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RESEARCH ARTICLE

Algae, bryophytes, and vascular plants of calcareous rocks of the Dumka Cave complex (Dniester Regional Landscape Park, Ukraine)

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Abstract. Research on chasmophytic communities of the calcareous cliff of the Dumka Cave complex in the Dniester Regional Landscape Park (Ivano-Frankivsk Region) has revealed diverse vegetation dominated by ferns, bryophytes, and algae. The cave complex was examined in three parts: the so-called "karst bridge" (pile of fragments of a cave vault), limestone blocks at the entrance to the cave, and the walls of the front grotto of the cave. In total, fifty-six species of algae (*Cyanobacteria* — 21 species, *Chlorophyta* — 23, *Charophyta* — 2, *Heterokontophyta* — 9), 25 species of bryophytes (*Marchantiophyta* — 8, *Bryophyta* — 17), and 21 species of vascular plants (*Pteridophytina* — 5, *Spermatophytina* — 16) were found in the studied habitat. The highest species diversity was recorded on the karst bridge and the walls at the entrance to the cave. In both locations, the algal cover was dominated by cyanobacteria and green algae. Algae and bryophytes on the walls of the front grotto were less diverse, vascular plants were completely absent. Cyanobacteria were absent, and trebuxiophycean green algae and diatoms predominated. A comparison of the species composition of algae and bryophytes using the Sørensen-Chekanovsky index showed a certain resemblance between the karst bridge and the walls at the entrance to the cave and the specificity of the front grotto of the cave. Among the discovered species of algae, two are first reported for Ukraine (*Synechococcus sciophilus* and *Synechocystis primigenia*). Several taxa are rare and noteworthy records (*Gloeocapsa coracina*, *Microcoleus vulgaris*, *Scotinosphaera* sp., *Pseudostichococcus undulatus*, etc.). Fifteen species of bryophytes are listed for the first time for the park; among them, *Pedinophyllum interruptum* and *Fissidens gracifolius* are new records for Ivano-Frankivsk Region. For the latter species, this is the second locality in Ukraine. For *Timmia bavarica*, a rare species in the Ukrainian Carpathians, this is the third locality in Ivano-Frankivsk Region. Vascular plants are characteristic of shaded epilithic habitats. Such communities belong to the biotope H32c "Cabonate rocks of the temperate zone, occurring on the plain and in the lower mountain belt", are characterized syntaxonomically as a group of the *Polypodietea* class, and belong to the second category of rarity and require protection. The main threat to the existence of this biotope is deforestation, which leads to increased light levels, heating of rocks, and moisture deficiency, as well as eutrophication due to recreational load.

Keywords: biodiversity, bryophytes, cyanobacteria, Dniester, Dumka karst cave, terrestrial algae, Ukraine, vascular plants

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Introduction

The Dumka Cave is part of the Odayiv karst cave complex, located in the territory of the Dniester Regional Landscape Park (RLP), Ivano-Frankivsk Region, Ukraine. The cave, which was formed by erosion and weathering in a tectonic fault that emerged during the split of the coastal plateau, is located on the high bank of the Dniester (Dnister) River among a hornbeam-oak forest. This is a large natural karst cavity, which is a cave of linear-horizontal structure. It begins with an entrance grotto and continues with a gallery 170 m long. The cave is embedded in a gypsum layer. Druses of gypsum crystals are observed on the vault and walls of the cave.

The temperature and humidity inside the cave are relatively constant throughout the year and are 13–15 °C, the humidity is moderate. Before the entrance to the cave, 10 m away, there is the so-called "karst bridge", a cluster of boulders that previously formed part of the cave vault, but as a result of rock collapses, remained standing separately, forming a natural arch. The cave is also valuable as an archaeological site. In particular, there is information about the discovery of flint products, tools, and reindeer bones from the Paleolithic age (Dniester…, 2023).

On the limestone cliffs of the cave complex, chasmophyte communities dominated by ferns, bryophytes, and algae develop in the shaded conditions of a hornbeam-oak forest. Such communities are considered a rare biotope and are indexed in Resolution 4 of the Bern Convention as H3.2 Basic and ultrabasic continental cliffs (Convention…, 1979).

Before the beginning of our research, there were no data on vascular plants, algae, and mosses of the Dumka Cave complex. Recently (Nyporko et al., 2023; Mikhailyuk, Vynogradova, 2024) preliminary data on terrestrial algae and bryophytes of the Dniester RLP have been published. About twenty species of mosses were reported in the pertinent literature from the territory that is now part of the park (vicinity of the villages of Nyzhniv, Dibrova, Nezvysko, Chernelytsia, Bukivna, Olesha, Gorodnytsia). Collectors were J. Krupa, A. Rehmann, and M.P. Slobodyan (Bachuryna, Melnychuk, 1987, 1988, 1989, 2003).

Materials and Methods

The material for the study (samples of algae, bryophytes, ferns, and vascular plants) was collected in May 2024 during an expedition to the Dniester Regional Landscape Park (village Odayiv, Tlumatsky [Tlumach] District, Ivano-Frankivsk Region). The Dumka Cave complex was examined in three parts: the so-called "karst bridge" (pile of fragments of a cave vault), calcareous boulders at the entrance to the cave, and the walls of the front grotto of the cave (Fig. 1). Six complete geobotanical descriptions of chasmophytic vegetation were carried out, recording the diversity of vascular plants and bryophytes on an area of 4 m^2, as recommended by Chytrý and Otýpková (2003).

In the laboratory, algal samples were previously studied using direct microscopy and then examined using the method of cultures (Kostikov et al., 2001). To obtain enrichment cultures, fragments of algal crusts were placed in Petri dishes with Bold (1N BBM) agarized medium (Bischoff, Bold, 1963). The cultures were grown under standard laboratory conditions: with a 12-hour alternation of light and dark phases and irradiation of 25 μmol photons • m^{-2} • s^{-1} at a temperature of +20 ± 5 °C. Microscopic observation of enrichment cultures began in the third week of cultivation. Isolated unialgal cultures were cultivated on Bold and BG-11 nutrient media (Stanier et al., 1971).

The identification of algae and bryophytes was carried out using MBS-9 and Olympus BX-53 light microscopes, according to generally accepted methods. Photomicrographs were taken using an Olympus LC30 camera. The frequency of occurrence (F) was defined as the ratio of the number of samples in which the species was detected to the total number of studied samples. The species composition of algae and bryophytes was compared using the Sørensen-Czekanowski floristic similarity index (Shmidt, 1980).

The names and taxonomic position of revealed species of cyanobacteria and algae as well as their ecological characteristics are given according to the compendium *Prodromus of Spore Plants of Ukraine: Algae* (Tsarenko et al., 2024a, 2024b) and *AlgaeBase* (Guiry, Guiry, 2025). The names of bryophyte species are given according to the *Prodromus of Spore Plants of Ukraine: Bryophyta* (Virchenko, Nyporko, 2022). The names of vascular plant species are given according to the *Euro+Med Database* (Euro+Med, 2006–onward). The names of higher syntaxa of chasmophyte vegetation are given according to Mucina et al. (2016).

Fig. 1. Dumka Cave complex. A, B: maps showing the location of the complex; C: karst bridge; D: boulders at the entrance to the cave; E, F: view of the front grotto of the cave

Results and Discussion

As a result of the direct microscopy and cultural studies of the samples from the Dumka Cave complex, 56 terrestrial species from 4 divisions and 7 classes of cyanobacteria and algae were identified (Table 1, Figs 2, 3). Representatives of the divisions *Chlorophyta* (41.4%) and *Cyanobacteria* (37.5%) notably prevailed in the species composition; the share of *Heterokontophyta* (17.8 %) and *Charophyta* (3.6%) in the studied habitats was significantly lower (Table 2). At the class level, *Cyanophyceae* (37.5%) and *Trebouxiophyceae* (28.6%) predominated, followed by *Bacillariophyceae* (14.3%) and *Chlorophyceae* (8.9%).

The generic spectrum of the algal flora of the Dumka complex included 49 genera, of which the vast majority (93.5%) is represented by one species. Seven genera had two species each. The frequency quotients of the identified species varied considerably. Thirty-two species (57.1%) were found in only one sample, and their proportion was different for different divisions. The rarest were yellow-green algae: all of them were found only once. The most common in the studied habitats were *Desmococcus olivaceus* and *Nannochloris* sp. (for both F = 100%). Frequently occurring species were *Bracteacoccus* cf. *minor* (F = 60%), *Gloeocapsa coracina*, *Coccomyxa* cf. *simplex*, and *Humidophila contenta* (F = 50% for each).

Table 1. **Species composition of cyanobacteria and algae of the Dumka Cave complex**
(D — dominating species; * — new species for Ukraine)

Taxon	Karst bridge	Cave entrance	Grotto
CYANOBACTERIA			
Cyanophyceae	**13**	**16**	**0**
Anathece endophytica (W. & G.S. West) Komárek, Kaštovský & Jezberová	+	–	–
**Synechococcus sciophilus* Skuja	+	–	–
**Synechocystis primigenia* N.L. Gardner	+	–	–
Gloeocapsa coracina Kützing	+	+	–
Gloeocapsa kuetzingiana Nägeli ex Kützing	–	+	–
Gloeocapsopsis magma (Brébisson) Komárek & Anagnostidis ex Komárek	+	+	–
Chroococcus helveticus Nägeli	D	+	–
Pseudocapsa dubia Ercegović	+	–	–
Cyanosarcina parthenonensis Anagnostidis	D	+	–
Aphanothece castagnei (Kützing) Rabenhorst	–	+	–
Gloeothece palea (Kützing) Nägeli	–	+	–
Leptolyngbya sp.	+	+	–
Phormidesmis sp.	–	+	–
Timaviella edaphica (Elenkin) O.N. Vinogradova & Mikhailyuk	–	+	–
Stenomitos frigidus (F.E. Fritsch) Miscoe & J.R. Johansen	+	+	–
Potamoline cf. *aerugineocaerulea* (Gomont) M.D. Martins & L.H.Z. Branco	+	+	–
Microcoleus vulgaris Strunecky, Komárek & J.R. Johansen	–	+	–
Desmonostoc muscorum (Bornet & Flahault) Hrouzek & S. Ventura	+	–	–
Nostoc calcicola Brébisson ex Bornet & Flahault	–	+	–
Nostoc edaphicum N.V. Kondrateva	–	+	–
Nodularia sphaerocarpa Bornet & Flahault	+	+	–
CHLOROPHYTA			
Chlorophyceae	**3**	**3**	**2**
Macrochloris dissecta Korshikov	–	+	+
Chlorosarcinopsis sp.	+	–	–

Table 1 (continued)

Taxon	Karst bridge	Cave entrance	Grotto
Bracteacoccus cf. *minor* (Schmidle ex Chodat) Petrová	–	+	D
Coelastrella cf. *rubescens* (Vinatzer) Kaufnerová & Eliás	+	+	–
Spongiochloris sp.	+	–	–
Trebouxiophyceae	**8**	**9**	**7**
Muriella terrestris J.B. Petersen	–	–	+
Desmococcus olivaceus (Persoon ex Acharius) J.R. Laundon	D	D	D
Diplosphaera chodatii Bialosuknia	–	+	–
Stichococcus bacillaris Nägeli	+	+	–
Pseudostichococcus undulatus (Vinatzer) Van & Glaser	–	+	+
Elliptochloris subsphaerica (Reisigl) Ettl & G. Gärtner	+	+	–
Coccomyxa cf. *simplex* Mainx	–	+	+
Coccomyxa cf. *viridis* Chodat	–	–	+
Gloeocystis cf. *vesiculosa* Nägeli	+	–	–
Chloroidium sp.	+	–	–
Parietochloris alveolaris (Bold) S. Watanabe & G.L. Floyd	+	–	–
Trochiscia granulata (Reinsch) Hansgirg	–	–	+
Lobosphaera cf. *tirolensis* Reisigl	–	+	–
Chlorella vulgaris Beijerinck	–	+	–
Chlorella sp.	+	–	–
Nannochloris sp.	+	+	D
Ulvophyceae	**1**	**1**	**1**
Pseudendoclonium cf. *arthopyreniae* (Vischer & Klement) Darienko & Pröschold	+	+	–
Scotinosphaera sp.	–	–	+
CHAROPHYTA			
Klebsormidiophyceae	**1**	**0**	**1**
Klebsormidium nitens (Kützing) Lokhorst	–	–	+
Klebsormidium cf. *subtile* (Kützing) Mikhailyuk, Glaser, Holzinger & Karsten	+	–	–
HETEROKONTOPHYTA			
Xanthophyceae	**0**	**1**	**1**
Botrydiopsis sp.	–	+	–
Heterococcus sp.	–	–	+
Bacillariophyceae	**0**	**5**	**4**
Aerophilia roeseana (Rabenhorst) Danz, Van de Vijver & Kociolek	–	+	–
Humidophila contenta (Grunow) Lowe, Kociolek, Johansen, Van de Vijver, Lange-Bertalot & Kopalová	–	+	+
Humidophila sp.	–	+	–
Achnanthes coarctata (Brébisson ex W. Smith) Grunow	–	–	+
Luticola cohnii (Hilse) D.G. Mann	–	+	–
Luticola nivalis (Ehrenberg) D.G. Mann	–	–	+
Nitzschia sp.	–	+	–
Hantzschia amphioxys (Ehrenberg) Grunow	–	–	+
Number of species, units	**26**	**35**	**16**

The studied sites of the cave complex showed some differences in the species composition and taxonomic structure of the epilithic algal flora (Tables 1, 2). If we compare the total number of species found in each site with the average number of species in the sample, we get the following distribution: karst bridge — 26/17.5, entrance to the cave — 35/15.7, and inside the grotto — 16/6.2 (see Table 2). Indeed, samples from the calcareous boulders of the karst bridge were characterized by high diversity, with an absolute predominance of cyanobacteria (50%) and green algae (46.2%) in the taxonomic structure; representatives of xanthophyceans and diatoms have not been revealed (see Table 2).

As it can be seen from Fig. 1C, the surface of the calcareous cliffs forming the karst bridge is covered with a continuous dark green coating. It was formed by the subaerophytic epilythic cyanobacteria *Chroococcus helveticus* (Fig. 2A), *Pseudocapsa dubia* (Fig. 2B), and *Cyanosarcina parthenonensis* (Fig. 2D) with the participation of the common terrestrial green alga *Desmococcus olivaceus* (Fig. 3D). Other representatives of pro- and eukaryotic algae were observed in insignificant quantities. Only in this part of the Dumka complex we found cyanobacteria *Anathece endophytica*, *Synechococcus sciophilus* (Fig. 2F), *Synechocystis primigenia* (Fig. 2E), *Desmonostoc muscorum*, chlorophytes *Chlorosarcinopsis* sp., *Spongiochloris* sp., *Gloeocystis* cf. *vesiculosa*, *Chloroidium* sp., *Parietochloris alveolaris*, etc., and *Klebsormidium* cf. *subtile* from *Charophyta.*

Calcareous boulders at the entrance to the cave also turned out to be a favorable habitat for the epilithic algal flora. A total of 35 species from three divisions have been identified. The share of cyanobacteria is most significant (45.7%), followed by *Chlorophyta* (37.1%); the diversity of *Heterokontophyta* (17.2%) was mainly due to the representatives of diatoms (14.3%). Charophytes have not been found in this habitat. Although cyanobacteria rank first in terms of the number of species found, unlike the pattern observed on the karst bridge, they did not participate in the formation of the visible cover on the rock surface. At the same time, a number of cyanobacterial species were common to the mentioned sites, namely *Gloeocapsa coracina* (Fig. 2I), *Gloeocapsopsis magma* (Fig. 2C), *Cyanosarcina parthenonensis*. Various species [*G. kuetzingiana*, *Aphanothece castagnei* (Fig. 2G), *Gloeothece palea* (Fig. 2H), *Phormidesmis* sp., *Timaviella edaphica*, *Microcoleus vulgaris* (Fig. 2L), *Nostoc calcicola* (Fig. 2M)] were found exclusively on the boulders at the entrance to the cave. Of *Chlorophyta*, ten species were found at the cave entrance. Abundant bright green cover on the rocks was formed by *Desmococcus olivaceus* (Fig. 3D); other species were registered singly. Those were *Macrochloris dissecta* (Fig. 3A), *Bracteacoccus* cf. *minor* (Fig. 3B), *Coelastrella* cf. *rubescens*, *Stichococcus bacillaris*, *Elliptochloris subsphaerica* (Fig. 2E), etc. Taxa of *Heterokontophyta* were represented by *Botrydiopsis* sp. and diatoms common for terrestrial habitats: *Aerophilia roeseana*, *Humidophila contenta*, *Luticola cohnii*, and *Nitzschia* sp. In general, the species composition of the algal communities at the entrance to the cave was similar to those found on the karst bridge. The main differences are the presence of heterokontophytes, not found on the bridge, and the absence of cyanobacteria among the dominant species.

The walls of the front grotto of the cave were characterized by a significantly lower total diversity of algae. Cyanobacteria were completely absent, green algae (62.5%) led in species richness; the most diverse were trebouxiophyceans (43.8%), among the division *Heterokontophyta* (31.2%), the leading group was diatoms, while xanthophyceans were represented by one species (*Heterococcus* sp.). Macroscopic cover on the rock surface was formed by *Desmococcus olivaceus* (Fig. 3D), sometimes *Nannochloris* sp. (Fig. 3C) or protonema of mosses. *Trochiscia granulata*, *Coccomyxa* cf. *viridis*, and *Klebsormidium nitens* were found only in this locality. Green algae were found singly: *Macrochloris dissecta*, *Bracteacoccus* cf. *minor*, *Muriella terrestris*, *Pseudostichococcus undulatus* (Fig. 3E, F), *Coccomyxa* cf. *simplex*, etc. Diatoms were represented by terrestrial forms: *Humidophila contenta*, *Humidophila* sp. (Fig. 3M), *Achnanthes coarctata*, *Luticola nivalis* (Fig. 3L), and *Hantzschia amphioxys*.

Our comparison of the species composition of algae in different sites of the Dumka Cave complex using the Sørensen-Chekanovsky similarity index showed the grouping of the studied samples into two clusters (Fig. 4): the front grotto of the cave (first cluster) and the karst bridge and the entrance to the cave (second cluster). There is only one exception, sample 49, which entered the cluster of the front grotto of the cave, although it was a sample from the entrance. That indicates the transitional nature of the algal communities of the entrance to the cave, since it has features of both the composition of algae from the karst bridge (predominance of cyanobacteria)

Table 2. **Taxonomic structure of the algal flora of the Dumka Cave complex**

Taxon	Number of species, units (%)			
	Karst bridge	Cave entrance	Grotto	In total
CYANOBACTERIA	**13 (50.0)**	**16 (45.7)**	**–**	**21 (37.5)**
Cyanophyceae	13 (50.0)	16 (45.7)	–	21 (37.5)
CHLOROPHYTA	**12 (46.2)**	**13 (37.1)**	**10 (62.5)**	**23 (41.1)**
Chlorophyceae	3 (11.5)	3 (8.6)	2 (12.5)	5 (8.9)
Trebouxiophyceae	8 (30.8)	9 (25.7)	7 (43.8)	16 (28.6)
Ulvophyceae	1 (3.8)	1 (2.9)	1 (6.3)	2 (3.6)
CHAROPHYTA	**1 (3.8)**	**–**	**1 (6.3)**	**2 (3.6)**
Klebsormidiophyceae	1 (3.8)	–	1 (6.3)	2 (3.6)
HETEROKONTOPHYTA	**–**	**6 (17.2)**	**5 (31.2)**	**10 (17.8)**
Xanthophyceae	–	1 (2.9)	1 (6.3)	2 (3.6)
Bacillariophyceae	–	5 (14.3)	4 (25.0)	8 (14.3)
Number of species, units (%)	**26 (100)**	**35 (100)**	**16 (100)**	**56 (100)**
Average number of species in the sample	**17.5**	**15.7**	**6.2**	**11.3**

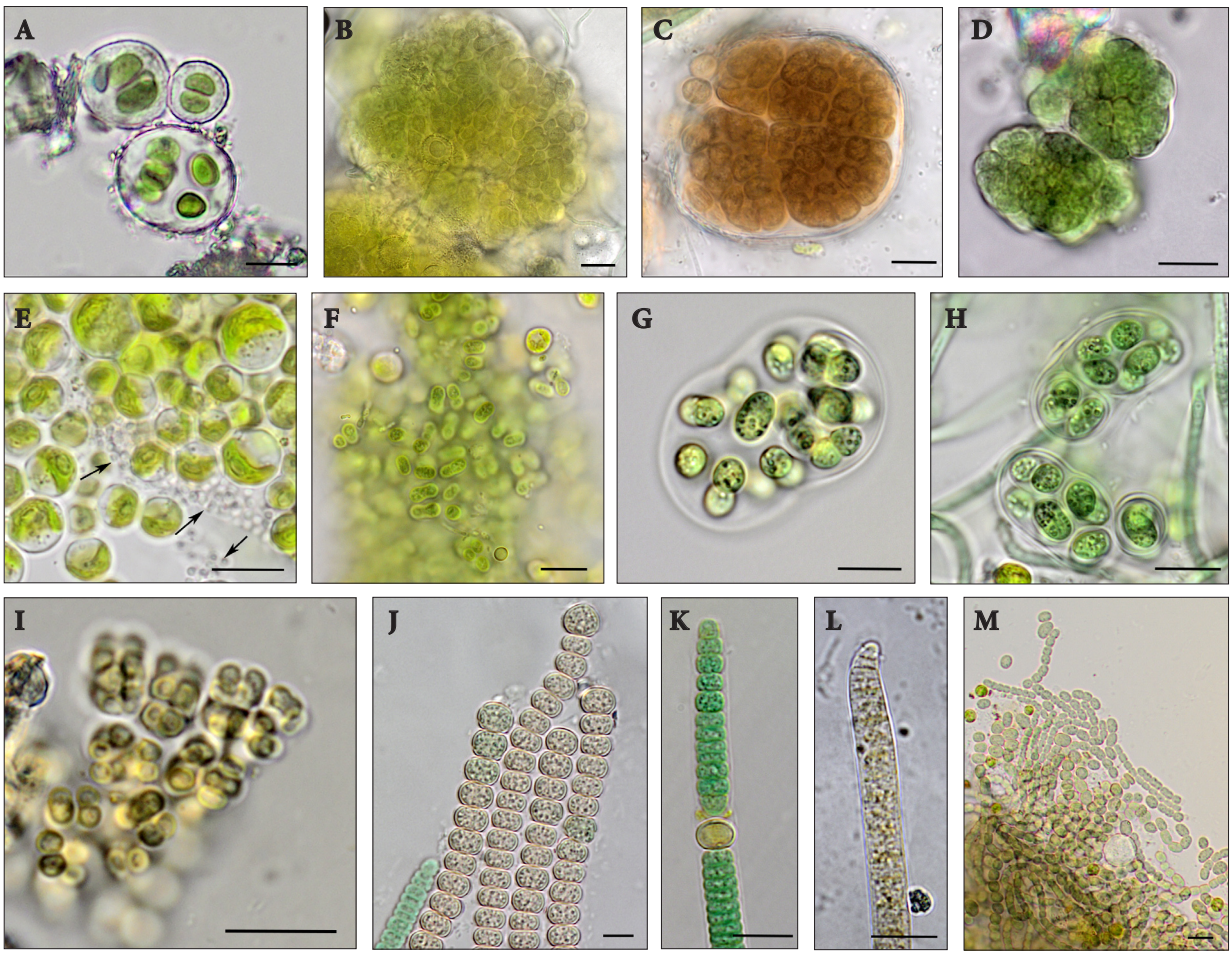

Fig. 2. Cyanobacteria of the Dumka Cave complex. A: *Chroococcus helveticus*; B: *Pseudocapsa dubia*; C: *Gloeocapsopsis magma*; D: *Cyanosarcina parthenonensis*; E: *Synechocystis primigenia* (arrows) among the cells of green alga *Elliptochloris subsphaerica*; F: *Synechococcus sciophilus*; G: *Aphanothece castagnei*; H: *Gloeothece palea*; I: *Gloeocapsa coracina*; J, K: *Nodularia sphaerocarpa* (J: chains of akinetes); L: *Microcoleus vulgaris*; M: *Nostoc calcicola*. Scale bars: 10 μm

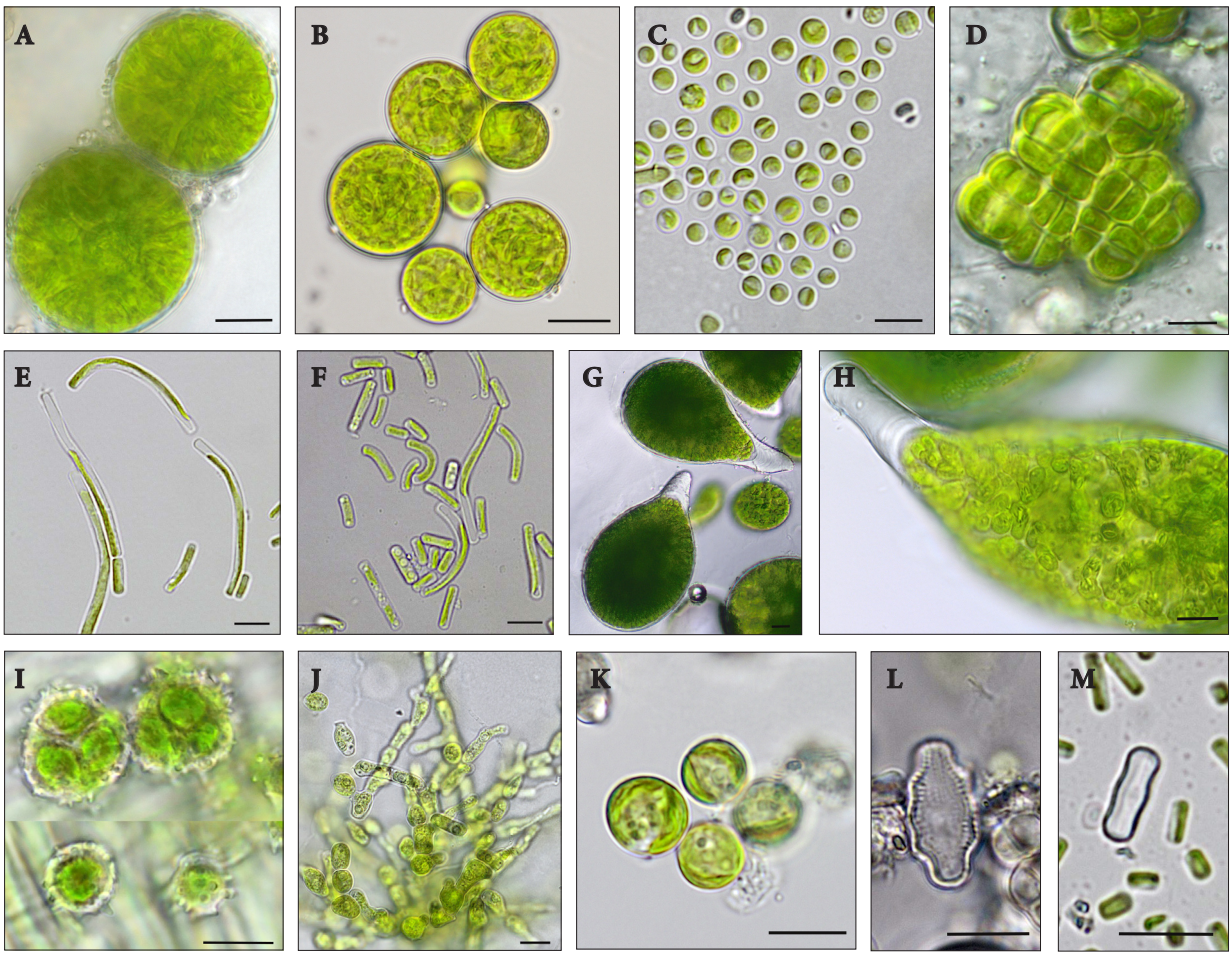

Fig. 3. Eukariotic algae of the Dumka Cave complex. A: *Macrochloris dissecta*; B: *Bracteacoccus* cf. *minor*; C: *Nannochloris* sp.; D: *Desmococcus olivaceus*; E, F: *Pseudostichococcus undulatus*; G, H: *Scotinosphaera* sp.; I: *Trochiscia granulata* (sporangia on top and vegetative cells on bottom); J: *Pseudendoclonium* cf. *arthopyreniae*; K: *Coccomyxa* cf. *viridis*; L: *Luticola nivalis*; M: *Humidophila* sp. Scale bars: 10 μm

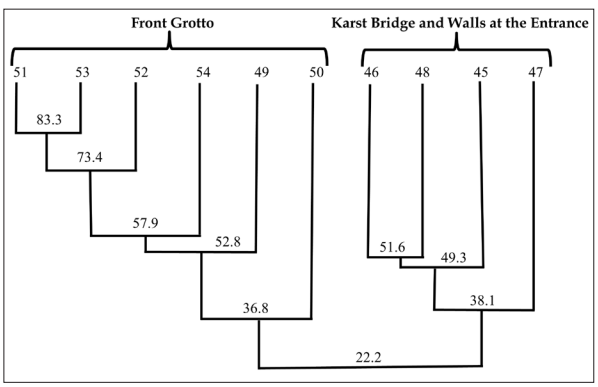

Fig. 4. Dendrite of the floristic similarity of the species composition of algae of the Dumka Cave complex according to the Sørensen-Chekanovsky index (%)

and from the front grotto (exclusive dominance of the green alga *Desmococcus olivaceus*). The species composition of algae on the walls of the front grotto of the cave is most peculiar, probably due to significant shading and more stable temperature and humidity conditions throughout the year.

As it is known (Vinogradova, Mikhailyuk, 2009; Lamprinou et al., 2012), in the speleological literature, three zones are distinguished according to the level of illumination; the present research covered two of them, the "entrance zone" and the "twilight zone". The data we obtained have certain similarities with the algal flora of similar localities in other countries, in particular, Slovakia (Šramková, Kováčik, 2005), Poland (Czerwik-Marcinkowska, Mrozińska, 2011; Czerwik-Marcinkowska et al., 2015), the

Table 3. **Taxonomic structure of the bryoflora of the Dumka Cave complex**

Taxon	Number of species, units (%)			
	Karst bridge	Cave entrance	Grotto	In total
MARCHANTIOPHYTA	**8 (38.0)**	**3 (23.1)**	–	**8 (32.0)**
Jungermanniopsida	5 (23.8)	2 (15.4)	–	5 (20.0)
Jungermanniales	3 (14.2)	2 (15.4)	–	3 (12.0)
Pelliales	1 (4.8)	–	–	1 (4.0)
Porellales	1 (4.8)	–	–	1 (4.0)
Marchantiopsida	3 (14.2)	1 (7.7)	–	3 (12.0)
Marchantiales	3 (14.2)	1 (7.7)	–	3 (12.0)
BRYOPHYTA	**13 (62.0)**	**10 (76.9)**	**2 (100)**	**17 (68.0)**
Bryopsida	13 (62.0)	10 (76.9)	2 (100)	17 (68.0)
Hypnales	8 (38.0)	5 (38.5)	1 (50)	9 (36.0)
Bryales	2 (9.6)	2 (15.4)	–	3 (12.0)
Pottiales	2 (9.6)	1 (7.7)	1 (50)	2 (8.0)
Dicranales	1 (4.8)	–	–	1 (4.0)
Encalyptales	–	1 (7.7)	–	1 (4.0)
Timmiales	–	1 (7.7)	–	1 (4.0)
Total number of species	**21 (100)**	**13 (100)**	**2 (100)**	**25 (100)**

Czech Republic (Wipplingerová et al., 2025), Serbia (Popović et al., 2017; Nikolić et al., 2020), etc. This applies to both species composition and taxonomic structure: in the latter, the greatest similarity is noted with the caves of the Polish Jura (Polish Jurassic Highland, Jura Krakowsko-Częstochowska).

Some species of cyanobacteria and algae revealed on the rocks of the cave complex are new and noteworthy records. In particular, two species of cyanobacteria are first records in Ukraine: *Synechococcus sciophilus* (Fig. 2F) and *Synechocystis primigenia* (Fig. 2E). Both taxa are typical of calcareous rocks, the latter is also found in caves (Komárek, Anagnostidis, 1998). For a number of cyanobacterial species, this is the second record in Ukraine. Among them, *Gloeocapsa coracina*, *Cyanosarcina parthenonensis* (Fig. 2D), and *Microcoleus vulgaris* (Fig. 2L) were reported from the caves and grottoes of the Podilsky Tovtry National Nature Park (Vinogradova, Mikhailyuk, 2010). Aerophyte *Pseudocapsa dubia* (Fig. 2B) was found on the rock in the Carpathian Biosphere Reserve (Kovalenko, Kyslova, 2008). Noteworthy records are cyanobacteria *Chroococcus helveticus* (Fig. 2A) and *Nodularia sphaerocarpa* (Fig. 2J, K), green algae *Coccomyxa* cf. *viridis* (Fig. 3K), *Scotinosphaera* sp. (Fig. 3G, H), *Pseudostichococcus undulatus* (Fig. 3E, F), *Pseudendoclonium* cf. *arthopyreniae* (Fig. 3J), *Macrochloris dissecta* (Fig. 3A), and terrestrial diatoms *Aerophilia roeseana*, *Achnanthes coarctata*, and *Humidophila contenta* (Tsarenko et al., 2024a, 2024b).

In total, 25 species of bryophytes were found in different parts of the cave complex, including eight species of liverworts (*Marchantiophyt*a) and 17 species of mosses (*Bryophyta*; Table 3). *Marchantiophyta* is represented by 2 classes (*Jungermanniopsida*, *Marchantiopsida*), 4 orders and 6 families (*Conocephalaceae* and *Plagiochilaceae* — 2 species each, *Pelliaceae*, *Lophocoleaceae*, *Marchantiaceae*, *Porellaceae* — 1 species each). All discovered representatives of *Bryophyta* belong to the class *Bryopsida*, 6 orders and 9 families (*Brachytheciaceae*, *Mniaceae*, *Plagiotheciaceae* — 3 species each, *Neckeraceae*, *Pottiaceae* — 2 species each, *Fissidentaceae*, *Encalyptaceae*, *Amblystegiaceae*, *Timmiaceae* — 1 species each).

The karst bridge had the highest species richness of bryophytes (21 species), and 13 species were found on the calcareous boulders at the cave's entrance. Due to the low lighting, cave's front grotto walls had extremely low bryophytes (2 species, Table 4).

The karst bridge turned out to be richest in bryophytes. A total of 21 species have been found here. The peculiarity of this site is the diversity of liverworts (8 species) of which only three species were found in other parts of the complex. The richness of the bryo- and hepaticoflora of the karst bridge is probably due to the greater variety of conditions, primarily the surfaces with different exposure and

Table 4. **Species composition of the bryoflora of the Dumka Cave complex**

Taxon	Karst bridge	Cave entrance	Grotto
MARCHANTIOPHYTA	**8**	**3**	**0**
Apopellia endiviifolia (Dicks.) Nebel & D. Quandt	+	–	–
Conocephalum conicum (L.) Dumort.	+	–	–
Conocephalum salebrosum Szweyk., Buczk. & Odrzyk.	+	+	–
Lophocolea heterophylla (Schrad.) Dumort.	+	–	–
Marchantia quadrata Scop.	+	–	–
Pedinophyllum interruptum (Nees) Kaal.	+	+	–
Plagiochila porelloides (Torr. ex Nees) Lindenb.	+	+	–
Porella platyphylla (L.) Pfeiff.	+	–	–
BRYOPHYTA	**13**	**10**	**2**
Anomodon viticulosus (Hedw.) Hook. & Taylor	+	+	–
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen	–	+	–
Campylophyllopsis calcarea (Crundw. & Nyholm) Ochyra	+	+	–
Encalypta streptocarpa Hedw.		+	–
Fissidens gracilifolius Brugg.-Nann. & Nyholm	+	–	–
Gymnostomum aeruginosum Sm.	+	+	+
Mnium marginatum (Dicks.) P. Beauv.	+	–	–
Mnium stellare Hedw.	+	+	–
Orthothecium intricatum (Hartm.) Schimp.	+	–	+
Plagiomnium rostratum (Schrad.) T.J. Kop.	–	+	–
Plagiothecium cavifolium (Brid.) Z. Iwats.	+	–	–
Plasteurhynchium striatulum (Spruce) M. Fleisch.	+	–	–
Platydictya jungermannioides (Brid.) H.A. Crum	+	+	–
Pseudanomodon attenuatus (Hedw.) Ignatov & Fedosov	+	+	–
Rhynchostegium murale (Hedw.) Schimp.	+	–	–
Tortula muralis Hedw.	+	–	–
Timmia bavarica Hessl.	–	+	–
Total number of species	**21**	**13**	**2**

different levels of illumination. Only 3 species (*Apopellia endiviifolia*, *Mnium stellare* (Fig. 5B), and *Pseudanomodon attenuatus*) were abundant in both shaded and illuminated places. *Conocephalum salebrosum* (Fig. 5C) dominated only on horizontal and semi-inclined periodically illuminated surfaces. Another species of this genus (*C. conicum*) was found only in shaded conditions of niches and vaults, where it grew as single thalli. *Orthothecium intricatum*, *Gymnostomum aeruginosum*, and *Pedinophyllum interruptum* form small turfs in the niches. *Fissidens gracilifolius* was found only at the foot of the bridge blocks, where a small layer of soil was formed. The most peculiar is the bryoflora of the horizontal surface of the top of the bridge arch. Variable lighting due to sparse tree stands and a thin layer of soil on the rock surface form specific conditions. *Marchantia quadrata* and *Lophocolea heterophylla* were found only here.

The species composition of bryophytes on the rocks near the cave entrance differed from that of the karst bridge, although the composition of dominant species was the same. A total of 13 species of bryophytes were found here. Three species (*Conocephalum salebrosum*, *Pseudanomodon attenuatus*, and *Mnium stellare*) formed expanded turphs on the rocks.

A characteristic feature of the rocks near the entrance was also large-sized turfs of *Timmia bavarica* (Fig. 5A) and *Anomodon viticulosus* (Fig. 5D). These species have relatively large gametophyte and, together with other dominants, create

Fig. 5. Bryophytes of the Dumka Cave complex. A: *Timmia bavarica*; B: *Mnium stellare*; C: *Conocephalum salebrosum*; D: *Anomodon viticulosus*; E: *Fissidens gracilifolius*; F: *Pedinophyllum interruptum*

a very characteristic appearance of almost completely moss-covered calcareous walls. They are joined by small spots of *Encalypta streptocarpa*, *Gymnostomum aeruginosum* with the addition of *Brachytheciastrum velutinum*, *Campylophyllopsis calcarea*, and *Platydictya jungermannioides*.

Table 5. **Taxonomic structure of vascular plants of the Dumka Cave complex**

Taxon	Number of species, units (%)			
	Karst bridge	Cave entrance	Grotto	In total
PTERIDOPHYTINA	**3 (30.0)**	**5 (31.25)**	**–**	**5 (23.8)**
Aspleniaceae	2 (20.0)	3 (18.75)	–	3 (14.2)
Cystopteridaceae	1 (10.0)	1 (6.25)	–	1 (4.8)
Polypodiaceae	–	1 (6.25)	–	1(4.8)
SPERMATOPHYTINA	**7 (70.0)**	**11 (68.75)**	**–**	**16 (76.2)**
Araliaceae	–	1 (6.25)	–	1 (4.8)
Brassicaceae	1 (10.0)	1 (6.25)	–	1 (4.8)
Campanulaceae	–	1 (6.25)	–	1 (4.8)
Caryophyllaceae	–	1 (6.25)	–	1 (4.8)
Celastraceae	–	1 (6.25)	–	1 (4.8)
Asteraceae	–	1 (6.25)	–	1 (4.8)
Crassulaceae	–	1 (6.25)	–	1 (4.8)
Geraniaceae	1 (10.0)	1 (6.25)	–	2 (9.6)
Grossulariaceae	1 (10.0)	–	–	1 (4.8)
Lamiaceae	1 (10.0)	1 (6.25)	–	1 (4.8)
Papaveraceae	1 (10.0)	–	–	1 (4.8)
Poaceae	–	1 (6.25)	–	1 (4.8)
Ranunculaceae	1 (10.0)	–	–	1 (4.8)
Rubiaceae	–	1 (6.25)	–	1 (4.8)
Viburnaceae	1 (10.0)	–	–	1 (4.8)
Total number of species	**10 (100)**	**16 (100)**	**–**	**21 (100)**

The walls of the front grotto of the cave were characterized by a very poor species composition of bryophytes. Only two species (*Orthothecium intricatum* and *Gymnostomum aeruginosum*) have been found here, growing on vertical surfaces in crevices where a thin layer of humus was formed. In general, environmental conditions in caves are quite unfavorable for bryophytes, even for sciophyte species. There is insufficient lighting with limited availability of nutrients, high humidity and relatively small temperature fluctuations. The bryoflora of cave complexes differs significantly from the bryoflora of the surrounding forest vegetation, and is often relict (Rena et al., 2021). Therefore, not many species are known from deep caves in Ukraine (Bachuryna, Melnychuk, 1987, 1988, 1989, 2003; Virchenko, Nyporko, 2022). Of the species that we discovered, only *O. intricatum* is known from other cave complexes in Ukraine. Bryofloras of cave complexes in some European countries are also somewhat similar to the one we discovered (Kubešová, 2001; Mulec, Kubešová, 2010), although they are usually richer at the species level.

A comparison of species composition using the Sørensen-Chekanovsky index showed the greatest uniqueness of the bryoflora of the front grotto of the cave (15%), while the bryoflora of the karst bridge and the cave entrance were quite similar (52%). There are 9 species shared by the karst bridge and the cave entrance. *Orthothecium intricatum* grows on the walls near the entrance and in the front grotto. Only *Gymnostomum aeruginosum* was found in all studied sites.

Some of the revealed bryophytes are noteworthy and rare species. For *Pedinophyllum interruptum* (Fig. 5F) and *Fissidens gracilifolius* (Fig. 5E), this is the second locality in Ivano-Frankivsk Region, and for the latter in Ukraine as well. V.M. Virchenko found *F. gracilifolius* on shaded limestones in Rivne Region (Virchenko, Nyporko, 2022). For *Timmia bavarica*, this is the third locality in Ivano-Frankivsk region. Previous records were dated by 1928 and 1936, and one of them was from the territory of the studied RLP: Tlumatsky District, near Nyzhniv village (Bachuryna, Melnychuk, 1989). Four species are rare for the Forest-Steppe: *Apopellia endiviifolia*, *Porella platyphylla*, *Plagiothecium cavifolium*, and *Plasteurhynchium striatulum* (Boiko, 2010). Fifteen species of bryophytes (*Anomodon viticulosus*,

Table 6. **Species composition of vascular plants of the Dumka Cave complex**

Taxon	Karst bridge	Cave entrance	Grotto
PTERIDOPHYTINA	**3**	**5**	**–**
Asplenium ruta-muraria L.	–	+	–
Asplenium scolopendrium L.	+	+	–
Asplenium trichomanes L.	+	+	–
Cystopteris fragilis (L.) Bernh.	+	+	–
Polypodium vulgare L.	–	+	–
SPERMATOPHYTINA	**7**	**11**	**–**
Lamium galeobdolon (L.) Crantz	+	+	–
Ribes uva-crispa L.	+	–	–
Geranium sanguineum L.	+	–	–
Sambucus nigra L.	+	–	–
Isopyrum thalictroides L.	+	–	–
Chelidonium majus L.	+	–	–
Arabidopsis arenosa (L.) Lawalrée	+	+	–
Geranium robertianum L.	–	+	–
Euonymus verrucosus Scop.	–	+	–
Hylotelephium maximum (L.) Holub	–	+	–
Poa nemoralis L.	–	+	–
Cicerbita muralis (L.) Wallr.	–	+	–
Moehringia muscosa L.	–	+	–
Galium intermedium Schult.	–	+	–
Campanula trachelium L.	–	+	–
Hedera helix L.	–	+	–
Total number of species	**10**	**16**	**–**

Brachytheciastrum velutinum, *Fissidens gracilifolius*, *Marchantia quadrata*, *Mnium marginatum*, *Orthothecium intricatum*, *Pedinophyllum interruptum*, *Plagiomnium rostratum*, *Plagiothecium cavifolium*, *Plasteurhynchium striatulum*, *Platydictya jungermannioides*, *Porella platyphylla*, *Pseudanomodon attenuatus*, *Rhynchostegium murale*, and *Tortula muralis*) are reported for the first time from the territory of the Dniester RLP.

It should be noted that the identified species composition of bryophytes turned out to be somewhat similar to the bryofora of previously studied localities in Western Ukraine, representing shaded forest limestone outcrops (Nyporko, 2021; Didukh et al., 2023; Nyporko, Vasheniak, 2024). These habitats of shaded chasmophyte communities of Ukraine are classified as biotopes H32c (Temperate lowland to montane base rich inland cliff) according to the new EUNIS classification (Chytrý et al., 2020). The communities are rare and have a limited distribution, with low potential for recovery (Didukh et al., 2023). According to our research, *Conocephalum salebrosum*, *Pseudanomodon attenuatus*, *Anomodon viticulosus*, and *Mnium stellare* frequently occur in such communities. Also on limestone shaded cliffs, *Apopellia endiviifolia*, *Gymnostomum aeruginosum*, and *Pedinophyllum interruptum* are common. Other species found in this locality mainly prefer calcium-containing substrates. In Ukraine, *Orthothecium intricatum* is quite common in crevices of limestone rocks, ravines, and caves (Bachuryna, Melnychuk, 2003). Thus, the bryoflora of the Dumka Cave complex is generally calcephytic and sciophytic.

Vascular plants identified in the studied sites of the Dumka Cave complex include five species of *Pteridophytina*; among them, three species of the family *Aspleniaceae* (*Asplenium ruta-muraria*, *A. scolopendrium*, and *A. trichomanes*). In addition, 16 species of *Spermatophytina* are companion

species of the chasmophytic communities, including mainly herbaceous plants of the families *Brassicaceae*, *Campanulaceae*, *Asteraceae*, *Poaceae*, succulents of the family *Crassulaceae* (*Hylotelephium maximum*), shrubs of the families *Celastraceae* (*Euonymus verrucosus*), *Viburnaceae* (*Sambucus nigra*), and *Grossulariaceae* (*Ribes uva-crispa*) (Tables 5, 6).

Among vascular plants, the dominant species are representatives of *Pteridophytina* (*Asplenium scolopendrium*, *Cystopteris fragilis*, *Polypodium vulgare*), which are characteristic of shaded rocky biotopes (Didukh et al., 2023), the projective cover of which is 20%. At the same time, the floristic core of chasmophytic communities is formed by representatives of *Spermatophytina* with a projective cover of 0.1–2%, which are mainly forest species (*Campanula trachelium*, *Hedera helix*, *Lamium galeobdolon*). Sometimes synanthropic species (*Chelidonium majus*, *Moehringia trinervia*) are associated in particular with a certain recreational load of the Dumka Cave complex.

It is worth noting that vascular plants are not calciphiles and do not indicate peculiar conditions of calcareous cliffs of the Dumka Cave complex, unlike mosses and algae. In general, such complexes of vascular plants and mosses can be classified as associations of *Cystopteridetum fragilis* Oberd. 1938 and *Asplenio-Phyllidetum scolopendrii* Redžić et al. 2002 within the class *Polypodietea* Jurko et Peciar ex Boşcaiu, Gergely et Codoreanu in Rațiu et al. 1966, reported for Ukraine (Didukh et al., 2023). They occur in semi-shaded and shaded conditions of hornbeam-oak forests, which occupy quite large areas on the upper terraces of the Dniester River valley. Such communities belong to the biotope H32c "Carbonate rocks of the temperate zone, occurring on the plain and in the lower mountain belt" (Chytrý et al., 2020) and are assessed as rare biotopes belonging to the second category (Didukh et al., 2023).

Conclusions

The study is the first attempt to assess the floristic diversity of chasmophytic communities of calcareous rocks of the Dumka Cave complex in the Dniester RLP. Diverse species and taxonomic composition of cyanobacteria, algae, cryptogamic and vascular plants were revealed: 56 species of cyanobacteria and algae (*Cyanobacteria* — 21, *Chlorophyta* — 23, *Charophyta* — 2, *Heterokontophyta* — 9), 25 species of bryophytes (*Marchantiophyta* — 8, *Bryophyta* — 17), and 21 species of vascular plants (5 — *Pteridophytina*, 16 — *Spermatophytina*). Interesting floristic records were made in the studied biotope. Two species of cyanobacteria (*Synechococcus sciophilus* and *Synechocystis primigenia*) are first reported for Ukraine. *Gloeocapsa coracina*, *Pseudocapsa dubia*, *Cyanosarcina parthenonensis*, and *Microcoleus vulgaris* have only been found in our country once before. Among bryophytes, noteworthy records are *Pedinophyllum interruptum* and *Fissidens gracilifolius*, for which this is the second locality in Ivano-Frankivsk Region, and for the latter in Ukraine as a whole. For *Timmia bavarica* (rare in the Ukrainian Carpathians) this is the third locality in Ivano-Frankivsk Region. On the other hand, among the identified vascular plants there are synanthropic species, which indicates the presence of certain anthropogenic impact. Therefore, further monitoring of the state of the biotope's vegetation is necessary.

The studied communities belong to the biotope H32c "Cabonate rocks of the temperate zone, occurring on the plain and in the lower mountain belt", according to the new classification of biotopes, are syntaxonomically characterized as a group of the *Polypodietea* class, referring to the second category of rarity and needing protection. The main threat to the existence of this biotope is deforestation, which leads to increased light levels, heating of rocks, and moisture deficiency, as well as eutrophication due to recreational load.

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The authors declare no conflict of interest.

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Водорості, мохоподібні та судинні рослини вапняків печерного комплексу "Думка" (Дністровський регіональний ландшафтний парк, Україна)

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Реферат. Досліджено хазмофітні угруповання вапнякових скель печерного комплексу "Думка" в Дністровському регіональному ландшафтному парку (Івано-Франківська область). Виявлено різноманітну рослинність, в якій домінували папороті, мохоподібні та водорості. Комплекс досліджували у трьох частинах: так званий "карстовий міст" (нагромадження уламків склепіння печери), вапняки біля входу до печери та стіни переднього гроту печери. Загалом у печерному комплексі виявлено 56 видів водоростей (*Cyanobacteria* — 21 вид, *Chlorophyta* — 23, *Charophyta* — 2, *Heterokontophyta* — 9), 25 видів мохоподібних (*Marchantiophyta* — 8, *Bryophyta* — 17) та 21 вид судинних рослин (*Pteridophytina* — 5, *Spermatophytina* — 16). Найвище видове різноманіття зареєстровано на карстовому мості та стінах при вході до печери. В обох місцезростаннях у водоростевому покриві домінували представники ціанобактерій і зелених водоростей. Водорості та мохоподібні на стінах переднього гроту були менш різноманітними, судинні рослини та ціанобактерії — взагалі відсутні, тут переважали требуксієфіцієві зелені водорості та діатомеї. Порівняння видового складу водоростей та мохоподібних за коефіцієнтом Сьоренсена-Чекановського показало певну спорідненість карстового міста і брил біля входу до печери та специфічність переднього гроту печери. Серед виявлених видів водоростей 2 види — *Synechococcus sciophilus* та *Synechocystis primigenia* — є новими для флори України, решта — рідкісними та вартими уваги таксонами (*Gloeocapsa coracina*, *Microcoleus vulgaris*, *Scotinosphaera* sp., *Pseudostichococcus undulatus* та ін.). 15 видів мохоподібних наводяться вперше для території парку. Для Івано-Франківської області вперше наводяться 2 види — *Pedinophyllum interruptum* та *Fissidens gracilifolius*, знахідка останнього є другою для території України. Для рідкісного в Українських Карпатах *Timmia bavarica* це третій локалітет в Івано-Франківській області. Судинні рослини є характерними для затінених епілітних місцезростань. Такі угруповання належать до біотопу H32c "Кабонатні скелі помірного поясу, що трапляються на рівнині та у нижньому гірському поясі", синтаксономічно характеризуються як угруповання класу *Polypodietea* і належать до другої категорії рідкісності та потребують охорони. Основною загрозою для існування цього біотопу є вирубування лісів, яке призводить до підвищення рівня освітленості, нагрівання скель та дефіциту вологи, а також евтрофікація, яка є результатом рекреаційного навантаження.

Ключові слова: біорізноманіття, Дністер, карстова печера "Думка", мохоподібні, наземні водорості, судинні рослини, Україна, ціанобактерії