ISSN 1573-160X, *PHYSICAL OCEANOGRAPHY*, Vol. 30, Iss. 4, pp. 468-483 (2023)
Original Russian Text © The Authors, 2023,
published in *Morskoy Gidrofizicheskiy Zhurnal*, 2023, Vol. 39, Iss. 4, pp. 512–527.

Original article

Results of Expeditionary Studies of the Onezhskiy Bay in the White Sea in September, 2019

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Abstract
Purpose. The purpose of the study consists in identifying the characteristic features of the distribution of hydrophysical and biogeochemical parameters of marine environment depending on the tide phases in the Onezhskiy Bay (the White Sea) in September.
Methods and Results. In the cruise of the R/V «Ekolog» (September 6–11, 2019), synchronous integrated hydrological and biogeochemical studies were for the first time performed in the Onezhskiy Bay depending on the phase of a tidal cycle in September. The standard methods applied for this purpose included two sections in the White Sea, namely along the Western Solovetskaya Salma Strait and through the Onezhskiy Bay from north to south. This permitted to determine the chlorophyll *a* and nutrients contents, the taxonomic composition, abundance and biomass of phytoplankton including its vertical distribution within the photic zone, as well as the qualitative and quantitative composition of zooplankton. Organic forms of nitrogen (0.62–0.83 mg/l) prevailed among the nutrients in the Onezhskiy Bay, the contents of P_{min} and P_{org} were close (on average 9 μg/l), the concentration of phosphorus mineral forms was predominant in the water bottom layer at the deep-sea stations. In the Western Solovetskaya Salma, the phytoplankton biomass average values during high and low water were 6.75 ± 1.18 mg C/m^3 and 10.25 ± 11.34 mg C/m^3, and in the Onezhskiy Bay – 8.07 ± 2.43 mg C/m^3 and 16.61 ± 13.54 mg C/m^3, respectively. Phytoplankton was represented by diatoms, dinophytes, cryptophytes and dictyochas. In the southern part of the Onezhskiy Bay, a significant increase in the abundance of all common zooplankton species was found at night.
Conclusions. In the area under study, the impact of the tidal cycle phases on spatial and temporal variability of the marine environment characteristics was manifested in a change in the thickness of the layer of temperature and salinity surface anomalies; position of the Onezhskiy frontal section shifted by 8–9 km; the changes in the nitrites, ammonium ions and chlorophyll *a* concentrations, and also in the phytoplankton biomass were statistically insignificant; the composition of dominant phytoplankton species did not change; the horizontal distribution of zooplankton, primarily its warm-forms, corresponded to the water temperature horizontal gradient: in the southern part of the Onezhskiy Bay, the abundance of boreal species is by orders of magnitude higher than that near the boundary with the basin.

Keywords: White Sea, Onezhskiy Bay, comprehensive research, nutrients, chlorophyll *a*, phytoplankton, zooplankton

Acknowledgements: The study was carried out within the state assignment "Comprehensive research of the White Sea and the watershed in the interests of the development of the Arctic zone of the Russian Federation" No. 121021700122-7 and the Development program of the Interdisciplinary Scientific and Educational School of the M. V. Lomonosov Moscow State University "The future of the planet and global environmental changes". The authors are grateful to the expedition members Nikishova E. P., Ph.D. (Geogr.) Konik A. A. and Ph.D. (Geogr.) Svergun E. I., as well as the crew of the R/V “Ecolog”.

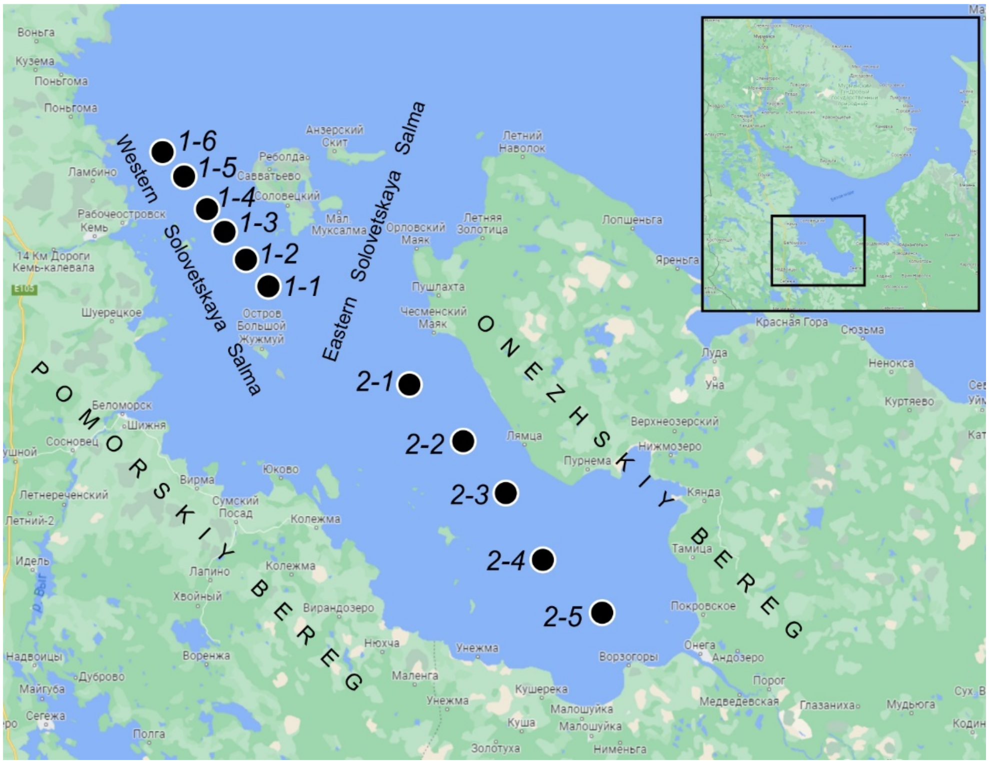
For citation: Tolstikov, A.V., Galakhina, N.E., Belevich, T.A., Usov, N.V. and Zdorovennov, R.E., 2023. Results of Expeditionary Studies of the Onezhskiy Bay in the White Sea in September, 2019. *Physical Oceanography*, 30(4), pp. 468-483.

Introduction

Regular seasonal integrated studies play an important role in studying patterns and forecasting physical, chemical, and biological processes in the White Sea based on observational and modeling data, as well as in assessing the transformation of ecosystems under the effect of climatic and anthropogenic changes. Expeditions to the White Sea have been carried out by the Northern Water Problems Institute of the Karelian Research Centre of RAS, together with several organizations (Shirshov Institute of Oceanology of RAS, Lomonosov Moscow State University, ZIN RAS, etc.) for about two decades. These works are focused primarily on obtaining information about the distribution of hydrological parameters, as well as functioning of marine ecosystems and the impact of abiotic and anthropogenic factors on them. The fulfillment of this task includes carrying out regular seasonal studies in one of the White Sea areas. For many years, the Onezhskiy Bay of the White Sea has been studied as the most logistically convenient in the warm period of the year. However, in past years, field works in this region were occasionally carried out in autumn, as, for example, in 2002 [1], when some of the authors of this paper took part in the expedition. Then the research purposed at studying suspended matter, and most of the stations were concentrated in the mouth areas of rivers. In 2017, only hydrophysical work using CTD-probes was carried out and chlorophyll *a* concentrations were determined [2]. In 2019, comprehensive expeditionary studies of the Onezhskiy Bay open part were carried out for the first time in September. The purpose of this work was to identify the characteristic features of distribution of hydrophysical and biogeochemical parameters of the marine environment depending on the tide phases in the Onezhskiy Bay of the White Sea in September.

The Onezhskiy Bay is a shallow area of the White Sea (only the Mezenskaya Bay is shallower) with depths in most of it less than 40 m, subject to vertical mixing in all seasons of the year due to morphometric features and tidal dynamics [3]. Water stratification is pronounced in the northern part of the Onezhskiy Bay in summer, as well as in the straits of the Western and Eastern Solovetskaya Salma (Fig. 1).

In the north, in the area of the Solovetsky Islands, a frontal zone [4], which prevents free water exchange between the Onezhskiy Bay and the Basin (a deep-sea region located northward of the Solovetsky Islands), is situated. In the southern part of the bay there is a frontal zone, which exists due to the Onega River runoff, the third largest river in the catchment of the White Sea after the Northern Dvina and the Mezen. For about half a year, most of the Onezhskiy Bay is covered with ice, mainly drifting hummocked ice, but fast ice covers significant area.



F i g. 1. Location of stations in the Western Solovetskaya Salma (section *1* – stations *1-1* – *1-6*) and the Onezhskiy Bay (section *2* – stations *2-1* – *2-5*). The inset shows the area under study in the White Sea

The morphometric features of the Onezhskiy Bay southeastern coast contribute to the active retention of matter for several months (the so-called “hydrodynamic trap”) [5]. There are shallow depths (less than 20 m) here and a lot of islands. The Pomorskiy Bereg is more indented than the Onezhskiy Bereg, along which a powerful northward discharge current flow.

Materials and methods

The comprehensive studies at two sections, in the Western Solovetskaya Salma Strait (section *1*) and in the Onezhskiy Bay from north to south (section *2*) (Fig. 1), were carried out on September 6–11, 2019 during the cruise of R/V “Ekolog”. Synchronous measurements of hydrological characteristics (temperature, salinity) were carried out; biogeochemical parameters (content of chlorophyll *a* (Chl), nutrients – mineral and organic forms of nitrogen and phosphorus), oxygen concentration were determined; the taxonomic composition, abundance and biomass of phytoplankton (PP), including vertical distribution within the photic zone, as well as the zooplankton taxonomic composition and abundance, were studied.

The hydrophysical measurements were carried out using the probes CTD90M Sea&Sun Technology (Germany), CTD RBRconcerto (Canada), CTD CastAway (USA), which were used to obtain the vertical distribution profiles of temperature, salinity, turbidity, Chl at all stations, and at majority of them – of dissolved oxygen content.

The hydrochemical studies were carried out at separate stations (*1-1*, *1-4*, *1-6*, *2-1*, *2-3*, *2-5*), where water samples were taken separately in the high tide phase and in the low tide phase from the surface and bottom horizons. Determination of ammonium ions [1], nitrites [2] and mineral phosphorus (P_{min}) [3] was carried out directly in the R/V laboratory, while the tests of nitrates [4], total nitrogen (N_{total}) [5] and total phosphorus (P_{total}) [6] were carried out after the expedition in the stationary Laboratory of Hydrochemistry and Hydrogeology of the Northern Water Problems Institute of the Karelian Research Centre of RAS.

To assess the species composition and abundance parameters of phytoplankton, as well as to determine the content of Chl and nutrients, water samples were taken with a 5-liter Niskin bottle. The selection of 46 samples for Chl determination was performed at 6 stations. To define the qualitative composition and quantitative characteristics of PP, 138 samples were taken from three or four horizons (surface, above and below the pycnocline, bottom) at the same stations. The Chl concentration was determined fluorimetrically in the acetone extract before and after acidification with an aqueous 1N HCl solution [6] using Trilogy Turner Designs fluorometer (USA). Water samples with the volume of 0.5–1 L were deposited on Whatman GF/F filters under vacuum at 0.3 atm underpressure. After filtration, the filters were dried at room temperature for one to two hours, frozen, and stored in liquid nitrogen for subsequent determination under laboratory conditions. The extraction was carried out with a 90% aqueous solution of acetone during the day. To study the PP,

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[1] RD 52.24.383-2018. *Mass Concentration of Ammonia Nitrogen in Water. Measurement Procedure by the Photometric Method in the Form of Indophenol Blue*. Approved 2018-02-04. Rostov on Don, 47 p. (in Russian).

[2] RD 52.24.518-2008. *Mass Concentration of Nitrites in the Water. Measurement Technique Using Photometric Method with Sulfanilamide and N-(1naphthyl) Ethylenediamine Dihydrochloride*. Approved 2008-01-02. Rostov on Don, 30 p. (in Russian).

[3] RD 52.24.382-2006. *Mass Concentration of Phosphates and Polyphosphates in Waters. Photometric Measurement Technique*. Approved 2006-27-03. Rostov on Don, 28 p. (in Russian).

[4] RD 52.24.523-2009. *Mass Concentration of Nitrates in Waters. Methods for Measuring by Photometric Method with Sulfanilamide and N-(1-naphthyl) Ethylenediamine Dihydrochloride after Reduction in a Cadmium Reducer*. Approved 2009-01-12. Rostov on Don, 34 p. (in Russian).

[5] RD 52.24.532-2016. *Mass Concentration of Total Nitrogen in Water. Measurement Procedure by Spectrophotometric Method with Sample Digestion in a Thermal Reactor*. Approved 2017-10-07. Rostov on Don, 34 p. (in Russian).

[6] RD 52.24.387-2006. *Mass Concentration of Total Phosphorus in Waters. The Method of Measurement Using the Photometric Method after Oxidation with Potassium Persulfate*. Approved 2006-01-04. Rostov on Don, 27 p. (in Russian).

water samples (volume of 1 L) were concentrated by reverse filtration [7] in a chamber equipped with a nuclear membrane filter (developed by the Joint Institute for Nuclear Research, Dubna) with a pore diameter of 2 μm. Concentrated samples were fixed with Lugol's solution and counted under a Micromed 3 light microscope in a 0.05 ml Nageotte chamber at a magnification of $40 \times 10 \times 0.65$. Linear dimensions of the cells were measured with an eyepiece micrometer. Identification was carried out to the lowest possible taxonomic rank using modern marine phytoplankton determinants [8]. The cell volume was calculated based on the volume of the corresponding stereometric figures [7]. The cellular carbon content was calculated from cell volumes using allometric dependences and taking into account systematic affiliation of algae [8]. Probing data were used to determine the depth of the euphotic zone (*Zeu*) (1% PAR). At stations where the probings were not performed, *Zeu* was reconstructed from the regional empirical dependence of the values of the diffuse attenuation coefficient of downward irradiance (*Kd*) on the visibility depth of the Secchi disk [9].

The zooplankton samples were taken at stations *1-6*, *1-1*, *2-3* and *2-5* in different phases of the tidal cycle (low and high tide) using a Jedy net with a mouth diameter of 37 cm and a filter sieve mesh of 100 µm, fixed with formalin (2–4%) and processed by the counting method. The sample volume was adjusted to 200 ml, 3 aliquots of 1 ml were taken from it, where mass forms were counted (> 5–10 individuals per aliquot). Then less numerous animals were counted in the entire sample.

Results and discussion

During the measurement period, the temperature of the upper 10-meter water layer was 9 °C at the most seaward station *1-6*, 10.5 °C – at station *1-1*, 3–14 °C – at station *2-3* and *2-5* (the southernmost station of section *2*). The difference between the surface and bottom temperatures was ~ 3 °C at section *1* and 2.5 °C at section *2*. Therefore, the temperature distribution with some assumption characterizes the situation in the entire water column. These data are qualitatively in good agreement with the values we obtained in September 2017 [2], namely: the temperature fluctuated within the range of 4.5–11.5 °C, salinity – within the range of 24–25.5, depending on the location of the station. The coldest areas of the surface layer were noted in the northern part of the Onezhskiy Bay, the warmest – in the central and southern parts. The vertical temperature distribution in the central part of the bay was characterized by relative homothermy. In the northern

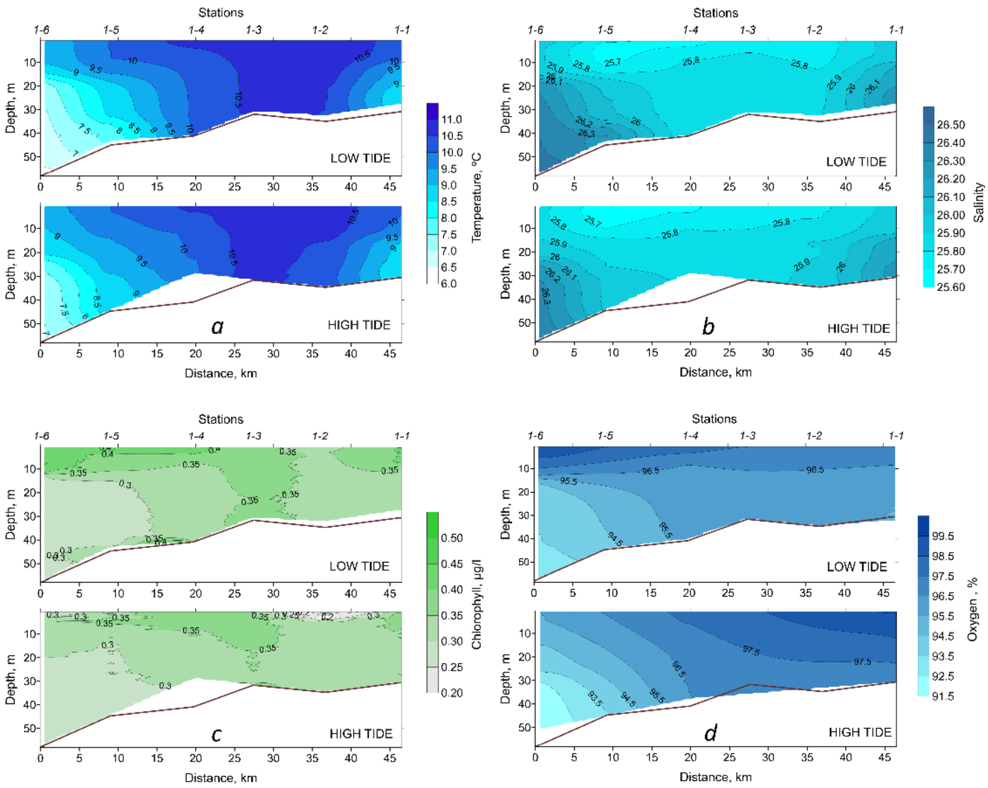
[7] Radchenko, I.G., Kapkov, V.I. and Fedorov, V.D., 2010. [*Practical Manual on Collection and Analysis of Samples of Marine Phytoplankton*]. Moscow: Mordvintsev Press, 60 p. (in Russian).

[8] Horner, R.A., 2010. Marine Phytoplankton. Selected Microphytoplankton Species from the North Sea Around Helgoland and Sylt, Kleine Senckenberg-Reihe 49, M. Hoppenrath, M. Elbrachter, G. Drebes, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany (2009), 264 pp., ISBN: 978-3-510-61392-2. *Harmful Algae*, 9(2), pp. 240-241. doi:10.1016/j.hal.2009.09.004

part of the Western Solovetskaya Salma, the temperature decreased with depth, and at the tip of the Onezhskiy Bay, warm waters near the surface were “covered” with a layer of cold waters.

The maximum salinity in 2019 was registered at stations *1-1* and *1-6* (~ 26 at the surface). The minimum values were observed at stations *2-3* (22 at low tide and 24 at high tide). At stations *2-5*, salinity on the surface was 25 at high tide and at low tide. The differences between the surface and the bottom did not exceed 0.5 at section *1*, at stations *2-3* the salinity gradient was 1 at high tide and 3 at low tide. At stations *2-5*, a complete homogeneity of the water column was observed.

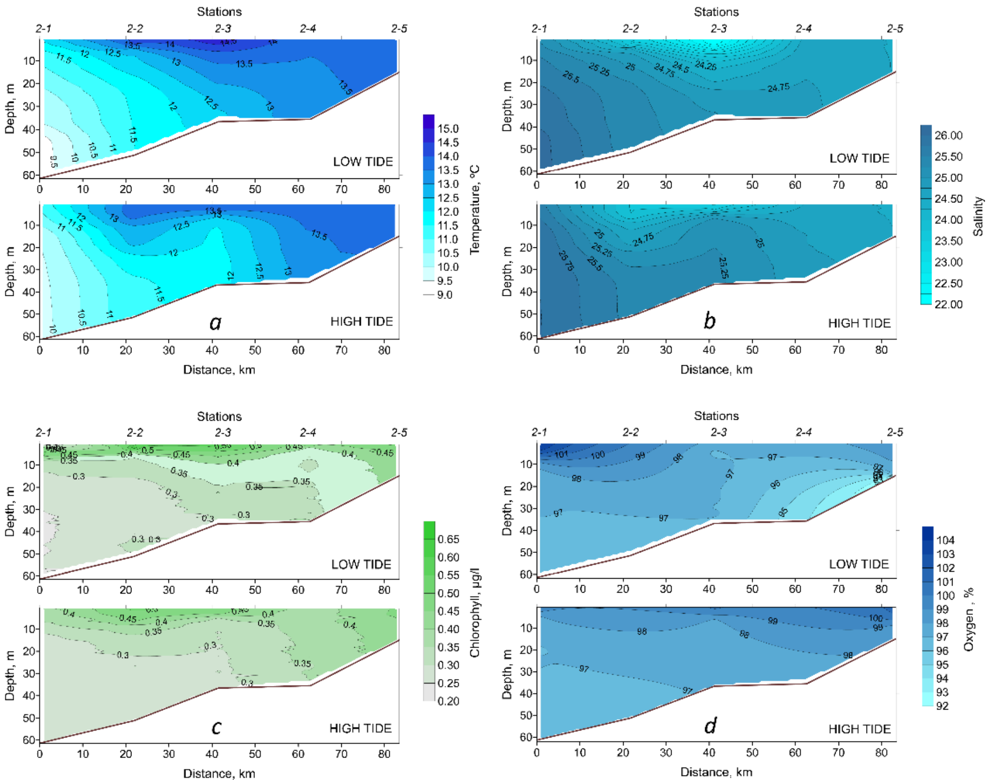
According to the long-term data [3], at the beginning of September, the temperature of the Onezhskiy Bay surface layer is ~ 7 °C, salinity is 26. At this time of year, as a rule, the water in the central part of the bay is well mixed due to the dynamics effect, in the Western and Eastern Solovetskaya Salma (straits from the east and west of the Solovetsky Islands) water stratification is observed, which is most pronounced at the boundary with the Basin (Fig. 2).



F i g. 2. Distribution of temperature (*a*), salinity (*b*), chlorophyll *a* (*c*) and oxygen (*d*) during the phase of high and low tide along section *1*

At section *2* (Fig. 3) in the Onezhskiy Bay, a pronounced inhomogeneity of the water temperature is probably associated with the Onega frontal zone, as indicated by the difference in temperatures between stations *2-1* and *2-2*, which is 2 °C.

The temperature distribution at the section is also subject to strong tidal variability: at stations *2-2*, the temperature anomaly extends to 20 m horizon at high tide, and at low tide the depth of its penetration decreases to 5 m. A similar pattern is observed in the salinity field, which can serve as evidence of the manifestation of the observed heterogeneities due to the hydrological frontal zone effect.



F i g. 3. Distribution of temperature (*a*), salinity (*b*), chlorophyll *a* (*c*) and oxygen (*d*) during the phase of high and low tide along section *2*

In September 2017 [2], in the southern part of the Onezhskiy Bay, freshened (up to 22) surface waters were released in the form of a spatially limited interlayer 5–10 m thick. Under the influence of tidal currents, a significant (8–9 km) position change of the Onega frontal section took place. It should be noted that the dynamics of chlorophyll *a* concentration coincided with the dynamics of salinity.

Nutrients content (NU) in both sections was similar (Table 1). The distribution of nitrogen forms was dominated by organic one, N_{org} concentration varied within the range of 0.62–0.83 mg N/L. A 2-3-fold increase in the nitrate concentration from the surface to the bottom was observed at the deep-water station *1-6*.

This pattern, as a rule, is characteristic of the spring-summer period. The concentration of nitrites and ammonium ions was low and was practically the same in various phases of the tidal cycle. The total phosphorus content in both sections varied within 14–29 µg/L; its maximum concentration was observed at station *2-5* (29 µg/L), which is due to the Onega River effect, and in the surface layer at station *1-1* in the low tide phase (28 µg/L). The ratio of mineral and organic forms of phosphorus was mainly 1:1, with the exception of its mineral form predominance in the bottom water layer at deep-sea stations *1-6* and *2-1* in the high tidal phase and of organic forms at the surface – at stations *1-6* and *1-1*, as well as near the bottom at station *2-5* at low tide.

T a b l e 1

Nutrient concentrations in the Onezhskiy Bay in September 2019

Section number	NH_4^+	NO_2	NO_3	N_{org}	N_{total}	P_{min}	P_{org}
Section *1*	0.009 (0.002) 0.005-0.011	0.002 (0.0004) 0.002-0.003	0.03 (0.02) <0.01-0.08	0.72 (0.06) 0.62-0.83	0.75 (0.06) 0.69-0.86	9 (2) 5-12	9 (4) 5-19
Section *2*	0.008 (0.002) 0.005-0.011	0.001 (0.0005) <0.001-0.002	0.02 (0.01) <0.01-0.03	0.71 (0.06) 0.62-0.81	0.73 (0.05) 0.66-0.84	10 (2) 6-11	9 (3) 6-18

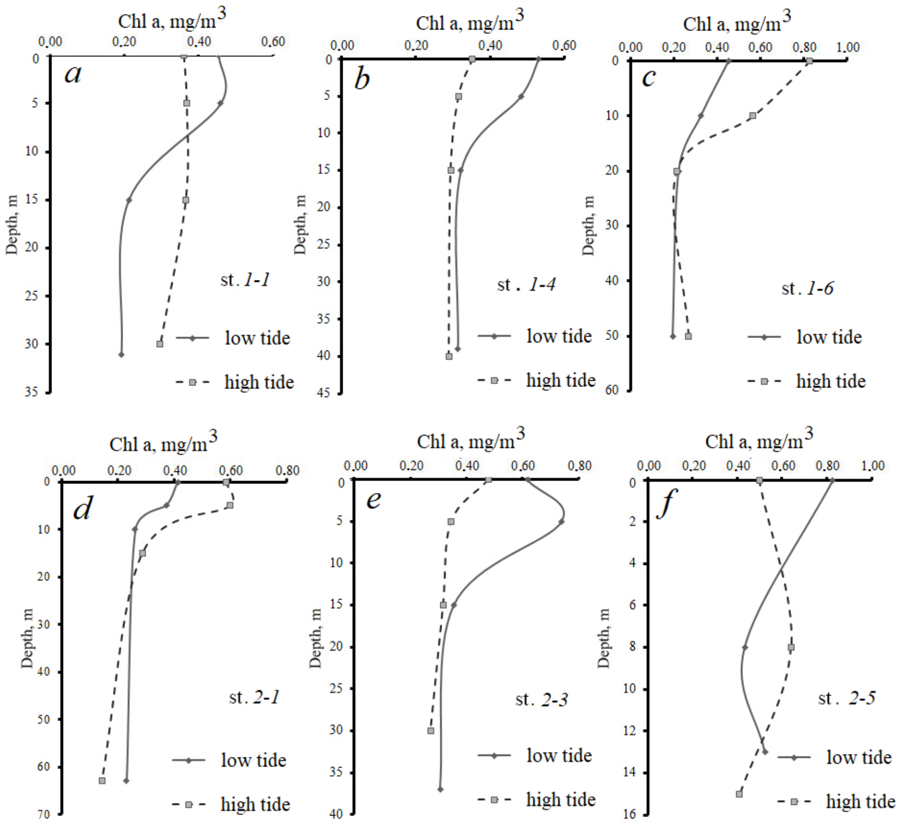
N o t e. The numerator indicates the average values and the standard deviation (in parentheses), the denominator – the fluctuation limits; P_{min} and P_{org} – in µg/l, the other parameters – in mg N/l.

Nutrient concentrations in the Onezhskiy Bay in September 2019

The chlorophyll *a* concentration at the Onezhskiy Bay surface horizon varied within the range of 0.35–0.83 mg/m^3. Its average content in the high and low tide phases was 0.52 ± 0.18 and 0.55 ± 0.15 mg/m^3, respectively, and did not significantly differ statistically (Fig. 4). Chl average content in the photic layer during high and low water was 0.51 ± 0.17 and 0.49 ± 0.04 mg/m^3, respectively; along section *2* – 0.55 ± 0.13 and 0.58 ± 0.13 mg/m^3. In the Western Solovetskaya Salma (section *1*), the highest Chl values were recorded at the surface horizon both in the high and low tide phases. The exception was station *1-1*, where the maximum concentration of Chl (0.46 mg/m^3) was recorded at 5 m horizon during the low tide phase. In the southeastern part of the Onezhskiy Bay (section *2*), the highest Chl value (0.83 mg/m^3) was noted in the surface layer at station *2-5* at low tide.

In 2017 [2], the chlorophyll *a* content in September ranged from 0.34 mg/m^3 at the surface to 0.26 mg/m^3 in the bottom horizon of the Onezhskiy Bay. The maximum Chl values (> 0.5 mg/m^3) were observed in the area of the Onega frontal zone formed by the Onega River runoff. These values are slightly lower compared to the data of 2019, but the dates also differ by almost two weeks: in 2017 – from September 18, in 2019 – from September 6.

The main changes in the concentration of NU in the photic layer are associated with different intensity of production-destruction processes depending on the season: the minimum content of mineral forms of nitrogen and phosphorus is observed in the spring-summer period, while their accumulation occurs in autumn. In September 2019, the surface water layer was still quite warm (Fig. 2, *a*), and eventually the production processes prevailed there (which is confirmed by the data on NU and Chl content), but they were less intense compared to the summer period. For comparison: in the summer of 2007–2011 the concentration of NU mineral forms was lower than in September 2019, and average NO_3^- content was 0.01 mg N/L, P_{min} – 5 µg/L [10]. In the near-bottom layer at deep-sea stations, destruction processes, accompanied by the accumulation of NU mineral forms, predominated.



F i g. 4. Vertical distribution of chlorophyll *a* at the stations of section *1* (*a* – *c*) and section *2* (*d* – *f*) in the Onezhskiy Bay of the White Sea (solid lines – during low tide, dashed lines – during high tide)

In September 2019, phytoplankton was represented by 84 taxa of eukaryotic algae. Diatoms (39 taxa) and dinophytes (32 taxa) were characterized by the highest species abundance. In addition, there were euglena, green, cryptophyte, dictyophyte, chrysophyte algae with the number of taxa in each group not exceeding three. *Ebria tripartita*, an alga of unclear taxonomic position, was also noted. Cyanoprokaryotes, which were found only at station *2-1* below the photic zone, are represented by one genus – *Oscillatoria spp*. In addition, some small-celled forms (3–8 µm) could not be identified even to the highest rank; they were combined into a group of small non-identified algal species (ns).

Along both sections, in the Western Solovetskaya Salma (section *1*) and the Onezhskiy Bay (section *2*), the samples were taken during high and low water to assess the effect of tidal dynamics on phytoplankton abundance. The depth of the photic layer (1% PAR) at the sections varied within 3–10 m. The biomass was relatively low and varied significantly at different stations within the same section (Table 2).

Table 2

Average values of PP biomass (PPB, mg C/m³) and chlorophyll *a* concentration (Chl, mg/m³) in the photic zone, the contribution of dominating species and algae groups to the total biomass (numbers in parentheses, %) during high and low water

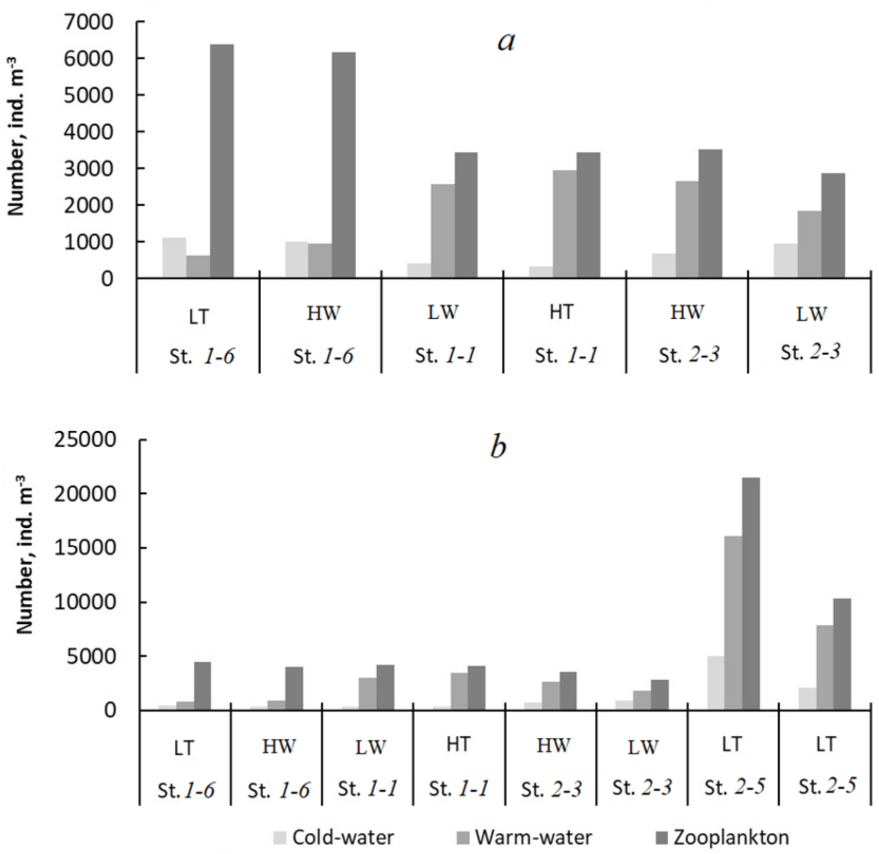
Station number	PPB	Chl	Dominating species and groups	PPB	Chl	Dominating species and groups
	High water			Low water		
Western Solovetskaya Salma						
1-1	7.72	0.42	*Thalassiosira spp.*1 (32)	1.04	0.46	*Thalassiosira spp.*1 (37)
1-4	7.11	0.40	*Heterocapsa rotundata* (12) *Thalassiosira spp.*1 (14)	6.37	0.53	*Heterocapsa rotundata* (14) *Thalassiosira spp.*1 (13)
1-6	5.44	0.70	ns * (20)	23.02	0.49	*Thalassiosira nordensksholdii* (26)
Onezhskiy Bay						
2-1	9.67	0.66	*Thalassiosira spp.*1 (20)	31.97	0.43	*Chaetoceros curvisetus* (22)
2-3	5.27	0.41	ns (17)	11.43	0.68	*Gymnodinium spp.* (20)
2-5	9.27	0.57	cryptophytes (22)	6.42	0.63	cryptophytes (24)

* ns – non-identified species small flagellates.

In the photic layer of the Western Solovetskaya Salma, the average values of PP biomass during high and low water were 6.75 ± 1.18 and 10.25 ± 11.34 mgC/m³, in the Onezhskiy Bay 8.07 ± 2.43 and 16.61 ± 13.54 mgC/m³, respectively. In both sections, the PP biomass in low water was higher than in high water (Fig. 4), but the differences were not statistically significant ($p > 0.05$). The biomass of the communities was dominated by diatoms and dinophytes. The main contribution was made by diatoms of the genera *Thalassiosira* (*T. nordenskioeldii*, *Thalassiosira spp.*), 13–37% of the total PP biomass, and *Chaetoceros* (22%), as well as dinoflagellates represented mainly by *Heterocapsa rotundata* (up to 14%) and *Gymnodinium spp.* (up to 20%).

The complex of dominant species as a whole did not change during different phases of the tidal cycle. The only exception was the southernmost station of section *2* (station *2-5*), which is under the effect of the Onega River runoff, where relatively large (> 10 μm) cryptophyte algae were the dominant groups. Their contribution to the total biomass varied within the range of 13–31% at different horizons.

The mesozooplankton was represented by 16 taxa of species and genus level and 7 higher level taxa (mainly larvae of benthic invertebrates). Copepods dominated the mesozooplankton at all stations both in terms of abundance and number of species. The total number of zooplankton reached the highest values (21500 ind./m^3) at station *2-5* (Fig. 5), located closest to the tip of the bay.

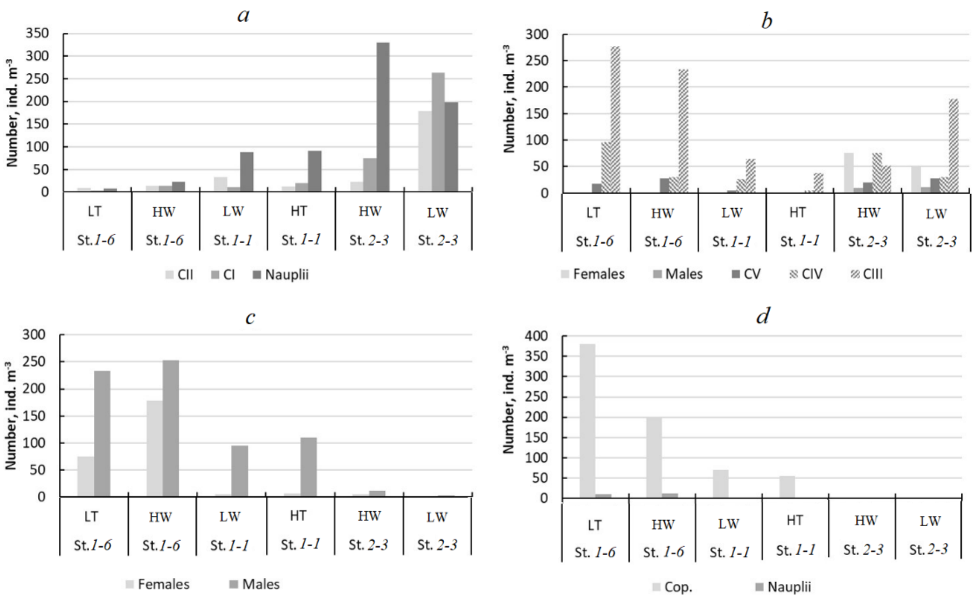


F i g. 5. Distribution and dynamics of the abundance of basic ecological groups and total abundance of zooplankton in the Onezhskiy Bay in the 0–20 m layer (*a*) and in the 0–10 m layer (*b*) (at stations *2-3*, the water layer is 0–30 m). Designations: LT – low tide, HW – high water, LW – low water and HT – high tide

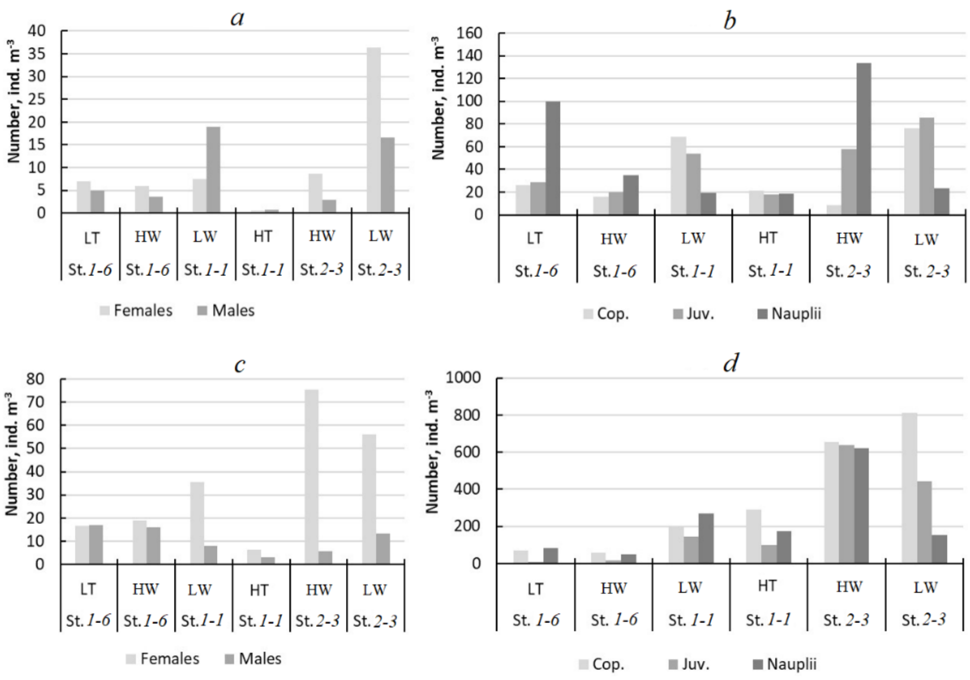
The 0–10 m layer was considered for comparison with station *2-5* in the innermost part of the bay, where samples were taken in the 0–11 m layer. At this station, boreal species and *Pseudocalanus spp.* were present in bulk. All mesozooplankton can be divided into two ecological groups in relation to temperature – cold-water and warm-water [11]. The belonging of particular species to one group or another will help to explain its distribution in the bay and its population dynamics. The cold-water group includes arctic species *Calanus glacialis* and *Metridia longa*, boreal-arctic species *Pseudocalanus spp.*, *Triconia borealis* and

Parasagitta elegans. Warm-water organisms are represented by boreal copepods *Temora longicornis*, *Centropages hamatus*, *Acartia longiremis,* cladocerans *Evadne nordmanni*, *Podon leuckarti* and *Pleopis polyphaemoides,* appendicularians *Fritillaria borealis,* and a cosmopolitan *Microsetella norvegica* (*Copepoda*). High abundance of cold-water organisms was noted both at the boundary with the Basin and in the southern part of section *2* (station *2-5*), and only species of the genus *Pseudocalanus* (97–100% of the group abundance) were found among cold-water organisms here. Warm-water species are most numerous at station *2-5* (16000 ind./m^3, or 75% of zooplankton), they are the fewest at the seaward station *1-6* (840 ind./m^3 in the 0–10 m layer). This distribution of groups is consistent with the horizontal distribution of water temperature.

Fig. 6 and 7 demonstrate the distribution of cold-water and warm-water forms of zooplankton depending on the tidal cycle phase.



F i g. 6. Distribution and dynamics of cold-water species in the Onezhskiy Bay in the 0–20 m layer: *a*, *b* – *Pseudocalanus spp.*; *c, d* – *Triconia borealis*; *Cop.* – older copepodite stages (CIV-CV) of *Triconia*. See other designations in Fig. 5



F i g. 7. Distribution and dynamics of warm-water species in the Onezhskiy Bay in the 0–20 m layer: *a*, *b* – *Temora longicornis*; *c*, *d* – *Acartia*; *Juv*. – junior copepodite stages (CI-CIII) of *Acartia*. The rest of the designations are in Fig. 5 and 6

Distribution of *Pseudocalanus spp.* depends on the development stage: nauplii and CI-CII gravitate towards the top of the bay, CIII, CIV and CV are numerous at the most seaward (at the exit from the Western Solovetskaya Salma) and the most southern stations, males and females are found in greatest numbers closer to the mouth of the Onega River (females up to 150 ind./m^3, males up to 12 ind./m^3). *Triconia borealis* is a boreal-arctic species, it is mesopelagic in the White Sea [12], during the year it adheres to the intermediate and near-bottom layers of the water column. It is expected that this species is most numerous in the open part of the bay, and *T. borealis* was practically absent in the south (single specimens were noted at station *2-3*, and it was completely absent at station *2-5*). *Acartia spp.* (*A. longiremis* and *A. bifilosa*) and *Temora longicornis* are typical boreal thermophilic species that develop from resting eggs in the warm season [13, 14]. The distribution of these species corresponds to their temperature preferences: they gravitate toward the southern part of the bay, at station *2-5* these species are the most numerous (4–6 thousand ind./m^3 after sunset, during daylight hours ~ 2 thousand ind./m^3). It is difficult to trace regularities in *T. longicornis* distribution due to a significant variation in abundance at different stations in different phases of the tidal cycle. The eurybiont *Oithona similis* demonstrated regularities only in the horizontal distribution: the maximum abundance of this species was noted at the most seaward point, it decreased towards the top of the bay.

Conclusion

1. For the first time, comprehensive expeditionary studies of the open part of the Onezhskiy Bay of the White Sea were carried out at the beginning of the autumn period in order to identify the distribution features of hydrological, hydrochemical and hydrobiological characteristics under conditions of intense tidal movements and water exchange through the frontal zones of the southern and northern parts of the bay.

2. Of nutrients, organic forms of nitrogen prevailed in the Onezhskiy Bay waters. P_{min} and P_{org} contents were similar, except for the predominance of its mineral forms in the bottom layer at deep-water stations, which indicates the occurrence of destruction processes characteristic of the autumn period. The exception is also organic forms of phosphorus at the surface of some stations as a result of production processes, which is confirmed by the data on the chlorophyll *a* content.

3. The Onezhskiy Bay phytoplankton was represented by diatoms, dinophytes, cryptophytes and dictyochae algae. Dinophytes and diatoms were characterized by the highest species abundance. The algae of the genus *Thalassiosira* and *Heterocapsa rotundata* dominated in the Western Solovetskaya Salma Strait. The southeastern part of the Onezhskiy Bay was dominated by *Chaetoceros curvisetus* and *Thalassiosira spp*.

4. The horizontal distribution of zooplankton, primarily warm-water one, corresponded to the horizontal water temperature gradient: in the Onezhskiy Bay southern part, the abundance of boreal species is orders of magnitude higher than near the boundary with the Basin. Of the cold-water species, only *Triconia borealis* follows the temperature gradient, while the distribution of *Pseudocalanus spp.* differs at different stages, which is associated with age-related changes in temperature preferences. Diurnal migrations of zooplankton were identified at station *2-5*: at night, a significant increase in the abundance of all mass species was noted, which corresponds to a pattern that is also characteristic of other high-latitude seas.

5. It was revealed that the effect of the tidal cycle phases in the study area on the spatial and temporal variability of the marine environment characteristics manifested itself as follows:

– the thickness of the layer of surface temperature and salinity anomalies in the frontal zone of the southern part of the bay varied within 0–15 m;

– the salinity variation in freshened areas was ~ 2;

– the position of the Onega frontal section shifted by 8–9 km;

– the ratio of mineral and organic forms of phosphorus in certain places deviated from the average for the region (1:1);

– variations in the concentration of nitrites, ammonium ions and chlorophyll *a* were statistically insignificant;

– changes in phytoplankton biomass were also statistically insignificant;

– the composition of the dominant phytoplankton species did not change;

– *Temora longicornis* showed a significant change in abundance at different stations and in different phases of the tidal cycle.

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Nikolai V. Usov – materials and methods, results and discussion (section on zooplankton), conclusion

Roman E. Zdorovennov – results and discussion (section on hydrological characteristics)

The authors have read and approved the final manuscript.
The authors declare that they have no conflict of interest.