Microphytobenthos in the Hypersaline Water Bodies, the Case of Bay Sivash (Crimea): Is Salinity the Main Determinant of Species Composition?

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Abstract: In hypersaline water bodies, the microphytobenthos plays a very important ecosystem role and demonstrates variability along with a salinity change. Due to anthropogenic activity, the sharp salinity increase in Bay Sivash occurred after 2014. To assess the changes in the microalgae community during the bay ecosystem transformation, the study was conducted four times in 2018 and 2019. At every sampling period, the samples were taken in a salinity gradient (from 7 to 10 sites). A total of 40 species of microalgae were identified during all research, including Cyanobacteria (Cyanophyceae, 2 species), Ochrophyta (Bacillariophyceae, 35 species), Haptophyta (Prymnesiophyceae, 2 species), and Miozoa (Dinophyceae, 1 species). According to the calculated similarity indices of Jaccard and Czekanowski–Sørensen–Dice, the species composition significantly differed during sampling periods. A total of 15 species were recorded at salinities of 80–90 psu, and 10 species at higher salinities, which contribute 64% of all species found in this study. The microalgae abundance was two times more in the floating green algae mat than on the bottom. There was no significant correlation between the number of species and salinity in all sampling periods. In November 2018, a significant positive correlation between the number of species in the sample and total suspended solids (TSS) and dissolved organic matter (DOM) was revealed. A significant correlation between the cell length in different species and salinity and DOM concentration was noted. Before the onset of the salinity increase, 61 species of microalgae were found in Eastern Sivash, of which only 12 have now been recorded, 31% of the currently found species. The characteristics of the total microphytobenthos abundance also significantly changed during all studies. Many characteristics have changed in the bay: the concentration of total suspended matter and dissolved organic matter, the temperature regime, composition of zoobenthos and plankton, and oxygen concentration. Due to this, it is unlikely that only the salinity increase caused the microphytobenthos changes in the lagoon.

Keywords: bottom microalgae; lagoon; hypersaline; long-term changes; salinity changes; species composition

1. Introduction

The term ‘Microphytobenthos’ (also ‘microalgae’ as a synonym in the text) is applied to the diverse associations of oxygenic photosynthetic cyanobacteria and eukaryotic algae thriving in aquatic environments at the bottom and every substrate. The Microphytobenthos is an important component in lagoons, marine lakes, and estuaries [1–3]. It plays a significant role in the total primary production, the biogeochemical processes, the stabilization of sediments, and the food webs [4–8]. Bottom microalgae may contribute up to 99% of the chlorophyll content when compared to phytoplankton in shallow lakes and lagoons [7,9–11]. Due to the wind and tidal activity, bottom microalgae resuspension plays a key role in the phytoplankton dynamics, and their proportions can be high in the phytoplankton abundance of shallow lakes and lagoons [7,12]. With decreasing water depth and increasing salinity, the contribution of microphytobenthos to the primary productivity of
aquatic ecosystems increases, while the contribution of phytoplankton decreases \([10,13–16]\). In hypersaline shallow water bodies, this contribution to total primary production will be especially high. Hypersaline lakes and lagoons, distributed worldwide, especially in the arid areas, are harsh environments. However, they often demonstrate an intense development of microphytobenthos with a high taxonomic diversity of microalgae \([3,15,17–24]\).

Regarding the influence of salinity on the total species richness of microalgae and their taxonomic composition, there are conflicting data that do not allow us to formulate the general patterns (see references above). The scarcity of generalizations on patterns of benthic microalgal variability on different spatial and temporal scales in a salinity gradient can be partly explained by the high diversity of saline water habitats all over the world. Only the accumulation of data on microalgae distribution in the particular water bodies of different regions can lead to finding the general regularities.

Currently, Bay Sivash (the Crimean Peninsula) is the world’s largest hypersaline lagoon with a strong salinity gradient from 30 to 100–120 psu \([25–27]\). Before 2014, the lagoon was brackish water, and only one study of microphytobenthos was conducted \([28]\). In 2018–2019, authors studied bottom microalgal composition and abundance along a salinity gradient in the bay. This was the first such study in the lagoon after it became hypersaline. The main goals of the study are (1) to provide new data on bottom microalgae of Bay Sivash in a spatial salinity gradient; (2) to analyze the temporal changes of microalgae composition after a sharp salinity increase in the bay; (3) to prove or disprove the hypothesis that salinity is the main or only driver of microalgae composition changes in a salinity gradient. Achievement of the set tasks will contribute to a better understanding of the patterns of ecosystem transformations under a sharp salinity increase. It would also support the organization of sustainable environmental management in the altered Bay Sivash ecosystem.

2. Materials and Methods

2.1. Study Area

Currently, Bay Sivash is Europe’s largest shallow semiclosed lagoon/marine lake (area of 2560 km\(^2\)), separated from the Sea of Azov by the narrow sand Arabat Spit of 112–116 km long \([27,29]\). There are only two narrow straits on the north connecting the sea with the lagoon (Figure 1).

The maximum depth does not exceed 2 m, with an average of 0.8–1.0 m. Two bay ecosystem transformations occurred in the last half-century. The lagoon was hypersaline, with an average salinity of about 140 psu, reaching up to >200 psu in the southern part before the North Crimean Canal (1963–1975) was constructed. The functioning of the North Crimean Canal gradually changed the lagoon ecosystem and its drainage area \([27,29]\). The Canal was supplied by Dnieper River freshwater, which was used for irrigation of agricultural lands, and drainage water from cropland was dumped into the lagoon. As a result of this, the average salinity has gradually decreased to 17.0–22.6 psu in 1989–1997 \([29]\). A different brackish water ecosystem formed with a new composition of abiotic parameters and biota \([29]\). In this brackish water state, only one study of microphytobenthos was conducted in the lagoon \([28]\). In April 2014, The Dnieper water supply was ceased into the North Crimean Canal as well as the freshwater discharge from irrigated lands into the lagoon. The sharp salinity increase (from 22 to 100 psu) began in the bay, with cardinal biotic changes in benthos and plankton \([25–27]\). Currently, there is a strong salinity gradient from 30 to 100 psu and higher. Floating and bottom mats formed by filamentous green algae \textit{Cladophora siwaschensis} (C.J. Meyer, 1922), having high biomass, occupy large areas in the lagoon, leading sometimes to hypoxic and even anoxic events under them \([25,26,29]\). These mats developed in Bay Sivash before the North Crimean Canal construction. Bay Sivash is divided into the Western Sivash and Eastern Sivash, connected by the narrow Chongar Strait.
Figure 1. Bay Sivash with sampling stations ((A)—Bay Sivash in Crimea; (B)—Crimea in the Black Sea).

2.2. Sampling and Processing

In different sites of Eastern Sivash, sampling was conducted three times in 2018 (May, June, and November) and in June of 2019 with a parallel evaluation of environmental parameters (Table 1, Figure 1). In total, to analyze the species composition and abundance of bottom microalgae, 39 samples of bottom sediments and 9 of floating green algae mats were taken.

In the mats, samples of 1 to 2 g (wet weight) were taken by tweezers in triplicate. The benthic samples were collected by a benthic tube (diameter 5 cm) in duplicate. Microalgae of bottom sediments were separated by repeated washing with distilled water, followed by sedimentation. Mat samples, washed in distilled water, were dried on filter paper and weighed by a WT-250 electronic balance (Techniprot, Pruszkow, Poland). Microalgae attached to Cladophora were removed from filaments by a soft synthetic brush and washed out into a Petri dish with filtered seawater (membrane filter, pore diameter 1 µm). This process was monitored under a microscope. The microalgae were brushed off from filaments, which were washed until a complete absence of microalgae was observed under a microscope using randomly selected fragments of filaments. The final suspension was fixed by 96% alcohol, 2 mL per 100 mL of a sample. Microalgae were analyzed using a light microscope Olympus BX53F (Olympus Corporation, Tokyo, Japan) at magnifications of 10 × 20, 10 × 40, and 10 × 100. Microalgae photography was carried out by a GRYPHAX ARKTUR (JENOPTIK Optical Systems GmbH, Jena, Germany) camera using the GRYPHAX microscope camera software at different magnifications. During all sampling, salinity and temperature were measured by a Kellong WZ212 (Kelilong Electron Co. Ltd., Fuan, China) manual refractometer and a PHH-830 (OMEGA Engineering, INC., Norwalk, CT, USA) electronic thermometer, respectively. In May and November of 2018 as well as in June of 2019, determination of the concentration of total suspended solids (TSS) and dissolved organic matter (DOM) was also conducted by Mr. A. Latushkin using the biophysical complex ‘Condor’ (produced by Akvastandart-Yug, Sevastopol, Russia) as described in [29]. The authors follow the current classification of Algae according to the AlgaeBase website [30].
Table 1. Characteristics of sampling points in Bay Sivash (2018–2019).

| Station | Coordinates | May, 2018 | November, 2018 | June, 2019 |
|---------|-------------|-----------|----------------|------------|
|         |             | S, psu    | TSS, mg L\(^{-1}\) |DOM, mg L\(^{-1}\) | S, psu | TSS, mg L\(^{-1}\) |DOM, mg L\(^{-1}\) | S, psu | TSS, mg L\(^{-1}\) |DOM, mg L\(^{-1}\) |
| 1       | 45°45'37.0" N 34°57'57.0" E | – | – | – | – | – | 70 | 3.72 | 3.40 |
| 2       | 45°37'9.0" N 35°04'40.0" E | – | – | – | 86 | 6.98 | 4.45 | 68 | 9.80 | 3.77 |
| 3       | 45°31'13.7" N 35°11'12.9" E | 76 | 16.95 | 4.16 | 90 | 1.88 | 3.76 | 84 | 26.66 | 13.32 |
| 4       | 45°29'04.7" N 35°13'27.9" E | 77 | 16.59 | 3.97 | 90 | 1.03 | 3.44 | 84 | 24.55 | 14.65 |
| 5       | 45°27'19.5" N 35°13'27.9" E | 77 | 23.15 | 3.68 | 82 | 4.56 | 4.36 | 84 | 26.66 | 13.32 |
| 6       | 45°24'43.5" N 35°17'33.8" E | 77 | 24.20 | 3.73 | 100 | 6.85 | 4.35 | 84 | 21.11 | 13.75 |
| 7       | 45°23'04.7" N 35°19'44.6" E | 77 | 20.81 | 4.09 | 89 | 6.47 | 4.31 | 84 | 15.95 | 12.85 |
| 8       | 45°17'14.3" N 35°28'01.2" E | 82 | 12.20 | 3.80 | 87 | 12.38 | 7.98 | 100 | 8.69 | 7.14 |
| 9       | 45°19'05.5" N 35°14'59.8" E | 75 | 18.56 | 4.12 | 92 | 70.16 | 21.56 | 88 | 14.92 | 7.36 |
| 10      | 45°21'04.2" N 35°06'06.5" E | 75 | 24.76 | 4.13 | 90 | 29.27 | 21.56 | 88 | 14.92 | 7.36 |
| 11      | 45°37'48.3" N 35°01'54.8" E | 56 | 5.64 | 3.21 | 63 | 3.55 | 3.76 | 70 | 14.32 | 6.46 |
| 12      | 45°40'48.8" N 34°54'55.2" E | 52 | 3.50 | 2.93 | 56 | 3.44 | 3.47 | 66 | 7.73 | 3.41 |
| 13      | 45°44'00.8" N 34°48'10.3" E | 39 | 5.53 | 2.90 | 42 | 23.83 | 11.92 | 54 | 4.83 | 3.36 |
| 14      | 45°52'38.8" N 34°44'33.3" E | 36 | 3.11 | 3.01 | 38 | 1.31 | 2.97 | 50 | 2.45 | 3.56 |
| 15      | 45°52'42.6" N 34°42'09.0" E | 30 | 2.37 | 2.66 | 30 | 24.02 | 11.84 | 35 | 9.87 | 2.98 |

S—salinity; TSS—total suspended solids; DOM—dissolved organic matter.

The number of microalgae was determined by counting cells using a light microscope in the Goryaev chamber (IBSS, Sevastopol, Russia) (volume of 0.9 mm\(^3\)), in triplicate. The total number of microalgae on the filaments was calculated:

\[
N = n \times V \times S^{-1} \times V_k^{-1} \tag{1}
\]

where N—the total number of microalgae, cells m\(^{-2}\); n—the number of cells in the Goryaev chamber; V—the sample volume, mL; \(S\)—total filament area in a sample, m\(^2\); \(V_k\)—Goryaev’s chamber volume equal to 0.0009 mL.

The filament specific surface area \((S_f/W)_{Cl}\) was calculated using the equation obtained by simple transformations, provided that the mass of Cladophora is equal to its volume, i.e., specific gravity is 1:

\[
(S_f/W)_{Cl} = 4 \times d^{-1} \tag{2}
\]

where \(S_f\)—total filament area in a sample, m\(^2\); W—the wet weight of mat sample, g; d—the average diameter of the Cladophora filaments, m, which, as shown earlier, is equal to \(2.45 \times 10^{-5}\) m [24].

The microalgae biomass was calculated:

\[
B = \varrho \times b \times V \times S^{-1} \times V_k^{-1} \tag{3}
\]
where \( B \) — biomass, mg m\(^{-2}\); \( \varrho \) — the specific microalgae gravity of \( 1.2 \times 10^{-9} \) mg \( \mu \)m\(^{-3}\) for benthic diatoms, or for others, \( 1 \times 10^{-9} \) mg \( \mu \)m\(^{-3}\) \[31\]; \( b \) — the total biological volume of cells in the Goryaev chamber, determined by \[32\], \( \mu \)m\(^3\); \( V \) — the sample volume, mL; \( S \) — total filament area in a sample, \( m^2 \); \( V_k \) — Goryaev’s chamber volume, mL.

Microalgae of soft-bottom sediments were separated by repeated washing with distilled water, followed by sedimentation. Then, after washing, the sedimented cells were placed in a measuring cylinder with a known diameter. The quantitative characteristics of microalgae were calculated for the volume of the sedimented cells in the sample using the formula for determining the volume of a cylinder:

\[
V_{sed} = \pi \times r^2 \times h
\]

(4)

where \( V_{sed} \) — the volume of the sediment obtained, cm; \( r \) — the radius of the measuring cylinder, cm; \( h \) — the height of the sedimented cells in the measuring cylinder, cm.

From this volume, 2 mL was taken three times, and samples were examined to identify the species and determine the quantitative characteristics. The number of cells per unit bottom area was calculated:

\[
N = \frac{V_{sed}}{S_t}
\]

(5)

where \( S_t \) — a benthic tube area equaling 15.9 cm\(^2\).

2.3. Data Analysis

In the standard program MS Excel 2007, we calculated average values, standard deviations (SD), coefficients of variation (CV), correlation (R), determination (R\(^2\)), and parameters of the regression equations. The confidence level (p) of correlation coefficients was calculated \[33\]. The evaluation of the significance of differences was made by Student’s t-test, with performing normality test \[34\] before this.

The general mat characteristics (biomass and total filaments area per \( m^2 \) of the bottom) were calculated according to \[24\]. To evaluate the similarity of the species composition in the different periods, the Jaccard and Czekanowski–Sørensen–Dice similarity indices were applied \[35\]:

\[
K_J = \frac{c}{a + b - c}
\]

(6)

\[
K_{CSD} = \frac{2c}{a + b}
\]

(7)

where \( K_J \) and \( K_{CSD} \) — Jaccard and Czekanowski–Sørensen–Dice similarity coefficients, respectively; \( c \) — number of species common to both plots or periods; \( a \) — number of species found in the first case; \( b \) — number of species found in the second case. Threshold values of 0.42 (Jaccard) and 0.59 (Czekanowski–Sørensen–Dice) were used to determine the similarity/dissimilarity of the species composition \[35\].

3. Results

Abiotic characteristics at sampling stations are given in Table 1. Salinity during the sampling period varied from 30 to 100 psu. In November 2018, there was a strong northeast wind, which affected the spatial distribution of suspended matter. At the leeward coast, the concentration of suspended matter was significantly higher.

A total of 40 species of microalgae were identified during all research, including Cyanobacteria (Cyanophyceae, 2 species), Ochrophyta (Bacillariophyceae, 35 species), Haptophyta (Prymnesiophyceae, 2 species), and Miozoa (Dinophyceae, 1 species) (Table 2). Salinity ranges are also given in (Table 2).

In May–June 2018, a total of 23 species were recorded at the bottom, and 11 species were recorded in floating mats. At the bottom, 13 species were found in November 2018 and 29 species in June 2019. In May–June 2018, microalgae were absent in two bottom samples out of 14 (in 14% of samples), and microalgae were present in all samples of the mats. In November 2018 and June 2019, microalgae were absent in two bottom samples out of 11 taken (in 18%). Those empty samples were excluded from further analysis. In May–
June 2018, the number of species in one bottom sample, where they occurred, varied from 1 to 10 species (average 5.4, CV = 0.48), and in mat samples, the number varied from 4 to 8 (average 6.0, CV = 0.28). There were no differences in the sets of species on the bottom and in the mats; it was just that the list of species encountered in the mats was shorter. The number of species in one bottom sample taken in November 2018 ranged from 1 to 5 (average 2.70, CV = 0.59), and in June 2019 ranged from 3 to 10 (average 6.10, CV = 0.33). There was no significant correlation between the number of species and salinity in all sampling periods.

In November 2018, a significant positive dependence of the number of species in the sample on TSS was revealed ($R = 0.721, p = 0.001$):

$$M = 1.083 + 0.838 \log(TSS)$$  (8)

where $M$ is the number of species; $\log(TSS)$ is the logarithm of the concentration of TSS, mg L$^{-1}$.

A similar reliable dependence of the number of microphytobenthos species on the amount of DOM was found ($R = 0.649, p = 0.03$):

$$M = 0.692 + \log(DOM)$$  (9)

where $\log(DOM)$ is the logarithm of the DOM concentration, mg L$^{-1}$.

No correlations were found for the samples collected in June 2018 and 2019.

Table 2. Species composition of microphytobenthos in Bay Sivash (2018–2019).

| Species                                | Salinity Range for a Species, Psu | Frequency of Occurrence, % | Found Before | The Sea of Azov | Eastern Sivash | Crimean Hypersaline Lakes |
|----------------------------------------|----------------------------------|-----------------------------|--------------|-----------------|----------------|--------------------------|
|                                        |                                  | May and June 2018 | November 2018 | June 2019 | Bottom | Mat | Bottom | Bottom | Before 2014 | Before 2014 | Before 2014 | Before 2014 |
| Ochrophyta                             |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Achnanthes adnata Bory, 1822           | 52–92                            | 67                          | 100          | 78       | 56     |     | [28]   | [28]   | [21,24]       | [21,24]       | [21,24]       | [21,24]       |
| Amphitretas antediluviana              | 88–90                            | 0                           | 0            | 11       | 11     | –   | –      | –      | –              | –              | –              | –              |
| (Ehrenberg, 1840)                     |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Amphora macilenta var. maeotica        | 87                               | 0                           | 0            | 11       | 0      | –   | –      | –      | –              | –              | –              | –              |
| Proshkina-Lavrenko, 1963               |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Amphora ovalis (Kützing)               | 100                              | 0                           | 0            | 0        | 11     | [28] | –      | –      | [21]           |               |                |              |              |
| Kützing, 1844                         |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Amphora sp.                            | 77                               | 17                          | 17           | 0        | 0      | –   | –      | –      | –              | –              | –              | –              |
| Ardissonea crystallina (C. Agardh)     | 66–92                            | 0                           | 0            | 11       | 11     | [28] | [28]   | [21,24] |                |                |                |              |              |
| Grunow, 1880                          |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Campylococcus neoformatosus Ruck and   | 38–90                            | 8                           | 0            | 44       | 22     | –   | –      | –      | [21]           |               |                |              |              |
| Nakov in Ruck et al., 2016             |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Cocconeis kujalnitzkensis             | 52–100                           | 67                          | 100          | 44       | 67     | –   | –      | –      | [21]           |               |                |              |              |
| Gusliakov and Gerasimiuk, 1992         |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Cocconeis placentula Ehrenberg, 1838   | 66–88                            | 0                           | 0            | 0        | 22     | [28] | –      | –      | [24]           |               |                |              |              |
| Cocconeis scutellum Ehrenberg, 1838    | 35–70                            | 0                           | 0            | 0        | 44     | [28] | [28]   | [21,24] |                |                |                |              |              |
| Coronia daemeliana (Grunow) Ruck and   | 52–70                            | 8                           | 0            | 0        | 11     | –   | –      | –      | –              | –              | –              | –              |
| Guiry, 2016                           |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
| Diploneis bombus (Ehrenberg) Ehrenberg | 52                               | 8                           | 0            | 0        | 0      | [28] | –      | –      | [21]           |               |                |              |              |
| 1894                                   |                                  |                            |              |          |        |     |        |        |                |                |                |              |              |
Table 2. Cont.

| Species | Salinity Range for a Species, Psu | Frequency of Occurrence, % | Found Before | Crimean Hypersaline Lakes |
|---------|----------------------------------|----------------------------|--------------|---------------------------|
|         |                                  | May-June 2018 | November 2018 | June 2019 | The Sea of Azov | Eastern Sivash Before 2014 |
|         | Bottom | Mat | Bottom | Bottom | | |
| Grammatophora marina (Lyngbye) Kützing, 1844 | 54–88 | 8 | 0 | 0 | 22 | [28] | [28] | [21] |
| Gyrosigma balticum (Ehrenberg) Rabenhorst, 1853 | 35 | 0 | 0 | 0 | 11 | [28] | [28] | – |
| Gyrosigma fasciola (Ehrenberg) J.W.Griffith and Henfrey, 1856 | 56 | 8 | 0 | 0 | 0 | – | – | – |
| Halamphora coffeiformis (C.A. Agardh) Levkov, 2009 | 52–100 | 50 | 67 | 11 | 56 | [28] | [28] | [21,24] |
| Lyrella lyroides (Hendey) D.G. Mann, 1990 | 88 | 8 | 0 | 11 | – | – | – | – |
| Mastogloia braunii Grunow, 1863 | 56–84 | 8 | 0 | 11 | 11 | [28] | – | [21,24] |
| Navicula meniscus Schumann, 1867 | 52–86 | 8 | 33 | 0 | 11 | [28] | – | [21,24] |
| Navicula sp. 1 | 52–100 | 58 | 100 | 0 | 33 | – | – | – |
| Navicula sp. 2 | 88 | 8 | 0 | 0 | 0 | – | – | – |
| Nitzschia hybrida var. hyalina Proschkina-Lavrenko, 1963 | 52–88 | 17 | 17 | 0 | 11 | [28] | – | [21,24] |
| Nitzschia sigma (Kützing) W. Smith, 1853 | 84 | 0 | 0 | 0 | 11 | [28] | [28] | [21,24] |
| Nitzschia teniaurostris Mereschkowsky, 1902 | 54–77 | 8 | 33 | 0 | 22 | [28] | – | [24] |
| Nitzschia sp. | 52–76 | 8 | 17 | 0 | 22 | – | – | – |
| Odontella aurita (Lyngbye) C.Agardh, 1832 | 88 | 0 | 0 | 0 | 11 | [28] | [28] | – |
| Parlibellus dolgoe (Van Heurck) E.J. Cox, 1988 | 54–100 | 0 | 0 | 0 | 22 | [28] | – | [24] |
| Pleurosigma elongatum W. Smith, 1852 | 35–75 | 17 | 0 | 0 | 11 | [28] | [28] | [24] |
| Rhabdonema Adriaticum Kützing, 1844 | 75 | 8 | 0 | 0 | 0 | [28] | – | – |
| Rhopalodia musculus (Kützing) O.F. Müller, 1899 | 92 | 0 | 0 | 11 | 0 | [28] | [28] | [21] |
| Surirella striatula Turpin, 1828 | 88 | 0 | 0 | 0 | 11 | [28] | – | [21] |
| Tabularia Tabulata (Agardh) Snoeijis, 1992 | 66–86 | 83 | 100 | 0 | 22 | [28] | [28] | [21] |
| Toxarium undulatum J.W. Bailey, 1854 | 92 | 0 | 0 | 11 | 0 | [28] | – | [21] |
| Tryblionella apiculata Gregory, 1857 | 52 | 8 | 0 | 0 | 0 | – | [28] | [21] |
| Total Diatoms | – | 21 | 10 | 10 | 25 | 22 | 12 | 26 |
| **Haptophyta** | | | | | | | | |
| Calcidius leptopus (G.Murray and V.H.Blackman) Loeblitch Jr. and Tappan, 1978 | 70 | 0 | 0 | 0 | 11 | – | – | [24] |
| Oolithotus fragilis (Lohmann) Martini and C.Müller, 1972 | 52 | 8 | 17 | 0 | – | – | – | – |
Table 2. Cont.

| Species | Salinity Range for a Species, Psu | Frequency of Occurrence, % | Found Before |
|---------|----------------------------------|---------------------------|--------------|
|         |                                  | May and June 2018 | November 2018 | June 2019 | The Sea of Azov | Eastern Sivash Before 2014 | Crimean Hypersaline Lakes |
|         |                                  | Bottom | Mat | Bottom | Bottom |                      |                           |
| Miozoa  |                                  |        |     |        |        |                      |                           |
| Prorocentrum balticum (Lohmann) Loeblich III, 1970 | 69–84 | 17 | 0 | 11 | 0 | – | – | 24 |
| Cyanobacteria |                              |        |     |        |        |                      |                           |
| Oscillatoria limosa C.Agardh ex Gomont, 1892 | 54 | – | – | 0 | 11 | – | – | 11 |
| Oscillatoria tenuis C.Agardh ex Gomont, 1892 | 38–70 | – | – | 11 | 11 | – | – | – |
| Total number of species | – | 23 | 11 | 13 | 29 | 22 | 12 | 27 |

Pairwise comparison of the lists of species in the three studied periods (May–June 2018, November 2018, and June 2019) using the calculated similarity indices of Jaccard and Czekanowski–Sørensen–Dice (Table 3) showed that the species composition significantly differed in different periods, because in all cases, the values of the similarity coefficients were below critical.

Table 3. Similarity indices between species composition in the different periods (Bay Sivash, 2018–2019).

| Index                          | Compared Pairs                |
|-------------------------------|------------------------------|
|                               | Critical Value | May–June 2018 vs. June 2019 | May–June 2018 vs. November 2018 | November 2018 vs. June 2019 |
| Jaccard                       | 0.42             | 0.32                          | 0.15                          | 0.29                          |
| Czekanowski–Sørensen–Dice     | 0.59             | 0.48                          | 0.26                          | 0.45                          |

According to the Student’s t-test, there were no differences in microalgal abundance and biomass at the bottom between May and June 2018 samples, and they were noted together later (Table 4). Differences in abundance and biomass between May–June of 2018, November 2018, and June 2019 samples were significant ($p = 0.05–0.0001$). In the benthic community, the minimal abundance and biomass were recorded in May 2018, and the maximal abundance and biomass in November 2018. In November of 2018, abundance was 171 and 12 times higher than in June of 2018 and June of 2019, respectively. Spatial variability (according to CV) was different in the different periods: the highest value was in June of 2019 and the lowest in May–June of 2018 (Table 4). At the same time, in May 2018, the microalgae abundance in the mat was two times higher than at the bottom. Cyanobacteria dominated only in one sample in November 2018 (station 14, Table 1), the same was observed in June 2019 (station 13, Table 1).
Table 4. Quantitative characteristics of microphytobenthos in Bay Sivash (2018–2019).

| Characteristics          | May 2018 | June 2018 | November 2018 | June 2019 |
|--------------------------|----------|-----------|---------------|-----------|
|                          | Bottom   | Mat       | Bottom        | Bottom    |
| Abundance, cells × 10^5 cm^-2 |          |           |               |           |
| Average                  | 0.67     | 1.30      | 0.6           | 111.1     |
| min                      | 0.45     | 0.07      | 0.05          | 0.8       |
| max                      | 0.80     | 6.59      | 0.84          | 405.3     |
| CV                       | 0.286    | 2.000     | 0.642         | 1.405     |
| Biomass, mg cm^-2        |          |           |               |           |
| Average                  | 0.06     | 0.143     | 0.13          | 6.57      |
| min                      | 0.009    | 0.038     | 0.01          | 0.002     |
| max                      | 0.14     | 0.400     | 0.20          | 39.25     |
| CV                       | 1.286    | 0.973     | 0.651         | 2.070     |
| Average cell mass in a sample, µg |           |           |               |           |
| Average                  | 7.5 × 10^-7 | 5.2 × 10^-6 | 2.3 × 10^-6 | 1.5 × 10^-7 | 5.03 × 10^-5 |
| min                      | 2.0 × 10^-7 | 6.1 × 10^-7 | 1.8 × 10^-6 | 2.2 × 10^-9 | 7.3 × 10^-8 |
| max                      | 1.7 × 10^-6 | 1.3 × 10^-5 | 3.1 × 10^-6 | 5.3 × 10^-7 | 3.3 × 10^-4 |
| CV                       | 1.276    | 0.844     | 0.231         | 1.406     |

In all other cases, diatoms dominated (Table 5). The composition of the dominant species is also distinguished in different periods (Table 5). In May–June 2018, four diatom species (Navicula sp. 1, Tabularia tabulata, Halamphora coffeiformis, and Grammatophora marina) dominated in different bottom samples, while only two species (T. tabulata and Achnanthes adnata) were dominant in floating mats. In terms of the contribution of various species to the total number of microalgae, the bottom community and the floating mat differed significantly (Table 5). In November 2018, nine species dominated in different samples, and in June 2019 there were eight such species (Table 5). Only one species, H. coffeiformis, was among the dominants in the bottom community during all three studied periods, and only one species, T. tabulate, was in two different periods. A. adnata was the most dominant species in the floating mat in May and the most common species in the bottom community in November 2018.

Table 5. The contribution of the different species in total microalgae abundance and their frequency of dominance in Bay Sivash (2018–2019).

| Species                  | Average Contribution, % | Minimal Contribution, % | Maximal Contribution, % | CV of Contribution | How Many Times Dominated |
|--------------------------|-------------------------|--------------------------|--------------------------|--------------------|-------------------------|
| Achnanthes adnata        | 9                       | 0                        | 28                       | 1.300              | 0                       |
| Cocconeis kujalnitzkensis| 8                       | 0                        | 23                       | 1.265              | 0                       |
| Grammatophora marina     | 13                      | 0                        | 80                       | 2.449              | 1                       |
| Halamphora coffeiformis   | 18                      | 0                        | 86                       | 1.937              | 1                       |
| Mastogloia braunii       | 2                       | 0                        | 11                       | 2.449              | 0                       |
| Navicula menisculus      | 6                       | 0                        | 21                       | 1.590              | 0                       |
| Navicula sp.1            | 27                      | 0                        | 62                       | 0.767              | 3                       |
| Prorocentrum balticum    | 3                       | 0                        | 12                       | 1.728              | 0                       |
| Tabularia tabulata       | 12                      | 0                        | 42                       | 1.210              | 1                       |
Table 5. Cont.

| Species                        | Average Contribution, % | Minimal Contribution, % | Maximal Contribution, % | CV of Contribution | How Many Times Dominated |
|--------------------------------|-------------------------|--------------------------|-------------------------|--------------------|-------------------------|
|                                | May–June 2018, Floating Green Algae Mat |                          |                          |                    |                         |
| Achnanthes adnata              | 20                      | 4                        | 50                      | 0.919              | 1                       |
| Cocconeis kujalnitzkensis      | 18                      | 4                        | 33                      | 0.639              | 0                       |
| Halamphora coffeiformis        | 5                       | 0                        | 7                       | 1.425              | 0                       |
| Navicula sp.1                  | 6                       | 1                        | 16                      | 0.928              | 5                       |
| Tabularia tabulata             | 58                      | 30                       | 83                      | 0.402              | 0                       |
|                                | November 2018, Bottom   |                          |                          |                    |                         |
| Achnanthes adnata              | 34                      | 0                        | 100                     | 1.244              | 3                       |
| Amphitetas antediluviana       | 2                       | 0                        | 20                      | 2.980              | 0                       |
| Ardessonea crystallina         | 4                       | 0                        | 33                      | 3.000              | 1                       |
| Campylodiscus neofastuosus     | 11                      | 0                        | 100                     | 3.000              | 1                       |
| Cocconeis kujalnitzkensis      | 16                      | 0                        | 60                      | 1.477              | 1                       |
| Halamphora coffeiformis        | 5                       | 0                        | 41                      | 3.000              | 1                       |
| Mastogloia braunii             | 6                       | 0                        | 56                      | 3.000              | 1                       |
| Oscillatoria tenuis            | 11                      | 0                        | 98                      | 3.000              | 1                       |
| Prorocentrum balticum          | 9                       | 0                        | 79                      | 3.000              | 1                       |
| Rhopalodia musculus            | 4                       | 0                        | 33                      | 3.000              | 1                       |
| Toxarium undulatum             | 2                       | 0                        | 17                      | 3.000              | 0                       |
|                                | June 2019, Bottom       |                          |                          |                    |                         |
| Achnanthes adnata              | 4                       | 0                        | 14                      | 1.453              | 0                       |
| Amphitetas antediluviana       | 9                       | 0                        | 79                      | 3.000              | 1                       |
| Cocconeis kujalnitzkensis      | 12                      | 0                        | 27                      | 0.907              | 0                       |
| Cocconeis placenta             | 11                      | 0                        | 90                      | 2.821              | 1                       |
| Cocconeis scutellum            | 10                      | 0                        | 65                      | 2.106              | 1                       |
| Grammatophora marina           | 1                       | 0                        | 10                      | 2.435              | 0                       |
| Gyrosigma balticum             | 6                       | 0                        | 50                      | 3.000              | 1                       |
| Halamphora coffeiformis        | 17                      | 0                        | 67                      | 1.658              | 2                       |
| Mastogloia braunii             | 2                       | 0                        | 14                      | 3.000              | 0                       |
| Navicula meniscus              | 3                       | 0                        | 30                      | 3.000              | 0                       |
| Navicula sp.                   | 4                       | 0                        | 29                      | 2.476              | 0                       |
| Nitzschia sigma                | 5                       | 0                        | 43                      | 3.000              | 1                       |
| Nitzschia tenuirostris         | 1                       | 0                        | 10                      | 2.859              | 0                       |
| Nitzschia sp.                  | 3                       | 0                        | 14                      | 2.016              | 0                       |
| Oscillatoria limosa            | 5                       | 0                        | 48                      | 3.000              | 1                       |
| Parlibellus delognei           | 1                       | 0                        | 10                      | 2.537              | 0                       |
| Pleurosigma elongatum          | 3                       | 0                        | 25                      | 3.000              | 0                       |
| Surirella fastuosa             | 1                       | 0                        | 13                      | 3.000              | 0                       |
| Tabularia tabulata             | 4                       | 0                        | 34                      | 2.722              | 1                       |
For all periods, there was a general trend of an increase of the bottom microalgae abundance with salinity, but it was insignificant.

In November 2018, a positive reliable correlation was found between the total number of microalgae and the number of species (R = 0.797, p = 0.005) (Figure 2); however, in other periods such a reliable unambiguous relationship was not noted.

![Figure 2. Dependence of the benthic microalgae abundance on the abundance of their species (Sivash Bay, June 2019).](image)

In May–June 2018 and June 2019, no correlations were observed between the abundance/biomass of benthic microalgae with salinity, the concentrations of TSS, and DOM. In November 2018, a significant positive correlation was noted between the concentration of TSS and the total biomass of algae (R = 0.985, p = 0.0005):

\[ B = 0.584 \times \text{TSS} - 2.992 \]  

where B is the biomass, mg cm\(^{-2}\), and TSS is the concentration of suspended matter, mg L\(^{-1}\).

According to the calculated CV values, the degree of spatial heterogeneity of abundance and biomass was minimal in May–June 2018, and maximal in June 2019 (Table 4). In May, the average cell mass was significantly greater in the mat than on the bottom (p = 0.05), on average by 5.3 times (Table 4).

In the bottom community, the average cell mass significantly changed over time (Table 4), the maximal was in November 2018 (average 15.0 × 10\(^{-2}\) µg), and the minimal in May 2018 (7.5 × 10\(^{-4}\) µg). The average cell size of *A. adnata* (average length 61 µm) was significantly (p = 0.05), at 1.6 times, larger in November 2018 than in the spring–summer months (average length 38.2 µm) (Table 6). For all other species, no significant temporal changes in cell size were observed (Table 6). In May–June 2018, a significant negative relationship between the cell length of *A. adnata* and salinity (R = −0.788, p = 0.005) and DOM concentration (R = −0.807, p = 0.005) was noted, which can be approximated by the following equations:

\[ L = 262.4 - 48.5 \ln (S) \]  

and

\[ L = 119.6 - 16.6 \text{DOM} \]

where L is the average cell length, µm, S is salinity, psu, and DOM is the concentration of DOM, mg L\(^{-1}\).

For other species, some correlations were not found. In November 2018, no correlations between the cell size and the measured environmental factors were revealed. In June 2019, the cell size of *Cocconeis scutellum* was significantly negatively correlated with salinity (R = −0.963, p = 0.02) and DOM (R = −0.901, p = 0.05):

\[ l = 27.7 - 0.7 s \]
and

\[ L = 27.7 - 1.6 \text{DOM} \]  

(14)

At the same time, an opposite pattern was noted for *Cocconeis kujalnitzkensis*, a linear positive correlation with salinity \((R = 0.812, \ p = 0.025)\) and with DOM concentration \((R = 0.744, \ p = 0.03)\):

\[ L = 0.2 \text{S} - 1.2 \]  

(15)

and

\[ L = 9.01 + 4.8 \text{DOM} \]  

(16)

For other species, the influence of these factors on the size was not revealed.

| Table 6. Averages sizes of different microalgae species (Bay Sivash, 2018–2019). |

| Species                              | May–June 2018 | November 2018 | June 2019 |
|--------------------------------------|--------------|---------------|-----------|
|                                      | Bottom       | Mat           | Bottom    | Bottom     | Bottom | Bottom | Bottom | Bottom   |
|                                      | \( L, \mu m \) | \( H, \mu m \) | \( L, \mu m \) | \( H, \mu m \) | \( L, \mu m \) | \( H, \mu m \) | \( L, \mu m \) | \( H, \mu m \) |
| **Ochrophyta**                       |              |               |           |           |        |      |       |        |
| Achnanthes adnata                    | 52.5         | 17.5          | 57.9      | 23.3      | 61.1   | 18.0  | 42.0   | 20.3    |
| Amphitetrus antediluvianus           | –            | –             | –         | –         | 94.0   | 76.0  | 81.0   | 75.0    |
| Amphora macilenta var. maeotica      | –            | –             | –         | –         | 34.0   | 13.0  | –      | –       |
| Amphora ovalis                       | –            | –             | –         | –         | –      | –     | 31.0   | 13.0    |
| Amphora sp.                          | –            | –             | 35.0      | 15.0      | –      | –     | –      | –       |
| Ardissonea crystallina               | –            | –             | –         | –         | 76.0   | 6.0   | 67.0   | 7.0     |
| Campylocnemus neofastuosus           | –            | –             | –         | –         | 93.0   | 76.0  | 97.0   | 83.0    |
| Cocconeis kujalnitzkensis           | 13.8         | 10.6          | 16.8      | 12.1      | 14.3   | 8.3   | 12.8   | 6.7     |
| Cocconeis scutellum                 | –            | –             | –         | –         | –      | –     | 21.0   | 13.5    |
| Cocconeis placentula                | –            | –             | –         | –         | –      | –     | 22.8   | 14.0    |
| Grammatophora marina                | 62.5         | 15.0          | –         | –         | –      | –     | 33.0   | 14.5    |
| Gyrosigma balticum                  | –            | –             | –         | –         | –      | –     | 342.0  | 32.0    |
| Halamphora coffeiformis              | 31.7         | 12.5          | 22.5      | 10.6      | 24.0   | 13.0  | 25.9   | 13.0    |
| Mastogloia braunii                   | 30.0         | 7.5           | –         | –         | 41.0   | 14.0  | –      | –       |
| Navicula meniscus                    | 20.0         | 5.0           | 25.0      | 4.4       | –      | –     | 18.0   | 3.0     |
| Navicula sp. 1                       | 11.8         | 2.7           | 12.5      | 2.7       | –      | –     | 12.0   | 3.0     |
| Navicula sp. 2                       | 10.0         | 2.5           | –         | –         | –      | –     | –      | –       |
| Nitzschia hybrid var. hyalina        | 25.0         | 5.0           | 20.0      | 5.0       | –      | –     | 36.0   | 13.0    |
| Nitzschia sigma                      | –            | –             | –         | –         | –      | –     | 72.0   | 3.0     |
| Nitzschia tenuirostris               | 29.5         | 2.5           | 22.5      | 2.0       | –      | –     | 20.5   | 3.0     |
| Nitzschia sp.                        | 50.0         | 2.5           | –         | –         | –      | –     | 52.0   | 3.5     |
| Odontella aurita                     | –            | –             | –         | –         | –      | –     | 56.0   | 40.0    |
| Parlibellus delognei                 | –            | –             | –         | –         | –      | –     | 26.5   | 6.0     |
| Pleurosigma elongatum                | –            | –             | –         | –         | –      | –     | 319.0  | 34.0    |
| Rhopalodia musculus                  | –            | –             | –         | –         | 34.0   | 31.0  | –      | –       |
| Surirella fastuosa                   | –            | –             | –         | –         | 106.0  | 84.0  | –      | –       |
| Tabularia tabulata                   | 50.3         | 4.0           | 55.0      | 4.1       | –      | –     | 59.0   | 5.5     |
| Toxarium undulatum                   | –            | –             | –         | –         | 583.0  | 67.0  | –      | –       |
Table 6. Cont.

| Species           | Cell Sizes | May–June 2018 | November 2018 | June 2019 |
|-------------------|------------|---------------|---------------|-----------|
|                   | L, µm      | H, µm         | L, µm         | H, µm     | L, µm      | H, µm         | L, µm      | H, µm     |
| **Haptophyta**    |            |               |               |           |           |               |           |           |
| Oolithotus fragilis | 15.0      | 15.0          | –             | –         | –         | –             | –         | –         |
| **Miozoa**        |            |               |               |           |           |               |           |           |
| Prorocentrum balticum | 12.5     | 8.8           | –             | –         | 15.0      | 13.0          | –         | –         |
| **Cyanobacteria** |            |               |               |           |           |               |           |           |
| Oscillatoria limosa | –        | –             | –             | –         | –         | –             | 22.5      | 4.5       |
| Oscillatoria tenuis | –        | –             | –             | –         | 11.0      | 5.0           | –         | –         |

L—cell length; H—cell width.

4. Discussion

A total of 27 species of microalgae were found in hypersaline lakes of Crimea previously (Table 2) [11,21,24]. The calculated similarity coefficients of Jaccard (32%) and Chekanovsky (51%) between species composition in the Crimean hypersaline lakes and that currently found in Bay Sivash turned out to be lower than their critical values. Therefore, it can be concluded that the modern complex of bottom microalgae in Sivash significantly differs from that of the Crimean hypersaline lakes. Of all diatom species found in the Sivash, 71% were also noted in the Sea of Azov (Table 2), while the total number of diatom species in the Sea of Azov is 1085 [28]. The calculated Jaccard’s and Chekanovsky’s indexes gave very small values of similarity, likely due to the number of species found in Sivash being much less than that found in the sea, at 1.5 orders of magnitude. Therefore, one can confidently assert that the species composition in the bay was primarily formed by the Azov–Black Sea species. Before the onset of the salinity increase, 61 species of microalgae were found in Eastern Sivash [28,36], of which only 12 have now been recorded, 31% of the current species richness. In the structure of the microphytobenthos in Eastern Sivash, after a sharp increase in salinity, substantial changes in the microalgal species richness and composition have occurred. The total number of identified species is currently 39, i.e., species richness decreased by 36% after the closure of the canal. A comparison of the lists of species before and after the closure of the canal indicated a significant change in the microphytobenthos species composition. Currently, the most common dominant species are *A. adnata*, inhabiting both the hypersaline lakes of the Crimea and the Sea of Azov, as well as *C. kujalnitzkensis*, only recorded in the hypersaline lakes of Crimea and lagoons of the Northwestern Black Sea (Table 2). Cyanobacteria (more than 100 species) are common components of the microphytobenthos of hypersaline water bodies of Crimea, including those found in Bay Sivash [11,37]. *Calcidiscus leptoporus* (Haptophyta) and *Prorocentrum balticum* (Miozoa) were previously found in the hypersaline lakes of Crimea [24], and in the Black Sea [38].

Several common diatom species in hypersaline waters have a very wide geographic distribution, which indicates the presence of mechanisms for their long-distance transport (winds or birds). For example, *H. coffeiformis*, *Cocconeis placentula*, *Amphora ovalis*, *Mastogloia braunii*, *Nitzschia hybrida*, *Campyldiscus neofastuosus*, and *Tryblionella apiculata*, are common species in the marine and continental hypersaline waters not only in Europe but also in Asia [22,39], North and South America [17–20,40], Australia [41,42], and Africa [43,44]. At the same time, *C. kujalnitzkensis* was previously found, in addition to Crimea, only in hypersaline lagoons of the northwestern part of the Black Sea [45]. Consequently, both narrow/local Azov–Black Sea endemics and cosmopolitans are represented in the composition of common species. The composition of species in the *Cladophora* mats and at
the bottom did not differ, but the number of species in the mats is lower, perhaps due to the mats’ shorter life, their destruction every year in the autumn–winter period and during rare strong storms in summer.

In our case, 15 species were recorded at salinities of 80–90 psu, and 10 species at higher salinities, which contribute 64% of all species found in our study. While it should be noted that 55% of all species were found singularly, some of them may be also highly halotolerant. Numerous studies showed that salinity in the range of 50–150 psu is not the main factor limiting the distribution of a sufficiently large number of benthic microalgae species [46–49]. One of the main mechanisms that allows algae to exist in a hypersaline environment is the release of a significant amount of exosaccharides (EPS) into the environment with the creation of an EPS matrix, in which cells live [50,51].

The noted quantitative development of benthic microalgae was quite high (Table 3), which was previously noted in other hypersaline water bodies of Crimea [21,24] and other regions [15,52]. Moreover, in May 2018, microalgae had a higher average abundance in the mats than on the bottom. The intensive development of microalgae on the Cladophora filaments is a well-known phenomenon and has been shown in different types of water bodies [24]. The highest values of microalgal abundance and biomass in November can be explained by the growth of the microphytobenthos from spring to autumn. The strong autumn–winter storms lead to the destruction of the microphytobenthos, as well as floating mats in the shallow bay, and total abundance, and as a result, the biomass of microalgae drops on the bottom. It should be noted that in June 2019, microalgal abundance and biomass were significantly higher than in May–June 2018, as was the average cell size (Table 3). Probably, to a certain extent, this is due to an increase in salinity during this period: the average salinity in May 2018 was 64 psu (CV = 0.292), in November 2018 it was 74 psu (CV = 0.292), and in June 2019 it was 73 psu. This assumption is consistent with the fact that, in the spatial distribution, the microalgae abundance also may positively correlate with salinity. The dependence of the microalgae abundance on the salinity growth can be partially explained by the fact that with the salinity increase, the number of animals capable of consuming microalgae decreases in the bay [25,26]. A positive relationship between the abundance of bottom microalgae and salinity was also noted for water bodies in other regions [15,48], in particular for Mediterranean lagoons [52,53].

However, it is unlikely that only the salinity increase caused an increase in the number of bottom microalgae in the lagoon. Many characteristics have changed in the bay, for example, the concentration of total suspended matter and dissolved organic matter has increased. The temperature regime and oxygen concentration have also changed in the lagoon, as shown before [27,29]. Some drops of oxygen content occurred due to a decreasing oxygen solubility with a salinity increase, and some increase of temperature may be explained by a decrease of the specific heat capacity of water due to a salinity growth. The significant changes in other biotic components (zooplankton and zoobenthos), including in the macrophyte community, were also recorded here before [27,29]. Powerful thickets of marine grass Zostera, on which epiphyton was massively developed, have disappeared [28], and mats of green filamentous algae Cladophora began to develop intensively [29].

It can be assumed that a sharp increase in salinity destabilized the benthic microalgal community, like other communities in the bay [25–27,29], with a decrease in their species richness and abundance. It is known that usually there is an increase in species diversity, average size, and total number of species in communities during restoration after ecological disasters [54–56]. It can be assumed that the species composition and indicators of quantitative development will stabilize soon after the cessation of salinity growth in the lagoon. Likely the frequent anoxia/hypoxia events occurring now in Sivash do not greatly inhibit this transition to the new stable state because experiments have shown that the microphytobenthos can recover from such events rather quickly [6].
5. Conclusions

Summarizing all the above, the authors can make a general conclusion that salinity in the range from 30 to 150 psu is not the only or main factor that determines the species composition of the microphytobenthos. Other factors (the concentration of total suspended matter, etc.) can play an equally important role. At the same time, quantitative indicators of microphytobenthos development may positively correlate with salinity. This study of the microphytobenthos in Bay Sivash during the period of its salinization is the first, and therefore, it does not provide answers to many interesting questions. The continuation of such studies will make it possible to understand more about the regularities of microphytobenthos transformation during the period of sharp changes in the environment.

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