The study of coastal meromictic water basins in the Kandalaksha Gulf of the White Sea by spectral and physicochemical methods

Anastasia V. Kharcheva[a], Andrey V. Meschankin[a], Igor I. Lyalin[a],
Elena D. Krasnova[b], Dmitry A. Voronov[c], Svetlana V. Patsaeva[a]
[a]Faculty of Physics, Lomonosov Moscow State University, GSP-1, Leninskie Gory, Moscow, 119991, Russia; [b]Nikolai Pertsov White Sea Biological Station, Biology Department Lomonosov Moscow State University, Poselok Primorskiy, Republic Karelia, Russia; [c]Institute for Information Transmission Problems of the Russian Academy of Sciences (Kharkevich Institute), Bolshoy Karetny per. 19, Moscow, 127994, Russia

ABSTRACT

Research is initiated to study water samples from stratified water basins in the Kandalaksha Gulf of the White Sea at different stages of their separation from the sea. The objects of research are lakes Elovoe and Nizhnee Ershovskoe located close to the Nikolai Pertsov White Sea Biological Station. Depth profiles of physico-chemical characteristics such as temperature, salinity, pH and dissolved oxygen were measured. Brightly colored green water layers were found in both lakes. Concentrations of photosynthetic organisms were estimated using absorption and fluorescence spectra of water samples from various depths.

Keywords: meromictic water body, absorbance, fluorescence, chlorophyll, bacteriochlorophyll, green sulfur bacteria.

1. INTRODUCTION

Shores of the White Sea near the Kandalaksha Gulf are elevating at a rate of about 4 mm per year, resulting in some marine lagoons gradually transforming into lakes.[1] These separating reservoirs are interesting objects to study because of their high degree of water stratification and multi-layer structure; water layers differ not only in temperature, salinity and other physico-chemical characteristics, but also in living micro-organisms, the content of dissolved organic matter and optical properties.

The aim of this research is to study characteristics of water from several stratified water basins in the Kandalaksha Gulf of the White Sea at different stages of their separation from the sea. Depth profiles of physico-chemical characteristics such as temperature, salinity, pH and dissolved oxygen were measured. Concentrations of photosynthetic organisms were estimated using absorption and fluorescence spectra of water samples from various depths.

2. WATER STRATIFICATION IN MEROMICTIC WATER BASINS

2.1. Meromictic lakes

Meromictic water basins are unique nature objects with specific hydrological and physico-chemical conditions strongly affecting their ecosystems. In such reservoirs water layers do not completely mix. The top layer, the mixolimnion, usually spreads for a meter under the surface of the lake, and is exposed to the atmosphere. The mixing of the mixolimnion usually occurs for the majority of the year. The one part of the year where mixolimnions in the northern meromictic lakes do not mix is during the winter when ice is covering the water surface. The bottom layer, the monimolimnion, is cut off from the atmosphere by the mixolimnion. In meromictic salt lakes these two layers are separated by a chemocline. Density is an important physical property of meromictic lakes. The more saline the water, the more dense it is. Therefore, very saline water will stay right above the sediments of meromictic lakes. The gradient in

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salinity is the reason for the chemocline. This varying in density throughout the meromictic lakes, especially in summer, is what controls most of the chemical processes within the lake.

Typical small separating basins in the Kandalaksha Gulf have almost fresh water in the mixolimnion due to rainwater, springs or runoff from bogs, and monimolimnion's water with salinity close to marine water in the White Sea. The intermediate layer, a chemocline, contains water with salinity increasing with depth. Chemocline occurs where local conditions favor the formations of deep water deficient in oxygen, where only anaerobic forms of life can exist.

Aerobic life is restricted to the region above the chemocline. The mixolimnion, can be home for numerous microbial communities that are present in freshwater lakes. These include various types of freshwater algae, aerobic bacteria and archaea.

Photosynthetic forms of anaerobic bacteria, like green and purple sulfur bacteria[1-3], cluster at the chemocline[4], taking advantage of both the sunlight from above and the hydrogen sulfide produced by the anaerobic bacteria below.

2.2. Sulfur photosynthetic bacteria

Relatively large group of organisms exist in nature, which carry out photosynthesis under anaerobic conditions, while oxidizing the sulfur compounds or many organic compounds.[5] The green sulfur bacteria are strictly anaerobic organisms whose efficient excitation energy transfer to the reaction centre occurs only in the absence of oxygen.[6]

The scientific interest to anoxygenic bacteria is due to their simple molecular structure and variety of their photosystems, which makes them good models for biochemical and biophysical study of photosynthetic mechanisms.[7]

Light-harvesting complexes, reaction centers, and the components of the electron transport chain are located in intracellular membrane systems of species-specific architecture. Under aerobic conditions, the excited states of antenna pigments are rapidly quenched, both in whole cells and isolated chlorosomes. Sulfur photosynthetic bacteria on the inner side of the cytoplasmic membrane contain chlorosomes. It is the largest photosynthetic light-harvesting antenna complexes.[8] All photosynthetic bacteria contain chlorophyll (Chl) and its close analog bacteriochlorophyll (BChl). Chlorosomes of green sulfur bacteria are filled with BChl aggregates with the number of monomeric molecules about 250000. Green sulfur bacteria contain mostly BChl *b*, *c* or *d* pigments.[9] In their cells there are located also Chl *a,* BChl *a,* carotenoids, lipids and proteins.

2.3. Spectral properties of chlorophyll and bacteriochlorophyll

In nature, photosynthetic bacteria evolve under cover of algae and higher plants, in the area of anaerobic medium and reduced light intensity. Their pigment system absorbs reduced light energy, which has passed algae and higher plants. Features of bacterial photosynthesis or existence of different kinds of bacteria can be provided by analysis of absorption spectra. Comparison of the wavelengths of absorption maxima for photosynthetic bacteria and higher plants shows that the distance between the absorption peaks of the first is more than that of the second. The absorption spectra of green sulfur bacteria are dominated by the BChl oligomers contained in chlorosomes. The chlorosomes of green sulfur bacteria contain Chl *a*, which has an absorption band in the blue (400-450 nm) and red (650-670 nm) spectral regions, as well as BChl *a*, *c*, *d* and *e*, having a characteristic absorption spectrum with maxima in the long-region 790-1040 nm. Chlorophyll *a* fluorescence spectra have two wide maxima at 675-685 and 730-740 nm wavelength. Fluorescence quenching that is dependent on the presence of oxygen or other oxidants and associated changes in redox potential have been observed in whole cells.[10]

3. OBJECTS AND METHODS

3.1. Objects of research

The work is devoted to the research of two lakes – Elovoe and Nizhnee Ershovskoe (Figure 1) - located in the vicinity of the Nikolai Pertsov White Sea Biological Station, belonging to the Biological Department of Lomonosov Moscow State University. The work was performed during an expedition to the White Sea in July 2013.

The maximal water depth is 3 m in the Lake N. Ershovskoe and 5 m in the Lake Elovoe. Both lakes are separated from the White Sea by low dam of soil and stones, so that the sea tides do not enter them. Due to runoff from the watershed and from bog-water streams flowing into lakes, the upper water layer in both lakes is almost fresh, and in the bottom recesses residual salt or brackish water.

Figure 1. Photos of lakes N.Ershovskoe (left) and Elovoe (right) made during expedition in July 2013.

3.2. Physico-chemical characteristics of water

All physico-chemical characteristics such as temperature, salinity, pH and concentration of dissolved oxygen were registered during water sampling. Temperature and salinity were measured with the conductometer, pH was measured with the pH-meter Mettler Toledo. Concentration of dissolved oxygen was measured with the use of a modified submersible oxymeter.

3.3. Water sampling and storage

A rowing boat was used for transportation, as it didn't mix different water layers as hard as motor boat did. Water samples were taken using a submersible pump from each 0.5 m until highly pigmented green water layer was found, then every 0.1 m. Water samples were stored in sealed bottles in refrigerator until spectral measurements.

3.4. Absorption and fluorescence measurements

All spectral measurements were performed in laboratory conditions. Absorption spectra were measured with the use of Unico spectrophotometer in the optical range 200-1100 nm. Measurements were done using a standard quartz quvette with a pathlength of 10 mm. Fluorescence spectra were measured with the use of Solar CM2203 luminescence spectrometer. Fluorescence emission spectra were registered with excitation wavelength of 270, 310, 390 and 440 nm.

4. RESULTS AND DISCUSSION

4.1. Depth profiles of water characteristics

Water temperature in the Lake N. Ershovskoe decreases from 16.8 ^{o}C at the surface to 15.4 ^{o}C at 1.5 m depth, then increases to 17.8 ^{o}C at the depth of 2.2 m, and finally decreases to 16.8 ^{o}C at the bottom. In the Lake Elovoe water temperature increases from 16.9 ^{o}C at the surface to 19.8 ^{o}C at the depth of 2 m and then rapidly decreases to 8.1 ^{o}C at the bottom.

Both lakes have fresh surface water. Then salinity is increasing with depth starting from 1 m in the case of N. Ershovskoe and from 1.5 m in the case of Elovoe. In Lake N. Ershovskoe salinity near the bottom was 7.7% at the time of the survey; in the lake Elovoe in the bottom layer salinity was 24.5%, similar to marine water in the Kandalaksha Gulf of the White Sea

Concentration of dissolved oxygen was constant for both lakes in the upper layers and equal to nearly 10.0 mg/ml. Then it strongly increases to 27.5 mg/ml at the depth 2.1 m for the Lake N. Ershovskoe and to 20.2 mg/ml at the depth 1.5 m for Lake Elovoe.

Bottom water masses of both lakes contain hydrogen sulfide. In the lake N. Ershovskoe the upper limit of its appearance was at the depth of 2.5 m in the Elovoe – 2.9 m.

In the chemocline area we discovered a green layer in both lakes. In the Lake N. Ershovskoe highly pigmented water layer was located at a depth of 2.5 m, its color was dull green and water had a smell of hydrogen sulfide. In the lake Elovoe a layer of bright green water at the depth of 2.7-3.0 m just above the distribution of hydrogen sulfide.

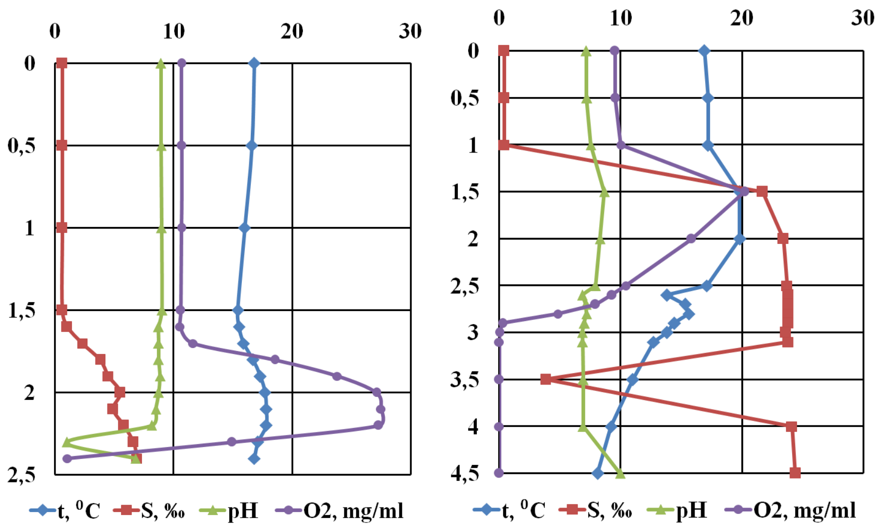

Figure 2. The depth profiles of water characteristics (temperature, salinity, pH, dissolved oxygen) in the lakes N.Ershovskoe (left) and Elovoe (right).

4.2. Absorption spectra of water layer with high pigmentation

Absorption spectra were registered for all selected water samples. Maximum at the wavelength 720-725 nm was obtained for water samples from N. Ershovskoe from the depth 2.3 m and deeper layers, even for the green layer (2.5). In the Lake Elovoe equal peaks appeared at the depth of 2.5 m. The most intensive maximum was at 3 m depth for green water. This is the indicator of presence of green sulfur bacteria. The intensity of the peak is proportional to the concentration of Bchl of green bacteria in the water.

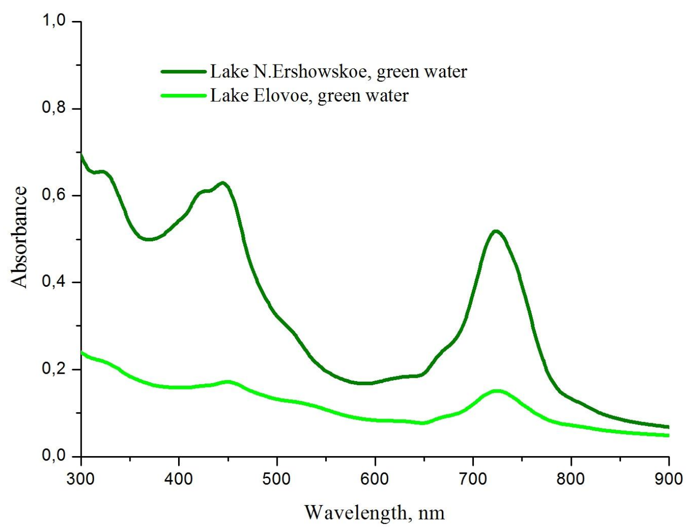

Figure 3.Absorption spectra for green-colored water layers from lakes Elovoe (depth 3 m) and N.Ershovskoe (depth 2.5 m).

4.3. Fluorescence spectra of water layer with green sulfur bacteria

Fluorescence spectra have an emission band with a maximum at 765 nm (lake N. Ershovskoe) and two bands of approximately equal intensity at 752 and 820 nm (lake Elovoe). These emission bands also indicate the presence of green sulfur bacteria the concentration of which in different layers can be determined by the height of the corresponding peaks in the absorption or fluorescence spectra.

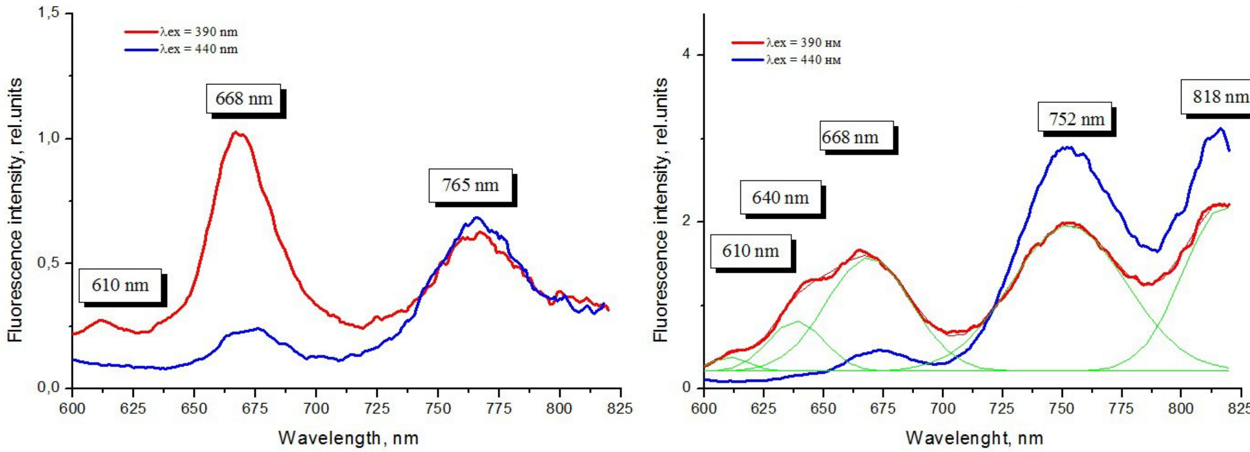

Figure 4. Fluorescence spectra for green-colored water layers: left – Lake N.Ershovskoe (depth 2.5 m), right – Lake Elovoe (depth 3 m).

5. CONCLUSIONS

The research was aimed to study characteristics of water in two lakes not long ago separated from the Kandalaksha Gulf of the White Sea. We received depth profiles of temperature and salinity which are very typical for meromictic lakes with non-mixing water layers. It was found that the intermediate chemocline was the warmest water layer in both lakes during our studies in July 2013. It contained high concentration of dissolved oxygen caused by active microbial photosynthesis.

Brightly colored green water layers with thickness of 10-30 cm were found in both lakes. In Lake N. Ershovskoe with maximal depth 3 m it was located at the depth of 2.5 m, had a dull green color and a smell of hydrogen sulfide. In the Lake Elovoe with maximal depth of 5 m the layer of intensive green water was found at the depth of 2.7-3.0 m, just above the distribution of hydrogen sulfide.

The absorption spectra of layers with an intense green coloring showed a band with maximum at 720-725 nm, indicating the presence of green sulfur bacteria. Fluorescence spectra demonstrated emission with a peak at 765 nm (N. Ershovskoe) or two bands at 752 and 820 nm (Lake Elovoe). These emission bands as well point out at the existence of green sulfur bacteria.

Concentrations of photosynthetic organisms (algae and green sulfur bacteria) were estimated using absorption and fluorescence spectra (Chl and Bchl peaks) for water samples from various depths. Depth profiles of phytoplankton and bacteria concentrations were consistent with oxygen distribution in water: maximal concentration of phytoplankton correlated on the slope of oxygen concentration peak, while green sulfur bacteria were found at maximal concentration just at the top of the anoxic layer.

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REFERENCES

[1] Gorlenko V. M., Dubinina G. A., Kuznetsov S. I. ”The ecology of aquatic micro-organisms”. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 252 pages (1983).

[2] Puchkova N. N., Imhoff J. F., Gorlenko V. M., “Thiocapsa litoralis sp. nov., a new purple sulfur bacterium from microbial mats from the White Sea”. Int. J. Syst. Evol. Microbiol. 50 (4), 1441-1447 (2000).

[3] “Anoxygenic Photosynthetic Bacteria”. Editors: Robert E. Blankenship, Michael T. Madigan, Carl E. Bauer. Springer (2004).

[4] Overmann J., JBeatty. T., Krouse H. R., Hall K. J., “The sulfur cycle in the chemocline of a meromictic salt lake,” Limnol. Oceanogr. 41 (1), 146-156 (1996).

[5] Dworkin M., Falkow S., Rosenberg E., Schleifer K.l-H., Stackebrandt E., “The Family Chlorobiaceae,” The Procaryotes. 7, 359-378 (2006).

[6] Alster J., Zupcanova A., Vacha F., Psencik J. “Effect of quinines on formation and properties of bacteriochlorophyll *c* aggregates”, Photosynth Res. Vol. 95, p. 183-189 (2008).

[7] Tamiaki H., Komada J., Kunieda M., Fukai K., Yoshitomi T., Harada J., Mizoguchi T., “In vitro synthesis and characterization of bacteriochlorophyll-f and its absence in bacteriochlorophyll-e producting organisms,” Photosynth. Res. 107, 133-138 (2011).

[8] Adams P.G., Cadby A.J., Robinson B., Tsukatati Y., Tank M., Wen J., Blankenship R.E., Bryant D.A., Hunter C.N. “Comparison of the physical characteristics of chlorosomes from three different phyla of green phototrophic bacteria”, Biochimica et Biophysics Acta. Vol. 1827, p. 1235-1244 (2013).

[9] Olson J.M. “Chlorophyll Organization and Function in Green Photosynthetic Bacteria”, Photochemistry and Photobiology. Vol. 67(1), p. 61-75 (1998).

[10] Hohmann-Marriott M.F., Blankenship R.E. “Variable fluorescence in green sulfur bacteria”, Biochimica et Biophysica Acta. Vol. 1767, p. 106-113 (2007).