Species composition and diversity of aero-terrestrial algae and cyanobacteria of the Boreč Hill ventaroles

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Abstract: The algal flora of the Boreč Hill ventaroles was examined and compared with the flora of their close surroundings. In comparison to unaffected sites, the ventaroles differ in seasonal temperature fluctuation as well as in soil pH. Winter exhalations caused by continual air circulation in the cranny system of rock massive result in a significant increase in air temperature and soil pH. The ventaroles were inhabited by a markedly richer and more diversified algal flora. Over half of investigated species occurred only in the ventaroles, including all chrysophyte, eustigmatophyte and desmid taxa. In contrast to the unaffected sites, different algal populations were discovered in the ventaroles. The investigated species could be separated into two groups: ventarole-specific ones preferentially occurred in both the ventaroles, and those occurred only in a large ventarole. There, water condensation in moss plants during winter exhalations enables a short-term occurrence of several algal species preferring aquatic environments. The diatom flora of the ventaroles resembles well the species composition found in the caves. By contrast, the desmid flora is rather similar to algal communities found in ephemeral water bodieslike temporary peat bog pools or dripping rocks. Thus, the Boreč Hill ventaroles represent a unique type of biotope, with a specific algal flora adapted to periodical periods of warm, moist air exhalations of several months' duration.

Key words: aerophytic algae, Chlorophyta, desmids, diatoms, ecology, soil pH, Streptophyta, terrestrial algae, ventaroles

Introduction

Debris fields are characterized by their unique air movement regime. In some cases, the cranny system of rock massive allows continual air circulation, resulting in the origin of summer ice holes and winter warm air exhalations, so-called ventaroles. The most famous ventarole locality in the Czech Republic is situated in the top parts of Boreč Hill (The České Středohoří Mts., Czech Republic). In winter, warm vapours rise from the top due to air circulation in the crevices. In spring and summer, the circulation is reversed and small ice stalagmites appear at the foot of the hill (Fig. 1). The differences in temperatures inside and outsides the ventaroles could reach 25°C (Ankert 1917, Kubát 1971).

The Boreč Hill ventaroles are especially unique due to occurrence of several plant and animal species, intolerant of freezing temperatures. The locality is known as the only one recorded habitat of the Mediterranean liverwort *Targionia hypophylla* L. in the Czech Republic (Pilous 1959). Rare plant, moss, and beetle species were recorded by several authors (Ložek 1954, Kubát 1971, Pujmanová 1990, Němcová 2001, Růžička 2003). In this paper, the algal flora of ventaroles is reported for the first time. The main aims of this paper were 1) to compare the algal communities of the ventaroles and neighbouring areas, and 2) to ascertain the effect of the ventarole regime on the species composition and total diversity.

Materials and Methods

The research was realized in the top parts of Boreč Hill, in the south-western part of The České Středohoří Mts., the Czech Republic. Four sampling sites were allocated: two sites situated inside the ventaroles characterized by intense winter air exhalations, and two sites situated in the neighbouring area without winter exhalations:

1. A large ventarole near the information table No. 5, probably artificially enlarged in the 1950s (Pilous 1959) (50°30'51.3" N, 13°59'19.4" E, 443 m. a.s.l.).

2. A small unaffected ventarole northwards to the site 1 (50°30’51.9” N, 13°59’19.8” E, 441 m. a.s.l.).
3. Area of 1 m^2 without winter exhalations, south-eastwards to the site 2 (50°30’51.7” N, 13°59’20.2” E, 443 m. a.s.l.).
4. Area of 1 m^2 without winter exhalations, north-westwards to the site 2 (50°30’52.1” N, 13°59’19.0” E, 439 m. a.s.l.).

The localities were regularly investigated in three-month intervals (from December 2000 to February 2003). Three microbiotopes were sampled on each sampling date: “soil” (surface sample from the horizon of 0–2 cm), “moss” (moss individuals or, in the winter, water squeezed from mosses growing in the ventaroles) and “rock” (mechanically scrapped rock surface). The samples were placed in sterile tubes and transported to the laboratory for analysis. Subsequently, the samples were both overfilled with liquid BBM medium (Bischoff & Bold 1963) and the sample suspension was spread on Petri dishes with BBM-agar. Algal microcolonies grown up after 8-10 weeks (at 15°C under daylight conditions) were isolated into unialgal cultures and cultivated at temperature 20°C under an illumination of 40 µmol.m^{-2}.s^{-1} provided by 18W cool fluorescent tubes (Philips TLD 18W/33). To prepare diatom slides, the organic matter was removed by soaking in hydrogen peroxide (H_2O_2; Krammer & Lange-Bertalot 1986). The frustules were dried on a coverslip and mounted in Pleurax resin. For a detailed investigation of diatom frustules and chrysophyte scales, drops were also dried onto formvar coated grids and examined with Philips 300 transmission electron microscope.

Individual species were identified using microscopic methods and Olympus BX51 light microscope with differential and phase contrasts and Olympus Z5060 microphotographic equipment. Identification was based on taxonomic monographs and reference books for terrestrial algae and cyanobacteria (Migula 1907, Geitler 1932, Koršikov 1953, Printz 1964, Prescott et al. 1972, Starmach 1972, Ettl 1978, 1983, Růžička 1981, Komárek & Fott 1983, Krammer & Lange-Bertalot 1986, 1988, 1991a, b, Ettl & Gärtner 1988, 1995, Hindák 1996, Lenzenweger 1996, Lokhorst 1996, Andreeva 1998, Krammer 2000, Lange-Bertalot 2001, Komárek & Anagnostidis 2005). Formation of zoospores was stimulated by transferring unialgal cultures to tubes with both diluted BBM medium and fresh distilled water. The tubes were placed in darkness at a temperature of about 10°C. Some of the unialgal cultures obtained were deposited either in the Culture Collection of Algae of Charles University in Prague (CAUP) or in the author’s private culture collection.

Statistical analyses were carried out using the programme Canoco for Windows (ter Braak & Šmilauer 2002) and results of ordination were summarized using the programme CanoDraw (ter Braak & Šmilauer 1998).

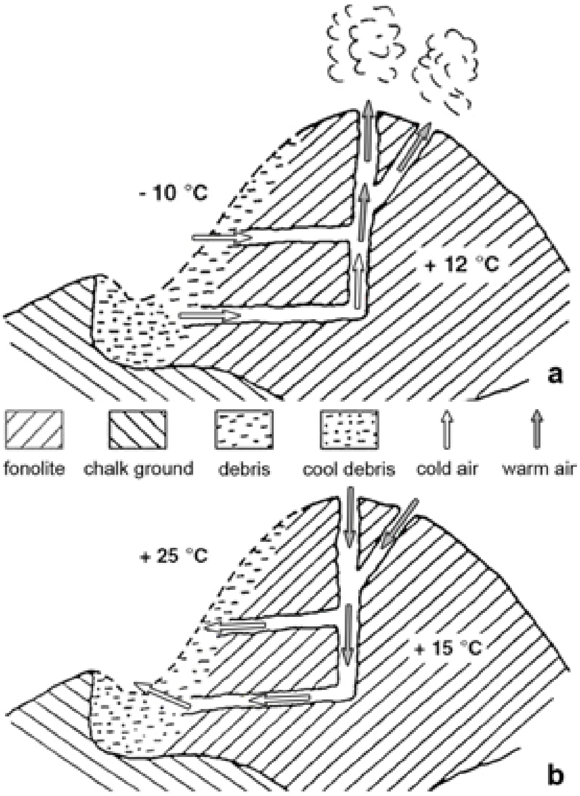


Fig. 1. Schematic drawing of the air circulation in the cranny system of rock massive in Boreč Hill: (a) winter air circulation; (b) summer air circulation (modified after Kučera 1999).

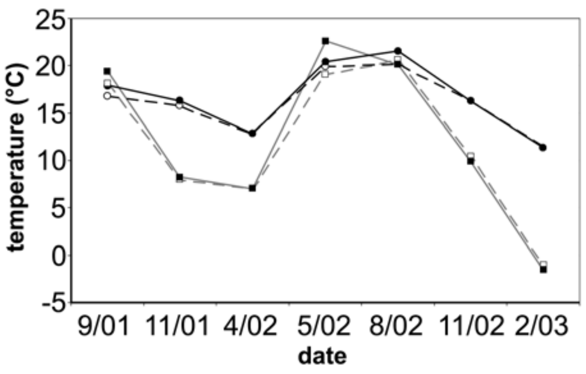


Fig. 2. Seasonal temperature fluctuation, measured in four investigated study sites (black circle, solid line – ventarole 1; white circle, dashed line – ventarole 2; white square, dashed line – sampling site 3; black square, solid line – sampling site 4).

Results and discussion

Analyses of environmental conditions

Seasonal temperature fluctuation significantly differs between the ventaroles and unaffected study sites (Fig. 2). Whereas differences in temperature measured in the winter and summer reached 25°C in the unaffected sites, the temperature in the ventaroles oscillated only in the range of 10°C. In the spring and summer, when the air circulation is reversed, the temperature was nearly identical in all the sites. However, during winter exhalations the ventaroles were distinctively warmer. The temperature of exhaled air was identical in both the ventaroles without reference to their size. A method of the continuous temperature measurement was used in 2003 to determine the lowest temperature that can occur in the ventaroles The lowest recorded temperature was 10.5°C (even acquired in the summer).

All four study sites are situated on phonolite, i.e. extrusive igneous rocks (lavas). Though the phonolite belongs to alkaline igneous rocks, measured soil pH had an acidic reaction (Fig. 3). This could be caused by several factors, e.g. human distractions like acidification and air pollution, rainwater leaching away basic ions, vegetation, or carbon dioxide from decomposing organic matter (Tamm & Hallbäcken 1986). Interestingly, obvious difference between the ventaroles and unaffected study sites was noted in soil pH, which was higher in both the ventaroles (Fig. 3). Although pH values slightly fluctuated during the year, no seasonal changes were observed. The ventaroles are situated closely to the unaffected study sites. Accordingly, the difference in pH reaction has to be caused by the ventarole conditions. In contrast to the temperature difference caused by winter exhalations, the disparity in soil pH is difficult to interpret but has a principal biological importance. As pH levels drop below 5.5, the population of soil microbes changes and is dramatically reduced due to aluminium and manganese toxicity and reduced nutrient availability (McFarland et al. 2001). By contrast, correct balance of trace elements is obtained where the soil pH is between 5.5 and 7.5. Therefore, the soil pH in the ventaroles (pH 4.7–5.8) offers more favourable conditions for algal growth in comparison to the adjacent localities (pH 3.7–4.4).

Species composition and diversity

Algal diversity of the ventaroles greatly exceeded that found in the adjacent sampling sites. The ventaroles were inhabited by a markedly richer and more diversified algal flora. From a total of 112 species, 107 species of cyanobacteria and algae were recorded in the ventaroles, in contrast to 42 species found in their vicinity. Chrysophytes, eustigmatophytes and desmids occurred only in the ventaroles. Just 5 species were found outside the ventaroles. The list of species is given in Table 1. The species were investigated using morphological criteria only, without any molecular investigation. Even if purely morphological data are sufficient for standard ecological studies (where comparison of individual morphotypes illustrates influences of investigated factors), accurate description of the algal flora is essential for potential future comparisons. Since the recent molecular studies have shown a high hidden diversity of aero-terrestrial algae with little morphological differentiation (Huss et al. 1999, Krienitz et al. 2004, Sluiman et al. 2008), I place emphasis on a detailed morphological description of the investigated species. Hence, the majority of the investigated species are illustrated (Figs 4–8). Moreover, numerous micrographs of the detected cyanobacteria and algae have been published on the Web (Škaloud 2008).

The difficulties of current determination of green aerophytic algae could be well demonstrated by the strain *Eutetramorus* sp. This alga morphologically resembles species of genera

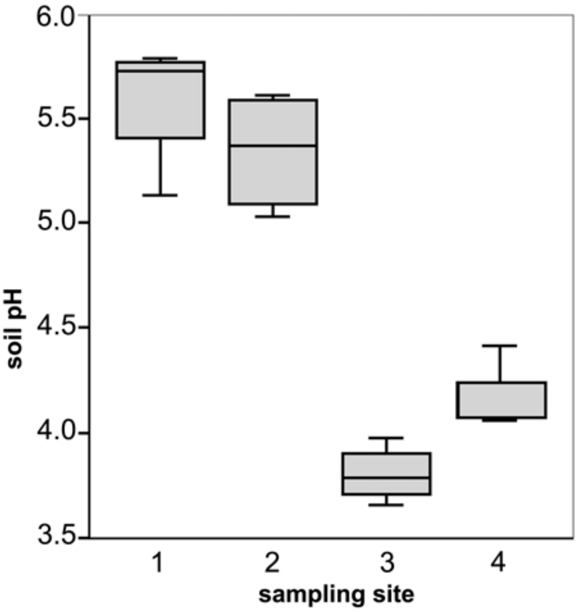


Fig. 3. Variability in the soil pH determined from five measurements in 2002 and 2003.

Radiococcus Schmidle or *Eutetramorus* Walton (Ettl & Gärtner 1995, Kostikov et al. 2002). However, whereas *Radiococcus* was determined to be a member of Chlorophyceae (Wolf et al. 2003), molecular investigation of isolated strains revealed that it belonged to Trebouxiophyceae (data not shown). On the other hand, *Eutetramorus* differs ecologically, as it has been so far recorded only from aquatic environments (Guiry & Guiry 2008). Taxonomic designation is thus very difficult or even impossible for many algae and cyanobacteria included in this study. Therefore, the occurrences of particular morphospecies could be well used for demonstrating the algal diversity of studied sites. However, comparisons with other morphologically based studies on aero-terrestrial algae should be made very carefully, keeping in mind high cryptic diversity and low taxonomic significance of many morphological features defining these organisms.

Ecological analyses

On the PCA ordination plot, the samples from both the ventaroles form separate clusters, whereas the two adjacent localities are clustered together (Fig. 9). While the first ordination axis separates the ventaroles from the other two sampling sites, the second ordination axis clearly discriminates the ventaroles from one another. The first ordination axis obviously correlates with the species richness of particular samples. The samples with the greatest species richness were obtained from the moss samples in the ventarole 1 during winter exhalations (two rightmost samples in Fig. 9). The unique conditions inside the ventaroles thus seem to cause distinct increase in algal diversity.

To test the effect of the ventarole regime on the species composition and total diversity, RDA analysis was performed to determine if the localities are inhabited by different algae. The species composition of the ventaroles and adjacent localities was significantly different (p-value 0.0002). Similarly to PCA, the RDA analysis revealed the difference between both the ventaroles, in contrast to almost similar algal composition of the adjacent sampling sites (Fig. 10). Two species groups can be distinguished on the RDA ordination plot: ***I*** Species preferentially occurring in the ventarole 1 (e.g. *Orthoseira* Crafword species, *Kentrosphaera gibberosa* and *Euastrum brevisinuosum*). ***II*** Species that were observed in both the ventaroles (e.g. *Scenedesmus oocystiformis*, *Luticola mutica* and *Cosmarium obliquum* var. *trigonum*). Whereas the group ***II*** encompasses species that can be indicated as ventarole-specific, the group ***I*** should comprehend species with affinity to some other environmental factors. The main difference between the ventaroles is their size and water regime. In contrast to the ventarole 2, the ventarole 1 is much larger, enabling water condensation in moss plants during winter exhalations. The effect of water condensation on the species composition was thus tested by another RDA analysis (Fig. 11). The result was highly significant (p-value 0.0004), demonstrating a different algal composition inside wet mosses during the winter exhalations. Even if the effect of condensed water was tested against all the remaining samples (including rock and soil samples in the ventarole 1 during the exhalations), the first and second ordination axes well corresponded with the species groups ***I*** and ***II*** (Fig. 10), respectively. Thus, the larger species diversity in the ventarole 1 can be interpreted by seasonal formation of specific conditions, enabling short-term occurrence of several algal species preferring aquatic environments.

Due to high hidden cryptic diversity of several aero-terrestrial algal groups (e.g. cyanobacteria and coccal green algae), a precise comparison of their occurrences with respect to literary data is impossible. However, several algal species (in particular desmids and diatoms) can be used in this way owing to their good morphological circumscription and known ecological preferences. The diatom flora of the ventaroles resembles well the species composition found in the caves (Garbacki et al. 1999). The most frequently occurred diatom genera, *Diadesmis* Kützing, *Hantzschia* Grunow, *Luticola* Mann and *Orthoseira*, have been repeatedly noted from various caves worldwide (Carter 1971, St. Clair & Rushforth 1976, Poulíčková & Hašler 2007, Selvi & Altuner 2007), including specific ice caves (Lauriol et al. 2006). Moreover, specifically aquatic diatoms, *Eunotia exigua*, *Navicula cryptocephala*, and morphologically similar species of genera *Frustulia* Rabenhorst and *Synedra* Ehrenberg, were reported from the crack cave in Ohio, the USA (Dayner & Johansen 1991).

Contrary to diatoms, the desmid flora of the ventaroles is rather similar to algal communities found in ephemeral water bodies like temporary peat bog pools, wet or dripping rocks, etc. (Růžička 1964, Ettl & Gärtner 1995,

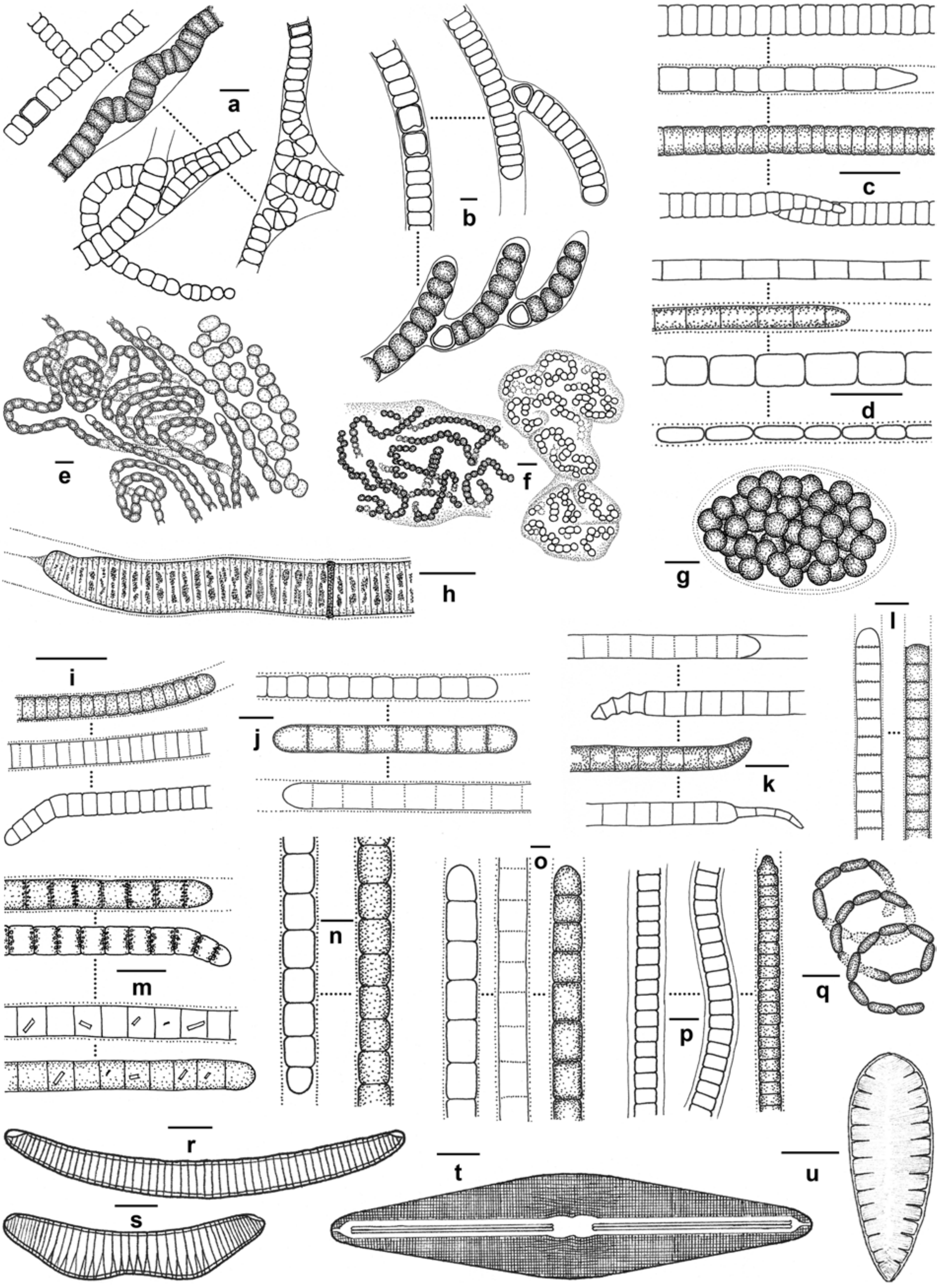


Fig. 4. (a) *Fischerella thermalis;* (b) *Hassallia byssoidea*; (c) *Leptolyngbya foveolarum*; (d) *Leptolyngbya tenuis*; (e) *Nostoc calcicola*; (f) *Nostoc* cf. *edaphicum*; (g) *Nostoc* sp.; (h) *Oscillatoria* cf. *curviceps*; (i) *Phormidium* cf. *ambiguum*; (j) *Phormidium* cf. *animale*; (k) *Phormidium autumnale*, (l) *Phormidium* sp. 1; (m) *Phormidium* sp. 2; (n) *Phormidium* sp. 3; (o) *Phormidium* sp. 4; (p) *Phormidium* sp. 5; (q) *Pseudanabaena* cf. *catenata*; (r) *Eunotia bilunaris*; (s) *Eunotia implicata*; (t) *Frustulia saxonica*; (u) *Surirella* cf. *minuta*. Scale bars 10 µm (Figs a–b, f–m); 5 µm (Figs c–d, n–u).

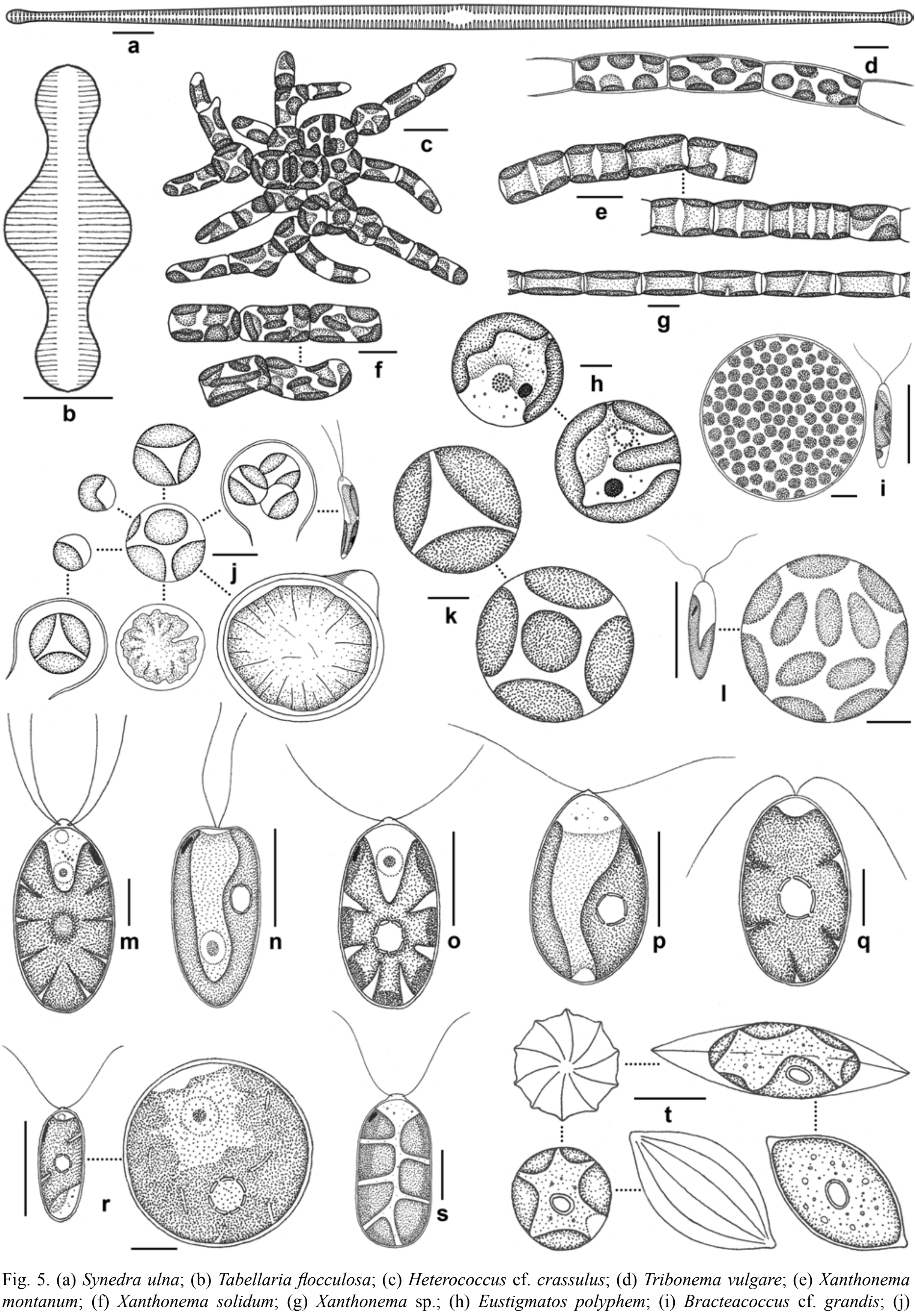


Fig. 5. (a) *Synedra ulna*; (b) *Tabellaria flocculosa*; (c) *Heterococcus* cf. *crassulus*; (d) *Tribonema vulgare*; (e) *Xanthonema montanum*; (f) *Xanthonema solidum*; (g) *Xanthonema* sp.; (h) *Eustigmatos polyphem*; (i) *Bracteacoccus* cf. *grandis*; (j) *Bracteacoccus minor*; (k) *Bracteacoccus pseudominor*, (l) *Bracteacoccus* sp.; (m) *Carteria* cf. *klebsii*; (n) *Chlamydomonas callunae*; (o) *Chlamydomonas pseudintermedia*; (p) *Chlamydomonas* cf. *sestinensis*; (q) *Chlamydomonas* sp.; (r) *Chlorococcum infusionum*; (s) *Chloromonas rosae*; (t) *Coelastrella oocystiformis*. Scale bars 10 µm (Figs a, c, i); 5 µm (Figs b, d–h, j–t).

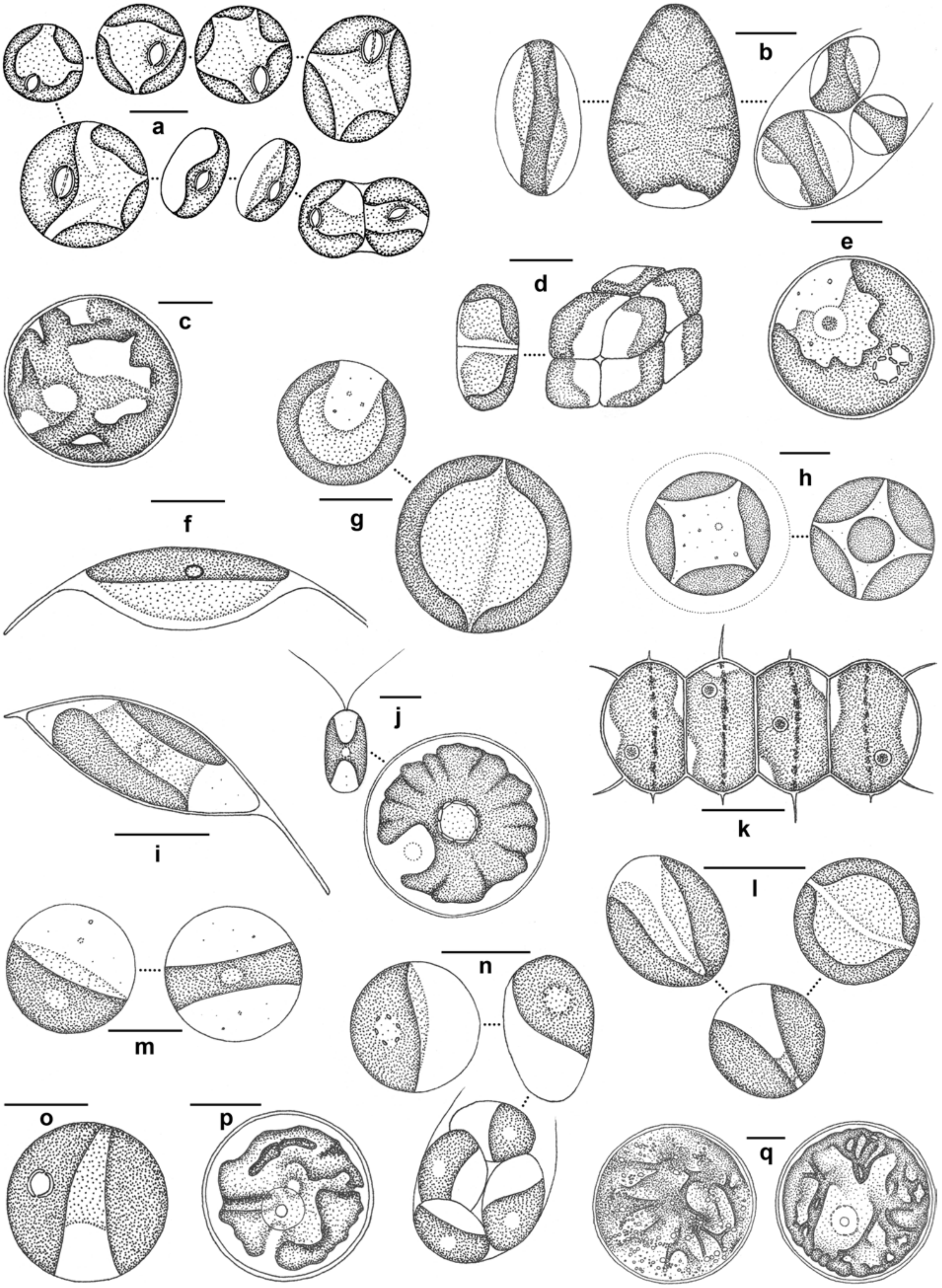


Fig. 6. (a) *Coelastrella vacuolata*; (b) *Coleochlamys* sp.; (c) *Dictyochloris pulchra*; (d) *Diplosphaera chodatii*; (e) *Fasciculochloris boldii*; (f) *Keratococcus bicaudatus*; (g) *Mychonastes homosphaera*; (h) *Phacomyxa* sp.; (i) *Podohedra bicaudata*; (j) *Radiosphaera minuta*; (k) *Scenedemsus soli*, (l) *Auxenochlorella protothecoides*; (m) *'Chlorella'* cf. *luteoviridis*; (n) *'Chlorella' mirabilis*; (o) *Chlorella vulgaris*; (p) *Dictyochloropsis reticulate*; (q) *Dictyochloropsis splendida*. Scale bar 5 µm.

Fig. 7. (a) *Dilabifilum printzii*; (b) *Dilabifilum* sp.; (c) *Eutetramorus* sp.; (d) *Geminella interrupta*; (e) *Lobosphaeropsis lobophora*; (f) *Muriella terrestris*; (g) *Myrmecia bisecta*; (h) *Pseudococcomyxa* cf. *simplex*; (i) *Rhexinema paucicellularis*; (j) *Schizochlamydella minutissima*; (k) *Schizochlamydella* sp., (l) *Stichococcus minor*; (m) *Stichococcus undulatus*; (n) *Trebouxia arboricola*; (o) *Trebouxia potteri*; (p) *Trebouxia* sp. Scale bar 5 µm.

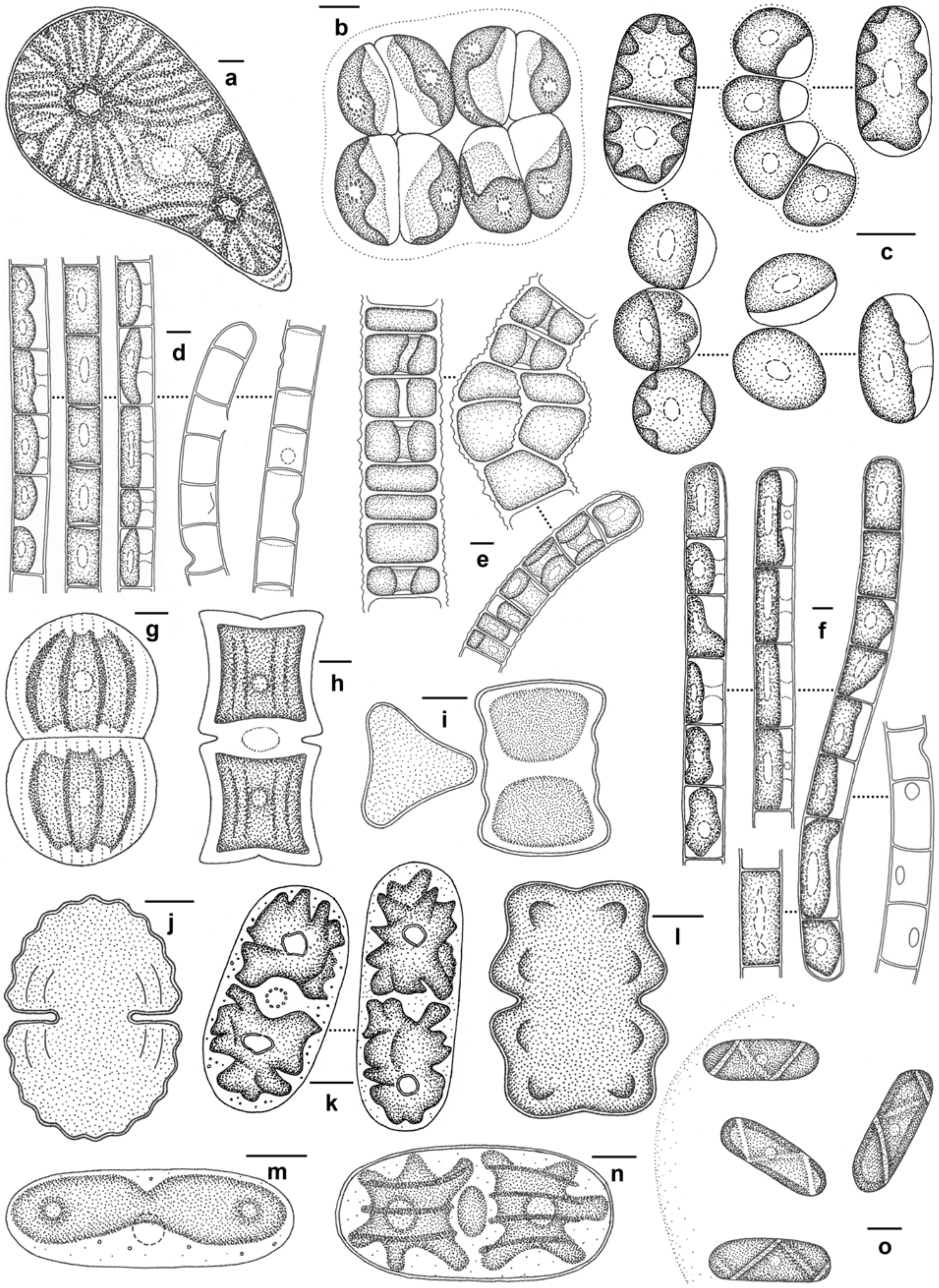
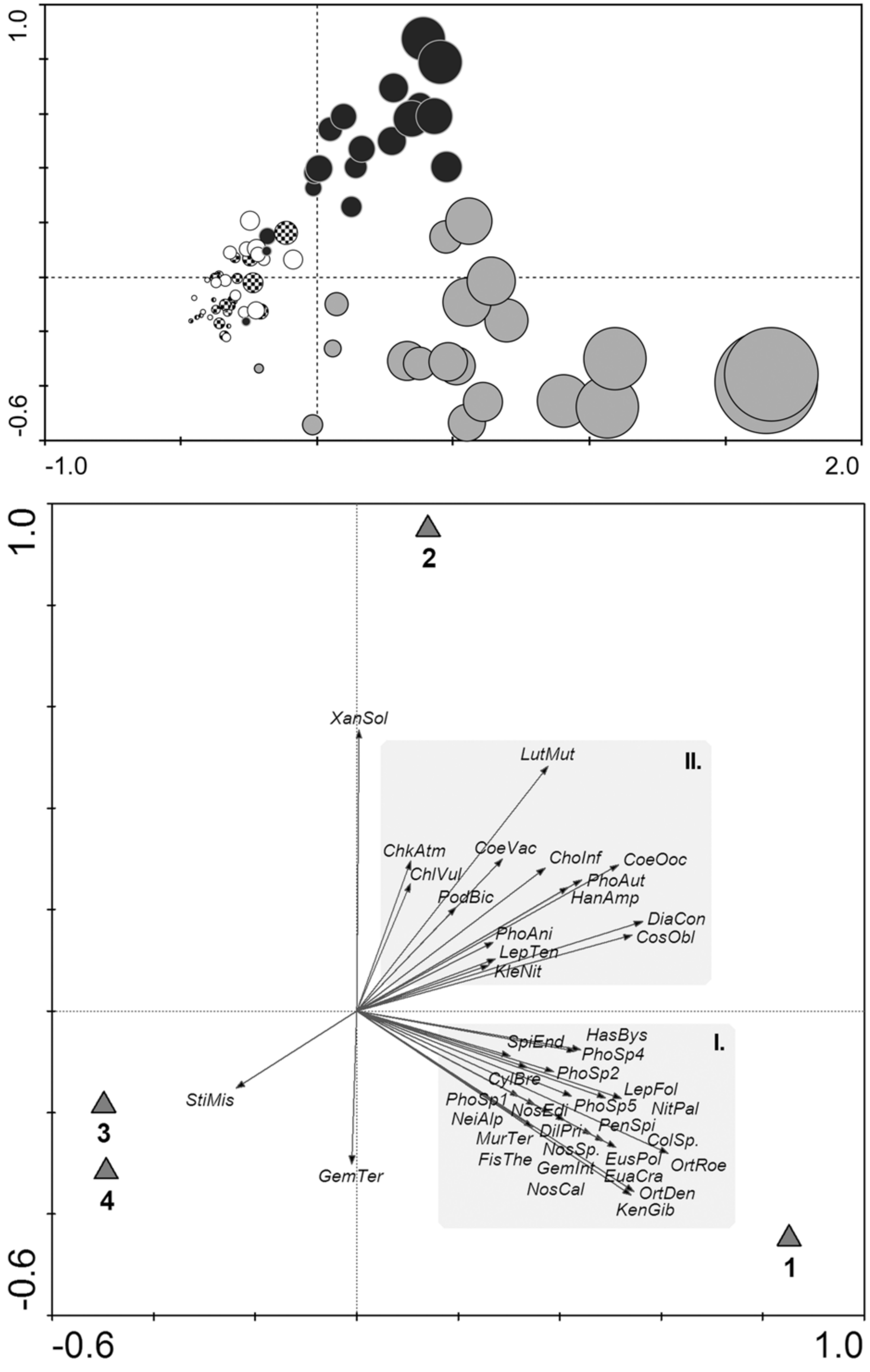


Fig. 8. (a) *Kentrosphaera gibberosa*; (b) *Chlorokybus atmophyticus*; (c) *'Geminella' terricola*; (d) *Klebsormidium flaccidum*; (e) *Klebsormidium mucosum*; (f) *Klebsormidium nitens*; (g) *Actinotaenium cucurbita*; (h) *Cosmarium decedens*; (i) *Cosmarium obliquum* var. *trigonum*; (j) *Cosmarium undulatum*; (k) *Cylindrocystis brebissonii*; (l) *Euastrum brevisinuosum*; (m) *Mesotaenium* cf. *endlicherianum*; (n) *Penium* cf. *spinospermum*; (o) *Spirotaenia endospira*. Scale bar 5 µm.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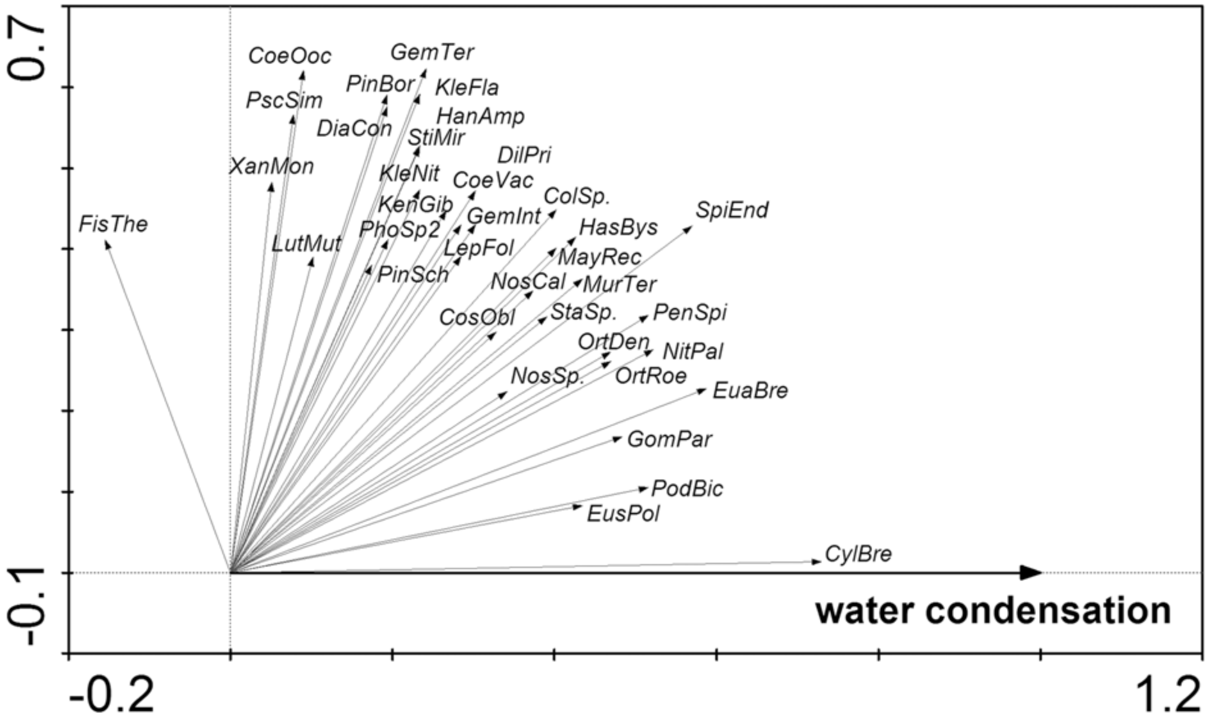

Fig. 11. The RDA ordination plot displaying preferences of the 37 best-fitted species to the moss samples saturated by condensed water during winter exhalations in the ventaroles. For the species acronyms see Table 1.

Fig. 9. The PCA ordination plot of the samples (grey – ventarole 1; black – ventarole 2; white – sampling site 3; chessboard – sampling site 4). Symbol sizes correspond with the species richness of the particular sample.

Fig. 10. The RDA ordination plot displaying preferences of the 41 best-fitted species to four sampling sites: (1,2) ventaroles; (3,4) adjacent sampling sites. I species preferentially occurring only in the large ventarole (sampling site 1), II species occurring in both the ventaroles. For the species acronyms see Table 1.

Table 1. List of species with "total occurrence" values (sums of species occurrences for the set of samples) in localities (1–4), microbiotopes [(m) moss; (r) rock; (s) soil)] and in relation to warm, moist winter exhalations (+ present, - absent; occurrences counted for the ventaroles only).

			Localities				Microbiotopes			Exhalations	
	Acronym	Figure	**1**	**2**	**3**	**4**	**m**	**r**	**s**	+	-
Cyanobacteria											
Fischerella thermalis Schwabe ex Gomont	*FisThe*	4a	7	-	-	-	2	6	3	4	2
Hassallia byssoidea Hassall ex Bornet et Flahault	*HasBys*	4b	8	3	1	-	7	7	3	7	4
Leptolyngbya foveolarum (Rabenhorst ex Gomont) Anagnostidis et Komárek	*LepFol*	4c	9	3	-	1	8	6	5	5	4
Leptolyngbya tenuis (Gomont) Anagnostidis et Komárek	*LepTen*	4d	7	6	2	3	6	9	9	8	4
Nostoc calcicola Brébisson ex Bornet et Flahault	*NosCal*	4e	5	-	-	-	4	2	5	3	2
Nostoc cf. *edaphicum* Kondrateva	*NosEdi*	4f	6	-	-	-	1	-	5	3	2
Nostoc sp.	*NosSp.*	4g	5	-	-	-	3	4	-	3	1
Oscillatoria cf. *curviceps* Agardh ex Gomont	-	4h	1	-	-	-	-	-	1	-	1
Phormidium cf. *ambiguum* Gomont	-	4i	1	-	-	-	-	-	1	1	-
Phormidium cf. *animale* (Agardh ex Gomont) Anagnostidis et Komárek	*PhoAni*	4j	4	5	-	-	7	3	-	2	5
Phormidium autumnale Agardh ex Gomont	*PhoAut*	4k	8	10	1	-	15	8	5	8	6
Phormidium sp. 1	*PhoSp1*	4l	5	-	-	-	1	-	4	2	3

			Localities				Microbiotopes			Exhalations	
	Acronym	Figure	**1**	**2**	**3**	**4**	**m**	**r**	**s**	+	-
Phormidium sp. 2	*PhoSp2*	4m	8	3	-	2	5	5	6	3	5
Phormidium sp. 3	-	4n	-	2	-	-	-	-	2	-	-
Phormidium sp. 4	*PhoSp4*	4o	7	2	-	-	6	2	5	3	3
Phormidium sp. 5	*PhoSp5*	4p	6	1	-	-	5	3	2	4	2
Pseudanabaena cf. *catenata* Lauterborn	-	4q	-	1	-	-	-	1	-	-	1
Bacillariophyceae											
Aulacoseira granulata (Ehrenberg) Simonsen	-	-	1	1	-	-	2	-	-	1	1
Cocconeis placentula Ehrenberg	-	-	1	-	-	-	1	-	-	1	-
Diadesmis contenta (Grunow ex Van Heurck) Mann	*DiaCon*	-	9	9	3	3	18	12	16	8	6
Eunotia bilunaris (Ehrenberg) Mills	-	4r	-	1	-	-	-	-	1	1	-
Eunotia implicata Nörpel, Lange-Bertalot et Alles	-	4s	1	-	-	-	1	-	-	1	-
Frustulia saxonica Rabenhorst	-	4t	-	-	-	2	1	1	-	-	-
Gomphonema parvulum (Kützing) Van Heurck	*GomPar*	-	2	1	1	-	1	2	3	1	-
Hantzschia amphioxys (Ehrenberg) Grunow	*HanAmp*	-	10	10	5	3	18	15	13	8	8
Kobayasiella sp.	-	-	3	2	-	-	1	-	4	2	2
Luticola mutica (Kützing) Mann	*LutMut*	-	7	10	1	1	13	8	13	8	6
Mayamaea recondita (Hustedt) Lange-Bertalot	*MayRec*	-	4	3	5	7	7	4	13	5	1
Navicula oligotraphenta Lange-Bertalot et Hofmann	-	-	1	-	-	-	1	-	-	1	-
Neidium alpinum Hustedt	*NeiAlp*	-	5	-	-	-	-	-	5	2	3
Nitzschia palea (Kützing) W. Smith	*NitPal*	-	9	2	1	-	7	5	8	4	3
Orthoseira dendroteres (Ehrenberg) Crawford, Haw. et Kelly	*OrtDen*	-	9	-	-	3	10	9	2	4	3
Orthoseira roeseana (Rabenhorst) O'Meara	*OrtRoe*	-	10	1	-	-	9	8	1	5	4
Pinnularia borealis Ehrenberg	*PinBor*	-	10	10	7	8	26	16	25	8	8
Pinnularia schoenfelderi Krammer	*PinSch*	-	4	5	-	2	4	4	7	5	4
Pinnularia sudetica (Hilse) Hilse	-	-	1	-	-	-	-	-	1	-	1
Stauroneis sp.	*StaSp.*	-	5	2	-	2	4	2	3	3	2
Surirella cf. *minuta* Brébisson	-	4u	1	-	-	-	-	-	1	-	1
Synedra ulna (Nitzsch) Ehrenberg	-	5a	1	-	-	-	1	-	-	1	-
Tabellaria flocculosa (Roth) Kützing	-	5b	2	-	2	-	2	-	2	2	-
Chrysophyceae											
Paraphysomonas vestita (Stokes) De Sadeleer	-	-	1	-	-	-	1	-	-	1	-
Spiniferomonas sp.	-	-	1	-	-	-	1	-	-	1	-
Synurophyceae											
Synura multidentata (Balonov et Kuzmin) Péterfi et Momeu	-	-	1	-	-	-	-	1	-	-	-
Xanthophyceae											
Heterococcus cf. *crassulus* Vischer	-	5c	1	-	-	-	-	-	1	1	-
Tribonema vulgare Pascher	-	5d	3	1	-	-	-	1	3	3	1
Xanthonema montanum (Vischer) Silva	*XanMon*	5e	4	7	2	5	10	7	13	5	5
Xanthonema solidum (Vischer) Silva	*XanSol*	5f	-	8	4	-	7	5	7	3	3
Xanthonema sp.	-	5g	1	-	-	-	-	-	1	1	-
Eustigmatophyceae											
Eustigmatos polyphem (Pitschmann) Hibberd	*EusPol*	5h	6	-	-	-	3	2	5	4	1
Chlorophyceae											
Bracteacoccus cf. *grandis* Bischoff et Bold	-	5i	1	2	2	-	2	1	3	2	1
Bracteacoccus minor (Chodat) Petrova	-	5j	3	-	-	-	-	1	2	3	-

			Localities				Microbiotopes			Exhalations	
	Acronym	Figure	**1**	**2**	**3**	**4**	**m**	**r**	**s**	+	-
Bracteacoccus pseudominor Bischoff et Bold	-	5k	-	-	1	-	-	-	1	-	-
Bracteacoccus sp.	-	5l	2	3	-	-	3	1	2	4	1
Carteria cf. *klebsii* (Dangeard) Francé	-	5m	3	-	-	-	3	-	1	3	-
Chlamydomonas callunae Ettl	-	5n	-	2	-	-	1	-	1	2	-
Chlamydomonas pseudintermedia Behre et Schwabe	-	5o	-	1	-	-	1	-	-	1	-
Chlamydomonas cf. *sestinensis* Gerloff	-	5p	2	-	-	-	2	-	-	2	-
Chlamydomonas sp.	-	5q	-	-	2	1	-	-	3	-	-
Chlorococcum infusionum (Schrank) Meneghini	*ChoInf*	5r	6	9	1	1	9	7	11	5	6
Chloromonas rosae (Ettl) Ettl	-	5s	1	-	-	-	1	-	-	1	-
Coelastrella oocystiformis (Lund) Hegewald et Hanagata	*CoeOoc*	5t	9	9	-	1	11	13	10	7	7
Coelastrella vacuolata (Shihira et Krauss) Hegewald et Hanagata	*CoeVac*	6a	4	5	-	-	6	5	5	6	3
Coleochlamys sp.	*ColSp.*	6b	6	-	-	-	5	5	-	3	3
Dictyochloris pulchra Deason et Herndon	-	6c	2	-	-	-	1	1	-	1	1
Diplosphaera chodatii Bialosuknia	-	6d	2	-	-	1	2	1	-	2	-
Fasciculochloris boldii McLean et Trainor	-	6e	-	1	-	-	-	-	1	1	-
Keratococcus bicaudatus (Braun) J.B. Petersen	-	6f	4	-	-	-	3	-	1	2	1
Mychonastes homosphaera (Skuja) Kalina et Punčochářová	-	6g	1	-	1	-	-	1	1	1	-
Phacomyxa sp.	-	6h	-	1	-	-	-	-	1	1	-
Podohedra bicaudata Geitler	*PodBic*	6i	3	4	-	-	6	-	2	4	2
Radiosphaera minuta Herndon	-	6j	1	-	-	-	-	1	-	-	-
Scenedemsus soli Hortobagyi	-	6k	1	-	-	-	-	1	-	-	-
Trebouxiophyceae											
Auxenochlorella protothecoides (Krüger) Kalina et Punčochářová	-	6l	2	-	-	-	1	2	1	1	1
‚Chlorella‘ cf. *luteoviridis* Chodat	-	6m	3	-	-	2	3	1	1	1	1
‚Chlorella‘ minutissima Fott et Nováková	-	-	2	3	-	-	2	-	3	4	1
‚Chlorella‘ mirabilis Andreeva	-	6n	2	1	1	-	3	-	1	-	2
Chlorella vulgaris Beijerinck	*ChlVul*	6o	1	3	-	-	3	-	2	3	-
Choricystis minor (Skuja) Fott	-	-	-	3	-	-	1	2	-	2	1
Dictyochloropsis reticulata (Tschermak-Woess) Tschermak-Woess	-	6p	-	1	1	1	2	-	1	-	1
Dictyochloropsis splendida (Geitler) Tschermak-Woess	-	6q	-	1	2	1	2	3	1	1	-
Dilabifilum printzii (Vischer) Tschermak-Woess	*DilPri*	7a	4	-	-	-	3	3	1	3	1
Dilabifilum sp.	-	7b	2	-	-	-	1	2	-	2	-
Eutetramorus sp.	-	7c	2	1	-	-	-	-	3	3	-
Geminella interrupta (Turpin) Lagerheim	*GemInt*	7d	5	-	-	-	2	5	1	4	-
Lobosphaeropsis lobophora (Andreeva) Ettl et Gärtner	-	7e	1	1	-	1	1	-	2	-	-
Muriella terrestris J.B. Petersen	*MurTer*	7f	6	-	2	-	3	4	4	4	2
Myrmecia bisecta Reisigl	-	7g	1	6	5	1	7	3	5	5	2
Pseudococcomyxa cf. *simplex* (Mainx) Fott	*PscSim*	7h	3	5	6	4	15	13	13	5	3
Rhexinema paucicellularis (Vischer) Geitler	-	7i	-	1	-	-	-	1	-	1	-
Schizochlamydella minutissima Broady	-	7j	1	2	-	-	1	1	2	3	-
Schizochlamydella sp.	-	7k	2	-	-	-	2	-	-	2	-
Stichococcus minor Nägeli	*StiMir*	7l	6	5	5	6	17	13	8	6	4
Stichococcus minutus Grintzesco et Péterfi	*StiMis*	-	-	-	-	5	2	4	2	-	-
Stichococcus undulatus Vinatzer	-	7m	1	-	-	-	1	1	-	1	-
Trebouxia arboricola De Puymaly	-	7n	-	-	2	-	-	2	1	-	-

			Localities				Microbiotopes			Exhalations	
	Acronym	Figure	**1**	**2**	**3**	**4**	**m**	**r**	**s**	+	-
Trebouxia potteri AHMADJIAN ex GÄRTNER	-	7o	-	2	-	-	2	-	-	2	-
Trebouxia sp.	-	7p	1	-	-	-	1	-	-	1	-
Ulvophyceae											
Kentrosphaera gibberosa VODENIČAROV et BENDERLIEV	*KenGib*	8a	10	-	2	2	7	8	8	4	4
Chlorokybophyceae											
Chlorokybus atmophyticus GEITLER	*ChkAtm*	8b	1	5	-	-	3	3	-	3	1
Klebsormidiophyceae											
‚Geminella‘ terricola J.B. PETERSEN	*GemTer*	8c	4	-	5	4	8	9	8	2	2
Klebsormidium flaccidum (KÜTZING) SILVA, MATTOX et BLACKWELL	*KleFla*	8d	8	8	9	8	25	23	22	8	5
Klebsormidium mucosum (J.B. PETERSEN) LOKHORST	-	8e	1	3	2	-	4	3	-	1	3
Klebsormidium nitens (MENEGHINI) LOKHORST	*KleNit*	8f	9	10	8	5	18	19	14	8	8
Zygnematophyceae											
Actinotaenium cucurbita (BRÉBISSON) TEILING	-	8g	2	-	-	-	2	-	-	2	-
Cosmarium decedens (REINSCH) RACIBORSKI	-	8h	1	-	-	-	1	-	-	1	-
Cosmarium obliquum NORDSTEDT var. trigonum W. WEST	*CosObl*	8i	10	9	-	-	15	11	2	8	7
Cosmarium undulatum CORDA ex RALFS	-	8j	1	-	-	-	-	1	-	-	-
Cylindrocystis brebissonii (MENEGHINI ex RALFS) de BARY	*CylBre*	8k	4	1	-	-	4	3	-	4	1
Euastrum brevisinuosum (NORDSTEDT) KOUWETS	*EuaBre*	8l	9	-	-	-	7	5	-	4	3
Mesotaenium cf. *endlicherianum* NÄGELI	-	8m	3	-	-	-	3	-	-	3	-
Penium cf. *spinospermum* JOSHUA	*PenSpi*	8n	5	-	-	-	4	4	-	4	-
Spirotaenia endospira (BRÉBISSON) ARCHER	*SpiEnd*	8o	3	1	-	-	4	2	-	4	-

WILLIAMSON 2000, ŠŤASTNÝ 2008). *Actinotaenium cucurbita*, *Cylindrocystis brebissonii*, *Cosmarium undulatum* and *Mesotaenium* NÄGELI species are commonly mentioned from aero-terrestrial substrata, having strong resistance to long-term desiccation (ETTL & GÄRTNER 1995, WILLIAMSON 2000). None of the observed desmid taxa could be indicated as an entirely aquatic species, though some of them are occasionally reported from aquatic environments (e.g. *Penium spinospermum* from acid boggy water bodies; KRIEGER 1937). Interestingly, even if several investigated taxa can be designated as extremely rare species (e.g. *Cosmarium obliquum*, var. *trigonum*, *Euastrum brevisinuosum*, *Spirotaenia endospira*), they were repeatedly found in high abundances during the winter exhalations. For example, mucilaginous algal mats of *Cosmarium obliquum*, var. *trigonum* were macroscopically visible in winter season inside the ventarole 1.

To summarize, the Boreč Hill ventaroles represent a unique type of biotope, with a specific algal flora adapted to the periodical periods of warm, moist air exhalations of several months' duration. As a whole, the algal composition could not be assigned to any known aero-terrestrial biotope. Rather, they can be considered as a specific type of transitional biotope between aero-terrestrial and freshwater environments. Moreover, the ventaroles are demonstrably inhabited by several very rare species. Thus, the Boreč Hill ventaroles definitely represent one of the most valuable aero-terrestrial localities in the region.

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