Features of summer ice-edge bloom in the Barents sea

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Abstract. The paper is devoted to the study of hydrochemical complex and pelagic phytocene in the ice-edge area of the Barents sea during summer. The peak of ice-edge area phytoplankton bloom with a characteristic set of biomass values and complex of dominant species was recorded in the course of the study in the surface layer zone of drifting ice. At the same time in sub-surface horizons diatom transition to the stage of sporulation and mass development of nanoalgae, which is characteristic of seasonal oligotrophy was observed. Based on these data, quite a relevant supposition concerning the intensive development of ice-edge blooming under the solid ice cover off the north of the area studied could be made. To the south of the ice edge area the dominance in the phytoplankton community is shifted: nanoforms occupy a leading position in the community in numbers and biomass compared to microalgae, the composition of the lattest is completely replaced by the summer forms of dinoflagellates. The distribution of silicon and nitrogen consumed in euphotic layer, is fully consistent with the biomass and the number of microphytoplankton – a decrease of these parameters off the north, from the station located in the ice edge towards the south is observed. The maximum depletion of phosphates corresponds well with the area of active proliferation of nanophytoplankton in the southern part of the study area.

1. Introduction.

In terms of global warming the problem of evaluation and prediction of biological productivity of the Arctic seas has become particularly acute. In this respect, the Barents sea represents a unique area, since its waters are partially covered with seasonal ice, its area is naturally shrinking from year to year. As a result the total length of the edge ice zone changes, which is associated with such an ecological phenomenon as near-edge phytoplankton blooming. The share of the latter accounts for 50-65% of the annual primary production in the Barents sea [1]. Despite the magnitude of this phenomenon many of the key issues remain are yet to be solved. This applies not only to the conditions and terms of its beginning, but the period of the process as a whole. Meanwhile, they are the factors that determine the duration of the season of planktonic phytocene vegetation in general, annual primary production and productivity of all parts of the food chain in the Arctic waters [2].

The study of the structure and functioning of a pelagic zone in the area of drifting ice is a complex process both in terms of field work and interpretation of the results. Actually, the ice edge is a hydrodynamically active area occupied with ice fields of different power and cohesion, which greatly complicates, and sometimes makes it impossible to conduct field research in the area. One of the main features of near-edge blooming – high spatial and temporal heterogeneity. The development of phytoplankton depends on the interaction of a number of biotic and abiotic components. The major factor limiting the intensity of production processes in the pelagic zone and determining the spatial
community structure of primary producers (microphytoplankton) is the dynamics of biogenic elements consumption.

Thus, the aim of this study was to examine the hydrochemical parameters and pelagic phytocene in the central part of the Barents sea, including the area of drifting ice.

2. Materials and methods.

The material was obtained in the expedition on R/V "Dal'niye Zelentsy" in July 2017. Samples were taken from the standard horizons (0, 10, 25, 50, 100 m and the bottom). The composition of the hydrochemical complex was examined in the following parameters: dissolved oxygen, pH and dissolved forms of biogenic elements – phosphorus of phosphate, silicon of silicic acid, nitrogen of nitrite and nitrate. The tests and the evaluation of the productivity of the study area were carried out by the methods described in the literature [3], [4], [5].

Samples were taken in the upper 50 m layer for the examining of phytoplankton. Microphytoplankton analysis was carried out according to the standard procedures [6], [7], [8]. For nanophytoplankton water samples with the volume of 25-50 ml were fixed with glutaraldehyde solution (final concentration 0.5%) and concentrated on nuclear filters (Dubna) with a pore diameter of 0.8 µm using a Janet's syringe with a filtration nozzle (diameter 22 mm). After colouring with primulinum [9] filters were studied under epifluorescent microscope "AXIO Imager. D1” at 1000x magnification. The nanoplankton cells were accounted in size fractions from 2 to 20 µm with the resolution of 1 µm (according to the graduation of the eyepiece micrometer). When analyzing the results grouping into three dimensional classes: 2-5 µm, 5-10 µm and 10-20 µm was accomplished. The dimensions of the cell were measured individually using eyepiece micrometer, spherical or spheroidal approximation of the cell shape was applied for the calculation of volumes.

3. Results and discussion

The survey was conducted in the northern part of the section "Kola Meridian“ - from 77° N. lat. directly to the ice edge area (78.7° n) (Fig. 1).

Two main components - nanoalgae with the diameter of cells 2-20 µm and a group of classical planktonic algae larger than 20 µm were examined in the composition of phytoplankton. The scope of changes in the total abundance of phytoplankton species in the studied water area ranged from 246 thousand to 3 million 580 thousand cells/l, however, no patterns in spatial distribution were noted. The maximum value was recorded at depth of 50 m and in the surface horizon regardless to the position of the ice edge. The share of nanofraction in the total community number was 85 – 99% in the main part of the study area with the exception of the layer 0 – 10 m directly in the ice edge (Fig. 2) where its share exceeded 70%, and at 10 m depth decreased to 39%.
Figure 2. Spatial distribution of specific values of a) number and b) biomass of major groups of micro- (green – diatoms, blue – dinoflagellates, purple – yellow-green algae) and nano- (red - 2-5 µm, yellow - 6-10 µm, blue - 11-20 µm) plankton. The arrow indicates the direction from the ice edge to the south.

The trend to the dominance of small cells number remains consistent in a more detailed analysis of nanofraction, where the cells with the largest diameter of 2 µm prevail.

The picture of the spatial arrangement of phytoplankton in the ice-edge zone area becomes complete when considering taxonomic composition of the second component of pelagic phytocene - microalgae. In general, more than 70 species and supra-species taxa of planktonic algae, which, due to their systematic position refer to diatoms (48%) and dinoflagellates (44%) are recorded in the studied area.

The dominance structure in the community is directly determined by the distance to the ice edge: if dinoflagellates are located in the water column evenly, the core of diatom distribution is clearly fixed to the drifting ice area. Indeed, in the upper 5-m layer in the ice edge, 85%-95% of the number of phytoplankton are diatoms - early spring colonial pennate and centric forms of gen. Achnanthes, Chaetoceros, Thalassiosira. Beneath, in the layer of 50m the relative proportion of diatoms decreases to 50% -60% and phytoplankton approximately is equally represented by dinoflagellates and early spring diatoms turning to the stage of sporulation. The described structure is maintained up to the depth of 50 meters, amid dramatic changes in the total abundance of phytoplankton species and a catastrophic decline in general (over 90 times) and specific (56% to 2%) number of microalgae.

Moreover, the predominance of diatoms at the depth of 50 meters mentioned above can be traced at a distance of 40 nautical miles off the south of the ice edge. In the remaining part of the study area, the algae group is represented by microalgae heterotrophic and mixotrophic species (gen. Gymnodinium, Gyrodinium, Protoperidinium).

The analysis of the biomass spatial distribution (Fig. 2) in the surface layer in the area of drifting ice clearly distinguishes the region of the maximum ice-edge blooming of the microalgae, where the absolute biomass values reach 4 – 8.5 mg/l, 80% to 99% of the community is represented by early spring diatoms. Integrated biomass for the layer 0 – 50 m at stations 27, 31, 34 were 1 gC/m², 2.7 gC/m², 65 gC/m²; the ratio of surface biomass to the integral value for the layer 0 – 50m (a measure of blooming intensity in the surface horizon) – 1.1, 0.6 and 2.5, respectively. The decline in biomass in 40 - 50 times is observed at a distance from the active proliferation point both in vertical and in horizontal direction. Besides, at a maximum distance from the ice edge (approximately 80 nautical miles) the dominance transition to nanoplanktonic size fraction was recorded.

Bioproductivity of water was estimated using stoichiometric model of Redfield-Richardson (23:16:1=Si:N:P) [10], and the data on the content of biogenic elements (nitrogen, phosphorus, silicon), accumulated during the winter and utilized by organisms in the vegetative activities. According to the literature data the complete stock of nutrients in the high latitudes is formed in the autumn-winter period. To assess the biological productivity of the water masses before the beginning of vegetation in hydrochemical parameters it is possible to use the calculated concentrations of
biogenic elements (preforms) in the residual cold layer (CL), which is resulted from winter convective mixing. These values can also be used as indicator of waters of different genesis [11], [5], [12].

The interaction of the Arctic water masses on the surface and at depths of the Barents sea determines the complexity of the hydrochemical regime in the study area [13], [14], [15], [16]. The hydrological state of waters varied considerably at separate sites of the studied area. Namely, CL with residual winter water of minimum temperature -1.82°C was at the depth from 15 to 100 m. In most cases its upper border corresponds the horizon of 40 m, except station 34, where the rise of CL to the depth of 15 m was observed. The concentration of mineral phosphorus in CL in the studied area changed from 0.1 µM to 0.25 µM, dissolved silicon - from 1.0 µM to 6.8 µM, the total amount of mineral nitrogen (nitrate and nitrite) ranged 1.2-2.5 µM.

If using the Kivva’s [5] and Arzhanova’s [12] methodical approaches preforms of biogenic elements in the studied area were calculated. The average initial phosphorus concentration of phosphate was approximately 0.13 µM/l, silicon of silicic acid – 3.3 µM, nitrate and nitrite nitrogen – 1.4 µM/l (table. 1). For silicon and nitrogen, the maximum preform concentrations corresponded to station 34 which located at the ice edge. A relative nitrogen deficiency was noted according to the results of calculating the ratios of the biogenic element preforms and their distribution at most stations, (Table 1, Fig. 3), but at stations 35 and 31, certain silicon deficiency was detected as well.

Table 1. The ratio of the estimated concentrations of nutrients in the study area in the photic layer

| № of station | Si/P | Si/N | N/P |
|--------------|------|------|-----|
| 31           | 21.5 | 11.5 | 1.9 |
| 34           | 37.1 | 2.2  | 16.9|
| 35           | 18.6 | 1.3  | 14.8|
| 36           | 34.6 | 2.2  | 15.8|
| 27           | 14.3 | 2.1  | 6.9 |
| Redfield-Richardson ratio | 23   | 1.4  | 16  |

Information about the "initial" amounts of nutrients provides the opportunity to assess the minimal potential primary production (PP) [4, 12]. Based on the mentioned above, the lowest value min PPN equals 78 mg/m³ calculated by the formula of V. V. Sapozhnikov [4] and was noted at station 27. The value minPPs at stations 34 and 36 in average was 256 mg/m³.

Figure 3. Charts of nutrients preform, presumably located in the photic layer before blooming. Trend lines correspond the ratios a) P:N=1:16, b) Si:N=23:16, c) Si:P=23:1.
The products formed on the basis of the winter reserves of nutrients, taking into account the nutrients consumed in the process of respiration in the euphotic layer are well-known and referred to in the literature as net community production (NCP) [17, 5] and provide the opportunity to evaluate biological productivity of the study area. The layer of photosynthesis in the study area in average reached 42 m, while at station 34, it was only 15 m, and at station 27 extends to the depth of 50 m. The average values of the net production of the community for phosphates, silica and nitrates approximate 227, 248 and 272 mg/m³, respectively. The values of NCP NO₃ are higher, and reach maximum values at station 34 (413 mgC/m³) and at station 35 (446 mgC/m³). Net production of the community, calculated for phosphate, is minimal at station 34 - 85 mgC/m³.

Based on the available data, the real primary production (RPP) for the layer of photosynthesis for each nutrient [4] was calculated. The average values were 8, 10, 14 gC/m² for silica acid, phosphates and nitrates, respectively, which correspond the literature data [2].

As the results of the calculations for silicon at stations 34, 31 and 27, the depletion of nutrients in the vegetation layer from the beginning of the blooming period was 33-65%, for phosphorus - 15-65% and for nitrogen – 78-91%. Fig. 4 presents the quantitative characteristics of the phytoplankton at stations 34-27 and the calculation result of the difference between the content of nutrients in the euphotic layer before the process of vegetation, and the measured concentrations at the time of the research (ΔSi, ΔP, AN). The most decline of silicon (ΔSi=1.73 µM) and nitrogen (ΔN=1.73 µM) was observed at station 34, which agrees well with the data obtained for phytoplankton, the abundance and biomass of which at this station is the highest. The maximum depletion of phosphate in the vegetation layer was recorded at station 27, where the maximum quantitative characteristics of nanophytoplankton were detected. The analysis of the data obtained and literature data [12] allows to explain high amount of ΔSi at station 34 by the growth of the biomass and abundance of diatoms. The arguments for this are the following: 1) the regeneration of this element occurs mainly outside the layer of photosynthesis at considerably low rates; 2) at station 34 diatoms were the dominant group - the main consumer of silicon silicic acid in the photosynthesis layer. Unlike silicon, an increase in ΔP in the direction from station 34 to station 27 at this stage cannot be unambiguously explained by the vital activity of nanophytoplankton, mainly due to the high velocity rate of this element. Therefore, this issue is a topic of further studies.

**Figure 4.** Depletion of nutrients (red - ΔN, yellow - ΔP, black - ΔSi; mgC/m³, left axis) in the photic layer during the vegetation season and quantitative characteristics: a) micro-(cells/m³) and b) nanophytoplankton (cells*10³/m³) (green - number, blue – biomass, mgC/m³, right axis)

4. **Conclusion**

Thus, the peak of ice-edge area phytoplankton blooming with a characteristic set of biomass values and complex of dominant species was recorded in July 2017 in the surface layer of the drifting ice area. At the same time in sub-surface horizons (below 10-meter layer) diatom transition to the stage of sporulation and mass development of nanoalgae (more than 3.5 million cells/l), which is characteristic of seasonal oligotrophy was observed. According to the literature [2], if the transition from the peak
blooming of microalgae to the stage of seasonal oligotrophy coincides spatially with the ice edge, the main core of ice-edge blooming could be located northwards – under the solid ice cover.

At the distance of over 40 nautical miles off the south of the ice edge diatoms were completely replaced by the summer forms of the dinoflagellates, the values of total biomass of phytoplankton did not exceed 100-200 µg/l.

The real primary production, calculated according to the concentrations of mineral forms of biogenic elements in the "winter" waters and in the photic layer averaged 11 gC/m².

During the time since the beginning of the vegetation season till the time of the study, the euphotic layer was deprived of 33-65% of silica, 15-65% of phosphorus and 78-91% of nitrogen.

The distribution of silicon and nitrogen consumed in euphotic layer, fully conforms the biomass and the number of microphytoplankton – a decrease of these parameters from the north, from the station located at the ice edge to the south. The maximum depletion of phosphates is well associated with the region of active proliferation of nanophytoplankton in the southern part of the study area.

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