containing chlorophyll *b* are present; at 2.2 - 2.4 m the peaks of light absorption spectra correspond to phycoerythrin and chlorophyll *a* and *b* from a large number of cryptophyte algae (genus *Rhodomonas*); at 2.4 - 2.7 m the concentration of pigments declines, one finds a small amount of green cocci with chlorophyll *b* and cryptophyte algae; at 2.7 - 4 m green sulfur bacteria are present.

After the spring tide in August 2014, stratification in the lake did not break. Seawater entered the lake at a depth of 1 - 1.6 m. Both tide-induced changes and cooling did not influence the lake water below 1.6 m. Similarly, the seawater inflow did not affect the coloured layer and the lake water below it in October 2012.

An equation of state for calculating the water density from temperature and salinity data allows us to successfully forecast the qualitative influence that spring tides have on the lake stratification.

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REFERENCES

1 Voronov D A, E D Krasnova, I I Lialin, A V Meschankin, S V Patsaeva, A V Kharcheva, N D Hoi, 2013. Summer Student Practice in the White Sea Biological Station for Research on coastal meromictic reservoirs Kandalaksha Bay, 2013. In: Second International Youth Scientific and Practical Conference of Marine Research and Education, October 28-30 (Lomonosov MSU, Moscow): 219-227

2 Shaporenko S I, 2004. Acidly-sweet lakes near polar circle. Priroda, 11: 23-30 [In Russian]

3 Bruchanov A L, V A Korneeva, T A Kanapatsky, E E Zakharova, E V Men'ko & N V Pimenov, 2009. Biodiversity of sulfate-reducing bacteria in the waters of the Black Sea. In: Abstracts of V youth school-conference with international participationn, Current Aspects of Modern Microbiology (MAKS Press, Moscow) 13-14 [In Russian]

4 Krasnova E D & A N Pantyulin, 2013. Sweet-and-sour lakes, full of wonders. Priroda, 2: 39-48 [In Russian]

5 Krasnova E D, A N Pantyulin, D N Matorin, D A Todorenko, T A Belevich, I A Milyutina & D A Voronov, 2014. Cryptomonad Alga *Rhodomonas* sp. (Cryptophyta, Pyrenomonadaceae) bloom in the redox zone of the basins separating from the White Sea. Microbiology, 83(3): 270-277