International Journal on Algae

VOLUME 21, ISSUE 4 2019

Solomon P. Wasser
Editor-in-Chief

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New York • Connecticut

International Journal on Algae, 2019, 21(4): 299–310

Cyanoprokaryota of the Salt Marshes at the Pryazov National Natural Park, Ukraine*

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ABSTRACT: *Cyanoprokaryota* of salt marshes were investigated at three scientific sites: in the upper Utlyuk Estuary, on the coast of Lake Sivashik, and at Fedotov Spit. Data on species composition, systematic structure, leading families, and genera are provided. In total, 71 species of cyanoprokaryotes representing 3 orders, 10 families, and 22 genera. The dominant complex included representatives of the genera *Schizothrix* Kützing ex Gomont, *Phormidium* Kützing ex Gomont, *Lyngbya* C.Agardh ex Gomont, *Leptolyngbya* (Gomont) Anagnostidis & Komárek, *Trichormus* (Ralfs ex Bornet & Flahault) Komárek & Anagnostidis, *Nostoc* Vaucher ex Bornet & Flahault, and *Nodularia* Mert. ex Born. & Flah. The identified species are analyzed for their biotopic nature and their valence to the level of environmental salinity. The distribution of the identified species within the Ukrainian territory is considered.

KEY WORDS: *Cyanoprokaryota*, salt marshes, Lake Sivashik, Fedotov Spit, Utlyuk Estuary

INTRODUCTION

The Pryazov National Natural Park (hereinafter referred to as the PNNP) is a nature conservation institution that ranks second among other national parks in Ukraine (78126.92 ha). The territory of the institution is located within the Prisivasko-Pryazovsky physical-geographical region (Yakimovsky, Melitopol, Pryazovsky, and Berdyansk districts of Zaporizhzhya Region).

The landscape feature of the PNNP is due to the maritime location and dynamics of the coastal strip (Barabokha et al., 2012). The territory of the park is evenly distributed and includes valuable nature conservation areas, namely: part of the water area of Lake

* Originally published in *Algologia,* 2019, 29(4), pp. 463–477 ISSN 1521–9429

Sivashik, with some salt marshes, Fedotov Spit as the coast of the lower part of the Utlyuk Estuary and the upper part of the Utlyuk Estuary (the mouth part of the river of Little and Big Utlyuk. The northern-western Pryazov'ya' saltines are important in the functioning and conservation of biodiversity and have a special algocomponent.

In the Ukrainian territory, algae studies of extracurricular habitats have been carried out since the second half of the 20th century (Kondratyeva, 1959, 1962; Prikhodkova, 1969a–c, 1971, 1974, 1992; Prikhodkova and Vinogradova, 1988). The beginning of the century was marked by a number of algologists of the N.G. Kholodny Intitute of Botany, NAS of Ukraine (Vinogradova and Darienko, 2008; Vinogradova, 2012). Begining in 2002, the species composition of algae in the steppe zone of Ukraine have been studied by algalogists of the Bogdan Khmelnytsky State Pedagogical University (Maltseva, 2004; Solonenko et al., 2004–2006; 2009a, b, 2010; Yarovoi et al., 2005a, b, 2007a, b, 2008a, b, 2011, 2012a, b; Bren, 2009; Solonenko and Yarovyi, 2009a, b; Arabadzhy-Tipenko, 2016, 2018a–c; Yarovyi et al., 2017), but no specific study of the species composition of *Cyanoprokaryota* was performed. Therefore, the aim of our work was to study the species composition of *Cyanoprokaryota* salt marshes of Lake Sivashyk, the lower and upper reaches of the Utlyuk and lower Milk Estuaries (Fedotov and Stepanovskaya spits, respectively) within the territory of the PNNP.

MATERIALS AND METHODS

Salt-water algae were studied during 2014–2018. Soil samples were sampled at 9 test sites within 3 study sites in the PNNP – on the coast of the Utlyuk Estuary (at the top at the mouth of the rivers Little and Big Utlyuk and below on the Fedotov Spit) and on the shore of Lake Sivashik (Fig. 1).

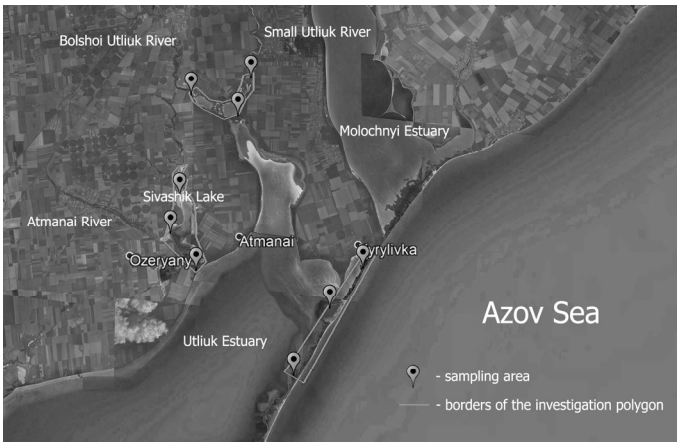

FIG. 1: Map-scheme of the study area

A total of 50 soil-algological samples were selected and investigated. The selection of the material was performed according to the standard methodology in soil algology, following the rules of sterility (Arce and Bold, 1958; Hollerbach and Shtina, 1969). Commercial processing of the material was carried out using culture methods, in three types of crops: 1) soil with fouling glasses, 2) agar on nutrient media Bold with normal, and triple the amount of nitrogen (1N BBM and 3 NBBM respectively), 3) soil (Kuzyakhmetov and Dubovik, 2001).

Pure algae were isolated to identify some species (Kostikov et al., 2001). In total, 22 pure cultures were stored in the laboratory of algaecological studies of terrestrial and aquatic ecosystems in the Department of Botany and Landscape Management of Melitopol Bogdan Khmelnytsky State Pedagogical University for the purpose of further molecular genetic studies.

Studies of algae cultures were performed using a stereoscopic microscope MBS-1, light binocular microscope Biolam P-14 and MICROmed XS-5520 using zoom lenses: $8^{\times}$, $20^{\times}$, $40^{\times}$, $90^{\times}$, $100^{\times}$.

The identification of algae was performed by domestic and foreign determinants (Hollerbach et al., 1953; Topachevskiy and Oksiyuk, 1960; Kondratyeva, 1968, 1984; Ettl, 1978; Ettl and Gantner, 1988, 1995; Komárek and Anagnostidis, 1999, 2005; Kovalenko, 2009). Names and volumes of divisions, classes, orders, families, genera, and species are given in accordance with the system adopted in the monograph: Kostikov et al., 2001, with updating on the summary Algae..., 2006, 2009, 2011, 2014 and taking into account the current nomenclature changes of individual species and intraspecific taxa (www.algaebase.org). The analysis of ecological characteristics of the species (biotopic timing and ecological valence in relation to the salinity level) was determined according to the monograph: Vinogradova, 2012.

Dominants were attributed to species with 100% incidence within one study site and with a relative number of 4 and 5 points («many» and «very many») on the Starmach scale (Starmach, 1955, cit. by Topachevskiy and Massjuk, 1984). Leading genera, families, and orders included taxa of different ranks that exceeded the mean value.

RESULTS AND DISCUSSION

The research revealed 71 species of *Cyanoprokaryota*, which were from 3orders, 10 families, and 22 genera (Table).

Species diversity was represented by the order *Oscillatoriales*, which included 5 families, 12 genera, and 44 species, and the *Nostocales* order: 2 families, 5 genera, and 20 species. The most abundant species rich were mostly represented by *Phormidiaceae, Nostocaceae, Pseudanabaenaceae* – 21, 18, and 15 species, respectively. The families

Oscillatoriaceae, *Synechococcaceae*, *Merismopediaceae*, *Chroococcaceae*, *Borziaceae*, *Schizotrichaceae*, and *Rivulariaceae* were less diverse. Five genera whose species richness was above the average were – 3: *Phormidium*, *Leptolyngbya*, *Nostoc*, *Trichormus*, *Anabaena* Bory ex Bornet & Flahault.

TABLE: The occurrence of *Cyanoprokaryota* species within the study sites

Taxon	Fedotov Spit	The upper reaches of the Utlyuk Estuary	Shore of Lake Sivashik
Aphanothece bachmannii Komárková-Legnerová & Cronberg 1994		+	
A. utahensis Tilden 1898		+	
Aphanocapsa salina Woron. 1929	+	+	
Gomphosphaeria salina Komárek & Hindák 1988			+
Gloeocapsopsis crepidinum (Thur.) Geitler ex Komárek 1993	+	+	
Chroococcus cohaerens (Brébisson) Nägeli 1849			+
C. pulcherrimus Welch 1965			+
Komvophoron minutum (Skuja) Anagnostidis & Komárek 1988			+
Schizothrix arenaria Gomont 1892	+	+	
S. coriacea Gomont 1892	+	+	+
Psedanabaena mucicola (Naumann & Hub.-Pest.) Schwabe 1964	+		
P. galeata Böcher 1949	+		
P. limnetica (Lemmerm.) Komárek 1974	+		
Planktolyngbya limnetica (Lemmerm.) Komarkova-Legnerova & Cronberg 1992	+		
Leptolyngbya amplivaginata (Goor) Anagnostidis & Komárek 1988	+	+	+
L. foveolara (Gomont) Anagnostidis & Komárek 1988	+	+	
L. fragilis (Gomont) Anagnostidis & Komárek 1988	+		+
L. frigida (Fritsch) Komárek & Anagnostidis 1988	+		
L. halophila (Hansgirg ex Gomont) Anagnostidis & Komárek 1988	+		+
L. lagerheimii (Gomont ex Gomont) Anagnostidis & Komárek 1988	+	+	
L. laminosa (Gomont) Anagnostidis & Komárek 1988			+
L. nostocorum (Bornet ex Gomont) Anagnostidis & Komárek 1988	+	+	
L. perelegans (Lemmerm.) Anagnostidis & Komárek 1988	+	+	
L. tenuis (Gomont) Anagnostidis & Komárek 1988			+
L. valderiana (Gomont) Anagnostidis & Komárek 1988		+	+
Phormidium ambiguum Gomont ex Gomont 1892		+	
P. autumnale Gomont 1892	+	+	+

Phormidium corallinae (Gomont ex Gomont) Anagnostidis & Komárek 1988	+	+	
P. corium Gomont 1892	+		
P. formosum (Bory ex Gomont) Anagnostidis & Komárek 1988	+	+	+
P. laetevirens (P.Crouan & H.Crouan ex Gomont) Anagnostidis & Komárek 1988	+		
P. lloydianum (Gomont) Anagnostidis et Komárek 1988		+	
P. lucidum Kütz. ex Gomont 1892	+		
P. molle Gomont 1892	+	+	+
P. okenii (C.Agardh ex Gomont) Anagnostidis & Komárek 1988	+	+	+
P. papyraceum Gomont ex Gomont 1892	+	+	+
P. paulsenianum J.B.Petersen 1930	+	+	+
P. retzii Kütz. ex Gomont 1892	+	+	+
P. subfuscum Kütz. ex Gomont 1892			+
P. subuliforme Gomont 1892	+	+	
P. tergestinum (Kützing) Anagnostidis & Komárek 1988		+	
P. uncinatum Gomont ex Gomont 1892		+	
Symploca muscorum Gomont ex Gomont 1892	+	+	
Symplocastrum friesii (Gomont) Kirchn. 1898	+		
Hydrocoleum homoeotrichum Kütz. ex Gomont. 1892		+	
Microcoleus chthonoplastes Thur. ex Gomont 1892	+		
Oscillatoria salina Biswas 1926		+	
O. tenuis C.Agardh ex Gomont 1892		+	
Lyngbya aestuarii Liebman ex Gomont 1892	+	+	+
L. salina Kützing ex Starmach 1966	+	+	
L. semiplena J.Agardh ex Gomont 1892	+	+	
Calothrix elenkinii Kossinsk. 1924	+		
C. fusca (Kütz.) Bornet et Flahault		+	
Anabaena bergii Ostenf. f. *minor* (Kisselev) Kossinsk. in Elenkin 1938		+	
A. bergii Ostenf. 1908			*
A. cylindrica Lemmerm. 1896		+	
A. solicola N.V.Kondrat. 1959			+
Trichormus khannae (Skuja) Komárek & Anagnostidis 1989	+		
T. propinquus (Setch. et Gardner) Komárek & Anagnostidis 1989	+	+	
T. thermalis (Vouk) Komárek & Anagnostidis 1989	+	+	+
T. variabilis (Kütz. ex Bornet et Flahault) Komárek & Anagnostidis 1989	+		
T. pseudovariabilis (Woron.) Komárek & Anagnostidis 1989	+		
Nodularia harveyana Thur. ex Bornet & Flahault 1886	+	+	+
N. spumigena Mert. ex Bornet & Flahault 1888	+	+	+
Nostoc commune Vaucher sensu Elenkin 1931		+	
N. edaphicum N.V.Kondrat. 1962	+		+
Nodularia linckia f. *terrestris* (Roth.) Born. & Flah. Elenkin 1938	+		+
N. linckia (Roth.) Born. & Flah. 1880	+	+	

Nodularia microscopicum Carmich. sensu Elenkin 1949	+		
N. paludosum Kütz. ex Bornet & Flahault 1886	+	+	+
N. punctiforme (Kütz.) Hariot.1891			
Total	47	43	29

The richest *Cyanoprokaryota* species were found in the Fedotov Spit salons. Forty-seven species of blue-green algae were identified. Representatives of the families were dominated by: *Schizotrichaceae*, *Pseudanabaenaceae*, *Phormidiaceae*, *Oscillatoriaceae*, *Nostocaceae*: *Schizothrix arenaria*, *Schizothrix coriacea*, *Phormidium paulsenianum*, *Lyngbya aestuarii*, *L. semiplena*, and *Leptolyngichum nocidaida frigidausocularida*. The salt marshes of the upper Utlyuk Estuary were less diverse. Only 43 species were found here. The dominant species were: *Schizothrix arenaria*, *S. coriacea*, *Leptolyngbya nostocorum*, *Phormidium paulsenianum*, *Trichormus thermalis*, and *Nostoc linckia*. Species composition of *Cyanoprokaryota* were depleted in the salt marshes of Lake Sivashik; only 29 species were found. Representatives of the families *Schizotrichaceae, Phormidiaceae, Nostocaceae*: *Phormidium paulsenianum*, *Nostoc linckia* f. *terrestris*, *N. paludosum*, *N. paludosum*, *Nodularia spumigena*, *N. harveyana*, *Schizothrix arenaria*, *S. coriacea*, and *Trichormus thermalis* dominated.

Macroscopic growths of *Cyanoprokaryota* algae on the soil surface were repeatedly observed in saline areas of the studied territories. This phenomenon is one of the essential features of such natural complexes and was repeatedly discovered by researchers both on the soils of the Northwest Azov and beyond these territories (Novichkova-Ivanova, 1980; Maltseva, 2004; Solonenko et al., 2004–2006, 2009a, b, 2010; Yarovoi et al., 2005, 2007a, b, 2008a, b, 2011, 2012a, b; Bren, 2009; Vinogradova, 2012; Arabadzhy-Tipenko, 2016, 2018a–c; Yarovyi et al., 2017). The predominant species of algae were the dominant algae species, which accordingly had the highest relative abundance rates: *Schizothrix arenaria*, *S. coriacea*, *Phormidium paulsenianum*, *Trichormus thermalis*, *Nodularia spumigena*, *N. harveyana*, *Nostoc paludosum*, *N. linckia*, *Lyngbya aestuarii*, *L. semiplena*, *Leptolyngbya nostocorum*, and *L. frigida*.

In order to more fully identify the specificity of the salt marshes of this region, we conducted an analysis of the distribution of algae species found in different physical and geographical zones of Ukraine (Kostikov et al., 2001; Algae…, 2006; Vinogradova, 2012). It turned out that 32 species (45.1% of the total number of algae species detected by us) were recorded in all physical and geographical zones of Ukraine. This indicates a certain degree of commonality of the partial flora of the southern part of Ukraine and its other territories. The largest number – 60 species (84.5%) already noted in the Steppe zone of Ukraine are typical of this natural zone.

According to the analysis of the biotopic timing of the cyanoprokaryotic species found, the vast majority belong to the aqua-terrestrial group – 33 species (46.5%). The second largest group of aquatic species was 29 species (40.9%). The territorial group is represented by the smallest number – 11 species (15.5%) (Fig. 2).

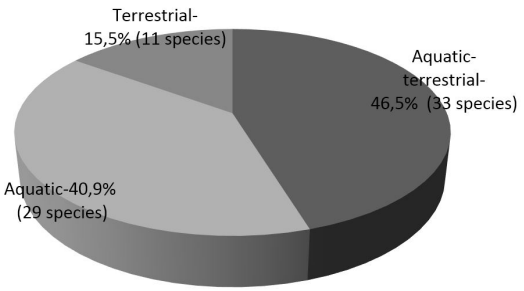

FIG. 2: Distribution of identified *Cyanoprokaryota* species by groups by biotopic timing

The predominance of the aqual-terrestrial group indicates a variable regime of watering-drying, which is typical for saline biotopes of the Ukrainian Black Sea and Pryazov'ya, and the high number of aquatic species indicates the immediate closeness of sampling points to water bodies and the prominent role of water bodies in the formation of the biota composition of the territory.

Cyanoprokaryota, depending on their ability to survive in saline biotopes, are divided into halotolerant species (0–30‰), halobionts (existence at high – 31–60‰, and very high content of salts in the environment – 70–330‰) and halophiles (species that tend to saline habitats) (Vinogradova, 2012). For species characteristic of terrestrial and aquatic-terrestrial biotopes, ecological valence to different levels of environmental salinity is presented (see below).

Groups of *Cyanoprokaryota* species in relation to the salinity of the medium: **halotolerants** – *Anabaena cylindrica*, *Calothrix elenkinii*, *Chroococcus cohaerens*, *Leptolyngbya foveolara*, *L. tenuis*, *L. valderiana*, *Nostoc commune*, *N. edaphicum*, *N. linckia* f. *terrestris*, *N. microscopicum*, *N. paludosum*, *N. punctiforme*, *Phormidium ambiguum*, *P. formosum*, *P. paulsenianum*, *Schizothrix arenaria*, *Symploca muscorum*, *Symplocastrum friesii*, *Trichormus variabilis*; **halobionts** – *Aphanothece utahensis*, *Gomphosphaeria salina*, *Leptolyngbya fragilis*, *Microcoleus chthonoplastes*, *Phormidium molle*; **halophiles** – *Anabaena solicola*, *Gloeocapsopsis crepidinum*, *Lyngbya aestuarii*.

Species composition analysis by the valence of each species to the level of the medium salinity let to reveale a group of terrestrial *Cyanoprokaryota* most typical for the salt marshes of the northern-western Pryazov'ya. The group included 27 species: halotolerants –

19, halobionts – 5, and halophiles – 3 species. These species are typical of saline terrestrial habitats, demonstrating different incidence rates and abundance scores on the study sites that corresponded to values from «few» to «very many».

Thus, the identified complex of cyanoprokaryote species of the studied polygons represents a specific biotic component of the natural ecosystems of the Steppe zone and is much less characteristic of other physical and geographical zones of Ukraine. The reasons for such distribution may be related to the conditions of existence, in particular, the biotopic identity of the species found and the possibility of existence in the aquatic-terrestrial biotopes of the coastal coast of the Steppe zone of Ukraine.

CONCLUSIONS

1. According to the results of the study of salt marshes within 71 polygons, 71 species of *Cyanoprokaryota*, from 3 orders, 10 families, and 22 genera have been found in the territory of PNNP. The largest species diversity was observed in saline soils of Fedotov Spit – 47 species. There are 43 and 29 species, respectively, found in landfills within the upper reaches of the Utlyuk Estuary and Lake Sivashik.
2. The following taxa were found to be the leading sites in the study sites: the order *Oscillatoriales* (12 genera and 44 species); families *Phormidiaceae* (21 species), *Nostocaceae* (18), *Pseudanabaenaceae* (15 species); genera *Phormidium* (17 species), *Leptolyngbya* (11), *Nostoc* (7), *Trichormus* (5), *Anabaena* (4).
3. Representatives of the genera *Schizothrix, Phormidium, Lyngbya, Leptolyngbya, Trichormus, Nostoc,* and *Nodularia* were included in the dominant complex. Dominant species were significantly larger in number than other species, gaining «many» and «very many» on a relative abundance scale. The occurrence of these species in the salt marshes of each individual study site was 100%.
4. The distribution of identified species across the territory of Ukraine indicates that the majority of identified species (84.5% of the total number of species) were repeatedly noted in the Steppe zone of Ukraine, while 45.1% of the total numbers of detected cyanoprokaryotes were recorded in all physical and geographical zones of Ukraine.
5. According to the biotopic analysis, most of the cyanoprokaryotic species identified belong to the aqua-terrestrial group (33 species, 46.5% of the total species) of the aqual group (29 species, 40.9%), which is explained by the variable hydrological regime of saline biotopes – northern-western Pryazov'ya and significant influence of moisture and water periods on the formation of the biota.

6. An analysis of species composition by valence to the level of environmental salinity revealed a group of terrestrial cyanoprokaryotic species specific to the northern-western Pryazov'ya. The group included 27 species which were comprised of halotolerants – 19, halobionts – 5, and halophiles – 3 species.

ACKNOWLEDGMENTS

The authors thank S.A. Yarovoi for advice in preparing the article.

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