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Floristic Composition and Taxonomic Structure of Algae in the Hyperhaline Reservoirs of the Northwestern Azov Sea Coast (Ukraine)*

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ABSTRACT: The article represents the results of long-term algological studies of hyperhaline reservoirs of the northwestern coast of the Azov Sea. The features of the floristic composition and taxonomic structure of algae in aquatic (water column and bottom), aquatic-terrestrial (water's edge, dried up water bodies, drying area) and terrestrial (elevated non-flooding areas) habitats of these objects are displayed. A specificity of the studied algoflora lies in the absence of representatives of certain characteristic phyla for the salt-water and non-saline land and water habitats of the territory of Ukraine. It was established that species composition of the studied reservoirs is depleted in comparison with other non-saline and marine ecosystems. Totally, 123 algae species were identified. They represented 7 divisions, 10 classes, 27 orders, 47 families, 68 genera. The largest number of species included three phyla: *Cyanoprokaryota* – 65 species (52.9% of the total number of identified species), *Bacillariophyta* – 26 (21.1%), *Chlorophyta* – 22 (17.9%). The first places among the six leading orders were taken by cyanoprocaryotes from *Oscillatoriales*, *Nostocales*, *Chroococcales* and diatoms from *Naviculales*. The most numerous species at the family level are trichomous cyanoprocaryotes from *Nostocaceae*, *Pseudanabaenaceae*, and *Phormidiaceae*. There were found 23 leading genera – their species richness exceeds the average indicator (1.81 species). According to the results of original studies, it was noted that all taxonomic levels of algoflora of the hyperhaline reservoirs shows features of not only saline habitats, but also of the freshwater, marine and terrestrial extreme ecosystems. Such diversity of the algal population indicates an unstable hydrological regime and complex relations of water exchange between the hyperhaline reservoirs and nearby terrestrial and aquatic habitats.

KEY WORDS: algae, hyperhaline, reservoir, salinity, Azov Sea, coast, peloids

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INTRODUCTION

Peloids is one of the main natural resources that has the practical use in balneology, medicine and recreation. Silt sulphide peloids are the most known in Ukraine. Their formation occurs in salt-water bodies. The most famous deposits in Ukraine are Lake Saki, Sivash, Kuyalnik estuary. At the same time, peloids are also observed in small reservoirs with an unstable hydrological regime (Isachenko, 1951; Vodop'yan, 1970; Gerasimenko et al., 2003; Samylina et al., 2010). Such reservoirs are called amphibial, ephemeral or hyperhaline (Prikhodkova, 1971a, b; Vinogradova, 2006, 2012; Solonenko, 2011a, b, 2012; Zakharov, 2019).

A specificity of the northwestern Azov Sea coast lies in the presence of numerous hyperhaline reservoirs. They are characterized by partial or complete drying out. Salinity of their waters can reach the high values and even a salt crust may appear on the surface of their dried out area. Peloidogenesis in such extreme conditions occurs with an active participation of algal populations (Solonenko et al., 2014, 2015).

Therefore, the aim of our work was to study the species composition and taxonomic structure of algae that participate in the formation of silt sulfide peloids in the hyperhaline reservoirs of the northwestern Azov Sea coast.

MATERIALS AND METHODS

Researches were carried out at 21 sample sites during 1997–2011 during route and stationary studies. The sample sites were located in the northwestern Azov Sea coast on the territory of Donetsk, Zaporizhzhya and Kherson regions (Figure).

FIGURE: Sample sites on the northwestern Azov Sea coast

They included reservoirs of various origin and water regime including the adjacent territories (water edge, dried up water bodies, drying area and elevated non-flooding areas with higher vegetation). In aquatic, water-land and land habitats were sampled 618, 771 and 396 samples, respectively.

The sampling was conducted according to the methods adopted in hydrobiology and soil algology (Abakumov, 1983; Hollebach, Shtina, 1984; Zilov, 2009).

We have used the direct microscopic examination and cultural methods using soil, soil-water and agar cultures to study algae. During cultivation, the main was Bold's Basal Medium with normal and triple nitrogen content (1N BBM and 3N BBM), both with or without extract from the studied soil (Kostikov et al., 2001).

The special guides were used in the identification of algae (Zabelina et al., 1954; Dedusenko-Schegoleva, Hollerbach, 1962; Huber-Pestalozzi, 1962; Ettl, 1978; Matviyenko, Dogadina, 1978; Vinogradova et al., 1980; Kondratyeva, 1984; Moshkova, Hollerbach, 1986; Ettl, Gärtner, 1988, 1995; Komárek, Anagnostidis, 1998, 2000). We use the system, which was described in the monographs *Algae of soils of Ukraine* (Kostikov et al., 2001) and *Algae of Ukraine* (2006, 2009, 2011, 2014) to assess the taxonomic parameters and compile a systematic list of algae, taking into account modern nomenclature changes of species and infraspecific taxa (www.algaebase.org).

RESULTS AND DISCUSSION

As a result of algological studies, there were identified 123 algae species, representing seven phyla: *Cyanoprokaryota* – 65 species, 52.9% of the total species quantity, *Bacillariophyta* – 26 (21.1%), *Chlorophyta* – 22 (17.9%), *Rhodophyta* – 6 (4.9%), *Dinophyta* – 2 (1.6%), *Xanthophyta* and *Cryptophyta* – 1 specie for each (0.8%) (Solonenko et al., 2004, 2005, 2006a, b, 2008, 2010; Iarovyi et al., 2007; Solonenko, Raznopolov, 2007; Yarovyi et al., 2007, 2008, 2017; Cherevko et al., 2008; Solonenko, Yarovyi, 2009a, b, 2011; Solonenko, 2014, 2016; Arabadzhy et al., 2016; Arabadzhy-Tipenko et al., 2019; Bren, Solonenko, 2019; Maltseva et al., 2019). These species belong to 10 classes, 27 orders, 47 families, 68 genera (Table 1).

It was noticed as a specific feature of the algal floristic spectrum that *Phaeophyta* and *Haptophyta* representatives (usual components of marine ecosystems) were absent. There were neither *Chrysophyta* (typical marine and freshwater organisms) nor *Euglenophyta* species (widely represented in fresh continental water bodies). No findings of *Eustigmatophyta*, the permanent algofloral component in soils of the temperate zone. Thus, algal flora of the studied territories of the northwestern Azov Sea coast has a combined variant, markedly depleted in the number of species and phyla.

The uniqueness of the studied algoflora is even more clearly traced by systematic structure at the level of orders (Table 2). The first places among the six leading ones were taken by cyanoprocaryotes from *Oscillatoriales*, *Nostocales*, *Chroococcales* and diatoms of *Naviculales*.

TABLE 1: The systematic structure of algae of the sample sites of the northwestern Azov Sea coast

Division	Number, units				
	classes	orders	families	genera	species*
Cyanoprokaryota	1	3	11	28	65 (52.9)
Xanthophyta	1	1	1	1	1 (0.8)
Bacillariophyta	2	10	15	17	26 (21.1)
Dinophyta	1	1	1	1	2 (1.6)
Cryptophyta	1	1	1	1	1 (0.8)
Rhodophyta	1	2	3	4	6 (4.9)
Chlorophyta	3	9	15	16	22 (17.9)
Total	10	27	47	68	123

* For species in parentheses indicate their percentage within the phyla in relation to the total number of the found ones on all sample sites.

TABLE 2: The leading orders of algoflora on the sample sites of the northwestern Azov Sea coast

Position	Order	Quantity of taxons
1	*Oscillatoriales*	35
2	*Nostocales*	19
3–4	*Chroococcales*	11
3–4	*Naviculales*	11
5–6	*Ulvales*	5
5–6	*Ceramiales*	5
Totally in orders		91

The last positions in the list of leading orders have taken the green and red algae (*Ulvales*, *Ceramiales*), which are usually among the leading ones in the algoflora of various fresh and brackish water bodies (Starmach, 1995; Aliya et al., 2009; Gromov, 2012).

The orders *Chlorococcales*, *Chlorellales* are leading in soil algal flora of zonal and halophilic types of vegetation in Ukraine. They are also present in the studied biotopes, however, but not among the leading ones. Such orders as *Mischococcales*, *Protosiphonales* are absent (Kostikov, 1991). In general, the leading orders unite 91 algae species (74.6% of the total species number).

Thus, the structure at the orders level determines the unique halophilic nature of the algoflora of the studied habitats and confirms the presence of inherent traits for freshwater, soil halophilic and marine algal groups.

Algoflora of the studied polygons is represented by 11 families, which include 77 species of algae, (62.6% of the total species number). The most part of them are multicellular cyanoprokaryotes from the families *Nostocaceae*, *Pseudanabaenaceae* and *Phormidiaceae* (Table 3). All these families are components of the soil algoflora of the steppe, dry-steppe and desert-steppe zones (Novichkova-Ivanova, 1980; Topachevsky, Masyuk, 1984; Kostikov et al., 2001).

TABLE 3: Leading families of the algal flora of the sample sites of the northwestern Azov Sea coast

Position	Family	Species quantity	% of total species quantity
1	*Nostocaceae*	18	14.6
2	*Pseudanabaenaceae*	16	13
3	*Phormidiaceae*	8	6.5
4	*Oscillatoriaceae*	7	5.7
5–7	*Ulvaceae*	5	4.1
5–7	*Merismopediaceae*	5	4.1
5–7	*Naviculaceae*	5	4.1
8	*Ceramiaceae*	4	3.3
9–11	*Chamaesiphonaceae*	3	2.4
9–11	*Schizotrichaceae*	3	2.4
9–11	*Bacillariaceae*	3	2,4
Totally species families		77	62.6
Total number of species		123	100

Most part of the cyanoprokaryotes have mucous sheaths. These structures are composed of hydrophilic colloidal polysaccharides and able to absorb and retain quickly large amounts of water. Such adaptive feature allows to withstand the drought and to counteract the physiological water deficit due to the high salt concentration. Such fact complies with the data of scientific publications about the dominance of these cyanoprocaryotic families in saline soils and in amphibial ecotopes with periodical salt-water flood (Vinogradova, 2012).

There were 23 leading genera on the territory of the northwestern Azov Sea coast – their species richness exceeded the average value (1.81 species). Here is a row of the leading ones in descending order: *Leptolyngbya* – 11 species (9.0% of the total number of species), *Nostoc* – 8 (6.6%), *Navicula*, *Anabaena*, *Ulva* – 5 species for each (4.1%)), *Phormidium* and *Oscillatoria* – 4 species for each (3.3%), *Trichormus*, *Pseudanabaena*, *Schizothrix*, *Ceramium* – 3 (2.5%), *Amphora*, *Chlorella*, *Cocconeis*, *Craticula*, *Dunaliella*, *Gyrosigma*, *Lyngbya*, *Merismopedia*, *Nitzschia*, *Nodularia*, *Spirulina*, *Ulothrix*, and *Prorocentrum* – 2 species for each (1.6%).

It is possible to determine the role of algal representatives of various biomes in formation of algal flora of the studied polygons by composition of the leading genera: marine ecosystems (*Ulva*), hyperhaline reservoirs (*Dunaliella*), terrestrial biotopes (*Chlorella*). The significant role have genera (especially from the *Cyanoprokaryota* and *Bacillariophyta*) which combine species with a wide ecological amplitude (Zabelina et al., 1954; Dedusenko-Schegoleva, Hollerbach, 1962; Huber-Pestalozzi, 1962; Matviyenko, Dogadina, 1978; Vinogradova et al., 1980; Kondratyeva, 1984; Moshkova, Hollerbach, 1986; Komárek, Anagnostidis, 1998, 2000; Barinova et al., 2006).

It should be noted that silt sulfide peloids were noticed on the researched sample sites (hyperhaline reservoirs, their dried up beds, water edge). Formation of these sediments occurs in presence and by means of algal population.

Probably, a special role is assigned to those species that are capable of biomass increasing. Such organisms form macroscopic growths on the bottom of reservoirs and causing “flowering” in the water column. The main limiting abiotic factors in hyperhaline reservoirs are the water regime and water salinity. These factors regulate the presence and quantity of such species and their algal communities.

CONCLUSIONS

1. There were identified 123 algae species in hyperhaline reservoirs of the northwestern Azov Sea coast. These species were the representatives of seven phyla: *Cyanoprokaryota* – 65 species (53%), *Bacillariophyta* – 26 (21%), *Chlorophyta* – 22 (18%), *Rhodophyta* – 6 (5%), *Dinophyta* – 2 (2%), *Xanthophyta* and *Cryptophyta* – 1 species for each (1%).

2. The algal species composition of the studied sampling sites is depleted comparing with freshwater and terrestrial biotopes of the steppe zone of Ukraine. Our research shows

the absence of typical phyla for the algoflora of Ukraine such as: *Phaeophyta, Haptophyta*, *Chrysophyta*, *Euglenophyta*, *Eustigmatophyta* representatives.

3. The prevailing groups of algae of hyperhaline reservoirs of the studied territories are trichomous and unicellular cyanoprokaryotes (52.9% of the total number of species). Green and diatoms (17.9% and 21.1%, respectively) also make a very significant contribution to the species richness.

4. The taxonomic spectrum at the phyla level and at lower levels indicates that studied algoflora has a combined character and has the features of freshwater, marine and terrestrial halophilic algal communities. Such a paradoxical diversity of representatives of various habitats indicates the unstable hydrological regime for the coastal hyperhaline reservoirs and the presence of water exchange with adjacent habitats.

5. There were found deposits of silt sulphide peloids in the studied hyperhaline reservoirs (in their dried out beds and along the edge of the water). Participants of peloidogenesis are algae species, which are capable to increase significantly biomass and to exist even in drought and high salinity conditions.

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