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Terrestrial algae of hypersaline environments of the Central Syvash islands (Kherson Region, Ukraine)*

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Abstract: In hypersaline environments of the Churiuk and Kuyuk-Tuk islands located in Central Syvash lagoon (Ukraine) 93 species of oxygenic phototrophs (49 Cyanoprokaryota, 29 Chlorophyta, 12 Bacillariophyta, 2 Xanthophyta, 1 Streptophyta, 1 Eustigmatophyta) are recorded. The sites studied represent four basic types of habitats: semi-terrestrial ecotone (littoral heavy-loam solonchak free of vascular plants), wet gleyic solonchak covered by sparce halophytic vegetation, gleyic solonetz under saline meadow vegetation, and chestnut solonetzic soil with *Steppa salsuginosa* formation. They differ in the taxonomic composition and species diversity of algae. The highest species diversity is observed at sites of wet gleyic solonchaks (71 species of five divisions), the lowest diversity (23 species belonging to three divisions) in the harsh littoral ecotone. The distribution and abundance of species in the four habitats are discussed with reference to their ecology. Descriptions and original drawings of noteworthy taxa of Chlorophyta and Xanthophyta are presented.

Key words: oxygenic phototrophs; diversity; hypersaline environments; Syvash; *Radiosphaera negevensis* var. *minor; Chlorosarcinopsis arenicola; Leptosira erumpens; Dilabifilum arthropyreniae; Pseudendoclonium printzii; Gloeobotrys* sp.; *Capitulariella radians*

Introduction

Hypersaline ecosystems are the striking examples of extreme environments, where organisms exist on the edge of biological limits (Oren & Seckbach 2001). Phototrophic biota found in aquatic and terrestrial habitats with high salt concentrations include representatives of both the bacterial and the eukaryotic domains. Cyanobacteria make a principal contribution to the primary production in these environments and they often determine their biological properties, but eukaryotic algae (mostly chlorophytes and diatoms) inhabit them as well (Borowitzka 1981; Gilmour 1990; Oren 2002). However, data on the species diversity of algae found in hypersaline environments are still incomplete and are mainly focussed on benthic mat communities in hypersaline lagoons, coastal salterns and inland hypersaline lakes (An 1992; Bauld 1981; Campbell & Golubic 1985; Cohen 1984; Oren 2000; Post 1981; Rothschild et al. 1994; Zavarzin et al. 1993). Edaphic phototrophs inhabiting solonchaks and other types of strongly saline soils are even less investigated (Novichkova-Ivanova 1980; Komaromy 1984; Prikhodkova 1992; Kirkwood & Henley 2006).

The Azovo-Syvashsky National Nature Park (ASNNP) in the south of Ukraine (Kherson Region) protects the largest in Central Europe area of hypersaline (50–300 ‰) lagoons and salt flats of thalassic origin. The Central Syvash ecosystem (45°42′ N, 33°38′ E) occupies about 49,000 hectares including water area and numerous small islands. It is the hottest and most arid region of Ukraine. The climate is moderately continental with hot summers and relatively short winters with infrequent snow cover; the annual precipitation is about 260 mm and summer droughts are common. Syvash is a sea gulf of the lagoon type, which was formed as a result of epeirogenic depression and inundation of lowlands by sea water. The depth of Syvash does not exceed 1.0–1.5 m, and is in average around 30–40 cm. In summer-autumn, as well as during periods when water is removed due to strong winds, large areas of Central Syvash turn to subaerial flats covered by salt deposits. The Syvash islands have a natural origin and became separated from the mainland as a result of the of sea current and wind erosion. Churiuk and Kuyuk-Tuk are the elongated, flat loess islands, which are divided into separate strips by numerous bays. Their soil cover is formed by chestnut middle and strongly solonetzic soils together with solonetz and grass solonchaks. Littoral ecotone is free of vascular plants; higher places are covered by salt marsh, salt meadow and salt steppe vegetation (Andriyenko et al. 1999).

Information about the algal diversity in the Syvash lagoon has been summarized in a number of publica-

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Table 1. Taxonomic composition of algae (in %) in hypersaline environments of the Central Syvash islands (Ukraine). Main habitat types: I – littoral heavy-loam solonchak without vascular plants; II – wet gleyic solonchak with true halophytic vegetation; III – gleyic solonetz with saline meadow vegetation; IV – chestnut solonetzic soil with saline steppe.

Taxon	Main Habitat Type				Ecological occurrence			Relative contribution to diversity
	I	II	III	IV	edaphic	epigeic	aerophytic	
Cyanoprokaryota	56.5	57.7	58.1	38.9	66.7	50.0	38.5	52.7
Bacillariophyta	3.4	11.3	16.3	11.1	12.3	12.9	15.4	12.9
Eustigmatophyta	–	1.4	–	5.6	1.8	1.4	–	1.1
Xanthophyta	–	2.9	2.3	5.6	1.8	2.9	7.7	2.1
Chlorophyta	39.1	25.3	21.0	33.3	15.7	31.5	30.8	30.1
Streptophyta	–	1.4	2.3	5.6	1.8	1.4	7.7	1.1
Total	100	100	100	100	100	100	100	100
Species number	23	71	43	18	57	70	13	93

tions (sumarized in Tsarenko et al. 2006). The algae of the solonchaks and strongly saline soils adjacent to Syvash have been studied by Prikhodkova (1969, 1989, 1992), Solonenko (1993) and Iarovyi et al. (2007). However, the algal diversity of the Syvash islands has not been studied before. The aim of our research was to assess the species diversity of algae in hypersaline environments of the Churiuk and Kuyuk-Tuk islands and to study their occurrence and distribution.

Material and methods

Material (soil and biological crusts) was collected in July 2005 from 29 sites situated on the Churiuk and Kuyuk-Tuk islands in central Syvash. Sampling sites were located across gradients of salinity and humidity, starting from the moist loamy littoral located at the lowest parts of the islands to the highest, most driest parts of islands. They represent four basic types of habitats:

I. littoral heavy-loam solonchak free of vascular plants (9 sites);

II. wet gleyic solonchak covered by sparse halophytic vegetation (formations of *Salicornieta*, *Suaedeta*, *Halocnemeta strobilacei* and *Halimioneta verruciferae*, 10 sites);

III. gleyic solonetz under saline meadow vegetation (*Puccinellieta* and *Aeluropeta litoralis* formations; 6 sites) and

IV. four sites of chestnut solonetzic soil with *Steppa salsuginosa* formation.

Cyanoprokaryota and eukaryotic algae formed visible crusts and films on the soil surface of most sites. Sampling included epigeic crusts and films, combined soil samples (10 individual soil samples of approximately 1 cm^3 randomly taken from each site and mixed together) and samples of aerophytic origin (collected on mosses on the roof of lodge). All samples were kept in sterilized paper envelopes. A total of 49 samples were studied (27 epigeic, 20 soil and 2 aerophytic).

In the laboratory, particles of soil and algal crusts/films were aseptically placed in Petri dishes with fresh agarized medium (K_2HPO_4 – 0.2 g; $MgSO_4$ – 0.2 g; $CaCl_2$ – traces; $FeCl_3$ – traces, H_2O dest. – 1000 mL, agar 1%, pH 7.8). For the detection of all species, which were present in our samples, cultures were observed several times over a period of five months starting from the first appearance of algal growth. Critical taxa of eukaryotic algae were isolated into unialgal cultures to study their life cycles in detail. For this purpose 1.5% agarized 3N BBM (Ettl & Gärtner 1995) was used. Cultures were incubated at 25 °C with illumination provided by cool white fluorescent lamps at 40 μE $m^{-2}sec^{-1}$ and a light : dark regime of 12 : 12 h.

Light microscopy was performed with a MBI-3 (LOMO) and a Micmed-2 photomicroscopes. All species were identified in the living state. Microphotographs were taken with a Leica DMRB microscope equipped with a Sony Power HAD digital camera and were assembled into plates with Adobe Photoshop v7.0.

For species identification, the keys of Kondratyeva (1968), Kondratyeva et al. (1984), Ettl (1978), Komárek & Fott (1983), Komárek & Anagnostidis (1998), Komárek & Anagnostidis (2005) and Ettl & Gärtner (1995) were used. Cyanoprokaryota and eukaryotes were classified according to Komárek & Anagnostidis (1989, 1998, 2005), and Ettl & Gärtner (1995) respectively.

Results and discussion

Algal diversity and distribution

All 29 samples except two (one from littoral and one from the meadow in which no algae were detected) were usually rich in species. The mean number of species revealed in studied samples was 7.8, varying from 3.5 species per sample from littoral up to 10.7 species per sample from wet gleyic solonchaks with open stand of halophytes.

A total of 93 algal taxa were found (see Table 1). The majority of species found in our study were cyanobacteria with a total of 49 species, representing 66.7% of the total diversity in the soil samples and 50% in epigeic growths. The next richest group with 29 species was the chlorophytes, which were especially diverse and abundant in algal crusts and films on the soil surface (32.9%), whereas in the soil their share was about half of that (17.5%). Diatoms (12 species) were a constant component of habitats studied, however, their diversity and abundance were much lower. In our study only few taxa of Xanthophyta (2 species) and Eustigmatophyta, represented by *Eustigmatos magnus,* were recorded.

The hypersaline environments of the Kuyuk-Tuk and Churiuk islands supported a high generic diversity. A total of 48 genera were found, in which the cyanobacteria and chlorophytes were equally dominant

Table 2. Frequency of occurrence (F, in %) of the most frequent species in the four main types of habitat of Central Syvash islands (Ukraine) (numbers as in Table 1) expressed as the percentage of sampling sites per environment type where a given species has been recorded. F_{total}, total occurrence over the four habitat types.

Species	I	II	III	IV	F_{total}
Leptolyngbya fragilis (Gom.) Anagn. et Komárek	11.1	66.7	66.7	–	48.9
Mychonastes homosphaera (Skuja) Kalina et Punč.	66.7	33.4	22.2	75.0	40.4
Leptolyngbya tenuis (Gom.) Anagn. et Komárek	–	45.8	22.2	–	29.8
Phormidium paulsenianum B. Petersen	11.1	29.2	66.7	–	29.8
Dilabifilum arthropyreniae (Vischer & Klement) Tschermak–Woess	22.2	33.4	44.2	–	29.8
Hantzschia amphioxys (Ehrenb.) Grunow	11.1	29.2	11.1	75.0	27.7
Nostoc linckia (Roth.) Born. et Flah.	–	12.5	88.9	25.0	25.5
Lyngbya aestuarii Liebman ex Gom.	11.1	29.2	22.2	–	21.3
Navicula pelliculosa (Bréb.) Hilse	–	20.1	33.3	–	17.1
Microcoleus chthonoplastes Thur. ex Hansg.	11.1	25.0	11.1	–	17.1
Porphyrosiphon luteus (Gom. ex Gom.) Anagn. et Komárek	11.1	12.5	33.3	–	14.9
Anabaena variabilis Kütz.	–	20.1	11.1	25.0	14.9
Nodularia harveyana (Thwait) Thur.	–	12.5	33.3	25.0	14.9
Chlorosarcinopsis arenicola Groover & Bold	–	16.7	22.2	25.0	14.9
Ch. dissociata Herndon	22.2	12.5	22.2	–	14.9
Chlamydomonas sp.	33.3	12.5	–	–	12.8
Aphanocapsa salina Voronichin	–	12.5	11.1	25.0	10.6
Phormidium autumnale (Ag.) Gom.	–	4.1	11.1	50.0	10.6
Leptolyngbya heningsii (Lemm.) Anagn.	–	4.1	11.1	50.0	10.6
Pseudendoclonium printzii (Visc.) Bourr.	22.2	8.2	–	–	10.6
Klebsormidium flaccidum Silva, Mattox & Blackwell	–	8.2	11.1	50.0	10.6
Lyngbya majuscula Harvey ex Gom.	–	25.0	–	–	10.6
Pinnularia borealis Ehrenb.	–	–	11.1	75.0	10.6

Remark. List includes those species whose frequency in certain types of habitat exceeds the F_{total} for this species.

(19 each); diatoms were represented by 8 genera. The mean number of species per genus in Cyanoprokaryota (2.6) was significantly higher than that in Bacillariophyta and Chlorophyta (1.5 in each case). *Leptolyngbya* Anagn. et Komárek was the richest in species (8), followed by *Calothrix* (Ag.) V. Poljansk. (5), *Synechocystis* Sauvageau, *Phormidium* Kütz. ex Gom., *Lyngbya* C. Agardh ex Gom. and *Chlorella* Bejer. (4 species each). *Anabaena* Bory, *Jaaginema* Anagn. et Komárek, *Nostoc* Vaucher ex Born. et Flah., *Luticola* Mann in Round et al., *Chlamydomonas* Ehrenb. and *Chlorosarcinopsis* Herndon were represented by three species each. Two species were found from each of the genera *Aphanocapsa* Näg., *Aphanothece* Näg., *Leibleinia* (Gom.) Hoffmann, *Nodularia* Mertens ex Born. et Flah., *Bracteacoccus* Tereg, *Elliptochloris* Tschermak-Woess and *Pseudococcomyxa* Korshikov. Twenty-nine genera (60.4%) were represented by one species.

The distribution of algal species among the four main habitat types was extremely heterogeneous (Table 2). Only *Mychonastes homosphaera* (Skuja) Kalina et Punč. and *Hantzschia amphioxys* (Ehrenb.) Grunow occurred at all 29 sites. The number of species recorded only once was 42 (55.2% of Chlorophyta, 50% of Bacillariophyta, 50% of Xanthophyta and 38.8% of Cyanoprokaryota). The frequency of species (F in Table 2) in the four habitat types differed significantly. Most of the species were peculiar to certain type of environment, where their frequency quotients were higher of the mean values calculated for each species (Table 2). *Leptolyngbya fragilis* (Gom.) Anagn. et Komárek and *Mychonastes homosphaera* were the most frequent species. The wide ecological tolerance of *M. homosphaera* allowed it to be frequent in different conditions, starting from the harsh littoral ecotone up to the hills covered by steppe on chestnut solonetzic soil. *Leptolyngbya fragilis* was common in hypersaline environments with both true halophytic and saline meadow vegetation. *L. tenuis* (Gom.) Anagn. et Komárek, *Dilabifilum arthropyreniae* (Vischer et Klement) Tschermak-Woess, *Lyngbya aestuarii* Liebman ex Gom., *Hantzschia amphioxys*, *Microcoleus chthonoplastes* Thur. ex Hansg. and *Lyngbya majuscula* Harvey ex Gom. were the most frequently observed taxa of wet solonchaks. *Nostoc linckia* (Roth.) Born. et Flah. (88.9%) was the most common species on sites of gleyic solonetz under saline meadow vegetation, followed by *L. fragilis* and *Phormidium paulsenianum* B. Petersen (in both cases 66.7%), *Dilabifilum arthropyreniae* (44.2%), *Navicula pelliculosa* (Bréb.) Hilse, *Porphyrosiphon luteus* (Gom. ex Gom.) Anagn. et Komárek and *Nodularia harveyana* (Thwait) Thur. (33.3% each). In the sites of saline steppe vegetation on chestnut solonetzic soil, *Mychonastes homosphaera, Hantzschia amphioxys, Pinnularia borealis* Ehrenb. (75.0% each), *Phormidium autumnale* (Ag.) Gom., *Leptolyngbya heningsii* (Lemm.) Anagn., *Klebsormidium flaccidum* Silva, Mattox et Blackwell (50% each) were mostly distributed.

As shown above, the four main types of habitats differed in taxonomic composition and species diversity of algae. In samples of algal growths collected from the surface of littoral heavy-loam solonchak completely free of vascular plants (habitat type I), 23 species were identified (Cyanoprokaryota 13; Chlorophyta 9, Bacillariophyta 1). Among 18 recorded genera, *Radiosphaera* Snow ex Herndon was only found in this habitat. Cyanoprokaryota were represented by unicellular chroococcalean (30.8%) and filamentous oscillatorian (69.2%) forms. A peculiar feature of this habitat was the absence of Nostocales. On the contrary, unicellular forms from the green algal classes Chlorophyceae (44.5%) and Trebouxiophyceae (32.3%) prevailed, whereas filamentous Ulvophyceae (22.2%) were less diverse. The diatom *Hantzschia amphioxys* was recorded only once in low numbers. Macroscopic crusts and films were produced by a number of Cyanoprokaryota and green algae. The dominant species of Cyanoprokaryota were exclusively filamentous forms: *Leptolyngbya foveolarum* (Rabenhorst ex Gom.) Anagn. et Komárek*, L. fragilis, L. halophila* (Hansg. ex Gom.) Anagn. et Komárek*, Oscillatoria subbrevis* Schmidle, *Phormidium paulsenianum* and *Microcoleus chthonoplastes.* Among the green algae both unicellular (*Chlamydomonas* sp., *Mychonastes homosphaera, Chlorella vulgaris, Radiosphaera negevensis*) and filamentous (*Dilabifilum arthropyreniae* and *Pseudendoclonium printzii* (Vischer) Bourr. species were abundant in macroscopic growths.

Wet gleyic solonchaks covered by formations of *Salicornieta*, *Suaedeta*, *Halocnemeta strobilacei* and *Halimioneta verruciferae* (habitat type II) were the most common and typical habitats on the Kuyuk-Tuk and Churiuk islands. The most rich and diverse composition of algae was revealed here: 71 species from five divisions of algae (Cyanoprokaryota 41; Chlorophyta 19; Bacillariophyta 8; Xanthophyta 2; Eustigmatophyta 1). They belong to 42 genera, of which 13 were only recorded here. The share of Cyanoprokaryota in habitat type II (57.7%) is nearly the same as in habitat type I (56.5%). However, their taxonomic composition was more diverse at the expense of nostocalean genera like *Anabaena*, *Calothrix*, *Nodularia*, *Nostoc* (24.4%). In the taxonomic spectrum of the green algae two additional orders (*Choricystidales* Kostikov and *Klebsormidiales* Stewart et Mattox) and one class (*Charophyceae*) appeared. Among the diatoms representatives of the Naviculales were the most diverse (62.5%). The recorded species of the Xanthophyta belonged to the families Heterococcaceae and Gloeobotrydaceae of the Mischococcales. A representative of the division Eustigmatophyta (*Eustigmatos magnus*) was repeatedly recorded in the samples from this type of habitat. The most abundant species that formed macroscopic crusts and films were the Cyanoprokaryota *Anabaena propinqua* Setchell et Gardn., *A. variabilis*, *Leptolyngbya fragilis*, *L. tenuis*, *Lyngbya aestuarii*, *L. major* Meneghini, *L. majuscula*, *Microcoleus chthonoplastes*, *Nodularia harveyana*, *N. spumigena*, *Nostoc linckia*, *N. punctiforme*, *Phormidium paulsenianum* and occasionally *Mychonastes homosphaera* and *Dilabifilum arthropyreniae.*

On the sites of gleyic solonetz with dense saline meadow vegetation (habitat type III), the taxonomic composition of algae was quite similar to that of the wet gleic solonchaks (type II). Cyanoprokaryota occupied a leading position in species diversity, with an increasing share of Nostocales (34.8%) compared to other sites. Among chlorophytes and diatoms, the Chlorellales (40.0%) and Naviculales (71.4%) respectively were the most diverse orders. The Xanthophyta was represented by only one species (*Gloeobotrys* sp.). Macroscopic growths in this type of habitat were formed by *Calothrix fusca* (Kütz.) Born. et Flah., *Leptolyngbya halophila*, *Porphyrosiphon luteus* and *Klebsormidium flaccidum.*

Sites of chestnut solonetzic soil with *Steppa salsuginosa* formation (habitat type IV) occupied the highest portions of the islands. They were the least salinized and the most arid and shadowed habitats among the habitat types studied. The algal flora differed from that in the other habitats in a number of respects. Cyanoprokaryota and green algae contributed equally (38.9%) to the taxonomic spectrum, the other divisions were similarly distributed as in the other habitat types (see Table 1). Amongst Cyanoprokaryota, more than half were nostocalean species (57.1%), however, *Phormidium autumnale* was the most abundant. The Ulvophyceae *Dilabifilum arthropyreniae* and *Pseudendoclonium printzii* were frequent and abundant in other habitats as well as species of the orders Chlorococcales and Trebouxiales, but were absent in steppe solonetzic soils. *Leptosira erumpens* (Deason & Bold) Lukešová (Microthamniales) was recorded only in this habitat. This species, as well as *Mychonastes homosphaera* and *Klebsormidium flaccidum* produced macroscopic growths.

Noteworthy taxa: descriptions and notes

Chlorophyta

Chlorococcales

Chlorococcaceae Blackman & Tansley

Radiosphaera Snow ex Herndon

Radiosphaera negevensis var. ***minor*** Ocampo-Paus et Friedmann (Figs 1, 2)

Algal colonies light-green, flat when grown on agar medium. Young vegetative cells ovoid, elliptic, sometimes dorsoventral, 5.2–6.2 μm in diameter. Cell wall thin becoming thicker at the apical pole of the cell. Chloroplast parietal, dissected and somewhat eccentric with single pyrenoid surrounded by large starch grains located in the central portion of the chloroplast. Numerous starch grains present in the chloroplast. Mature vegetative cells spherical, with an asteroid chloroplast and a large central pyrenoid, often irregular, 12–15 μm in diameter. Cytoplasm often vacuolated, with numerous red inclusions. Cell wall thin, 1.2–1.5 μm. Old cells spherical, filled with numerous bright yellow droplets of oil.

Asexual reproduction by zoospores and aplanospores. Zoospores appearing after the transfer of old cultures to fresh solid or liquid medium, 6.0–7.2 × 3.6 μm in size, with a small anterior stigma, a parietal deeply lobed chloroplast and a posterior nucleus, often with numerous small inclusions. Flagella as long as the zoospore. Number of zoospores 16–32 per sporangium, released by rupture of the sporangium wall.

Occurrence. Azovo-Syvashsky National Nature Park,

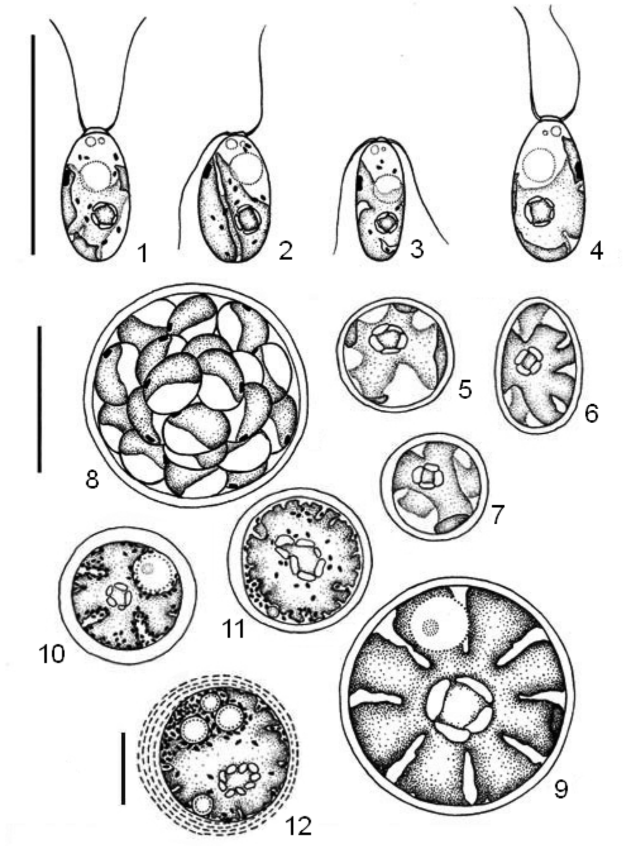

Fig. 1. *Radiosphaera negevensis* var. *minor*. 1–4 – zoospores; 5–7 – young vegetative cells; 8 – aplanosporangium; 9 – mature vegetative cell; 10/12 – old cells; scale 10 μm.

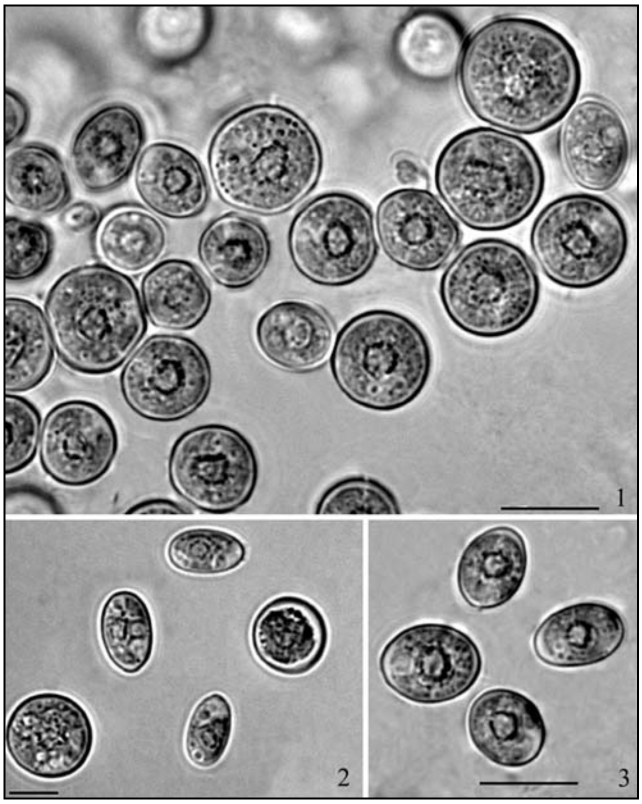

Fig. 2. *Radiosphaera negevensis* var. *minor*. 1 – mature vegetative cells; 2–3 – young vegetative cells; scale 10 μm.

Churiuk Isl., Syvash Lagoon coast, in the film on the surface of wet littoral heavy-loam solonchak without vascular plant cover.

Ecology and distribution. This is a rare species with two forms, described from chasmoendolitic and hypolithic habitats of the Negev Desert, Israel (Ettl & Gärtner 1995) that had been considered an Israelian endemic. *R. negevensis* var. *minor* was later found in subaerial algal deposits on walls of Carthago, Tunisia (Darienko & Hoffmann 2006b). The typical variety was unexpectedly recorded twice in the Ukraine in the soil of lowland and mountainous coniferous forests (Kostikov et al. 2001). Our finding of *R. negevensis* var. *minor* fits better with the ecological characteristic for this species and is a first record of this variety for the Ukraine.

Chlorellales

Chlorosarcinaceae Bourrelly ex Groover et Bold

Chlorosarcinopsis Herndon

Chlorosarcinopsis arenicola Groover et Bold (Fig. 3)

Algal colonies crustose when grown on agar medium. Single cells spherical, 5–10 μm in diameter. Chloroplast parietal, not dissected, slightly wavy, with a small, often indistinct pyrenoid. Cells laterally compressed in packages. Packages often in dense parenchyma-like clusters surrounded by a thin firm mucilage envelope. In old cells numerous oil droplets often colouring the cultures bright yellow. Number of zoospores 2–4–(8) per sporangium, 6–11 × 2–3.5 μm in size, strongly metabolic, with an anterior stigma and nucleus.

Occurrence. Azovo-Syvashsky National Nature Park, Kuiuk-Tuk Isl., wet gleic solonchaks 50–100 m from the Syvash Lagoon coast, on the soil surface and in the soil under sparse halophytic succulent-grass and subshrub vegetation; Churiuk Isl., wet gleic solonchak 20 m far from Syvash, in crusts on the soil surface under *Halocnemum strobilaceum* thicket; hill covered by dense steppe vegetation, on chestnut solonetzic soil.

Ecology and distribution. This is a desert species described from Port Aransas (Texas, USA) sand dunes (Ettl & Gärtner, 1995). Later it was also found in epigean crusts from different soil types (sandy, brown, solonchak, loam) of South Africa (Darienko, unpubl. data). It has a high pH tolerance since the pH values in those sites varied in the range 4.5–7.5–8.0 This is the first record of this species for Ukraine and Europe.

Remark: This species is easily misidentified as *Gloeotilopsis sarcinoidea* (Groover et Bold) Friedl. For the correct identification, it is necessary to study the complete life cycle in culture.

Chaetophoraceae Greville

Subfam. Leptosiroidea Bourrelly

Chaetophorales

Leptosira Borzi

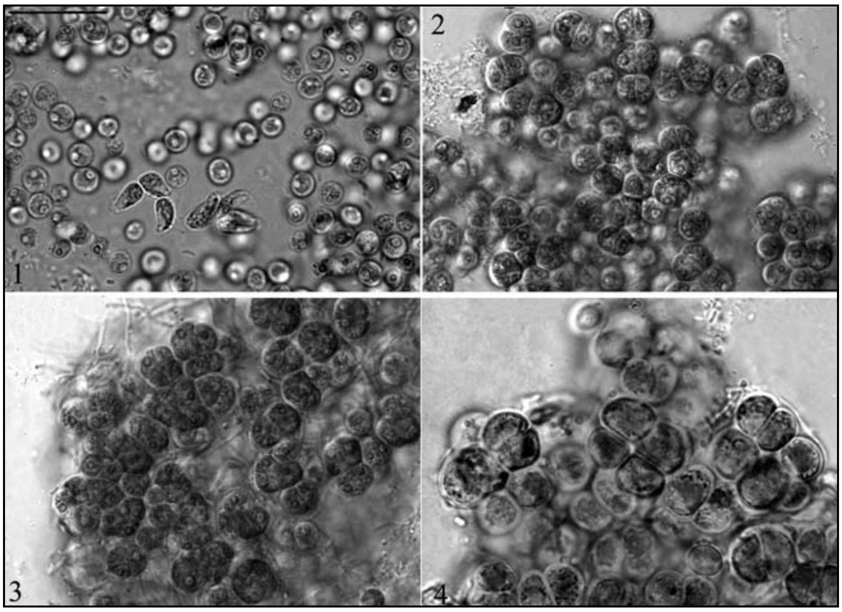

Fig. 3. *Chlorosarcinopsis arenicola.* 1 – zoospores; 2, 3 – parenchymatous aggregations from young cells packets; 4 – parenchymatous aggregations from old cells packets; scale 10 μm.

Leptosira erumpens (Deason et Bold) Lukešová (Fig. 4)
[syn. *Pleurastrum erumpens* Deason et Bold; *Rhexinema erumpens* (Deason & Bold) Printz]
Thallus radially branched when grown on agar medium. Single cells varying in shape from spherical, elliptical, to pyriform, 20–30 μm in diameter or 35–50 × 10. 6 μm in size. Cell wall of young cells thin, thickening with age. Chloroplast parietal, divided in 3–4 lobes, with single (rarely two) large pyrenoid(s) surrounded by several rows of starch grains. Nucleus solitary, clearly visible, usually lateral with a clearly visible, eccentric nucleolus. Old cells coloured by large bright yellow vacuoles. Reproduction by vegetative fission, zoospores and aplanospores. Zoosporangia sacciform and pyriform in shape. Sporangium cell wall containing unilateral thickenings. Number of zoospores 64–128 per sporangium, released in a mucilaginous vesicle, naked, with two flagella, a parietal chloroplast and a medial-posterior stigma. Motile zoospores immediately after liberation pyriform, 6.0–8.6 × 3.6–5.7 μm, becoming spherical after a short period of motility, diameter 6–7 μm.
Occurrence. Azovo-Syvashsky National Nature Park, Churiuk Isl., in chestnut solonetzic soil of a hill covered by dense steppe vegetation.
Ecology and distribution. This is a rare species with unclear ecological range. It was described from arid soils of Texas (USA). Later it was found in forest soils of Canada, Czech Republic and Russia (Ettl & Gärtner, 1995). In Ukraine, *L. erumpens* was recorded in pine forest soil of Polissya (Kostikov et al. 2001) and on archeological artefacts in the ancient town Olvia on the Black Sea coast (Darienko & Hofmann 2003). In hypersaline environment it was found for the first time.
Remark: Our material differs from the protologue by the smaller zoospores.

The species is critical from a morphological and taxonomic point of view. For a correct identification, observation of its complete life cycle in culture is required.

Dilabifilum Tschermak-Woess
Dilabifilum arthropyreniae (Vischer et Klement) Tschermak-Woess (Fig. 5)
(syn. *Pseudopleurococcus arthropyreniae* Vischer et Klement in Vischer)
Thalli forming a firm dark green brush-like growth comprising submerged and somewhat erect filaments when grown on agar medium, after 2–3 weeks developing small densely branched bushes of which all lateral branches of the first order originate from one cell. Cells elongated cylindrical, (2.1–) 3.4–7.1 × 20–60 μm with thin walls and strongly vacuolated cytoplasm. Chloroplast parietal lateral containing a single pyrenoid surrounded by 2–4 starch grains. Cells of lateral branches often rounded in cultures older than 3 months. Filaments often disintegrated into separate cells of various shapes: rounded, rounded with a long filamentous outgrowth, cylindrical with unilateral outgrowth or small aggregations of few cells.
Occurrence. Azovo-Syvashsky National Nature Park, Kuiuk-Tuk Isl., wet gleic solonchak with sparse halophytic succulent-grass and subshrub vegetation, on soil surface and in soil; on hill with saline meadow vegetation on gleyic solonetz. Churiuk Isl., Syvash Lagoon coast, in a film on the surface of wet littoral heavy-loam solonchak without vascular plants cover; wet gleic solonchak, sparse halophytic succulent-grass and subshrub vegetation, on soil surface and in soil; saline meadow vegetation on gleyic solonetz, in soil. One of the most frequent species in studied sites.
Ecology and distribution. *D. arthropyreniae* is a noteworthy representative of the taxonomically critical

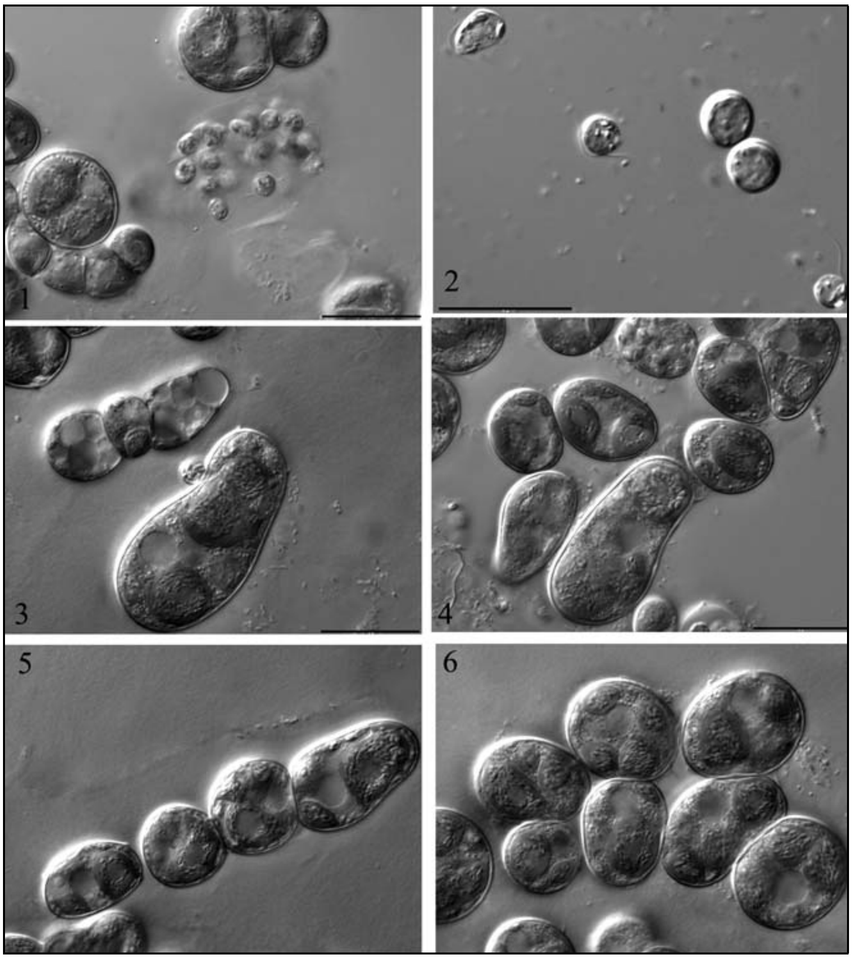

Fig. 4. *Leptosira erumpens.* 1 – liberation of zoospores; 2 – zoospores; 3, 5 – filaments, 4, 6 – mature vegetative cells; scale 20 μm.

genus *Dilabifilum.* This species was described as a photobiont of the lichen *Arthropyrenia kelpii* growing on the shell of the mollusk *Littorina littorea.* It is also known as a photobiont of the lichen *Verrucaria aquatilis* from sandy-calcareous substrate (Ettl & Gärtner 1995). In the free-living state *D. arthropyreniae* is known from algal growth on ancient ceramic artifacts (Olvia, Ukraine) (Darienko & Hoffmann 2003) and walls of casemates in Luxembourg (Darienko & Hoffmann 2006a).

Remark. Our material differs from the protologue by the longer filaments in certain stages of life cycle.

Ulotrichales

Ulotrichaceae

Pseudendoclonium Wille

Pseudendoclonium printzii (Vischer) Bourrelly (Fig. 6)

Algal colonies light green, consisting of ramified submerged filaments when grown on agar medium. Central portion of the thallus comprising single cells covered by thick stratified envelope; peripheral portions containing long filaments with rounded barrel-shaped cells. Lateral branching rare. Young cells with thin walls thickening with age. Chloroplast parietal, lobed, with a single pyrenoid, surrounded by 2–4 starch grains. Cytoplasm often strongly vacuolated. In cultures over 3 months old, filaments disintegrating into separate rounded or sacciform cells with thickened walls. Cytoplasm strongly vacuolated, giving the impression of a spongiose chloroplast. Rounded cells 5–7 μm in diameter, sacciform cells (possibly akinetes) 20 μm. After transfer to fresh nutrient medium, cells in filaments developing long, thin filaments up to 100 μm long. Cells of newly formed filaments cylindrical with often wider basis, containing a chloroplast located near the cross walls or in the central part of the cell, pyrenoids not always visible. Ramified, often unilateral branches developing from cells in newly formed filaments. Germination of sacciform cells initiated by multiplication of pyrenoids followed by rupture of stratified envelope and appearance of package-like aggregations giving rise to sparsely branched filaments. Reproduction by zoospores not observed.

Occurrence. Azovo-Syvashsky National Nature Park, Kuiuk-Tuk Isl., in films on the surface of wet gleic solonchak under sparse halophytic succulent-grass vegetation 50 m from Syvash. Churiuk Isl., Syvash Lagoon coast, in the film on the surface of wet littoral heavy-loam solonchak free of vascular plants; wet gleic solonchak, in soil covered by sparse thickets of red *Salicornia europea.*

Ecology and distribution. This species has an interesting ecology. It was described from a swamp in the vicin-

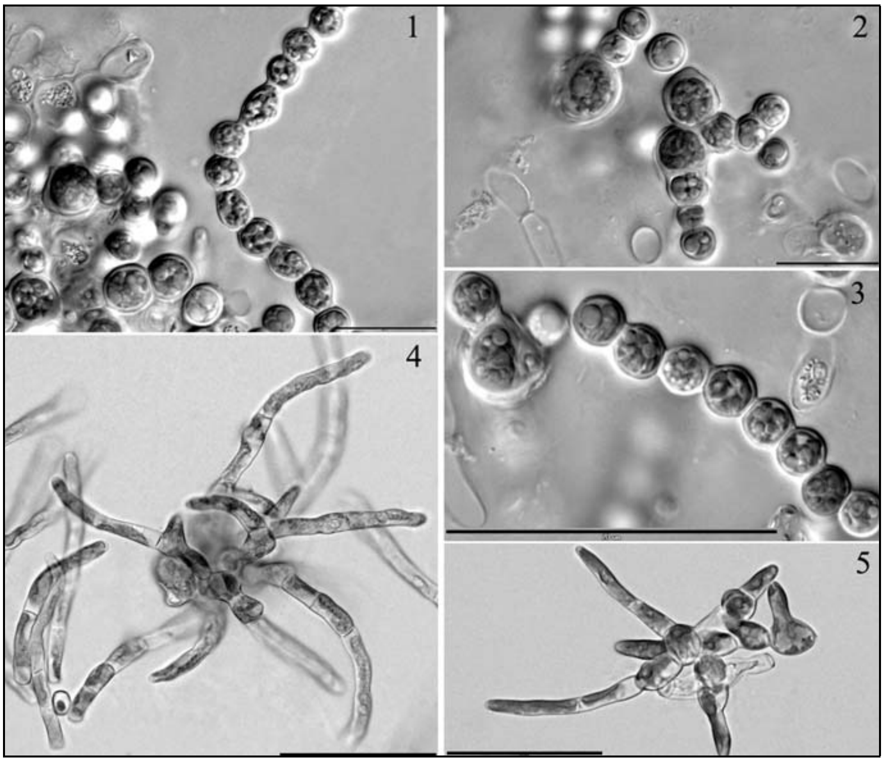

Fig. 5. *Dilabifilum arthropyreniae.* 1–3 – fragments of old filaments; 4–5 – fragments of filaments of 2–weeks old culture; scale 20 μm.

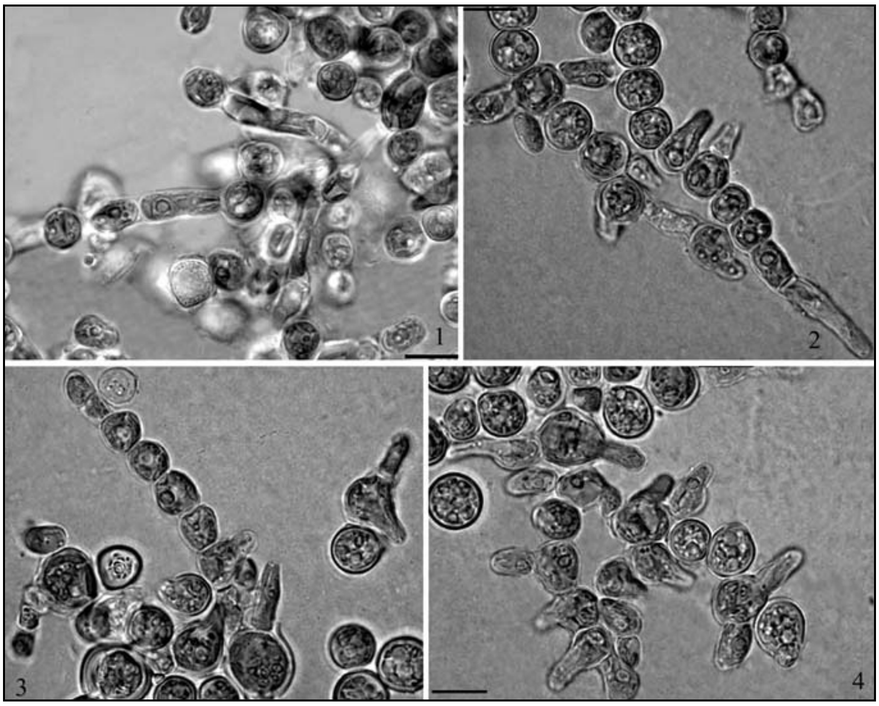

Fig. 6. *Pseudendoclonium printzii.* 1–4 – fragments of filaments of 4-weeks old culture; scale 10 μm.

ity of Basel (Switzerland) with a pH of about 5. Later it was repeatedly found as an epiphyte on submerged tree branches or on the calcareous banks of streams with an alkaline pH (Johnson & John 1990). In terrestrial habitats *Pseudendoclonium printzii* is known from soil, bark of trees, as a photobiont of lichens (Ettl & Gärtner1995) and epilithic on sandstone in Luxembourg (Darienko & Hoffmann 2006a, b). In Ukraine, it was recorded twice: in the soil of irrigated lawns (Kostikov et al. 2001) and on the walls of subterranean calcareous galleries (Darienko, unpubl. data). It is probably a pH-tolerant species. In hypersaline environment it was found for the first time.

Xanthophyta
Mischococcales

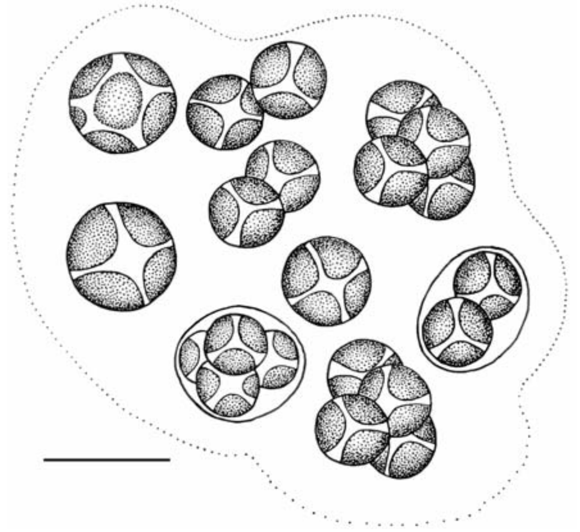

Fig. 7. *Gloeobotrys* sp., general view of part of colony; scale 10 μm.

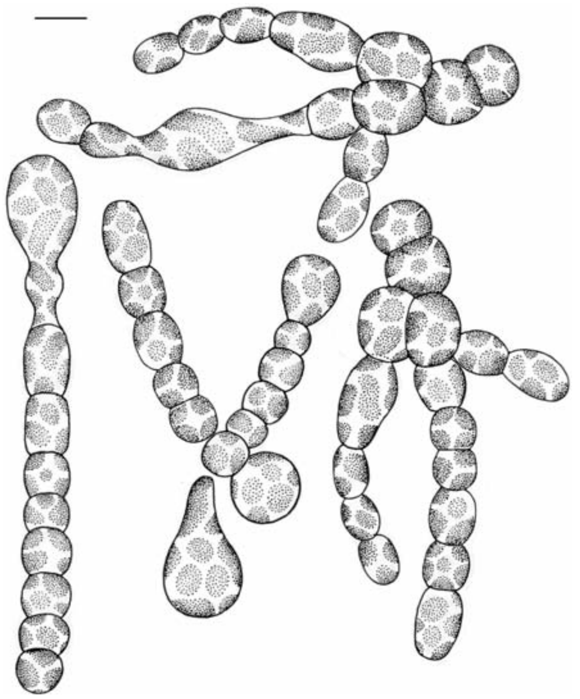

Fig. 8. *Capitulariella radians*, general view of thalli; scale 10 μm.

Gloeobotrydaceae Pascher
Gloeobotrys Pascher
Gloeobotrys sp. (Fig. 7)
Colonies elliptical to spherical, very soft when grown on agar medium. Cells spherical, containing 4–6 rounded chloroplasts, 8.5–9.5 μm in diameter, arranged in four-celled groups covered by amorphous mucilage, rarely single cells or two-celled groups. Cells and groups of cells arranged loosely and irregularly in the mucilage. Cell wall thin. Reproduction by 4 autospores.
Occurrence. Azovo-Syvashsky National Nature Park, Churiuk Isl., 30 m from Syvash Lagoon coast, in the soil of wet gleic solonchak covered by *Salicornia europea*; on a hill with saline meadow vegetation on gleyic solonetz, in the soil; in chestnut solonetzic soil of a hill covered by dense steppe vegetation; on moss growing on the roof of a hunter's lodge.
Remark. Our material shares features with *Gloeobotrys arborum* Geitler and *Gloeobotrys chlorinus* Pascher. It is morphologically most similar to *G. arborum,* but there are ecological differences in that *G. arborum* was described from the bark of a tree in vicinity of Vienna (Austria). It has been considered as a doubtful species, and Ettl (1978) did not include it in his classical summary of the Xanthopyta. According to Ettl & Gärtner (1995) *G. arborum* was never recorded again. Recently, however, this species was found in the soil of an Ai-Petri mountain pasture, Crimea, Ukraine (Kostikov et al. 2001) and on the wall of Sefunim Cave in Israel (Levanets, unpubl. data). Our alga differs from *G. chlorinus* in its larger cell size (8.5–9.5 μm compared to 4.5–5.0 μm), in the absence of cells with two chloroplasts and the lack of a pale colour of the chloroplasts. *G. chlorinus* prefers mainly sandy soils; it is widely distributed in the soils of Central Asia (Ettl 1978; Matvienko & Dogadina 1978). Thus, our material differs from *G. arborum* ecologically, and from *G. chlorinus* also morphologically; hence it is referred to as *Gloeobotrys* sp.

Tribonematales
Heterococcaceae Silva
Capitulariella Pascher
Capitulariella radians Pascher (Fig. 8)
Thallus radially branched consisting of small poorly branched or unbranched 5–10 celled filaments when grown on agar medium. Vegetative cells ovoid to spherical, 8.1–10.2 μm in diameter, often pyriform or variously bent in shape, easily disintegrating into separate cells. Terminal cells differing strongly from other cells, often twice in size, reaching 16.9 $\times$ 11.9 up to 22.0 $\times$ 18.6 μm, pyriform, sacciform or capitate. Vegetative cells in the filament usually containing 5–7 chloroplasts, more in terminal cells (probably sporangia).
Occurrence. Azovo-Syvashsky National Nature Park, Kuiuk-Tuk Isl., wet gleic solonchaks 50 m far from the Syvash Lagoon coast, in the soil under sparse halophytic succulent-grass vegetation.
Ecology and distribution. The species was described from films on wet clay soil in the Czech Republic (Ettl & Gärtner 1995). Our finding is the second report and represents a new record for Ukraine.
Remark. Our material differs from the genus *Heterococcus* Chodat in the lack of erected filaments, the peculiar radial appearance of young thalli and the formation of spores from the terminal cells of filaments. It differs from the genus *Heteropedia* Pascher by the absence of a parenchymatous organization of the thallus.

Ecological comments
Terrestrial algae in hyperhaline environments are subjected to salinity stress combined with fluctuations of temperature, solar radiation and available water. Such conditions exert strong selective pressures, and a spe-

cialized microbial flora is formed. Our study has revealed a high species diversity from six divisions of algae in the hyperhaline habitats of the Central Syvash islands. As expected, cyanobacteria represented over the half of the recorded species (52.7%). Most of them are known as being restricted to marine or hypersaline environments, and a minority of the cyanobacterial species are aerophytic and edaphic forms (Komárek & Anagnostidis 1998, 2005). The Chlorophyta ranked next in the species diversity (31.2%), half of which being representatives of the class Chlorophyceae, in which secondary carotenoids were accumulated for protection against excess solar radiation. The class Trebouxiophyceae (35.7%) was mainly represented by single records of widely distributed species (*Chlorella trebouxioides*, *C. vulgaris*, *Stichococcus bacillaris*, *Pseudococcomyxa minor*). The filamentous forms of the class Ulvophyceae differed in ecology and distribution: *Dilabifilum arthropyreniae* is a terrestrial species, and *Pseudendoclonium printzii* occurs both in aquatic and terrestrial habitats. In the species composition of the Bacillariophyta, euterrestrial cosmopolitan forms prevailed in our samples. *Hantzschia amphioxys, Luticola mutica, L. cohnii, Pinnularia borealis* are common in xeric environments. All these species are able to survive at 500–1000 mg Cl L^{-1} (Johansen 2001). *Achnantes anceps* and *Cocconeis placentula* are inhabitants of salty reservoirs. Xanthophytes mainly prefer wet and cool regions. However, a number of genera (*Botrydiopsis* Borzi, *Heterococcus* Chodat, *Gloeobotrys* Pascher, *Chloridella* Pascher) inhabit desert (including brackish and saline) soils (Novichkova-Ivanova 1980).

The divisions Streptophyta and Eustigmatophyta were represented in the studied hypersaline ecosystem by the cosmopolitan terrestrial species *Klebsormidium flaccidum* and *Eustigmatos magnus*.

Attempts to analyze the literature concerning the species diversity of phototrophs inhabiting salt marshes and hypersaline soils are hampered by the scanty information that is available and by the unstable taxonomy of cyanobacteria and green algae. Nevertheless, it can be assumed that the type of salinity (thalassic or athalassic) affects the diversity of green algae and diatoms in hypersaline environments. According to our results, in the thalassohaline ecosystem of Central Syvash the Chlorophyta were the second most diverse group after the Cyanobacteria in terms of species number, followed by the Bacillariophyta. Similar data were demonstrated by Novichkova-Ivanova (1980), who summarized literature and original data on algal flora of a number of thalassohaline sites in the deserts of Central Asia and North Africa. In the taxonomic spectrum of all salt marshes and clay hypersaline soils (shotts and sebhas) near Mediterranean, Kaspian and Aral seas, the green algae contributed 11.8–31.0% of species diversity, and the share of Bacillariophyta was 1.9–7.6%. In solonchaks of the coast plains of the Persian and Oman gulfs (Southern Iran) diatoms were not recorded and a list of algae included species of cyanobacteria, chlorophytes and xanthophytes (Novichkova-Ivanova 1980). On the contrary, in the edaphon of athalassohaline environments Bacillariophyta exceeded chlorophytes in species diversity (Komaromy 1984; Major et al. 2005). The question of how to accommodate these seemingly contradictory observations will require more extensive research on the species diversity and ecophysiological properties of taxa inhabiting hypersaline environments of various origins.

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