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Monitoring of chlorophyll-a concentration in the ice edge zone of the Barents Sea in 2017-2018

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Abstract. A study of chlorophyll-a concentration of in the water column during the annual succession cycle of the pelagic microfitoplankton was conducted in the vast area of the Barents Sea including the ice edge zone in the west, north and east. The Active "ice edge blooming" of pelagic algocenosis, with chlorophyll concentrations $\geq 5 \text{ mg/m}^3$, was found during the spring period (April-May) in both the western and eastern parts of the Barents Sea. A significant decrease of chlorophyll-a concentration at a distance from the ice edge, the so-called "ice edge effect" gradually fades out at a distance of about 60 miles. The short-term phase of maximum activation in summer is replaced by the stage of seasonal oligotrophy with the deepening of the maximum of chlorophyll and the descent of the blooming core to the horizon of 50 m ($< 2 \text{ mg/m}^3$). With the onset of the winter period, destructive processes dominate in the phytoplankton community of the edge zone. The concentration of chlorophyll does not exceed 0.3 mg/m^3 . The results of the work will contribute to a holistic view of the spatial-temporal dynamics of such a complex and poorly studied phenomenon as "ice edge blooming" in the Barents Sea waters. New data on the concentration of chlorophyll-a in the water column will make possible to estimate production potential not only of the surface horizon but also of the deeper layers of the photic zone.

1. Introduction

The ice edge zone is a unique biotope where two components of primary producers are inextricably linked - the pelagic and ice flora that create the primary organic matter of the Barents Sea. The ice edge zone is one of the most dynamic and productive areas in the oceans, the production of which has not yet been assessed, but its role is great [1]. This is the core of the "spring bloom" of pelagic phytocenosis. In the Barents Sea, ice edge zone bloom accounts for more than 60% of the annual primary production [2]. The ice edge is a hydrodynamically active zone occupied by ice fields, which makes it difficult or impossible to carry out expeditionary research in this area. Therefore, the "ice edge zone blooming" in the Barents Sea is a phenomenon, although it is known, but little studied [3]. Till now, there is no consensus on the timing and conditions of its onset [4, 5], on the spatial influence of "ice edge zone blooming" at a distance from the ice edge [6, 7].

Thus, the purpose of this work is to study the main phytoplanktons photosynthetic pigment – chlorophyll-a content in the zone of the ice edge of the Barents Sea. Information on the concentration and variability of chlorophyll-a in a water body can serve as a criterion in assessing biomass stocks and pelagic algocenosis production and analyzing the "ice edge effect".



2. Materials and methods

During the expedition of research vessel "Dalnie Zelentsy" in 2017-2018 (July 13 - August 1, 2017; November 9 - December 8, 2017; April 17 - May 29, 2018) in the ice edge zone of the Barents Sea water samples were taken to study concentration of microphytoplankton and chlorophyll-a. Stations were grouped into arbitrary cuts (Fig. 1).

Samples of seawater with a volume of 2 to 3 litres were taken by Multi Water Sampler Hydrobios MWS 12 or by bathometer OTE PVC at standard hydrological horizons (0, 10, 25, 50, 100 m, and bottom). Overall 282 samples were taken. Water was filtered by a vacuum pump (produced by GAST). The Vladipor MFAS-OC-4 membranes, with 0.6 µm pore size were used. After filter homogenization, the pigments were extracted with 90% acetone.

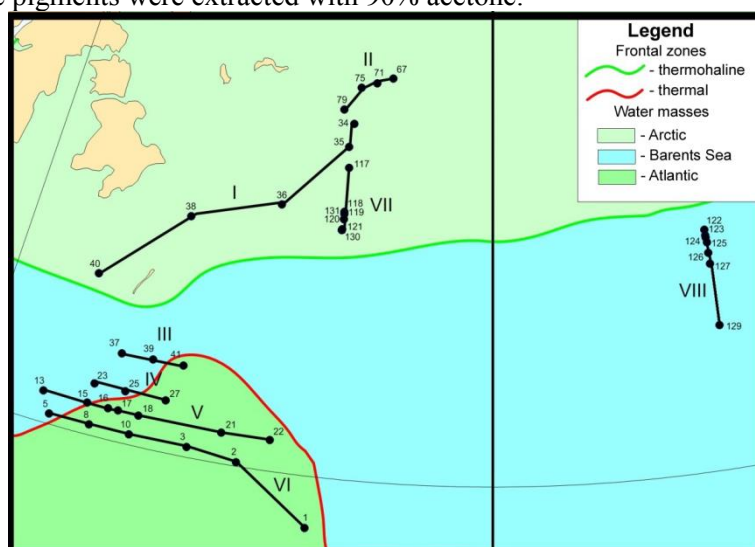


Figure 1. Stations and cuts in the Barents Sea in 2017-2018, within the borders of water masses.

The pure extract was separated from the precipitate in centrifuge OPN-8 at 8000 rpm. The concentration of chlorophyll-a was measured spectrophotometrically. UV-Visible spectrophotometer Nicolett Evolution 500 (by Spectronic Unicam) was used. The concentration of chlorophyll-a (C_{ch_a} , mg/m³) was calculated by standard formulas [8]. From the concentration of the main phytopigment in the samples, the value of the primary production was established indirectly according to the equation by V.Ye. Shemshur et al.s [9].

$$\lg P_0 = 1.56 + 0.92 \lg C_0,$$

where P_0 — primary production, mg C/m³ per day; C_0 — chlorophyll-a concentration, mg/m³. The temperature and salinity were measured by SEACAT SBE 19 plus.

3. Results and discussion

In July 2017, material was collected in the northwest of the Barents Sea (Fig. 2).

The water column had a complex hydrological structure. The surface waters of the studied area were of arctic origin (Fig. 1). The temperature of the upper part of the photic layer at the stations of cut I varied in the range from −1.40 to 3.30 °C, salinity from 31.45 to 33.87 ‰. The content of the main photosynthetic pigment in surface waters varied greatly (from 0.26 to 1.51 mg/m³). The local peak of values (1.51 mg/m³) was related to the ice section with the lowest water temperature. Concentrations fit in the range of summer values in the coastal [10] and northern parts [11] of the sea. The primary production of the surface layer calculated from concentrations of chlorophyll-a varied from 10.37 to 53.11 mg C/m³ per day. Comparable ranges of phytoplankton production (13.3–26.6 mg C/m³ per day) were obtained in June – July in the polar front region in the Barents Sea [12].

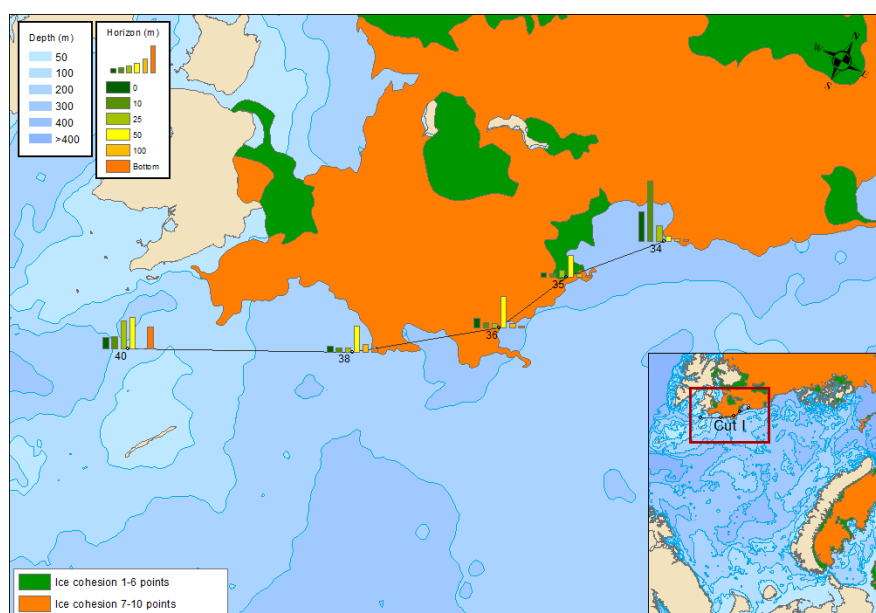


Figure 2. Chlorophyll-a concentration (mg/m^3) and ice conditions (by AARI - Arctic and Antarctic research institute data) in July 2017. Cut I.

At the depths of 30–80 m, the presence of the Barents Sea water mass was revealed, as well as the warmer Atlantic waters underlying it (at the depth 80–160 m). At stations 35, 36 (depth 230–250 m), deep waters with negative temperatures were detected at the bottom. At all stations of the cut, the maximum of chlorophyll-a concentration was located in the depth of the photic layer. Subsurface maximum of phyto-pigment at the coldwater station (st. 34) reached $3.05 \text{ mg}/\text{m}^3$ (at 10 m). At all other stations, the maximum of chlorophyll-a concentrations was found at a depth of 50 m, corresponding to an interlayer of the Barents Sea water mass. The range of the studied component values of the pelagic phytocenosis on this horizon was small from 1.13 to $1.62 \text{ mg}/\text{m}^3$. Such values are corresponding to the stage of seasonal oligotrophy of phytoplankton. A parallel study of nanophytoplankton also revealed the descent of the blooming core from the surface horizon to a depth of 50 m [3]. On the 100 m and the bottom horizons, there was a decrease of chlorophyll-a concentrations. The average concentration of phytopigment was $0.18 \text{ mg}/\text{m}^3$. In the shallow-water station 40 (depth 80 m), high values of chlorophyll-a concentration were also founded in the bottom layer ($1.13 \text{ mg}/\text{m}^3$).

In November 2017, the material was collected in the deep-water (depth 260–300 m) of the northern part of the Barents Sea (Fig. 3).

Cut II is made in the zone of dominance of the Arctic water mass (Fig. 1). The formation of young ice (mostly pancake ice) occurred at the time of the study. The surface layer of water had a low temperature with a gradient close to 0 (for st. 79, 71, 67 - layer 0–10 m), and at station 75 in a layer of 0–30 m. Starting from a depth of 10–30 m, the water temperature gradually increased and cross 0°C at the depth 100–150 m. Depths of 0–100 m were related to the surface layer of the Arctic waters and were characterized by low temperatures (from -1.68 to -1.81°C) and low salinity (from 33.96 to 34.11 ‰). The concentration of chlorophyll-a varied in this layer from 0.07 to $0.30 \text{ mg}/\text{m}^3$. Such low values are typical for micro phytoplankton community of high latitudes in the winter hydrological season [13], this indicates stagnation of algocenosis, the predominance of destructive processes and heterotrophy in it. The calculated values (average per day) of phytocenosis primary production in the surface layer was $6.80 \text{ mg C}/\text{m}^3$, which is slightly higher than known values (1.2 – $5.9 \text{ mg C}/\text{m}^3$ per day) for the central and eastern parts of Barents Sea [14].

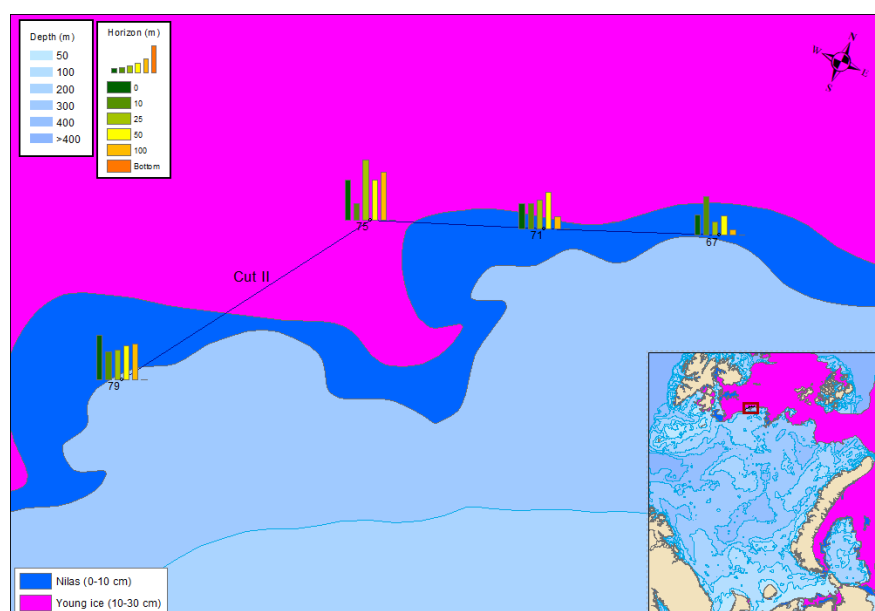


Figure 3. Chlorophyll-a concentration (mg/m^3) and ice conditions (by AARI data) in November 2017. Cut II.

Under the Arctic waters at a depth of 100–200 m there was a layer of partially transformed Atlantic waters with higher temperatures (from -0.6 to 0.7 °C) and salinity (from 34.72 to 34.88 ‰). At stations 71, 75, 79, a layer of deep waters with negative temperatures was also found. At the depth below 100 m, concentrations of chlorophyll-a were present in trace amounts.

In April 2018, under difficult ice conditions, in the western sector of the Barents Sea, 19 stations were performed. Stations were combined into four random cuts (Fig. 4).

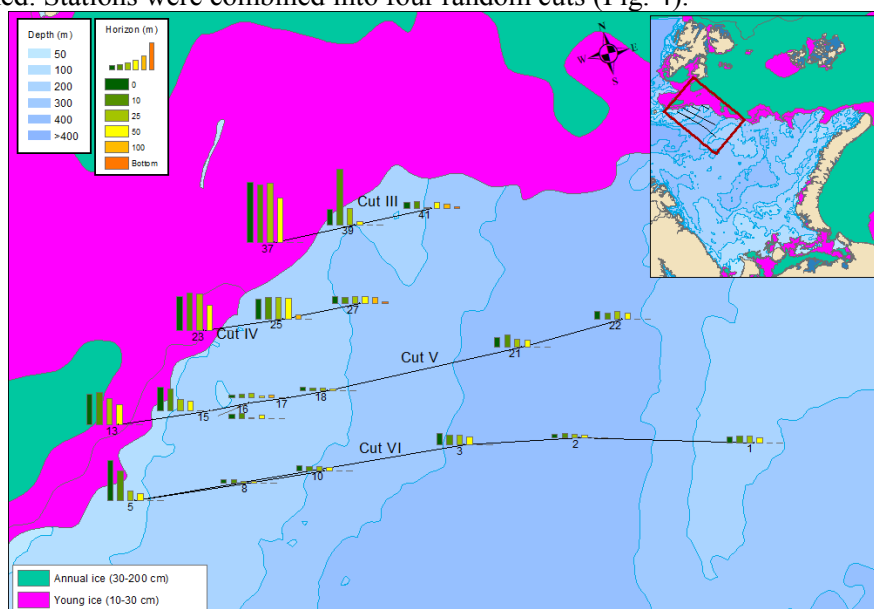


Figure 4. Chlorophyll-a concentration (mg/m^3) and ice conditions (by AARI data) in April 2018. Cuts III, IV, V, VI.

Station of cut III (st. 37, 39) was located in the zone of young ice and they had a two-layer structure. At station 37 to a depth of 50 m, lays the surface layer of the Barents Sea water mass. It's temperature (-1.25 °C) and salinity (34.55 ‰) were homogeneous (Fig. 1). At the depths below, warmer and saltier Atlantic waters were located. Changes between the layers were quite contrasted,

the surface waters were separated from the deep waters by a thin layer of mixed waters (at the depth of 50–70 m). At station 39, the homogeneous surface layer was thinner (0–20 m). The contrast of transformation between the layers decreased, the thickness of the mixed layer increased (20–100 m). The highest concentrations of chlorophyll at these stations were localized in a homogeneous surface layer of arctic water at station 37 (4.23–5.69 mg/m³), at station 39 (1.46–5.25 mg/m³). At station 41, the water column from the surface to the bottom was homogeneous. It was represented by weakly transformed waters of Atlantic origin with an average temperature of 1.39 °C and a salinity of 34.98 ‰. The concentration of chlorophyll-a at these waters (station 41) were significantly lower than at the other stations of the cut (0.07–0.65 mg/m³).

Station 23 (cut IV) was located in the zone of young ice. There were two distinct homogeneous water layers determined at the station: Barents Sea waters (temperature -1.58 °C, salinity 34.56‰) and a deep water mass (temperature -1.72 °C, salinity 34.60 ‰). At a depth of 40–50 m pycnocline was located. The concentration of chlorophyll-a varied in a layer of 0–50 m in a rather narrow range (2.45–3.60 mg/m³). The water column at station 25 had a two-layer structure. The surface layer of Barents Sea water, (with homogeneous temperature (-0.96 °C) and salinity (34.7 ‰), was located up to a depth of 50 m. The layer of mixed surface and Atlantic waters was located below. This layer characterized by a slight linear increase in temperature and salinity with increasing depth. The concentration of chlorophyll-a slightly decreased compared to the previous station (1.84–2.01 mg/m³).

The water column at station 27 was homogeneous from surface to bottom. It was represented by weakly transformed waters of the Atlantic origin with an average temperature of 0.86 °C and a salinity of 34.92‰. The concentration of chlorophyll-a reached a maximum of 0.72 mg/m³ and it was significantly lower than at any other station of cut IV.

The water column at station 13 (cut V) was homogeneous from surface to bottom. Its temperature was -1.85 °C and salinity 34.63 ‰, which corresponds to the Barents Sea water mass. The concentration of chlorophyll-a in a layer of 0–50 m, varied from 1.86 to 3.05 mg/m³. At station 15, which was located in the zone of active mixing of Atlantic and Barents Sea waters, the concentration of chlorophyll was lower than at the previous station (0.9–2.2 mg/m³). Stations 16–22 were performed in the region under influence of the Atlantic water mass which had a highly homogeneous vertical distribution of temperature and salinity. The influence of Atlantic water increased with the movement from NW to SE, which was affected to the gradual increase of temperature and salinity from station 16 to 22. The average concentrations of phytopigments at station 16–18 in the 0–50 m layer did not exceed 0.30 mg/m³, which was significantly lower than at the other stations of the cut. The slight increase of chlorophyll-a concentration (0.59 - 1.20 mg/m³) was found at station 21 and 22.

Station 5 (cut VI) was located within the Barents Sea water mass. A weak stratification of the water column with a gradual increase of temperature from -1.63 °C to -1.07 °C and salinity from 34.48 ‰ to 34.69 ‰ was observed here. The concentration of chlorophyll-a (depth 0–10 m) reached the maximum of 3.79 mg/m³, and it was decreasing to 0.68 mg/m³ at the lower layers. All other stations of the cut located in the area under influence of the Atlantic water mass and they had a highly homogeneous vertical distribution of temperature and salinity. The influence of Atlantic water increased with the movement from NW to the SE, which leads to gradual increase of temperature and salinity of water while moving from the station 8 to 1. The deep-water stations (2 and 3 depths 340–380) had a clearly pronounced layer of deep cold waters with high salinity at depths more than 200 m. The average concentrations of phytopigment at station 8–10, in the 0–50 m layer did not exceed 0.31 mg/m³. The concentration of chlorophyll-a increased again at station 3 (0.78–1.05 mg/m³). The average concentration at stations 1–2 was 0.46 mg/m³.

Thus, the highest concentration of chlorophyll-a was registered in the photic layer of stations located directly in the ice edge zone. The concentrations of phytopigments in the surface layer at these stations varied in the range of 2.84–5.69 mg/m³. This shows the active seasonal “bloom” of the microphytoplankton in the ice age zone. The concentrations in the layer from 0 to 50 m was distributed homogeneously, it's valued rapidly decreases with depth below the 50 m horizon. Primary production (values calculated from chlorophyll concentration) in the surface layer, at these stations,

varied from 94.78 to 179.81 mg C/m³ per day, and it was decreasing by at the other stations. Comparable ranges of phytoplankton production were found in May in the Atlantic waters of the western Barents Sea (36–524 mg C/m³ per day) [13].

Based on a large amount of factual material, it was shown that the distribution of chlorophyll-a in the ice edge zone on each of the studied cuts was characterized by a gradual decrease of its concentration at distances from the ice edge. This fact shows that the ice edge effect occurred in the northern part of the Barents Sea in April 2016 [15, 16]. On cuts III and IV, this effect occurred on the entire length of the cuts (47 miles each). On longer cuts V and VI, the effect was observed only up to the middle of the length (63 and 57 miles, respectively). Attenuation of the “edge effect” and some increase in chlorophyll-a concentrations occurred as the distance from the ice edge increased.

In May 2018, the material was collected in the zone of young broken ice (Fig. 5). Cut VII was located in the northern part of the Barents Sea (depths of 173–195 m). It included the “main” stations performed on May 19–20, 2018 and the “additional” stations dated May 24, 2018 (stations 130, 131). At all stations of the cut, the structure of the water column was almost identical. The water column had a two-layer structure.

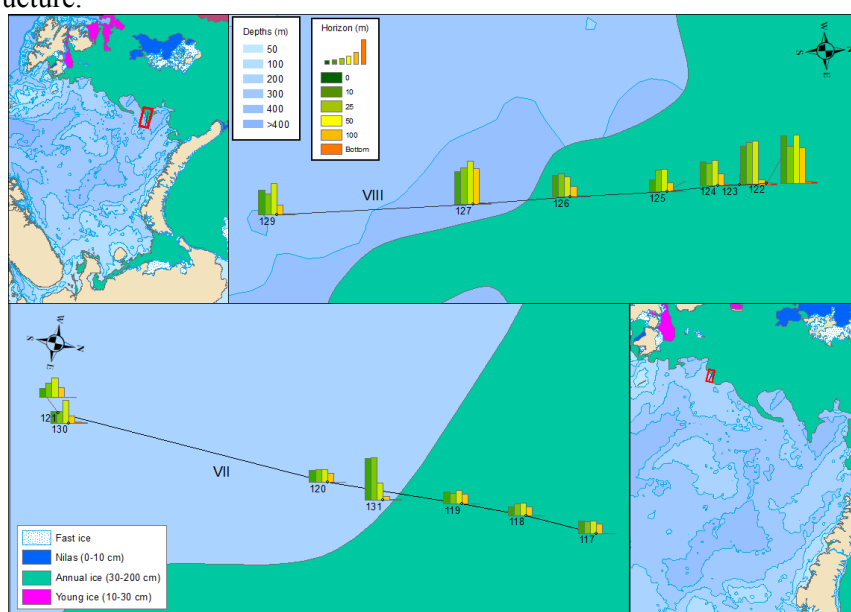


Figure 5. Chlorophyll-a concentration (mg/m³) and ice conditions (by AARI data) in May 2018. Cuts VII, VIII.

The surface layer was represented by well-mixed arctic waters with a temperature from -1.8 to -1.4 °C and salinity from 34.30 ‰ to 34.40 ‰ (Fig. 1). Thermocline and pycnocline detected at a depth of 75–120 m. Below 100–120 m there was a layer of warmer (from 0.7 to 1.0 °C) and saline (from 34.80 ‰ to 34.90 ‰) Atlantic waters. The concentration of chlorophyll-a at the “main” stations of cut VII in the surface layer did not exceed 1.47 mg/m³. It was increasing with a depth (horizon 25 m) to 2.75 mg/m³. The maximum pigment concentration was observed in the layer 0–50 m. Low concentrations of chlorophyll-a, along with the presence of a subsurface maximum, indicated the precipitation of cells from the surface horizon under the influence of limiting factors, and also the absence of a phase of the active vegetation of pelagic algal flora. A few days later, the situation changed at the “additional” station of the northern cut (station 131). The concentrations of phytococci increased rapidly to 4.96–5.12 mg/m³ in a layer of 0–10 m. Such values correspond to the rapid development of pelagic algocenosis and the stage of ice edge “blooming”. The calculated values of phytococci primary production in the surface layer was about 46.89 mg C/m³ per day (average for all cut). Its maximum reached 158.35 mg C/m³ per day at station 131.

Cut VIII was made May 22–23, 2018 in the zone of young broken ice in the eastern sector of the Barents Sea (depths of 283–398 m). Similar water column structure was observed at all stations of the

cut (Fig. 1). The surface homogeneous layer of water was separated from the underlying layer by pycnocline (30–60 m) and had a temperature from -1.70 to -1.80 °C and salinity from 34.5 to 34.6 ‰. Below the pycnocline there was a layer of transformed Atlantic waters, which retained a high salinity (from 34.86 to 34.90 ‰), but consumed thermal stock (from 0 to -0.3 °C). At depths of more than 200 m, a deep water mass was determined with the same salinity, but differing in even lower temperatures (from -0.6 to -0.7 °C). The concentration of chlorophyll at few of stations (st. 122, 123, 127) corresponded to the phase of active vegetation and “blooming” of pelagic microphytoplankton. The phytopigment concentration in the photic layer varied from 4.38 to 5.77 mg/m³. At a depth of 100 m and in the near-bottom horizon, the concentration of chlorophyll was significantly reduced. The average values for the cut were 0.14 mg/m³. At the other stations the average values of phytopigment in the layer 0–50 m was 2.74 mg/m³. The primary production of the surface layer, calculated from concentrations of chlorophyll-a, in averaged was about 112.00 mg C/m³ per day, with a maximum value of 177.50 mg C/m³ per day. Comparable ranges of phytoplankton production were found in May in the open waters of the southeastern Barents Sea (23–162 mg C/m³ per day) [13].

4. Conclusion

It is known that in ice edge zone the phytoplankton succession cycle has a complex multistage character and the following phases are distinguished in its structure: initial, growth, maximum activation (peak) and seasonal oligotrophy [4]. In this work, during the annual succession cycle of pelagic algocenosis in the vast waters of the Barents Sea, covering the western, northern and eastern regions, we were able to observe all the stages of the “near ice edge” development of the phytocene.

In April, in the western part of the Barents Sea, the highest concentrations of chlorophyll-a (2.84–5.69 mg/m³) were concentrated in the 0–50 m layer of stations located directly in the ice edge zone. That indicate a maximum peak activation of the pelagic microphytoplankton spring “bloom”. At the remaining stations, a low content of chlorophyll-a characterized the onset and growth in the succession cycle of algocenosis. With the distance from the ice edge area - the content of chlorophyll-a significantly decreased. The “ice edge effect” was observed. This effect fades with the distance (about 60 miles from the ice edge).

The “near ice edge bloom” as a phenomenon – is a very short-term process. According to satellite data, the active phase at each specific point lasts no more than 5–6 days [6]. In May, in the northern part of the Barents Sea, the growth phase of the microfitoplankton succession cycle (chlorophyll-a 1.47–2.75 mg/m³) for several days changed to the stage of its rapid “bloom” and maximum activation (chlorophyll-a 4.96–5.12 mg/m³). In the eastern part of the water area at the same time, we observed a phase of active vegetation of the pelagic phytocenosis, with chlorophyll concentrations of 4.38–5.77 mg/m³ in the photosynthesis layer. The data obtained during one succession cycle may differ significantly and reflect the complex spatial-temporal organization of near ice edge bloom. For example, according to the literature, in May 1999, in the surface layer at a distance of only a few kilometers, the chlorophyll concentration differed by an ordinal value, and the phytoplankton community was at different stages of the succession cycle [5]. Subsequently, spring bloom in the Barents Sea reaches its maximum in May over the entire ice-free area, including the drift ice zone, and fades out in the summer months. The outbreaks of phytoplankton noted in some cases in the summer in regions near the ice edge have are secondary [17]. It is known that the “blooming” in the surface is very short and soon falls on a layer of seasonal pycnocline, where a deep maximum of chlorophyll is formed and production continues throughout the summer period [18]. In July, in the ice edge zone of the northwestern part of the Barents Sea, a subsurface maximum of chlorophyll-a concentration was found (3.05 mg/m³) at a depth of 10 m. The mass accumulation of phytopigments in this area was concentrated on the horizon of 50 m (1.13 - 1.62 mg/m³) and corresponded to the stage of seasonal oligotrophy and lowering of the blooming core of the phytoplankton community. The duration of the entire cycle in the Barents Sea is 2–3 months [6]. The low concentration of chlorophyll-a (≤ 0.3 mg/m³) in the near ice edge area of the northern part of the Barents Sea in November testified to the stagnation of algocenosis, the prevalence of destructive processes and heterotrophy in the community.

Acknowledgments

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