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**The biological soil crusts in Central European ecosystems, with special reference to taxonomic structure and ecology of the surface crusts at Czech ore-waste and ash-slag sedimentation industrial basins**

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# CONTENTS

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# 1. Introduction

JIŘÍ NEUSTUPA

This volume is devoted to biological soil crusts, a unique microecosystem composed mainly of microorganisms and non-vascular plants. Johnston (1997) provided the following characterization of a biological soil crust: *"Microbiotic crusts are formed by living organisms and their by-products, creating a surface crust of soil particles bound together by organic materials."* Biological soil crusts form an important part of dryland ecosystems (Evans & Johansen 1999; Belnap & Lange 2001; Bowker 2007). Usually, they are composed of cyanobacteria, algae, lichens, mosses and liverworts (Johnston 1997; Evans & Johansen 1999; Deines et al. 2007). Crusts are considered key components of arid ecosystems as they stabilize the soil surface thus reducing wind and water erosion (Evans & Johansen 1999; Belnap 2003) and they increase soil fertility by biotic nitrogen and carbon fixation (Johnston 1997; Hawkes & Flechtner 2002).

In temperate ecosystems of Central Europe biological soil crusts scarcely occur in natural habitats. The only small-scale exceptions are dynamic microhabitats with continuous mechanical disturbance that include e.g. the bases of sandstone cliffs or the slopes of erosion gorges in clay sediments. However, the most extensive areas in Central European landscape with biological soil crusts covering most of the substrate surface are the tree-less parts of abandoned ore and ash-slag sedimentation basins (Pohlová 2004). These toxic localities resist revitalization attempts and vascular plant diversity is usually extremely low (Vaňková & Kovář 2004). Sedimentation basins serve as disposal sites for sludge waste from industrial activity. Ash-slag deposits result from coal heating and power plant operation and ore-washery sedimentation basins are associated with ore mines. In the Czech Republic – a country with 150 years of industrial history – restoration of these habitats has been an important social and scientific issue (Prach 1987; Moldan & Schnoor 1992; Štýs & Braniš 1999; Kovář 2004). However, sedimentation basins with high concentrations of heavy metals also remain largely tree-less and unvegetated, even after decades of succession and repeated reforestation attempts (Figs. 1–6). In such localities, the substrate surface is mostly covered by biological soil crusts which are physiognomically quite similar to their counterparts in semiarid and desert ecosystems (Evans & Johansen 1999; Pohlová 2004). The natural crusts in semiarid ecosystems were found sensitive to mechanical disturbance that led to decrease in productivity and key eco-physiological parameters, as well as to a decrease in diversity (Johnston 1997; Evans & Johansen 1999).

This study is the first attempt to characterize composition, diversity and stability of biological soil crusts at the Central European ash and ore sedimentation basins. We chose five sedimentation basins in the Czech Republic with microbiotic crust cover and we conducted a two-year long investigation of their species composition and diversity. In addition, at the Chvaletice ore-waste sedimentary basin we did experimental mechanical disturbance of the crust cover to evaluate stability of species composition and eco-physiological features of the main organismal groups composing the crust.

Most of the work presented in this volume is a result of a three year project of the Czech Ministry of Environment (no. SM/2/90/05, 2005–2007). This project was primarily devoted to investigation of biodiversity and ecological dynamics of biological soil crusts on anthropogenic substrata of sedimentation basins. We mainly concentrated on four major organismal groups that constitute biological soil crusts as a whole – cyanobacteria and algae, lichens, fungi and mosses (Evans & Johansen 1999). In addition, the project aimed at the comparison of species composition and richness of man-made crust habitats, and several similar natural crust localities, in the temperate Central European landscape. Finally, the soil surfaces of two agricultural localities in Central Bohemia were incorporated into the project as examples of primarily non-crust microhabitats. Here, we specifically looked for possible presence of crust-like micro-communities in order to compare the eventual similarities in their species composition with natural and man-made crust ecosystems.

In individual chapters, we present data on species composition, data on principal abiotic factors and statistical interpretations in order to demonstrate the mutual affinities and differences between individual localities and most interesting species occurring on small-scale natural microbiotic crust localities and on the synanthropic ore-mine habitats.

Mechanical disturbance that distorts the compactness of a crust and enhances erosion is considered one of the most important external ecological factors that hampers or affects the crust development in semiarid habitats (Evans & Johansen 1999; Belnap & Lange 2001; Johansen et al. 2001; Belnap 2002). However, nothing was known on disturbance resistance of temperate crusts on toxic substrates. Therefore, we conducted investigation specifically aimed at the characterization of disturbance effect on diversity, abiotic parameters and ecophysiological properties of crusts in two localities in Czech Republic.

We believe that the presented volume will provide a source of information on diversity and ecology of biological soil crusts in Central European landscape for future studies of this interesting and remarkable microhabitat. In fact, we hope that our research will assist in promoting the future investigation of these habitats in temperate ecosystems.

Finally, we thank both referees of the project at the Czech Ministry of Environment, and the reviewers of mid-term drafts of the project for their valuable comments and recommendations.

# 2. Biological soil crusts on natural substrata

JIŘÍ NEUSTUPA

In temperate landscapes dominated by forest, meadow and agricultural components, biological soil crusts develop mostly on places with any type of regular disturbance that hampers vascular plant cover. In our project, we chose several localities on natural substrata with microbiotic crust surface in order to compare their principal biotic components (cyanobacteria, algae, fungi, mosses and lichens). In addition, we asked whether there is any perceivable similarity between species composition of crusts from semiarid subtropical ecosystems and our Central European localities. Biological soil crusts are definitely a rare phenomenon in temperate landscape. Thus, our investigation was in most cases limited to localities of just one, or a few, square meters. We report the species composition of these sites and we compare their diversity with the published data (Belnap & Lange 2001; Johansen 1993) on microphytic biota of large-scale natural biological soil crusts of different ecosystems.

The presentation of floristic data differs in individual chapters concentrated on particular groups composing the crusts. The algal and cyanobacterial species composition was mostly characterized by moderate species richness and relatively high stability of species composition. Therefore, the data were interpreted using a set of standard multivariate methods of ecological ordination and we presented the figures of most conspicuous species. On the other hand, microscopic fungi were extremely diversified and variable so that the usual ordination methods have rather limited applicability and the mosses and lichen data characteristic by their very low diversity are only presented as the floristic list.

The data from comparative agricultural non-crust localities were only included into fungal and bryophytes chapters. Algae and cyanobacteria have no single species occurring jointly in crusts and on the non-crust soil surfaces and lichens were even completely missing from these microhabitats. Therefore, the chapters dealing with these groups only include the crust localities data.

# 2.1. Description of investigated localities

ONDŘEJ PEKSA & PAVEL ŠKALOUD

The location of investigated localities is given in Fig. 2.1.1.

**Localities on natural substrata**

*České Švýcarsko National Park (Bohemian Switzerland NP)* (Figs 2.1.2a, b)

The large sandstone area (Elbe Sandstone Mountains) situated in North Bohemia is characterised especially with rock ledges and plateaus, deep valleys and gorges. The biological soil crusts were investigated in five selected localities:

CS1 – the valley of Vlčí potok brook, vertical rock cliff with green-coloured biological soil crust, 50°55′36″N, 14°25′43″E, alt. 360 m.

CS2 – the valley of Malý Vlčí potok brook, wet vertical rock cliff with mucilaginous algal mat, 50°55′27″N, 14°25′54″E, alt. 360 m.

CS3 – the valley of Kamenice river, brown-coloured algal mat in the surface of wet vertical cliff, alt. 200 m

CS4 – Borový důl, deep sandstone gorges – sandy slope under a rock cliff, 50°52′59″N, 14°18′24″E, alt. 400 m.

CS5 – Babylon Nature Reserve, deep gorges and sun-exposed sandstone rocks covered by relic pine forests, 2.5 km northwest of Jetřichovice, alt. 300–380 m.

*The former military airport Ralsko* (Figs 2.1.2c, d) (50°37′17.3″N, 14°42′51.4″E, alt. 273 m)

The military airport occuring 3.5 km southwards from Mimoň was vacated by army army in 1991. The abandoned area around the landing runway has been gradually colonized by vegetation (pines, birches, etc.). Well developed biological soil crusts mainly cover the areas of naked soil among the tufts of grass and heather shrubs in the west part of the airport near Hradčany village.

*Střezovská rokle Natural Monument* (Figs 2.1.2e, f) (50°24′8.3″N, 13°26′15.4″E, alt. 270–310 m)

The deep gorge in North-West Bohemia (1 km eastwards from Březno u Chomutova was formed in Miocene sediments by water erosion. Sunny slopes and upper parts are covered by xerothermous vegetation, hygrophilous plants grow at the bottom of the gorge with periodical water coursing. Studied biological soil crusts were found especially in the central part of the gorge, in the rests of steppes on the steep slopes and small open sunny plateaux.

**Agricultural localities**

*Netluky* (50°02′22.5″N, 14°36′56.2″E, alt. 393 m).

Grassy pasture in Netluky exploited for horses. Surface soil layer covered by musci together with grasses.

*Uhříněves* (50°01′53.2″N, 14°36′48.2″E, alt. 391 m).

Stubble-field after lucerne, in Prague-Uhříněves. Surface soil layer covered by mosses together with remains of *Medicago sativa*.


**Fig. 2.1.1.** Location of the study sites. **1** – České Švýcarsko National Park, **2** – former military airport Ralsko, **3** – Střezovská rokle Natural Monument.

# 2.2. Species composition of algae and cyanobacteria in surface crusts on natural substrata

PAVEL ŠKALOUD, MARIE PAŽOUTOVÁ, JANA VESELÁ & JIŘÍ NEUSTUPA

## INTRODUCTION

Many studies have pointed out the biological importance of biological soil crusts (Belnap & Lange 2001). Descriptions of the general biological diversity of biological soil crusts are common in the literature (Johansen 1993). This chapter describes the cyanobacterial and algal populations of biological soil crusts and isolated cultures from sandy loam in Střezovská rokle and wet sand-stone cliffs in the National Park České Švýcarsko.

Microorganisms living on those substrates represent an important component of the ecosystem, serving as the first colonizers of the abiotic substrates. Algal communities may distinctively differ among various localities, depending on the type of substratum or climatic parameters. In tropical ecosystems cyanobacteria generally dominate, while temperate regions are characterized by high proportions of green algae. Finally, accessible humidity and pH of substrata make a great difference for algal composition.

## MATERIALS AND METHODS

The biological soil crusts were investigated in a single sampling site in Střezovská rokle and three sampling sites situated in the area of National Park České Švýcarsko. Detailed characteristics of the localities are given in chapter 2.1. Střezovská rokle crust locality consists of eroded Miocene clay sediments. As a result of intense erosion, a gorge in clay bedrock has developed in the cetral part of the reserve. On steep slopes of this gorge in places with regular erosion of sediments, the only biotic cover consists of a biological soil crust that was investigated in this study. The biological soil crusts in České Švýcarsko National Park develop on similarly disturbed microlocalities on bases and slopes of sandstone cliffs with regular erosion hampering the vascular plants succession. In each locality, the samples were taken randomly from the whole biological soil crust by scraping of the substratum with a sterile knife. The samples were placed into sterile bags and transported to the laboratory for analysis. The material was preserved at low temperature.

The algae were either determined directly from the sampled material or further cultivated as follows. A small proportion of each sample was mixed with 10 ml of distilled water. The suspension was mixed by a magnetic mixer for 15 minutes. Aliquots of 0.5 or 1 ml were spread in duplicate on agar solidified BBM medium (Bischoff & Bold 1963; Ettl & Gärtner 1995) and DY IV medium (Andersen et al. 1997). In addition, another proportion of the sample was merged to the liquid BBM medium. Cultures were sealed with parafilm and incubated at 20–25 °C under daylight conditions (the plates were placed beside a north facing window) until good growth had been obtained (3–6 weeks). Algal microcolonies were examined directly from agarized plates using an Olympus BX 51 microscope with Nomarski DIC optics and photographed using Olympus Camedia digital camera C-5050 Zoom. Standard cytological stains (Lugol's solution, methylene blue, acetocarmine, chloraliode solution) were used for visualisation of pyrenoid, cell wall structures or mucilage. For detailed investigation of some strains, the algal colonies were transferred to agarized BBM culture tubes and then cultivated at 18 °C, under an illumination of 20–30 μmol $m^{-2} \cdot s^{-1}$ and 16:8 h light-dark cycle. Identification was made on the basis of life history and morphological criteria using standard authoritative references (Printz 1964; Fott & Nováková 1969; Ettl 1978; Punčochářová & Kalina 1981; Komárek & Fott 1983; Krammer & Lange-Bertalot 1986, 1991; Ettl & Gärtner 1995; Hindák 1996; Lokhorst 1996; Andreeva 1998; Komárek & Anagnostidis 1998, 2005). A NMDS ordination analysis was performed using the statistical program PAST 1.74 (Hammer et al. 2001) to ordinate localities based on their algal composition.

## RESULTS AND DISCUSSION

### *General conclusions*

A total of 38 algal species representing 26 genera were recovered from four studied localities (Table 2.2.1). Five widespread taxa (diatoms *Diadesmis laevissima*, *Eunotia exigua* and *Eunotia fallax*; and green algae *Pseudococcomyxa simplex* and *Klebsormidium flaccidum*) were found in three localities. Generally, diatoms represented the most species-rich group of autotrophic organisms, in spite of their absence in Střezovská rokle (Figs 2.2.1, 2.2.2). In all samples from České Švýcarsko, diatoms comprised at least 50% of all determined species. However, species-poor green algae were more abundant in samples CS1 and CS2. There, capsal green alga *Gloeocystis* sp. forms macroscopically visible

**Table 2.2.1.** Algal distribution in 4 investigated sampling sites (CS – National Park České Švýcarsko, SR – Střezovská rokle).

| | Sampling site | | | |
|---|---|---|---|---|
| | CS1 | CS2 | CS3 | SR |
| ***Cyanobacteria*** | | | | |
| *Aphanocapsa muscicola* (Meneghini) Wille | × | | | |
| *Aphanothece caldariorum* Richter | × | | | |
| *Chroococcus varius* A. Braun in Rabenhorst | | × | | |
| *Cyanothece aeruginosa* (Nägeli) Komárek | | | × | |
| *Pseudanabaena catenata* Lauterborn | | | × | |
| ***Bacillariophyceae*** | | | | |
| *Achnanthes* cf. *subatomoides* (Hustedt) Lange-Bertalot et Archibald | | | × | |
| *Caloneis aerophila* Bock | × | × | | |
| *Diadesmis contenta* (Grunow ex Van Heurck) Mann | × | | | |
| *Diadesmis laevissima* (Cleve) Mann | × | × | × | |
| *Eunotia exigua* (Brébisson ex Kützing) Rabenhorst | × | × | × | |
| *Eunotia fallax* A. Cleve | × | × | × | |
| *Eunotia glacialis* Meister | | | × | |
| *Eunotia meisterii* Hustedt | | | × | |
| *Eunotia paludosa* Grunow | × | | | |
| *Eunotia praerupta* var. *bigibba* (Kützing) Grunow | × | × | | |
| *Frustulia saxonica* Rabenhorst | × | × | | |
| *Microcostatus krasskei* (Hustedt) Johansen et Sray | | × | × | |
| *Pinnularia borealis* Ehrenberg | | × | | |
| *Pinnularia pseudogibba* K. Krammer | | × | × | |
| *Pinnularia schoenfelderi* K. Krammer | | | × | |
| *Pinnularia subcapitata* W. Gregory | | | × | |
| ***Euglenophyta*** | | | | |
| *Euglena geniculata* Dujardin | × | | | |
| ***Chlorophyceae*** | | | | |
| *Bracteacoccus* sp. | | | | × |
| *Chlorococcum* sp. | | | × | |
| *Coelastrella striolata* Chodat | | | × | |
| *Diplosphaera chodatii* Bialosuknia em. Vischer | | | | × |
| *Neodesmus* sp. | | × | | |
| *Scotiellopsis oocystiformis* (J.W.G. Lund) Punc. et Kalina | | | × | |
| ***Trebouxiophyceae*** | | | | |
| *Apatococcus* sp. | | | × | |
| *Chlorella* cf. *trebouxioides* Puncocharova | × | | | |
| *Chlorella vulgaris* Beijerinck | | | | × |
| *Microthamnion kuetzingianum* Nägeli | | | × | |
| *Pseudococcomyxa simplex* (Mainx) Fott | | × | × | × |
| *Gloeocystis* sp. | × | × | | |
| ***Klebsormidiophyceae*** | | | | |
| *Klebsormidium crenulatum* (Kützing) Lokhorst | | | | × |
| *Klebsormidium flaccidum* (Kützing) Silva, Mattox et Blackwell | | × | × | × |
| *Klebsormidium mucosum* Boye Petersen | | | | × |
| ***Zygnematophyceae*** | | | | |
| *Cosmarium orthopunctulatum* Schmidle | | | × | |

algal mats on the surfaces of sandstone cliffs. Only in the brown-coloured algal mat (sample CS3) the diatoms constituted both the most abundant and the most species-rich component of the algal population. The above-mentioned differences can be explained by diverse physico-chemical characteristics, present at the sampling sites. While favourable light conditions of the sampling sites CS1 and CS2 give support to the massive development of green algae, the shadowed conditions of site CS3 prioritized diatoms. Although several green algal species were also determined in the CS3 sampling site, they did not dominate. Even more, green alga *Gloeocystis* sp., dominant in both others sampling sites in České Švýcarsko, was not found there.

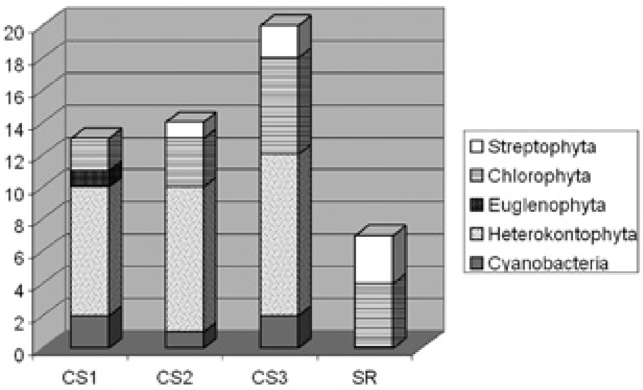



**Fig. 2.2.1.** Species richness expressed as the number of taxa found in each locality. Assignment of taxa to the four algal groups is displayed.

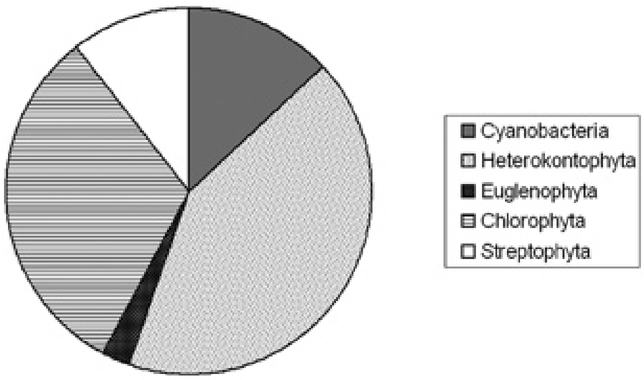



**Fig. 2.2.2.** Proportional occurrence of five algal groups, determined in all investigated localities.

Algal population in Střezovská rokle considerably differed from all the others. It differentiated in a small number of determined taxa as well as by an entire absence of some algal groups (e.g. cyanobacteria and diatoms). Formation of this unique algal population can be explained by unstable environmental conditions caused by continuous erosion of sediments from steep slopes.

In general, species composition among the localities substantially differed, as seen from the results of the NMDS ordination analysis (Fig. 2.2.3). The differences are distinct among the three sampling sites in the České Švýcarsko lo-

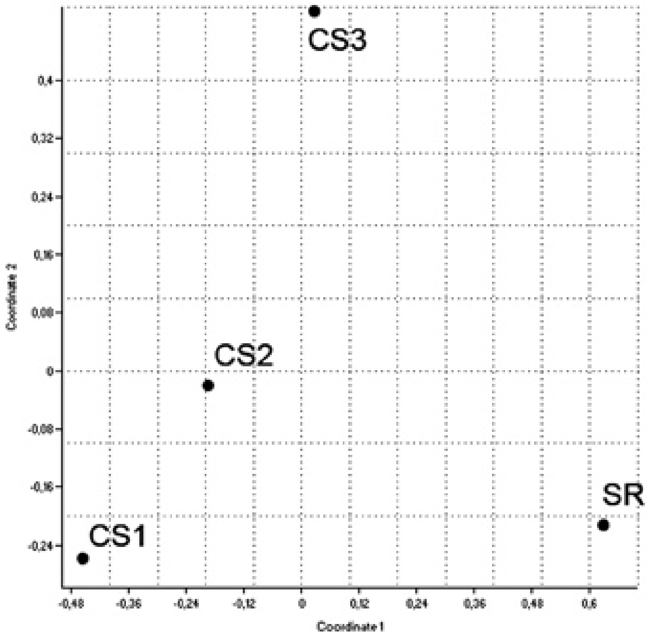



**Fig. 2.2.3.** The NMDS ordination diagram showing the position of samples in the range of the first two ordination axes (**CS** – National Park České Švýcarsko, **SR** – Střezovská rokle).

cality as well as between the two investigated localities (České Švýcarsko and Střezovská rokle). In principle, the differences between the sampling sites CS1–CS3 and CS1–SR are comparable. In worldwide comparison to other natural biological soil crusts, the principal algal composition seems to be comparable, as cyanobacteria, diatoms and green algae represent the dominant algal groups occurring (e.g. Johansen et al. 1981; Ashley et al. 1985; Grondin & Johansen 1993; Evans & Johansen 1999). However, the species composition within these algal groups could considerably differ. For example, cyanobacterial genera *Nostoc* and *Microcoleus* are frequently recorded from desert soils, forming there the dominant component of total algal flora (Flechtner et al. 1998; Evans & Johansen 1999). In our samples, however, none of these genera occurred. Conversely, the dominant component of biological soil crusts in České Švýcarsko, green algal genus *Gloeocystis*, was never recorded for desert soil crusts.

### *Floristics*

The morphology of selected widespreading species is illustrated in Fig. 2.2.4. The following pages provide detailed descriptions of several taxa found in the investigated localities.

***Eunotia Ehrenberg*** (Figs 2.2.4f–i)

Diatom genus *Eunotia* is characterized by biraphid frustules, asymmetrical to the apical axis and symmetrical to the transapical axis. Dorsal margin is convex, smooth or undulate, ventral margin straight or concave. Raphe does not occupy much of the axial area, but it is restricted to the ends along the valve mantle and curving slightly or strongly onto the valve face at the apices. Terminal nodules are usually conspicuous. Frustules are box-like or rectangular in girdle view. Raphe branches are evident in girdle view.

A total of six species of *Eunotia* were found in the biological soil crusts developed on the surface of sandstone cliffs in České Švýcarsko. Two of them, *E. exigua* and *E. fallax*, were determined in all three sampling sites. Together with *Diadesmis laevissima*, they formed the most abundant diatom component of the whole algal population.

The genus is widespread. *Eunotia* species occur mainly epiphytic on the surface of filamentous algae. They prefer the acid habitats, occurring in the moorlands, peat-bogs, acidificated waters and aquatic or wet biotopes on the silicate substrata (Kramer & Lange-Bertalot 1991). Some of the determined species are often reported from the wet surfaces of sand-stone rocks (Alles et al. 1991). However, determination of *Eunotia glacialis* and *E. meisterii* represents the first record of these species in the aerophytic biotope (Ettl & Gärtner 1995).

***Euglena geniculata*** Dujardin (Fig. 2.2.4k)

Cells of *Euglena geniculata* frequently appeared in the sample CS1 (vertical sandstone cliff with green-coloured biological soil crust, České Švýcarsko). Cells were nearly cylindrical to bluntly spindle-shaped, with rounded anterior and pointed posterior end. The pellicle was very finely and closely striated, almost parallelly with the longitudinal axis of the cell. Band-shaped chloroplasts were arranged into two star-like groups. Paramylon bodies were numerous, short, rectangular or rod-shaped, located in the chloroplast centres. Cells exhibit slow euglenoid movement.

The species of *Euglena* are cosmopolitan, most commonly found in shallow and quiet waters, such as ponds and ditches. Some species are confined to low pH waters such as *Sphagnum* peat-bogs, others usually in water major organic pollution (Wołowski & Hindák 2003). Euglena is mostly a freshwater genus, only a few of species were recorded from aero-terrestrial biotopes (Ettl & Gärtner 1995). Just one of these species is *Euglena geniculata*, isolated e.g. from soil in England and Switzerland or from wet sandy shore in Czech Republic (Schlösser 1994).

***Neodesmus sp.*** (Fig. 2.2.4l)

Green alga, isolated form sampling site CS2, was characterized by fusiform to cylindrical cells, with acute or obtuse poles. Cell dimensions varied between 5–9 µm in length and 1.5–3 µm in width. Cell wall was smooth. The cells were uninucleate, possessing one parietal chloroplast with one pyrenoid. Asexual reproduction took place by autospores; 2 per sporangium.

The morphology of determined alga corresponds well to the description of green chlorophycean alga *Neodesmus*. Although *Neodesmus* represent the coenobial alga closely related to *Desmodesmus* and *Scenedesmus*, it can disintegrate into single cells if cultivated. Morphologically, the isolated strain resembles the species *Neodesmus pupukensis*, described from stagnant inshore waters of eutrophic freshwater Lake Pupuke, Auckland, New Zealand (Kalina & Punčochářová 1987). The second described species of the genus, *N. danubialis*, is recorded from the plankton of eutrophic freshwater, including rivers and fish ponds (Guiry & Guiry 2007).

Regarding the above-mentioned differences in ecology of both *Neodesmus* species and the isolated strain, we suppose that this strain very probably represents the new species of the genus *Neodesmus*, even more the new genus within Chlorophyceae. However, because of the scarcity of morphological features, taxonomic position of this strain could be resolved only with the appropriate aid of the molecular biology techniques.

***Gloeocystis sp.*** (Fig. 2.2.4m)

Algal genus *Gloeocystis* represents a widely distributed aerophytical organism, characterized by formation of distinct mucilaginous colonies. The colonies are microscopic with cells embedded in an irregular mucilaginous envelope and forming spherical to pyramidal to amorphous masses to about 55 μm diameter. Mucilaginous material is often distinctively lamellate around each cell or group of cells. Cells are spherical, with smooth cell walls, and uninucleate. Chloroplast is single and parietal, with single pyrenoid. Asexual reproduction takes place by autospores; 2–8(–16) per sporangium (Kostikov et al. 2002). *Gloeocystis* has a broad ecological range, occurring planktonic in freshwater or aerophytic on rocks or wood, terrestrial or associated with mosses.

Cells of *Gloeocystis* sp. constituted the dominant component of algal flora in two investigated sampling sites (SC1 and CS2). There, it forms macroscopically visible mucilaginous algal mats on the surfaces of sandstone cliffs. Cell dimensions, shape and autospore number correspond well to the description of *Gloeocystis vesiculosa*. However, taxonomic concepts vary among recent authors with *Gloeocystis* species and distinguishing features of *Gloeocystis* and various related genera, as well as for individual species, requiring re-evaluation (Kostikov et al. 2002; Wolf et al. 2003).

***Cosmarium orthopunctulatum*** Schmidle

The rare desmid species *Cosmarium orthopunctulatum* was determined in the material sampled in the CS3 sampling site. Cells were medium-sized, a little longer than broad, with moderately deep median constriction. The sinus was distinctively open and acute-angled. Semicells were elliptic, with angles acutely rounded. Cell wall was ornamented by small granules, densely arranged in about 17 to 18 vertical series and 8 to 11 very indistinct horizontal series. In vertical view cells were subrhomboid with poles rounded. Cell dimensions varied between 29–36 μm in length and 26–39 μm in width, isthmus 9–12 μm.

The species *C. orthopunctulatum* was originally described from the Austrian Alps (Schmidle 1895). Afterwards, it was sporadically recorded from other places in the Alps (Migula 1907; Ducellier 1918; Messikommer 1942), Canada (Croasdale & Grönblad 1964) and Senegal (Compere 1991). Till this time, the total number of records does not exceed a ten. Therefore, determination of such rare species deserves consideration. Our finding represents not only the first record of *C. orthopunctulatum* in the Czech Republic, but also the first European record outside the Alps. In addition, determination of this species on wet sand-stone rocks further contributes to our knowledge about its ecological preferences.

## CONCLUSIONS

Algal communities of natural biological soil crusts were investigated in two locations (National Park České Švýcarsko and Střezovská Rokle) in the Czech Republic. Microscopic examination of three samples in České Švýcarsko reveals similar community structures, always consisting of cyanobacteria, diatoms and green algae. The green algae that occur in crusts are morphologically simple unicells, packets of cells, or weak filaments, yet represent a diverse assemblage of taxa spanning the classes Chlorophyceae, Trebouxiophyceae, and Klebsormidiophyceae. In the two samples, green algae were more abundant than cyanobacteria and diatoms, with *Gloeocystis* sp. being the most common species. The dominance of certain algal groups or individual species can be affected by various physico-chemical characteristics such as light conditions, the influence of which was observed in this study. Algal population in Střezovská rokle was found considerably different, as compared to České Švýcarsko. The algal community consisted only of quickly growing R-strategist green algae, which we interpret as the impact of intense environmental disturbance caused by continuous erosion of sediments from steep slopes (Kuncová et al. 1999).

## ACKNOWLEDGMENT

I thank Správa Národního Parku České Švýcarsko, especially Iva Marková, for support of lichenological survey of Babylon Nature Reserve.

# 2.3. Species composition of lichens in surface crusts on natural substrata

ONDŘEJ PEKSA

## INTRODUCTION

Lichens play an important role in soil-crust communities. As autotrophic organisms, they participate markedly in carbon fixation, and cyanolichens also show N-fixation activity (Belnap 2001). Lichen/moss crust obstructs a fast water runoff by roughening soil surfaces. Subterranean structures of lichens (hyphae, rhizinae) contribute considerably to soil stability and resistance to wind and water erosion (Warren 2001).

Both phycolichens and cyanolichens with different thallus types occur in soil crusts (crustose, foliose, fruticose) including special forms of arid regions like Fensterflechten (window lichen) (Belnap et al. 2001). In total, 13 cyanolichen and 69 phycolichen genera are reported from soil crusts of the Earth. The proportion of lichens in the crusts is higher on substrates with more carbonate, gypsum and silt content than on poor soils (Büdel 2001).

Lichens occur in biological soil crusts of different geographical areas and vegetation types. Within the European temperate region, specific soil-lichen communities can be found in xerothermic steppe formations, coastal as well as inland dunes, on open soil in heaths and very often on less or more extensive, often anthropogenic, disturbed areas (sand-pits, quarries, roadsides, etc.; Büdel 2001). In the Czech Republic, biological soil crusts with a predominance of lichens occur except antropogenic substrata, mainly in natural habitats of sandstone regions or isolated inland dunes and in steppe formations of warm regions.

This chapter describes terricolous lichens of biological soil crusts founded in three (semi)natural habitats: Střezovská rokle ravine, the margin of airport in Ralsko and Nature Reserve Babylon in Bohemian Switzerland.

## MATERIAL AND METHODS

This chapter contains the results of a floristic study performed in the period 2005–2007 in selected localities: the Natural monument Střezovská rokle, the Ralsko airport and the Nature reserve Babylon in Bohemian Switzerland National Park (see chapter 2.1). Complete results of the floristic approach of Babylon Nature Reserve are included in Svoboda et al. (2006). Only terricolous lichens associated with biological soil crusts are included.

The specimens of lichenized fungi have been studied using routine lichenological methods. For determination of collected specimens, the works of Coppins (1987), Giralt et al. (1993), Purvis et al. (1992), Tonsberg (1992), Wirth (1995), and other taxonomic publications have been used. The nomenclature of lichens follows Santesson et al. (2004) or respective works included in references. All investigated specimens have been deposited in the PL.

## RESULTS AND DISCUSSION

In all localities, well-developed biological soil crusts with distinct participation of lichens were observed. Moreover, there occur some areas with dominance of terricolous lichens in each of the localities (open sites with naked soil and low competion of vascular plants). A total of 46 taxa of terricolous lichens were recorded during the recent floristic approach (summarized in Table 2.3.1.). The major part of the records belongs to the genera *Cladonia* (30) and *Placynthiella* (4). The most frequent species occurring in all of localities are *Cladonia coccifera*, *C. furcata*, *C. macilenta*, *C. pyxidata* and *Placynthiella icmalea*, which represent the common species of acidic substrates in open habitats (naked soil, humus, rotted wood). Several records are considered to be an uncommon or rare species to the Czech Republic, e.g. *Cladonia incrassata*, *C. polycarpoides*, *C. portentosa* and *C. subcervicornis*.

The highest diversity (33 species) of terricolous lichens was detected in sandstone rocks and gorges of the Nature Reserve Babylon, probably due to the highest variety of microhabitats and good natural state of the locality.

*Babylon Nature Reserve*

is characterised with presence of climatically very different habits: deep cold humid gorges and dry plateaus of sandstone rocks covered by relic pine forests. Due to this microclimatic diversity together with the climatic conditions of Bohemian Switzerland as whole, some species with different ecological requirements (sub-Atlantic, mountain) meet in this area.

The locality is characterized by high number of recorded terricolous lichens (33), especially Cladonia species (23 compared with 13 and 14 in other two localities) including rare species *Cladonia incrassata*, *C. portentosa* and *C. sub-*

**Table 2.3.1.** The list of recorded lichen species. **1** – the Babylon Nature Reserve (* Palice et al., 2002, & Svoboda et al., 2006), **2** – airport in Ralsko, **3** – Střezovská rokle ravine.

| Taxon | 1 | 2 | 3 |
|---|---|---|---|
| *Baeomyces rufus* | + | + | |
| *Cetraria aculeata* | + | + | + |
| *Cetraria islandica* | + | | |
| *Cladonia arbuscula* ssp. *arbuscula* | + | + | |
| *Cladonia arbuscula* ssp. *mitis* | | | + |
| *Cladonia cervicornis* | + | + | |
| *Cladonia ciliata* | | + | |
| *Cladonia coccifera* | + | + | + |
| *Cladonia coniocraea* | + | | + |
| *Cladonia cornuta* | + | + | |
| *Cladonia deformis* | + | + | |
| *Cladonia digitata* | + | | |
| *Cladonia fimbriata* | + | | + |
| *Cladonia foliacea* | | | + |
| *Cladonia furcata* | + | + | + |
| *Cladonia glauca* | * | | |
| *Cladonia gracilis* | + | + | |
| *Cladonia chlorophaea* | | + | + |
| *Cladonia incrassata* | + | | |
| *Cladonia macilenta* | + | + | + |
| *Cladonia ochrochlora* | + | | |
| *Cladonia polycarpoides* | | | + |
| *Cladonia polydactyla* | + | | |
| *Cladonia portentosa* | + | | |
| *Cladonia pyxidata* | + | + | + |
| *Cladonia ramulosa* | + | | + |
| *Cladonia rangiferina* | + | | |
| *Cladonia rangiformis* | | | + |
| *Cladonia rei* | | + | + |
| *Cladonia squamosa* | + | | |
| *Cladonia subcervicornis* | *+ | | |
| *Cladonia subulata* | | + | + |
| *Cladonia uncialis* | + | | |
| *Cladonia verticillata* | + | | |
| *Dibaeis baeomyces* | | | + |
| *Icmadophila ericetorum* | + | | |
| *Peltigera didactyla* | | + | |
| *Placynthiella dasaea* | + | + | |
| *Placynthiella icmalea* | + | + | + |
| *Placynthiella oligotropha* | *+ | + | |
| *Placynthiella uliginosa* | + | + | |
| *Steinia geophana* | | | + |
| *Thelidium zwackhii* | | | + |
| *Trapelia coarctata* | | | + |
| *Trapeliopsis glaucolepidea* | + | | |
| *Trapeliopsis granulosa* | + | + | |
| *Vezdaea acicularis* | | + | |

*cervicornis*. Mainly on the plateaus, often near the rims of sandstone rocks with relatively thin humus layer and low participation of vascular plants, species rich community of terricolous lichens is developed (Fig. 2.3.1). It is composed mostly of crustose lichens from the genera *Placynthiella* and *Trapeliopsis* and fruticose "Cladonias" headed by "reindeer lichens" *Cladonia arbuscula*, *C. portentosa*, *C. rangiferina* and other species like *C. gracilis* and *C. uncialis*.

Sandy slopes as well as rotting wood in humid gorges might be covered by crust lichens adapted to the lack of light like *Baeomyces rufus* and *Icmadophila ericetorum* as well as much less conspicuous *Trapeliopsis glaucolepidea*. Due to the specific character of sandstone (high porosity, etc.), these primary terricolous species can also often grow directly on rocks, especially weathered and moist.

*Ralsko airport*

represents „semi-natural" habitat – initially probably bare and open (grassy?) area not far from the runway is recently colonized by pines, birches, etc. Biological soil crusts with predominance of terricolous lichens are well developed especially in the heather moor – on naked sandy soil among the heather shrubs with minimal participation of other vascular plants (Fig. 2.3.2). The composition of the local lichen community is similar to that of open sites of Babylon (except the rare species!) due to similar substrate – sandy soil. Several species of *Cladonia* (*C. coccifera*, *C. furcata*, *C. macilenta*, *C. pyxidata* and *C. subulata*) together with *Cetraria aculeata* and crustose lichens from the genus *Placynthiella* predominate in the biological soil crust. Some *Cladonia* species (predominantly squamules of *Cladonia pyxidata*) are often infected by lichenicolous fungus *Arthrorhaphis aeruginosa*, which evokes an atypical deep bluegreen colouration of the thallus. Naked soil, mosses and lichens, are often covered by inconspicuous apothecia and goniocysts of *Vezdaea acicularis* observable especially during wet periods of the year.

*Střezovská rokle ravine*

differs from other two localities mainly by the presence of species typical for sunny habitats with more alkalic substrates, e.g. *Cladonia foliacea* (Fig. 2.3.3), *C. polycarpoides* and *C. rangiformis*. The mentioned species are bound to the small grassy plateaous on the ridges and upper parts of the steep slopes of erosion cones, together with other dominants as *Cetraria aculeata*, *Cladonia mitis* and *C. subulata* (Fig. 2.3.4). In shaded humid sites at the bases of slopes, ephemeral microscopic lichens like *Steinia geophana* and *Thelidium zwackhii* can be found. Small rests of heat stands are occupied mainly by pioneer lichens like *Dibaeis baeomyces*, *Cladonia coccifera*, *C. coniocraea*, *C. macilenta*, *C. pyxidata* and *Trapelia coarctata* (the last species grows here except the small pebbles also directly on naked soil).

### *Noteworthy lichen species*

#### *Cladonia incrassata*

Suza (1938) calls *C. incrassata* a characteristic "peat-lichen", solely due to it's ecological relationship to the peat bogs (pine-forest bogs) of the Bohemian massif. Litterski

& Ahti (2004) described it as a holarctic oceanic species with a disjuncted distribution pattern, occuring in Europe especially on peaty soil in bogs. In the locality of Babylon, this red-fruited species with small podetia was collected at the base of an old pine in a relic pine forest on sandstone rock. In the same habitat, its typical companions *C. macilenta*, *C. deformis* and *Trapeliopsis granulosa* were also recorded.

***Cladonia polycarpoides***

Conspicious species typical for sun-exposed habitats with more alkalic sandy or stony soils mainly in xerotherm regions (steppes), often growing together with *Cladonia foliacea* (Kovář 1912; Suza 1947; Wirth 1995). The rests of steppe vegetation in the locality of Střezovská rokle ravine represent a typical habitat of the species.

***Cladonia subcervicornis***

Rare species with the centre of distribution in the Atlantic floristic province (Litterski & Ahti 2004). In the Babylon Nature Reserve was firstly recorded in 2002 – commented together with other species with similar ecology (*Cladonia glauca*, *C. portentosa*) in Palice et al. (2002) and Palice et al. (2007). Compared with recently known distribution of *C. subcervicornis* (Litterski & Ahti 2004), the region of Bohemian Switzerland represent very isolated and inland locality of the species.

## CONCLUSIONS

Terricolous lichens of biological soil crusts were studied in the three natural or seminatural localities in the North Bohemia. A total of 46 taxa of terricolous lichens were recorded during the recent floristic approach. The highest diversity of lichens was detected in the Nature Reserve Babylon in Bohemian Switzerland, probably due to the highest variety of microhabitats and good natural state of the locality.

The major part of the lichen records belongs to the genera *Cladonia* (30) and *Placynthiella* (4). The most frequent species occuring in all of localities (*Cladonia coccifera*, *C. furcata*, *C. macilenta*, *C. pyxidata*, *Placynthiella icmalea*) represent common “pioneer lichens” typical for acidic substrates in open habitats (often disturbed). Several records belong to rare species of well–preserved plant communities (*Cladonia incrassata*, *C. portentosa*, *C. subcervicornis* – Babylon, *C. polycarpoides* – Střezovská rokle).

# 2.4. Species composition of fungi in biological soil crusts on natural substrata compared with agricultural habitats

ALENA KUBÁTOVÁ & KAREL PRÁŠIL

## INTRODUCTION

While lichens, cyanobacteria or algae frequently form conspicuous macroscopic biological soil crusts on soil surfaces and are intensively studied by lichenologists and phycologists, fungi are somewhat neglected. Although in an early study of biological soil crusts by Fletcher & Martin (1948) the free-living fungi are considered as important components of the crust structure, they were for a long time ignored. At present we have only limited information on species composition of fungi and their function in crusts. A fundamental mycological study on biological soil crusts is found in the work of States & Christensen (2001), dealing with biological soil crusts in desert grasslands in USA. Another recent study is that of Grishkan et al. (2006) dealing with soil crust microfungi in the Negev desert. Knowledge on diversity and function of fungi in the biological soil crusts of Central Europe is very scarce. The only paper which mentioned some fungus in biological soil crusts, is the algological study by Hoppert et al. (2004).

In this chapter, results of our pilot study of microfungal communities in the biological soil crusts or surface soil layer on two natural localities (Střezovská rokle ravine and Borový důl ravine) compared with two agricultural localities (all in the Czech Republic) are given.

## MATERIALS AND METHODS

*Localities and sampling of biological soil crusts or surface soil layer:* Střezovská rokle ravine (June 2005, see Figs 2.1.1.c, d), Borový důl ravine (November 2005), a field near Uhříněves and pasture near Netluky (November 2005). Characteristics of the localities studied are given in the Chapter 2.1. Biological soil crust was developed only at Střezovská rokle ravine. From each locality, one composed sample of biological soil crust or soil layer (of ca 0.5 cm thickness) was taken into a sterile plastic bag. For the mycological analysis the same material of soil crusts was used as for study of algae and cyanobacteria.

*Cultivation and identification:* Microscopic fungi in biological soil crusts were studied by cultivation methods. For isolation of fungi, both soil dilution method and direct inoculation of soil were applied. Samples were inoculated onto four different isolation media: soil agar with rose bengal and glucose (SEGA), wort agar (WA), Sabouraud's agar (SAB), and potato carrot agar (PCA) (Fassatiová 1986). All media contained streptomycin to suppress bacteria (0.1 g/l). For one sample of biological soil crust or surface soil layer, some 16 isolation Petri dishes were used (Fig. 2.4.1a). Incubation of the Petri dishes was made at 25 °C. After the $7^{th}$ day of incubation, the visible colonies were transferred to other agar media for identification. These media were malt extract agar (MEA), Czapek yeast extract agar (CYA), soil extract agar (SEA), wort agar (WA), potato carrot agar (PCA), corn meal agar (CMA), potato succrose agar (PSA) and synthetic nutrient agar (SNA) – see in Nirenberg (1976), Fassatiová (1986), Samson et al. (2004).

Identification of soil micromycetes was made on the base of microscopic and macromorphological features according to Gams (1971), Pitt (1979), Ramírez (1982), Burgess et al. (1988), Domsch et al. (1993), Schroers (2001), Samson et al. (2004), Zare & Gams (2004) and other relevant literature. Several fungal strains were deposited at Culture Collection of Fungi (CCF), Department of Botany, Charles University, Prague, Czech Republic (see in Tab. 2.4.1).

## RESULTS AND DISCUSSION

A list of fungal species isolated from biological soil crust or surface soil layer on four localities studied during 2005 is given in the Tab. 2.4.1. Altogether 50 taxa (species, forms, and undetermined isolates) of microscopic fungi belonging to 26 genera were discovered.

The majority of the fungi isolated are anamorphs of *Ascomycota* (40 taxa, 80%); nine taxa (18%) belong to *Zygomycota*. One isolate (cf. *Pythium* sp.) is member of *Peronosporomycota* (fungi-like organisms). The most frequent genera were *Penicillium* (7 species), F*usarium* (6 species) and *Trichoderma* (5 species).

The most frequent fungi were *Cladosporium cladosporioides*, *Clonostachys rosea* f. *rosea*, and *Mucor* sp., which occurred with higher frequency on two localities, and *Alternaria* sp., *Aspergillus flavus*, *Epicoccum nigrum*, *Fusarium crookwellense*, *Penicillium pulvillorum*, *Penicillium spinulosum*, *Trichoderma polysporum*, *T. viride*, and *Umbelopsis angularis*, which were frequently isolated on one of four localities. The majority of isolated microfungi occurred in low frequency, and many species were found only once. All

**Table 2.4.1.** Microscopic fungi isolated from biological soil crust or surface layer on natural and agricultural localities.

| | Locality | | | |
|---|---|---|---|---|
| **Microscopic fungi** | **S** | **B** | **U** | **N** |
| *Absidia spinosa* | | | | 1 |
| *Acremonium sp.* | | | 1 | |
| *Alternaria alternata* | | | 1 | |
| *Alternaria sp.* | 2 | | | |
| *Arthrinium arundinis* | 1 | | | |
| *Aspergillus flavus* | 2 | | | |
| *Cladosporium cladosporioides* | | 1 | 2 | 2 |
| *Cladosporium herbarum* | 1 | 1 | 1 | |
| *Clonostachys rosea f. catenulata* | | | | 1 |
| *Clonostachys rosea f. rosea* | | | 2 | 2 |
| *Curvularia sp.* | 1 | | | |
| *Epicoccum nigrum* | 2 | | | |
| *Fusarium crookwellense* ***CCF 3619*** | | | 2 | |
| *Fusarium culmorum* | | | 1 | 1 |
| *Fusarium tricinctum* | | | | 1 |
| *Fusarium spp. (3)* | 1 | | 1 | 1 |
| *Geomyces pannorum* | | 1 | | |
| *Metarhizium anisopliae* | | 1 | | |
| *Mortierella spp. (2)* | 1 | | | 1 |
| *Mucor hiemalis f. hiemalis* | 1 | | | |
| *Mucor sp. (2)* | | | 2 | 2 |
| *Mycocladus sp.* | | 1 | | |
| *Myrothecium roridum* | | | 1 | |
| *Paecilomyces lilacinus* | 1 | | | |
| *Penicillium cf. coalescens* | | 1 | | |
| *Penicillium daleae* | 1 | | | |
| *Penicillium pulvillorum* ***CCF 3720*** | 2 | | | |
| *Penicillium simplicissimum* | 1 | | | |
| *Penicillium spinulosum* | 1 | 2 | | |
| *Penicillium spp. (2)* | 1 | | | |
| *Phoma cf. eupyrena* | | | | 1 |
| *Phoma spp. (2)* | 1 | 1 | | |
| *Pochonia bulbilosa* | | 1 | | |
| *cf. Pythium sp.* | | | 1 | |
| *Rhizopus arrhizus* | | | 1 | 1 |
| *Torulomyces lagena* | 1 | | | |
| *Trichoderma polysporum* | | 2 | | |
| *Trichoderma viride* | | 2 | | |
| *Trichoderma spp. (4)* | 1 | 1 | 1 | 1 |
| *Umbelopsis angularis* | 1 | 2 | | |
| *undetermined pycnidial fungus* | | | 1 | |
| **Total No. of taxa: 50** | **20** | **13** | **14** | **12** |

*Notes:* CCF = Culture Collection of Fungi, Prague, CZ; Localities: **S** = Střezovská rokle ravine, **B** = Borový důl ravine, **U** = field near Uhříněves, **N** = pasture near Netluky; Occurrence: **1** = rarely isolated species, **2** = frequent species.

the fungi isolated are known as saprotrophic soil and litter fungi equipped by many enzymes useful for destruction of substrates (Domsch et al. 1993). Some of them are also phytopathogenic (*Acremonium*, *Clonostachys*, *Fusarium*), food-borne (*Aspergillus flavus*), coprophilous (*Mucor*), or entomogenous (*Metarhizium anisopliae*).

In the Tab. 2.4.1, comparison of fungal species richness of localities and data on the structure of fungal communities are given. Comparing the four localities, the numbers of species isolated are: 20 for Střezovská rokle ravine, 14 for field near Uhříněves, 13 for Borový důl ravine, and 12 for pasture near Netluky.

The spectrum of discovered fungi on these localities differs (see also Figs 2.4.1b–d). On the locality Střezovská rokle dominated *Alternaria sp.*, *Aspergillus flavus*, *Epicoccum nigrum* and *Penicillium pulvillorum*. Nevertheless, only *Alternaria* sp. and *Epicoccum nigrum* belong to typical soilborne and litter fungi. *Aspergillus flavus* is a food-borne toxigenic fungus occurring in our country mainly on imported foods and feeds. *Penicillium pulvillorum* in the Czech Republic was recorded mainly on anthropogenic localities, e.g. in substrate of an abandoned ore-washery settling pit in Chvaletice (Kubátová et al. 2002). On the locality Borový důl were the most frequent *Penicillium spinulosum*, *Trichoderma polysporum*, *T. viride* and *Umbelopsis angularis*. All four fungi are typical in our country for forested localities (e.g. Šumava Mts., see Kubátová et al. 1998). On agricultural localities (field near Unříněves and pasture near Netluky) *Cladosporium cladosporioides*, *Clonostachys rosea* f. *rosea*, *Fusarium* spp., and *Mucor* spp. dominated. *Fusarium* species are commonly associated with cereals and their remains (e.g. straw), *Mucor* species are soil and coprophilous fungi, therefore their high occurrence on these localities is not surprising. While the structure of fungal communities of biological soil crusts on these agricultural localities is somewhat similar, the structure of fungal communities on Střezovská rokle and Borový důl is very different (see Fig. 2.4.2).

Fungal species composition in biological soil crusts is little known. In early studies only rare mentions are present. For example, Fletcher & Martin (1948) discovered on desert soil in Tucson, USA, a distinct biological soil crust composition of cyanobacteria *Oscillatoria*, *Microcoleus*, and *Nos-*

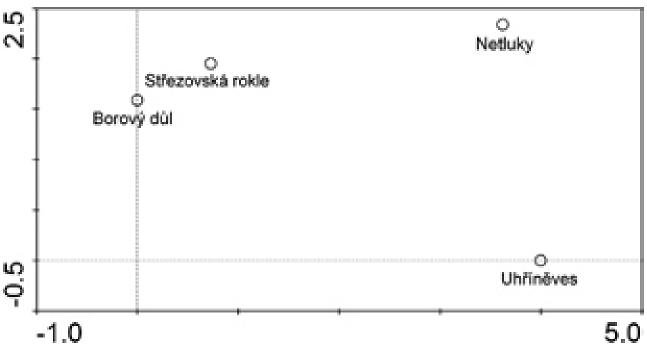



**Fig. 2.4.2.** Testing of differences in fungal species richness and composition of biological soil crusts on four localities. DCA ordination diagram showing the position of samples in the range of the first two ordination axes.

*toc* and fungi *Rhizopus*, *Mucor*, and *Botrytis pyramidalis* related fungus (*Botryosporium pulchrum* in present sense). The most comprehensive recent paper is by States & Christensen (2001). They found in biological soil crusts in desert grasslands of Utah and Wyoming, USA, numerous crust associated fungi not previously reported from soil (e.g. basidiomycete *Cyphellostereum* sp., loculoascomycetes *Kalmusia utahensis*, *Macroventuria wentii* etc.). Among other fungi they discovered also members of *Cladosporium*, *Trichoderma*, *Alternaria*, *Epicoccum*, *Fusarium*, *Phoma* etc., as in our study. Hoppert et al. (2004), who studied algae in biological soil crust on sandy soil in Germany, also found *Fusarium*. It parasited on the conjugate alga *Zygogonium*, which dominated the biological soil crust studied. Grishkan et al. (2006) in their detailed study of microfungi diversity and structure of biological soil crust in the Negev desert discovered 87 species, dominant among them being melanin containing fungi (*Alternaria*, *Ulocladium*, *Embellisia* etc.). In our study, due to the climate of our temperate region, the proportion of dark pigmented fungi was relatively lower.

Results of all inventorial surveys strongly depend on the methods used and intensity of sampling (see also Gams 2007). In our study, we were restricted by several factors. (1) Unrepeated sampling severely limits the number of fungal isolates obtained. Undoubtedly, the species accumulation curve would grow with repeated samplings. (2) We discovered only culturable microscopic fungi that were able to grow on the agar media used. Other recently used molecular methods could reveal other organisms living in and forming biological soil crusts. (3) We could not effectively differentiate fungi actively growing in biological soil crust and forming mycelium from fungi grown on agar media from inactive spores only. Better results could be gained by particle filtration techniques (Bills et al. 2004). However, this method is not used as widely as the dilution method, mainly because it is more time-consuming.

Thus, the present study could be considered as only a partial contribution to knowledge of the fungal diversity of biological soil crusts.

## CONCLUSIONS

Microfungi of biological soil crusts recorded during this survey belong mostly to the known soil and litter fungi. Fungal species composition of biological soil crusts or surface soil layer on the localities studied was very different reflecting the different abiotic and biotic factors. CCA analysis, comparing species richness and composition, differentiated natural localities from agricultural localities. The sampling was unrepeated, which strongly limits the number of fungal isolates obtained. Thus, the results present only partial contribution to the fungal diversity of biological soil crusts on studied localities.

# 2.5. Species composition and diversity of bryophytes in biological soil crusts on natural substrata

ZDENĚK SOLDÁN

## INTRODUCTION

Bryophytes play a very important role in natural habitats with well-developed biological soil crusts, primarily as pioneer organisms during early stages of succession. Due to their often using the life strategy of colonists, or shuttle-species, they are able to be no less than the dominant part of vegetation within a short period, in these types of substrates. Their role is equally important for the stability of substrates and the resistance of such substrates with the respect on possible water regime as well as wind and water erosions, and the creation of suitable conditions for the subsequent succession of vascular plants.

From the bryological point of view, no special studies of questions connected with bryophytes forming biological soil crusts have yet been published in the Czech Republic, yet. The majority of information is of only floristic character and is usually only included for comprehensiveness. It can be mentioned here that there is very concentrated interest among bryologists on the vegetation of bryophytes in the regions of sandstones, where very well developed communities with dominating bryophytes on bases of rocks (particularly on shaded places) are sometimes very rich, and bryophytes role very dominant.

## MATERIAL AND METHODS

After field collection bryophytes were microscopically determined in a lab. The nomenclature follows the paper Kučera & Váňa (2004); all specimens have been consecutively deposited in the herbarium of the Faculty of Natural Sciences of the Charles University in Prague (PRC).

In the case of Střezovská rokle, only the bryophytes growing and forming biological soil crusts on the surface of slopes (exposed as well as shaded) were included. No bryophytes are mentioned from wider surroundings of these habitats (e.g., epiphytes, bryophytes growing along a brook, etc.).

However, all bryophytes species have been included from the wider surroundings of study plots in the case of locality Ralsko.

The results of bryological research in pasture locality at Netluky near Prague are attached in this paper as a demonstration of the typical composition of bryophytes in so-called “agrocenoses”. Study of these habitats is usually overlooked in the Czech Republic; on the other hand, some such papers concerning to this problem have been published in Slovakia in the past (e.g., Kresáňová 2006).

## RESULTS AND DISCUSSION

The list of bryophytes collected in the above mentioned localities is submitted in a form of synoptic table.

In total, 31 bryophytes (26 mosses and 5 liverworts) were discovered on the locality Střezovská rokle. The species composition of biological soil crusts is influenced especially by the degree of shading of relevant slope. Species like *Fissidens bryoides* and *Dicranella heteromalla* dominated in shaded places, exposed slopes are typical habitats for other species – *Ceratodon purpureus* or *Polytrichum piliferum*. The most interesting species of this locality is definitely hepatic *Riccardia incurvata*. It is very rare frondose liverwort, evaluated as an endangered species in the “Red List of Bryophytes” in the Czech Republic (Kučera & Váňa 2004). It grows mostly in submontane and montane elevations, on acidic as well as on basic substrates (sandstone soil, peat soil, among grasses or among other bryophytes). This species was discovered by O. Peksa here in 2002 (Kučera 2004). The distribution of this species is very tessellated in the Czech Republic (recent data are known from the vicinity of Veselí n. Lužnicí and a record from Jestřebí near Česká Lípa was confirmed recent occurring on the base of an older finding).

In total, 28 species of bryophytes (26 mosses and 2 liverworts) were discovered in the Ralsko locality. They are relatively frequent or common species of bryophytes with a wide ecological valency. The most surprising findings represent the moss *Oligotrichum hercynicum*, which dominates usually at higher altitudes (mountains near the state border). Its occurrence in such altitudes probably represents its lowest locality in the Czech Republic.

18 species of bryophytes (15 mosses, 1 liverwort and 1 hornwort) were collected from the small pasture near Netluky. They represent relatively common species, which are typical for so-called “agrocenoses” or fields or pastures and they are very rare on other types of habitats.

**Table 2.5.1.** The list of bryophytes collected in the natural localities (Netluky, Ralsko, Střezov). (Used symbols: + = the species present, – = the species absent)

| Taxon | Netluky | Ralsko | Střezov |
|---|---|---|---|
| *Aneura pinguis* | – | – | + |
| *Anthoceros agrestis* | + | – | – |
| *Atrichum undulatum* | + | – | + |
| *Barbula fallax* | – | – | + |
| *Barbula convoluta* | – | – | + |
| *Barbula unguiculata* | + | + | + |
| *Blasia pusilla* | – | + | – |
| *Brachythecium albicans* | + | + | – |
| *Brachythecium rutabulum* | + | + | + |
| *Brachythecium salebrosum* | + | – | + |
| *Bryum argenteum* | + | + | + |
| *Bryum bicolor* | + | – | + |
| *Bryum caespiticium* | – | – | + |
| *Bryum capillare* | – | + | + |
| *Bryum rubens* | + | – | – |
| *Bryum subapiculatum* | + | – | – |
| *Cephalozia bicuspidata* | – | – | + |
| *Cephaloziella divaricata* | – | + | + |
| *Ceratodon purpureus* | + | + | + |
| *Climacium dendroides* | – | + | – |
| *Dicranella heteromalla* | – | + | + |
| *Dicranella staphylina* | + | – | – |
| *Dicranum scoparium* | – | + | + |
| *Dicranum polysetum* | – | + | – |
| *Ditrichum heteromallum* | – | + | – |
| *Eurhynchium hians* | + | – | + |
| *Fissidens bryoides* | – | – | + |
| *Fissidens taxifolius* | – | – | + |
| *Fossombronia wondraczekii* | + | – | – |
| *Funaria hygrometrica* | + | + | – |
| *Gymnocolea inflata* | – | – | + |
| *Hypnum cupressiforme* | – | + | + |
| *Oligotrichum hercynicum* | – | + | – |
| *Physcomitrium pyriforme* | – | – | + |
| *Plagiomnium affine* | – | + | – |
| *Plagiomnium cuspidatum* | – | + | – |
| *Pleurozium schreberi* | – | + | – |
| *Pohlia annotina* | – | – | + |
| *Pohlia nutans* | – | + | + |
| *Polytrichastrum formosum* | – | – | + |
| *Polytrichum juniperinum* | – | + | – |
| *Polytrichum piliferum* | – | + | + |
| *Pogonatum urnigerum* | – | + | – |
| *Riccia glauca* | + | – | – |
| *Riccardia incurvata* | – | – | + |
| *Rhizomnium punctatum* | – | – | + |
| *Rhytidiadelphus squarrosus* | – | + | – |
| *Scleropodium purum* | – | + | + |
| *Syntrichia ruralis* | – | + | + |
| *Tortula acaulon* | + | – | + |
| *Tortula muralis* | – | + | – |
| *Tortula ruralis* | – | + | – |
| *Tortula truncata* | + | – | – |

# 3. Biological soil crusts on anthropogenic substrata – species composition and diversity

JIŘÍ NEUSTUPA

In Central European landscape, sedimentation basins represent a principal habitat with biological soil crusts (Kovář 2004). Most of these localities arose from ore mining in the second half of the $20^{th}$ century. As a result, the substrates of sedimentation basins typically have high concentrations of metals and heavy metal toxic elements and relatively low pH (Rauch 2004; chapter 3.2). These abiotic factors effectively hamper the succession of vascular plant cover, so that relatively large parts of sedimentation basins have resisted past restoration actions, typically involving the planting of several species of tree seedlings (Kovář 2004). The relatively scarce vascular plant cover consists of just a few species (chapter 3.3) and the total cover mostly does not exceed 15%. Thus, the competition of vascular plants is highly limited and most of the surface is covered by typical biological soil crust as defined by Johnston (1997).

In this part of the project, we aimed at the enumeration of species composition from several sedimentation basin localities with a well developed biological soil crust. In addition, we investigated two active cinder-washery basin localities (the Ostrov and Dvůr Králové sampling sites). In this locality, we sampled the surphace cover of a substrate in order to compare the biotic components of this site with typical crusts of other sedimentation localities.

For characterization of our localities, we measured numerous abiotic data involving basic physico-chemical parameters, concentrations of several microbiogenous elements, concentrations of heavy metal elements, nutrient concentrations and several eco-physiological parameters of crusts. In the following chapters, we present our results of biodiversity investigations, we compare the species compositions of individual investigated sedimentation basins, and we identify the abiotic factors that significantly influence the biotic components of crusts. Regarding the extremely low diversity of bryophytes at the investigated localities, this chapter includes additional data on population dynamics of dominant taxa on linear transects in relation to humidity on investigated localities. On the other hand, in more diversified microbial groups we concentrated more on investigation of species richness and comparison of species composition data between individual localities.

# 3.1. Description of investigated localities

JIŘÍ NEUSTUPA & PAVEL ŠKALOUD

We investigated biological soil crusts at four ore and ash sedimentation basin localities in Czech Republic:

1) *Měděnec* ore sedimentation basin (50°26′9.657″N, 13°5′59.46″E, altitude 805 m a.s.l., Figs 3.1.1a–c) is situated close to the former lodestone mine that was erected in 1967. In 1997 this mine was closed and since then, the sedimentation basin with 12 ha area was abandoned and nowadays it consists of large exposed areas without significant vascular plant cover. The sampling site experiences repeated periods of water saturation and overflow related to snow melting in sub-mountainous altitude.
2) *Radvanice* ore sedimentation basin (49°48′56.232″N, 18°22′51.736″E, altitude 280 m a.s.l., Figs 3.1.1d–f) was abandoned in the 1970's after the local copper-ore mine closed. In past the 30 years, reforestation by *Pinus sylvestris* was several times unsuccessfully attempted. The area now includes about 4 ha of exposed tree-less habitat with biological soil crust covering most of the surface.
3) *Dvůr Králové I* ash sedimentation basin (50°25′7.242″N, 15°48′52.404″E, altitude 288 m a.s.l., Figs 3.1.2a–c) represent the active locality close to the brown coal heating plant. The abandoned parts of the locality include about 2 ha of exposed tree-less areas with the biological soil crust cover. For our investigation, we chose a site on the margin of the locality that was not recently flooded by waste-water from a heating plant. However, short-term overflows related to elevation of water level in periods with high precipitation cannot be excluded.
4) *Ostrov II* ash sedimentation basin (50°17′43.116″N, 12°56′58.985″E; altitude 400 m a.s.l., Figs 3.1.2d–f) was founded in 1987 and it represents a highly active ash sedimentation basin of a brown coal heating plant. The ash wastewater regularly overflows most parts of the 7.5 ha basin area. However, the marginal parts of this locality are now largely un-flooded and they consist of exposed surfaces without any vascular plants.

# 3.2. The abiotic and eco-physiological parameters of biological soil crusts of ash-slag and ore-waste sedimentation basins

KATEŘINA ČERNÁ

## INTRODUCTION

Human activities such as ore-mining or ash-slag depositions greatly influence soil abiotic and ecophysiological characteristics. High concentrations of toxic metals connected with low nutrient availability lead to specific characteristics of such soils and development of specific bacterial communities that are able to survive in these unfavourable conditions.

## MATERIALS AND METHODS

Samples of biological soil crusts including just the upper 0,5 cm-layer of soil were collected on the study sites in spring of 2006. Laboratory analyses were carried out by the Analytical Laboratory of the Section of Plant Ecology of the Czech Academy of Science in Třeboň. Soil samples were sieved through a 2-mm mesh and air-dried (Zbíral 1995, ISO 11464). Soil pH was determined with a glass electrode in a 1-to-5 (w/w) soil-to-deionized water mixture (5M KCl, respectivelly) (ISO/DIS 10390). Electrical conductivity was measured in a 1-to-5 soil-to-water mixture at 25° C (ISO/DIS 11265). The concentrations of nitrate ions ($NO_3$-N), ammonium ions ($NH_4$-N) and dissolved reactive phosphorus (DRP) in the soil suspension were determined colorimetrically with a continuous flow analyser (FIA-STAR, Tecator, Sweden). The gas diffusion method was used for the estimation of the concentration of $NH_4$-N (Karlberg & Twengström 1983). The concentration of $NO_3$-N was determined after its reduction to nitrite in a Cd-Cu column and the subsequent reaction of nitrite with sulfanilamide and N-(1-naphthyl)-ethylenediamine. Standard phosphomolybdenum complex method was used for the DRP estimation (Parsons et al. 1984). Total nitrogen (TN) and total phosphorus (TP) concentrations were determined as $NO_2$-N and DRP respectively, after mineralization of the samples by persulphate (Grasshoff et al. 1983). Basal respiration of microbial assemblages was determined after incubation of soil samples in 25° C for 24 hours. Samples were incubated in air tight jars along with 10 ml of 1 M NaOH. The $CO_2$-C evolved was determined by titration by HCl (Anderson 1982). Soil incubation was also used for determination of ammonification and nitrification rates. Soil samples (10 g of soil each) were moistened to 60% of max WHC and incubated for three weeks at 20° C in aerobic conditions. $NH_4$-N and $NO_3$-N were extracted before and after the incubation and their concentration was determined with continuous flow analyzer. The ammonification and nitrification rate was computed from the differences in the concentration of $NH_4$-N and $NO_3$-N at the beginning and at the end of incubation. Fluorescein diacetate (FDA) hydrolysis rate was estimated as described in Schnürer and Rosswall (1982) using an incubation period of 1 h at 28° C. To determine the heavy metals concentration soil samples were firstly digested with $NO_3$ and HCl in ratio 1-to-3 (w/w). Then samples were subjected to atomic absorption spectrometry and the concentration was determined by FAAS using air acetylene flame.

## RESULTS

We attempted to identify soil parameters that influence the development of biological soil crusts at studied localities. We found no difference in soil pH/$H_2O$ (measured in soil-water mixture). Soil pH values between 7.77 and 8.24 were measured at all localities (Fig. 3.2.1), the highest value of pH was found in Dvůr Králové. Differences in pH/KCl values (measured in soil-KCl mixture) were found – the values of pH were lower than those measured in soil-water mixture. The range of measured values was detected from 6.47 to 8.06 the highest value was measured in Dvůr Králové. We detected differences in measured values of electrical conductivity in localities. The highest electrical conductivity was measured at the locality in Dvůr Králové (280 µS/cm) the smallest conductivity was measured at the locality in Měděnec (27.5 µS/cm). The highest measured value was ten times higher compared to the lowest one (Fig. 3.2.1). Measured concentrations of $NH_4^+$ differed between studied localities. The highest concentration was detected in Radvanice (0.0217 mg/g) which exceeded many times the concentration in other places (Fig. 3.2.2). In Ostrov the concentration of $NH_4^+$ was lower than 0.0001 mg/g. Concentrations of $NO_3^-$ in all localities were low, the highest value was measured in Měděnec (0.00092 mg/g), in Ostrov and Dvůr Králové the concentrations of $NO_3^-$ were lower than 0.0001 mg/g. The amount of $PO_4^{-3}$ in the soil of studied localities ranged between 0.000116 to 0.00052 mg/g, the highest value measured in Ostrov (0.00052 mg/g). Differences in the amount of total nitrogen and total phosphorus in soils of studied localities were detected (Fig. 3.2.3). The

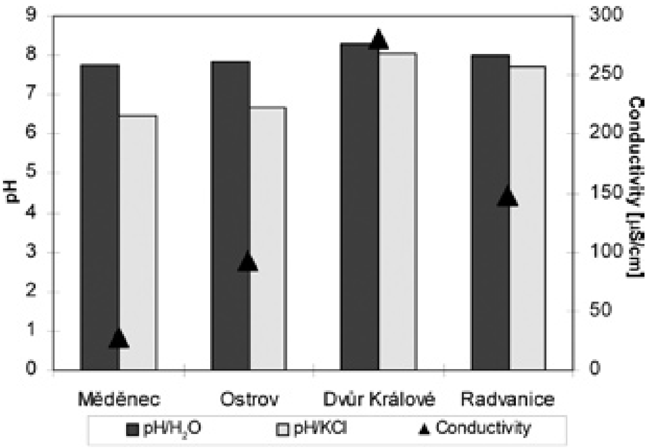



**Fig. 3.2.1.** The values of pH and chemical conductivity measured at studied localities.

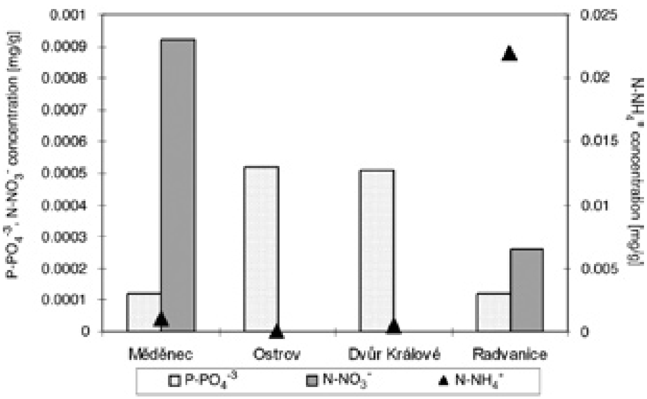



**Fig. 3.2.2.** Concentrations of $NH_4^+$, $NO_3^-$ and $PO_4^{-3}$(DRP) measured at studied localities.

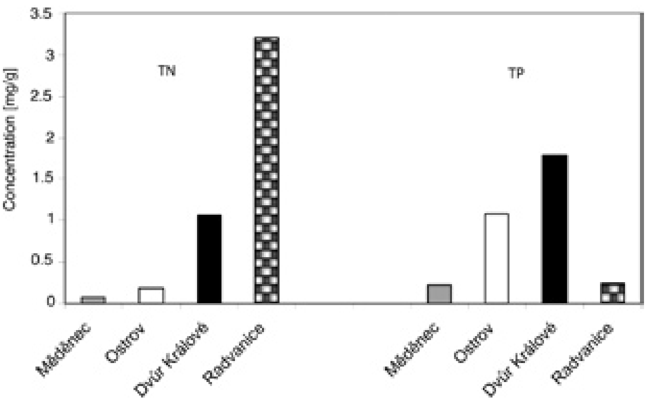



**Fig. 3.2.3.** Total concentrations of nitrogen and phosphorus at studied localities.

concentration of total nitrogen ranged between 0.08 mg/g in Měděnec and 3.2 mg/g in Radvanice. Concentration of total phosphorus was high in Ostrov (1.08 mg/g) and Dvůr Králové (1.8 mg/g). In Radvanice and Měděnec, measured concentrations were low (0.24 mg/g, 0.23 mg/g, respectively). Measured ammonification and nitrification rates showed that at localities where the rate of ammonification was higher, the rate of nitrification was low. The highest rate of ammonification was measured in Ostrov (0.067 µg/g·d). The highest rate of nitrification was measured in Radvanice (3.35 µg/g·d), this rate was many times higher than in other localities (Fig. 3.2.4). Studied localities differed in measured values of basal respiration and hydrolysis FDA (Fig. 3.2.5). In Měděnec and Ostrov these values were low in both cases of measured parameters. The lowest value of basal respiration was measured in Ostrov (0.66 µg C-$CO_2$/g·h), hydrolysis FDA was lowest in Měděnec (0.21 A/g·h). By contrast, in Dvůr Králové and Radvanice, high values of basal respiration and hydrolysis were detected. The highest value of basal respiration was measured in Radvanice (11.64 µg C-$CO_2$/g·h) some twenty times higher than in Ostrov. The highest hydrolysis FDA was detected in Dvůr Králové (0.36 A/g·h) and was more than ten times higher than in Měděnec. The concentrations of heavy metals illustrated the Radvanice locality as the most toxic-loaded site among the investigated sedimentation basins (Tab. 3.2.1). However, in the Dvůr Králové ash sedimentation basin the highest concentrations of Al and $SO_4^{2-}$ were detected.

**Table 3.2.1.** The concentrations of heavy metals at the studied localities. (Highest values are highlited in bold-italics).

| | Měděnec | Ostrov | Dvůr Králové | Radvanice |
|---|---|---|---|---|
| **Al [mg/g]** | 19.9 | 31.3 | ***36.5*** | 7.09 |
| **Fe [mg/g]** | 46.8 | 23.6 | 18.6 | ***77.8*** |
| **$SO_4^-$ [mg/g]** | 1.08 | 9.69 | ***14.9*** | 10.8 |
| **Mn [mg/g]** | 0.42 | 0.3 | 0.31 | ***5.46*** |
| **Cu [mg/g]** | 0.04 | 0.19 | 0.23 | ***0.53*** |
| **Zn [mg/g]** | 0.06 | 0.08 | 0.17 | ***1.04*** |
| **Cd [mg/g]** | 0.0014 | 0.0015 | 0.0023 | ***0.0055*** |
| **Pb [mg/g]** | 0.017 | 0.023 | 0.062 | ***0.128*** |

## DISCUSSION

Substrates of ash-slag deposits have been proved to have generally higher pH values. Their alkalinity is derived from the chemical qualities of deposits which contain high Mg, K and Ca concentrations (Townsend & Hodgson 1973). The pH values of ore sedimentation basins substrates is mainly influenced by the type of mineral originally mined and tends to be mostly acidic (Choi & Wali 1995). However, as gradually the acidic compounds are washed out from the upper layer of the substrate so pH values increase (Slavíková 1986). This could be the case of our sedimentation basin localities with higher pH/$H_2O$ value. The higher pH could be connected with the relatively long time since mining termination – in Radvanice the ore-mining activities were terminated in 1965, in Měděnec in 1997. We assumed that the high conductivity level of the Dvůr Králové ash sedimentation locality could be connected with a regular deposition of ash-slag that brings diluted salts to the locality. The low concentrations of ammonium and nitrate ions in the Dvůr Králové and the Ostrov localities could be explained by the generally low amounts of nitrogen in ash-slag deposits (Kolář 1969) and the lower activity of soil microbiota in an unstable environment in still-active industrial sedimentation areas. On the other hand, high amounts of phosphate comes with ash-slag deposits (Kolář 1969). In Měděnec and Radvanice, concentration of ammonium and nitrate ions was higher and we can see that despite the high toxic metal concentrations in these localities, specific crust communities nevertheless developed. The biotic parameters of substrates at the investigated localities (basal respiration, hydrolysis FDA, ammonification and nitrification rates) indicated a relatively low activity of microbial communities in comparison with the literature records (Yuan et al. 2007; García-Gil et al. 2004; Boyle et al. 2007). The nitrification rate reflected substrate nutrient concentration at all the localities. In Radvanice there was the highest nitrification rate and a high initial concentration of $NH_4^+$. As there was no obvious limitation of any other nutrients or pH and the lowest concentrations of aluminium were measured, we can expect a well developed community of nitrifying bacteria. We assume that microbial activity at our localities is influenced mostly by non-availability of nutrients, phosphorus especially, in basic conditions. Phosphorus requires a pH between 6.0 and 7.0 and becomes chemically immobile outside this range, forming insoluble compounds with calcium (Ca) in calcareous soils. In addition, high concentrations of toxic metals could be also ascribed to low microbial acitivity. But, in conditions of pH higher than 7.0 toxic metals are non-available and constitute insoluble compounds. In conclusion, microbial activity of biological soil crusts of anthropogenic substrates is mostly influenced by low availability of nutrients and the unstable condition of ash-slag deposits. High concentrations of toxic metals in the studied localities are connected with mining history in Měděnec and Radvanice or with ash-slag chemical parameters, but in current conditions their influence is not as important.

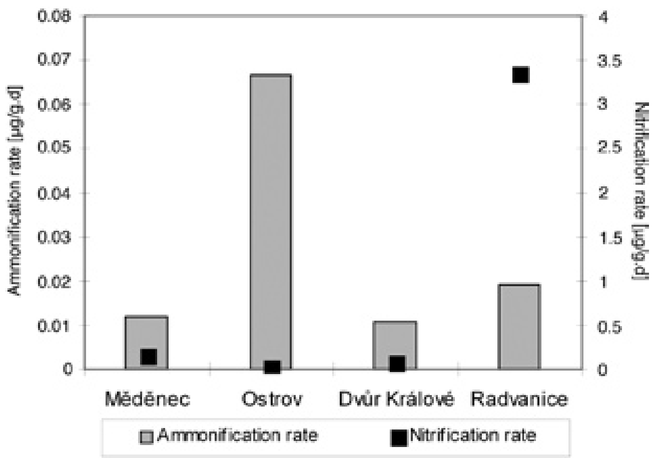



**Fig. 3.2.4.** The values of ammonification and nitrification rates at studied localities.

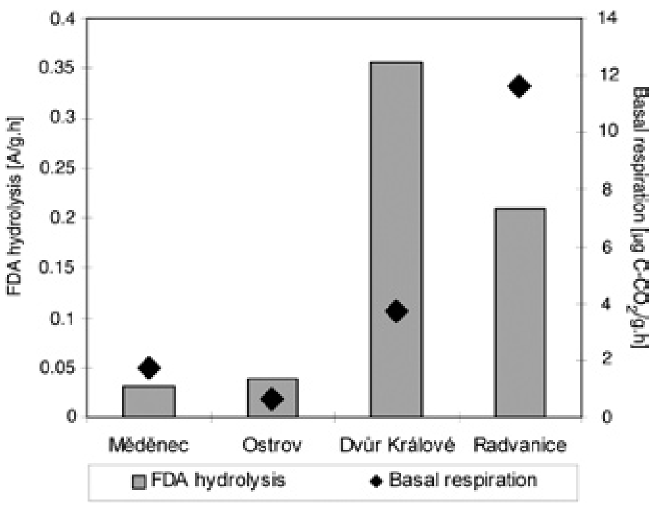



**Fig. 3.2.5.** The values of hydrolysis FDA and basal respiration at studied localities.

## CONCLUSIONS

The anthropogenic substrates of ash-slag deposits and ore-sedimentation basins are characterized by high concentrations of toxic heavy metals, mostly higher pH values (but see chapter 4.5.) and the generally low nutrient concentrations. We conclude that these characteristics lead to development of specific microbial communities that are able to sustain in these conditions and to diminution of vascular plant competition.

# 3.3. The vegetation overview of investigated sites

JAROSLAV VOJTA

Non-reclaimed sedimentation basins represent sites that are hostile for vascular plants because the harsh physical environment (Hroudová & Zákravský 2004) and the extreme chemical properties of the soil (Rauch 2004) cause germination, establishment (Jiráčková & Dostál 2004), and growth limitations (Vaňková & Kovář 2004). For example, there was no seed germination on the bare ground in an experiment in Chvaletice ore washery (Jiráčková & Dostál 2004). As a consequence, derelict sedimentation basins are dominated by stress-tolerant species that, once established, are able to survive for a long time despite the hostile environment (pioneer trees *Betula pendula*, *Populus tremula*, clonal herbs *Calamagrostis epigeios*, *Phragmites australis*, and others, Vaňková & Kovář 2004). Although the species diversity of sedimentation basins is lower than that in the surrounding landscape, the basins form a habitat of unique character (Vaňková & Kovář 2004). In general, the following characteristics of surveyed localities support this statement.

1) The *Měděnec* ore sedimentation basin

This locality is free of tree and shrub layer, only seedlings and isolated young trees (Betula pendula) occur accidentally. The following herbs are the most frequent on the locality: *Deschampsia cespitosa*, *Tussilago farfara*, *Taraxacum* sp., *Agrostis stolonifera*, *Epilobium angustifolium*, *Achillea millefolium*, *Sagina procumbens*, *Cerastium holosteoides*.

2) The *Radvanice* ore sedimentation basin

The locality is partly overgrown by *Pinus sylvestris* (planted, Vaňková 2004), *Picea abies*, *Betula pendula* and *Alnus incana* with its centre being almost free of woody vegetation. The centre of the locality is surrounded by dense growth of *Phragmites australis*, but the most central part is nearly vegetation free with some sprouts of *Phragmites* and some tussocks of halophilous species *Puccinelia distans*. Some of the rare and even endangered species occur there (*Epipactis atrorubens*, *Linum catharticum* etc.). The other frequent species follow: *Agrostis stolonifera*, *Taraxacum* sp., *Prunella vulgaris*, *Eupatorium cannabinum*.

3) The *Dvůr Králové I* ash sedimentation basin

The washery is overgrown mainly by *Phragmites australis*. The other species are for example: *Salix purpurea*, *S. cinerea*, *Tussilago farfara*, *Phalaris arundinacea*, *Tanacetum vulgare*.

4) The *Ostrov II* ash sedimentation basin

The surface of the basin is vegetation free except of patches of *Phragmites australis* and *Salix cinerea*, which are able to break through the newly deposited layers. Seedlings of *Pinus sylvestris* occur accidentally. This sharply contrasts with the situation reported by Vaňková (2004), she found there 108 species of vascular plants. Also the earlier photography (Vaňková 2004) indicates there a mosaic of relatively large vegetation patches, small pools, and vegetation-less patches. This indicates high dynamics of the surface that depends on technological processes.

# 3.4. Algae – species composition and diversity

PAVEL ŠKALOUD, JIŘÍ NEUSTUPA & MAGDA ŠKALOUDOVÁ

## INTRODUCTION

Algae and cyanobacteria form an important part of soil microbial communities. Due to their primary photosynthetic production, easy dispersion and fast growth, soil algae are very important in the colonisation of pioneer biotopes (Evans & Johansen 1999). In the following chapter, we characterize the algal communities of four ore-washery basins, differing by their soil chemical characteristics and industrial activity. In addition to detailed description of selected prominent species, we discuss differences in the algal composition of biological soil crust communities among the localities.

## MATERIALS AND METHODS

In each site, samples from the 0–3cm layer were taken randomly from physiognomically uniform areas of the size 5–15 m$^2$. The samples were placed into sterile bags and transported to the laboratory for analysis. The composite samples were crushed and mixed to produce a homogenous sample. A 1-g aliquot was removed and added to 50 ml of distilled water. The soil suspension was mixed by a magnetic mixer for 15 minutes. Aliquots of 0.5 or 1 ml were spread in duplicate on agar solidified BBM medium (Bischoff & Bold 1963; Ettl & Gärtner 1995). Cultures were sealed with parafilm and incubated at 20–25 °C under daylight conditions (the plates were placed beside a north facing window) until good growth had been obtained (3–6 weeks). Algal microcolonies were examined directly from agarized plates using an Olympus BX 51 microscope with Nomarski DIC optics and photographed using Olympus Camedia digital camera C-5050 Zoom. Standard cytological stains (Lugol's solution, methylene blue, acetocarmine, chloraliode solution) were used for visualisation of pyrenoid, cell wall structures or mucilage. For detailed investigation of some strains, the algal colonies were transferred to agarized BBM culture tubes and then cultivated at 18 °C, under an illumination of 20–30 μmol $m^{-2} \cdot s^{-1}$ and 16:8 h light-dark cycle. Identification was made on the basis of life history and morphological criteria using standard authoritative references (Printz 1964; Fott & Nováková 1969; Ettl 1978; Punčochářová & Kalina 1981; Komárek & Fott 1983; Krammer & Lange-Bertalot 1986; Ettl & Gärtner 1995; Hindák 1996; Lokhorst 1996; Andreeva 1998; Komárek & Anagnostidis 1998, 2005). The quantities of algae on Petri dishes were evaluated as belonging to one of three classes: 1 – single algal colony found, 2 – rare species with several colonies on the dishes, 3 – dominant species in the sample. Following statistical methods were used to detect patterns in the data. The localities were clustered, based on Sorensen floristic similarity (Sorensen 1948) utilizing the single linkage in statistical program PAST 1.74 (Hammer et al. 2001). Principal component analysis (PCA) was performed using Canoco 4.5 (Ter Braak & Šmilauer 1998) to ordinate localities based on their algal composition.

## RESULTS AND DISCUSSION

### *General conclusions*

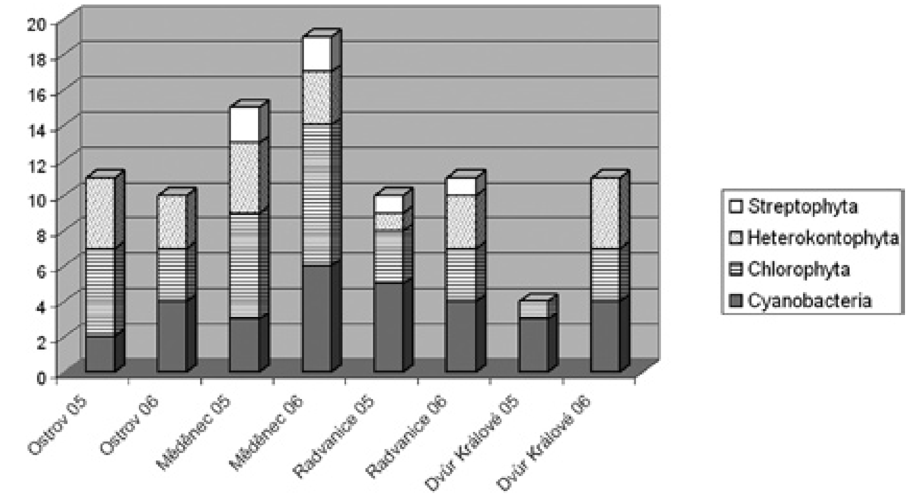
A total of 49 algal species representing 33 genera were recovered from four studied ore-washery basins (Table 3.4.1). Two widespread taxa (cyanophyte *Leptolyngbya* sp. 2 and the diatom *Nitzschia* sp.) were found in at least three localities. All but one of the localities were characterized by a few (up to three) species, forming a dominant component of total algal flora (Ostrov locality was typical by dominance of *Leptolyngbya* spp., *Bumilleriopsis filiformis* and *Chlorella lobophora*; the soil sample from Radvanice was dominated by *Nostoc* cf. *edaphicum* and *Eustigmatos polyphem*; and among the most abundant algae in Dvůr Králové were *Nostoc* sp. 2 and *Scenedesmus* sp.). Algal population in Měděnec differed in balanced presence of many algal species, without any predominant taxa. Moreover, the locality Měděnec was characterized by the highest number of determined taxa (22 taxa, compared to 14, and 11 taxa found in Ostrov and Radvanice, and Dvůr Králové, respectively). Most taxa were rare, with 27 of the 49 species identified appearing in a single locality in rare to low abundances (1 or 2 in semi-quantitative scale).

Generally, cyanobacteria and green algae were the most dominant groups of autotrophic organisms in all investigated localities (Figs 3.4.1, 3.4.2). From a total of 49 species found, they comprise the 70% majority. Cluster analysis, based on the species similarity among the samples, apparently associates the samples originating from the same locality (Fig. 3.4.3). Moreover, the active ore-washery basins

**Table 3.4.1.** Algal distribution in 8 investigated samples (**O** – Ostrov, **M** – Měděnec, **R** – Radvanice, **D** – Dvůr Králové).

| | | Sampling site, year of sampling | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Fig.** | **O 2005** | **O 2006** | **M 2005** | **M 2006** | **R 2005** | **R 2006** | **D 2005** | **D 2006** |
| ***Cyanobacteria*** | | | | | | | | | |
| *Anabaena* cf. *cylindrica* Lemmerman | 3.4.5 a,b | | 2 | | | | | | |
| *Aphanothece* sp. | | | | | | 1 | 2 | | |
| *Chroococcidiopsis* sp. | | | | | | | 2 | | |
| *Chroococcus* cf. *helveticus* Nägeli | | | | 2 | 1.5 | | | | |
| *Gloeothece* cf. *tepidariorum* (A. Braun) Lagerheim | 3.4.5 c | | | | | 2 | | | |
| *Leptolyngbya* sp. 1 | 3.4.5 d | 3 | 3 | | 2 | | | | 2.5 |
| *Leptolyngbya* sp. 2 | 3.4.5 e | | | 3 | 3 | | | | |
| *Leptolyngbya* sp. 3 | 3.4.5 f | 3 | 2 | | | | | | |
| *Leptolyngbya* sp. 4 | 3.4.5 g | | | | | | | 1 | 1 |
| *Leptolyngbya* sp. 5 | 3.4.5 h | | | | | 2 | 2 | | |
| *Nostoc* cf. *calcicola* | 3.4.5 i | | | | | | | 2 | 2 |
| *Nostoc* cf. *edaphicum* | 3.4.5 j | | | | 1 | 3 | 3 | | |
| *Nostoc* sp. 1 | 3.4.5 k | | | 2 | 2.5 | | | | |
| *Nostoc* sp. 2 | | | | | | | | 3 | 2 |
| *Phormidium* cf. *autumnale* | 3.4.5 l | | 2 | | | | | | |
| *Phormidium* sp. 2 | | | | | 1 | | | | |
| *Synechocystis* sp. | | | | | | 2 | | | |
| ***Bacillariophyceae*** | | | | | | | | | |
| *Achnanthidium* cf. *minutissimum* (Kützing) Czarnecki | | | | | | | 1 | | |
| *Nitzschia* sp. | 3.4.6 a,b | 1 | 3 | 3 | 3 | | 1 | | 3 |
| *Mayamaea atomus* (Kützing) H. Lange-Bertalot | | 2 | 1 | 2 | | | | | 1 |
| ***Xanthophyceae*** | | | | | | | | | |
| *Botrydiopsis arhiza* Borzi | | 1 | | | | | | | |
| *Bumilleriopsis filiformis* Vischer | 3.4.6 c,d | 3 | 2.5 | | | | | | 2 |
| *Pleurochloris polychloris* Pascher | 3.4.6 e,f | | | | | | | | 2 |
| *Xanthonema* cf. *montanum* (Vischer) Silva | 3.4.6 g | | | 1 | 1 | | | | |
| ***Eustigmatophyceae*** | | | | | | | | | |
| *Eustigmatos polyphem* (Pitschmann) Hibberd | 3.4.6 h | | | | | 3 | 3 | | |
| *Eustigmatos vischerii* Hibberd | 3.4.6 i,j | | | 2 | 2.5 | | | | |
| ***Chlorophyceae*** | | | | | | | | | |
| *Bracteacoccus* cf. *aggregatus* Tereg | 3.4.6 k,l | 1 | | 2 | 2 | | | | |
| *Chlamydomonas* sp. 1 | 3.4.7 a | | | | 1.5 | | | | |
| *Chlamydomonas* sp. 2 | | | | | | | | | 2 |
| *Chlorococcum* cf. *minutum* Starr | | | | 1 | | | | | |
| *Chlorococcum* sp. | | 2 | 1 | | | | | | |
| *Deasonia multinucleata* | 3.4.7 b | | | | 1 | | | | |
| *Diplosphaera chodatii* Bialosuknia em. Vischer | | | | | | 1 | | | |
| *Scenedesmus* cf. *obtusiusculus* Chodat | 3.4.7 c-e | | | | | | | 2 | 3 |
| *Scotiellopsis reticulata* Puncocharova et Kalina | | | | 3 | 2.5 | | | | |
| *Scotiellopsis* sp. | | | 1.5 | | | | | | |
| ***Trebouxiophyceae*** | | | | | | | | | |
| *Auxenochlorella protothecoides* (Krüger) Kalina et Puncocharova | | 2 | | | | | | | |
| *Chlorella ellipsoidea* Gerneck | | | | | 1.5 | | | | |
| *Chlorella lobophora* Andreeva | 3.4.7 f | 2.5 | 3 | | | | | | |
| *Chlorella saccharophila* (Krüger) Migula | | | | | | | 1 | | |
| *Chlorella vulgaris* Beijerinck | | | | | | | | | 1 |
| *Choricystis chodatii* (Jaag) Fott | | | | | 1 | | | | |
| *Dictyochloropsis* sp. | 3.4.7 g,h | | | | | 1 | 2 | | |
| *Jaagiella* sp. | 3.4.7 i | | | 2 | 1 | | | | |
| *Muriella terrestris* J. B. Petersen | | | | 2 | | | | | |
| *Mychonastes zofingiensis* (Dönz) Kalina et Puncocharova | | 1 | | | | | | | |
| *Pseudococcomyxa simplex* (Mainx) Fott | | | | 3 | 1 | 3 | 1 | | |
| ***Klebsormidiophyceae*** | | | | | | | | | |
| *Klebsormidium flaccidum* (Kützing) Silva, Mattox et Blackwell | 3.4.7 j | | | 2 | 1 | | | | |
| ***Zygnematophyceae*** | | | | | | | | | |
| *Cylindrocystis brebissonii* Meneghini var. *desertii* Flechtner et al. | 3.4.7 k,l | | | 2.5 | 2 | 1 | 1 | | |

**Fig. 3.4.1.** Species richness expressed as the number of taxa found in each locality. Assignment of taxa to the four algal groups is displayed.



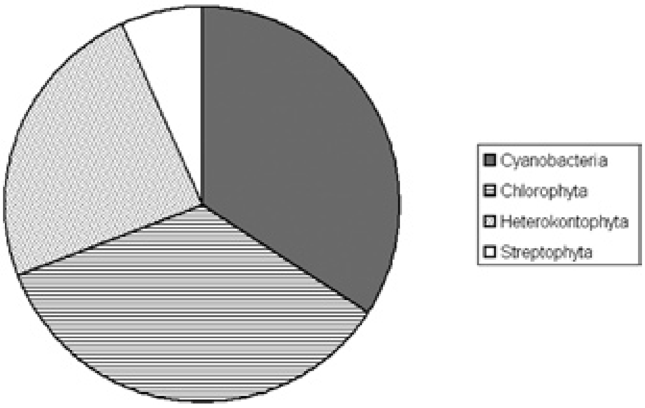




**Fig. 3.4.2.** Proportional occurrence of four algal groups, determined in all investigated localities.

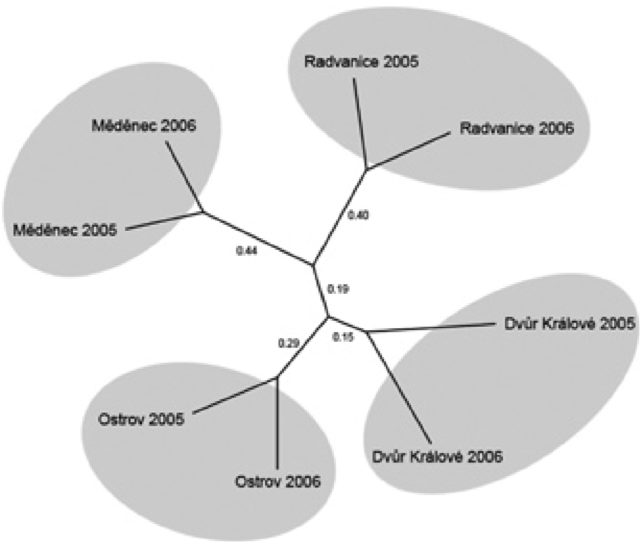



**Fig. 3.4.3.** Unrooted single linkage dendrogram of investigated samples, generated on the basis of Sorensen floristic similarities. Branch lengths are displayed near the internal branches.

(Dvůr Králové and Ostrov) and the abandoned industrial sedimentation basins (Měděnec and Radvanice) cluster together, showing some similarities of the algal composition in relation to the industrial activity. The PCA ordination plot reflects other interesting patterns in data investigated (Fig. 3.4.4). First, it clearly demonstrates that algal composition of the active ore-washery basins is much more similar than of the abandoned industrial sedimentation basins. Similarities in algal flora of active basins are probably caused by extreme conditions associated with the industrial activity. By contrast, the abandoned industrial sedimentation basins Měděnec and Radvanice forms separate clusters, in the PCA ordination plot. Those distinct differences in algal composition could be explained by locality-specific soil chemical parameters (e.g. very high manganese concentration in Radvanice, see chapter 3). Finally, the PCA ordination plot shows differences in population stability of the active ore-washery basins. While Ostrov exhibits high floristic similarity within two years (Sorensen index 0.67), the algal composition in Dvůr Králové significantly changed after a year (Sorensen index 0.53). This difference was caused by quite high number of algal species, observed only in 2006 (e.g. *Leptolyngbya* sp. 2, *Nitzschia* sp. or *Bumilleriopsis filiformis*). We attribute it to distinctive changes of soil water regime, caused by the periodical flushing of the locality by the ash followed by the relatively long period of increased soil humidity.

### *Floristics*

Following pages provide detailed descriptions of several taxa, found in the investigated localities. The taxa were selected due to their high abundance in the samples or by remarkable occurrence in such type of biotope as ore-washery basins are.

***Leptolyngbya*** Anagnostidis & Komárek (Figs 3.4.5 d–h)

Filamentous cyanobacterial genus with fine, 0.5–3.2 μm wide trichomes, imbedded into thin usually colourless facultative sheaths opened at the apical end. Rarely, false branching can occur, usually with only one lateral branch. Trichomes are cylindrical, usually with rounded or conical apical cells, not constricted or constricted at the crosswalls, nonmotile. Cells are cylindrical, isodiametrical or longer than wide, with a homogeneous content, without aerotopes. Heterocytes and akinetes are absent. *Leptolyngbya* species are very common in soils and in periphyton and metaphyton

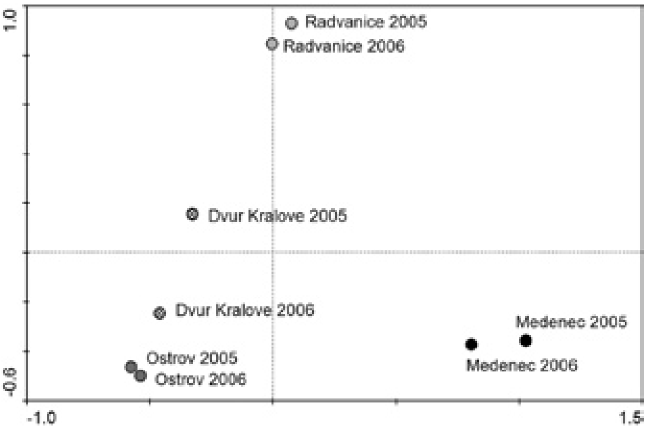



**Fig. 3.4.4.** PCA ordination diagram showing the position of samples in the range of the first two ordination axes.

of freshwater and halophilous (marine) biotopes. However, taxonomy is not well known in respect of their morphological simplicity.

We determined five *Leptolyngbya* morphospecies growing in the studied localities. They differ in cell dimensions, trichome width variability, colour and disintegration rate. Due to the scarce morphological features and high morphological variability, it is very difficult to judge if morphologically similar *Leptolyngbya* species isolated from several samples represent a single species or not. Therefore, in this study we operate at the level of morphospecies.

The most common morphospecies, determined in localities Ostrov, Měděnec and Dvůr Králové (*Leptolyngbya* sp.1) is characterized by nearly straight trichomes, up to 1 µm wide, brown-green, pale green, brown or brown-red, obviously constricted at the cross-walls. Colonies are brown, consisted by mainly parallelly-arranged filaments. *Leptolyngbya* sp. 2, found in high abundances in Měděnec, is characterized by very variable width of filaments, varying between 0.8–3 µm. Trichomes are green or pale-green, slightly constricted at the cross-walls. The third most abundant species, *Leptolyngbya* sp. 3, was determined in the locality Ostrov. It is characterized by short, easily disintegrated trichomes of blue-green colour. Width of cylindrical cells varies between 1.5–2 µm.

***Nitzschia Hassall*** (Figs 3.4.6 a, b)

A diatom genus with structurally asymmetrical valves, with off-centre placed raphe system. The valves are symmetrical or asymmetrical about the longitudinal axis. They are usually highly elongate, and have rounded, rostrate or capitate poles. Transverse striae are sometimes visible but often delicate, very fine or unresolvable in light microscope. Raphe system is fibulate, usually appearing to run along one edge of the valve but subcentral in a few species. *Nitzschia* is relatively large genus with hundreds of freshwater and marine species. Most species are epipelic in microhabitat but *Nitzschia* also contains planktonic, epilithic, and epiphytic species. A small proportion of species (up to 30) is also mentioned from aerophytic or terrestrial biotopes.

Species of Nitzschia were found in all studied localities. Cells were 15–23 µm long x 3–4 µm wide. Morphology and dimensions of the valves were very similar among the localities. However, we were unable to determine the species name only by means of light microscope. The determination of *Nitzschia* species in all localities correspond with a broad range of genus occurrence and high adaptation to metal rich soils (Starks & Shubert 1982; Lukešová & Komárek 1987; Lukešová 2001; Neustupa & Škaloud 2004).

***Eustigmatos polyphem*** (Pitschmann) Hibberd,
***Eustigmatos vischerii*** Hibberd (Figs 3.4.6 h–j)

Two *Eustigmatos* species were found in the localities Měděnec and Radvanice. The cells are spherical, uninucleate, up to 11–14 µm (*E. vischerii*) or 22 µm (*E. polyphem*) in diameter. Cell wall is smooth and unornamented, in one piece. The cells contain single lobed parietal yellow-green chloroplast with stalked polyhedral pyrenoid and large central vesicle with red contents.

The genus *Eustigmatos* represents a common component of soil floras; isolated from Europe, Africa, New Zealand, USA and Japan (Ettl & Gärtner 1995). *Eustigmatos* species also occur in the swimming pools, where called „mustard algae“ (Adamson and Sommerfeld 1978). Various eustigmatophycean species were recorded from metal-rich soils in Central Europe (Lukešová & Komárek 1987; Lukešová 2001).

***Bumilleriopsis filiformis*** Vischer (Figs 3.4.6 c, d)

A large population of xanthophycean species *Bumilleriopsis filiformis* was recorded from the locality Ostrov. Especially in 2005, this species constitute the dominant component of the algal flora. Cells are solitary or incidentally clustered, of elongate, cylindrical shape, straight or curved. Dimensions of cells vary between 9–13 µm in width and 13–54(80) µm in length. Cells are uninucleate, with several to many parietal plastids.

The species was described by Vischer (1945) from a sample of meadow soil in Switzerland. Since then, *B. filiformis* was recorded very rarely from various floristic studies (Neustupa & Škaloud 2004). Since no abundant population of *B. filiformis* was recorded till this time, we can suppose that the physico-chemical soil properties give it an advantage over all other algal species living in the locality. This advantage caused a remarkable development of the alga, impossible in natural terrestrial biotopes.

***Scotiellopsis reticulata*** Punčochářová et Kalina

This species was observed as highly abundant in both samples from the locality Měděnec. The cells are single, up to 16(–19) µm long x 12(–13) µm wide. Autospores and young cells are fusiform, citriform, adult cells often oval with distinct apical thickenings; old cells globose. Cell wall with meridional ribs converging at the poles; ribs straight, sometimes anastomosing to form a network. Chloroplast is parietal, consisting of polygonal plaques or stripes; in one part of the chloroplast with the pyrenoid having homogeneous stroma surrounded with starch envelope. Asexual reproduction take place by autospores, 2 (–16) per cell; released by rupture of parental cell wall.

All species of *Scotiellopsis* are reported from soils and wet ground, from Europe and China. However, the genus is very probably cosmopolitan. However, ecological preferences as well as biogeography of *S. reticulata* are still unclear due to insufficient data about its distribution (Ettl & Gärtner 1995). This study brings the first report of its occurrence in the microbial communities of biological soil crusts.

***Scenedesmus* cf. *obtusiusculus*** Chodat (Figs 3.4.7 c–e)

A well-known, broadly distributed genus *Scenedesmus* is characterized by single celled or colonial thalli, forming 2- to 32-celled, usually 4- or 8-celled coenobia. Cells can be arranged linearly, alternating or in 2–3 rows, touching with the lateral walls or in subpolar region only. Cell wall is usually smooth, chloroplast single and parietal with single pyrenoid. *Scenedesmus* represents typical planktonic genus, occurring mainly in eutrophic freshwater ponds and lakes, rarely in brackish water. However, *Scenedesmus* also encompass a few frequently distributed aero-terrestrial species (e.g. *S. rubescens* or *S. vacuolatus*). It is necessary to note, that these are morphologically well-defined, characterized by absent or very rare formation of coenobia and "Chlorella"-like morphology.

We found very abundant *Scenedesmus* species in both samples carried out in the locality Dvůr Králové. Interestingly, morphologically it corresponds to some freshwater species, occurred very rarely in the terrestrial biotopes. Determined taxon is characterized by a large degree of morphological variability. Most commonly, it forms 4- to 8-celled coenobia composed by fusiform cells, without any cell wall ornamentation and very short polar spines. Sometimes however, the coenobia disintegrate into single cells of oval, ovoid or nearly spherical shape, without spines. Chloroplast of disintegrated cells occasionally contains two pyrenoids. Dimensions of coenobial cells varies between 8–14 μm in length, 4–5 μm in width, single cells up to 11 μm in diameter.

All the above-mentioned morphological characteristics correspond well to *S. obtusiusculus*, rare species occurring in small or large pools and clear lakes. Once, the species was even isolated from the soil (Komárek & Fott 1983). The determination of this preferably freshwater species in the microbial community of biological soil crusts can be explained by the water regime of the locality. Dvůr Králové is characterized by periodical flushing of the substrate by the ash followed by the formation of environmental conditions acceptable for some freshwater algal species.

***Cylindrocystis brebissonii*** Meneghini **var. *desertii*** Flechtner, Johansen et Clark (Figs 3.4.7 k, l)

The desmid *Cylindrocystis brebissonii* was found in the soils from the localities Měděnec and Radvanice. The cells are solitary, but sometimes can form short filaments or aggregations of cells in a common gelatinous matrix. Cell dimensions vary in the range of 17–68 μm x 9–14 μm. Cells are elliptic to elongate-cylindrical, straight or slightly curved, with broadly rounded ends. Chloroplasts are two per cell, axial, stellate in end view, each with large, often elongate pyrenoid. Cell wall is continuous around protoplast, ultrastructurally two-layered.

*Cylindrocystis brebissonii* is a cosmopolitan, widely distributed species, occurring in subaerial, acidic aquatic or bog habitats. Several varieties of this species were described. Interestingly, investigated alga correspond very well to *C. brebissonii* var. *desertii* Flechtner, Johansen et Clark, described from the biological soil crusts of the Central Desert of Baja California in Mexico (Flechtner et al. 1998). We observed smaller cell dimensions as well as clearly elongated, lobed chloroplast ridges that characterize this variety. Discovery of this morphological variety in the algal community of studied biological soil crusts may point to the existence of undescribed species of *Cylindrocystis*, distinguished from a widely distributed *C. brebissonii* by its distinctive ecological delimitation.

## CONCLUSIONS

From phycological point of view, the abandoned ore-washery sedimentation basin Měděnec represents the locality most resembling the naturally-formed biological soil crusts. From all other investigated localities, Měděnec differentiates in the relatively high number of species found and by the absence of distinctively predominant taxa. Conversely, the algal population of Měděnec is characterized by balanced occurrence of present algal species. This natural character we interpret by long-term industrial inactivity, enabling the succession of the algal community to the more natural stages. However, this succession was not found in Radvanice, another abandoned ore-washery sedimentation basin. There, the soil chemical parameters still inhibit the development of species rich community, even if the industrial activity terminated many decades before.

# 3.5. Lichens – species composition and diversity

ONDŘEJ PEKSA

## INTRODUCTION

In the European temperate region, biological soil crusts with participation of lichens occur besides natural habitats, very often in various anthropogenic areas. Roadsites, quarries, sand-pits, mine waste dumps, sedimentation basins, etc. provide suitable conditions for soil lichens, especially microlichens and pioneer species from the genera *Cladonia*, *Peltigera*, etc.

A number of records of terricolous lichens occuring in man-made habitats are included in various floristic, taxono-mic or ecological studies. Only several studies (from British Isles and Scandinavia) describing terricolous lichen communities are oriented directly to human-influenced substrates (Gilbert, 1980, 1990; Purvis & Halls, 1996; Thor, 1993).

There exist also a few works on lichens growing on industrial substrates from Central Europe. Palice & Soldán (2004) published the results of an extensive study of lichens and bryophytes in sedimentation basins Chvaletice and Bukovina. Banásová (2006), Banásová et al. (2003, 2006), Lackovičová et al. (1977) and Lackovičová (1984) investigated vegetation including lichens of mine waste from the extraction of metals and the waste from ore smelters in Slovakia, which are substantially enriched in heavy metals compared to natural soils. Banásová & Lackovičová (2004) observed the degradation of grasslands in the vicinity of copper plant in the town of Krompachy (Slovakia). They mentioned the occurrence of a crust from tolerant lichens *Cladonia rei*, *C. fimbriata*, *Diploschistes muscorum*, *Placynthiella icmalea* and moss *Ceratodon purpureus* on naked soil and the rest of plants in bare immission areas.

This chapter describes lichens associated with biological soil crusts in three sedimentation basins in the Czech Republic.

## MATERIAL AND METHODS

This chapter contains the results of a floristic study performed in the period 2005–2007 in ash-slag sedimentation basin near Chvaletice and ore-washery basins near Měděnec and Radvanice (localities are characterized in chapter 3.1). Two active cinders-washery basins in Ostrov a Dvůr Králové were excluded from the approach due to absence of soil lichens caused by periodical overflowing. Only top-plateaus (slag) and the nearest surroundings (dams of the sedimentation ponds, a part of access road to Chvaletice sed. basin) of the sedimentation basins were explored. Only lichens associated with biological soil crusts (growing on soil and plant debris) are included in this study.

The specimens of lichenized fungi have been studied using routine lichenological methods. For determination of collected specimens the works of Breuss (1996), Coppins (1983, 1987), Giralt et al. (1993), Orange (1991), Purvis et al. (1992), Wirth (1995) and other taxonomic publications have been used. The nomenclature of lichens follows Santesson et al. (2004) or respective works included in references. All investigated specimens have been deposited in the PL.

## RESULTS AND DISCUSSION

During the recent floristic approach, 33 lichen taxa associated with biological soil crusts were found. A total of 44 terricolous lichens were noted in four sedimention basins in the Czech Republic, 35 of them were already recorded by Z. Palice in the period 1994–2002 in sedimentation basins Chvaletice and Bukovina (Palice & Soldán, 2004 and several previous works cited in their study). The results are summarized in Table 3.5.1.

Three lichen taxa – *Atla wheldonii*, *Placidiopsis oreades* and *Staurothele geoica* represent new records to the Czech Republic.

The major part of lichen species growing in sedimentation basins belong to pioneer lichens characteristic for antropogenic habitats including specialists for man-made or man-affected substrates like *Psorotichia lutophila* (Palice & Soldán, 2004), *Verrucaria bryoctona* (Orange, 1991) or *Vezdaea leprosa* (Ernst, 1995). Poelt & Vězda (1990) classify a number of founded taxa among short-living (ephemeral) microscopic lichens (e.g. species of the genera *Absconditella*, *Thelocarpon* and *Vezdaea*). A number of these incospicuous species were often collected from heavy-metal-rich substrates (e.g. *Sarcosagium campestre*, *Steinia geophana* and *Vezdaea* spp. together with some *Cladonia* and *Peltigera* species – Purvis & Halls, 1996).

11 species can be considered to be typical for sedimentation basins (they were recorded in two or three localities): *Cladonia coniocraea*, *C. fimbriata*, *C. chlorophaea*, *C. pyxi-*

**Table 3.5.1.** The list of recorded lichen species. **1** – Chvaletice and Bukovina sedimentation basins (* Palice & Soldán, 2004, species founded only in Bukovina basin are marked *B), **2** – Měděnec ore-washery basin, 3 – Radvanice ore-washery basin.

| | 1 | 2 | 3 |
|---|---|---|---|
| *Absconditella celata* | *+ | | |
| *Absconditella delutula* | *B | | |
| *Atla wheldonii* | | | + |
| *Bacidina sp.* | * | | |
| *Baeomyces rufus* | | + | |
| *Cladonia carneola* | * | | |
| *Cladonia coccifera* | *+ | | |
| *Cladonia coniocraea* | *+ | + | |
| *Cladonia fimbriata* | *+ | + | |
| *Cladonia humilis* | * | | |
| *Cladonia chlorophaea* | *+ | + | |
| *Cladonia macilenta* | *+ | | |
| *Cladonia pyxidata* | + | + | |
| *Cladonia ramulosa* | + | | |
| *Cladonia rei* | *+ | + | + |
| *Cladonia subulata* | *+ | | |
| *Collema limosum* | * | | |
| *Collema tenax* | * | | + |
| *Diploschistes muscorum* | *+ | | |
| *Everni prunastri* | + | | |
| *Lecanora saligna* | *B | | |
| *Leptogium byssinum* | * | | |
| *Micarea denigrata* | + | | |
| *Micarea sp.* | *+ | | |
| *Peltigera didactyla* | *+ | + | |
| *Peltigera rufescens* | | + | |
| *Placidiopsis oreades* | | | + |
| *Placynthiella icmalea* | *+ | + | |
| *Placynthiella oligotropha* | *+ | | |
| *Placynthiella uliginosa* | *+ | | |
| *Psorotichia lutophila* | * | | |
| *Sarcosagium campestre* | *+ | + | |
| *Staurothele geoica* | | | + |
| *Steinia geophana* | *+ | + | |
| *Thelidium zwackhii* | *+ | | |
| *Thelocarpon epibolum* | * | | |
| *Thelocarpon intermediellum* | * | | |
| *Thelocarpon sp.* | *+ | | |
| *Thrombium epigeaum* | *+ | | |
| *Trapeliopsis granulosa* | *+ | | |
| *Verrucaria bryoctona* | * | + | + |
| *Vezdaea acicularis* | *+ | | |
| *Vezdaea leprosa* | *+ | | |
| *Vezdaea retigera* | * | | |

*data*, *C. rei*, *Peltigera didactyla* (Fig. 3.5.3.), *Placynthiella icmalea*, *Sarcosagium campestre*, *Steinia geophana* and *Verrucaria bryoctona*.

The diversity of lichens is influenced except the light and moisture mainly with stability and pH of a substrate. From five studied localities, lichens growing directly on the slag in sedimentation basin were found only in Chvaletice and Radvanice basins. The sediment of ore-washery basin in Měděnec is formed by extremely unstable and dusty material not suitable for growth of lichens. Similar effect was described by Palice & Soldán (2004) from the Bukovina sedimentation basin. The basins in Ostrov and Dvůr Králové are still active – periodical overflowing of the basins unfortunately precludes development of soil associated lichen flora.

The highest number of lichens (38) was detected in the locality of Chvaletice probably due to occurrence of both acidic and basic substrates. The major part of sedimentation basin (ash-slag) as well as the margin of the basin and access road is acidic. This area is occupied mainly by *Cladonia* spp. (*C. coniocraea*, *C. rei*, *C. chlorophaea*, *C. macilenta* and *C. coccifera* predominate; the first three species are often invaded by *Diploschistes muscorum*, Fig. 3.5.1., 3.5.2.), *Micarea* sp., *Placynthiella icmalea* and *Vezdaea acicularis*. On the lime-enriched soils, cyanolichens and pyrenocarpous species were collected, e.g. *Collema* spp., *Leptogium byssinum*, *Psorotichia lutophila*, *Thelidium zwackhii* and *Verrucaria bryoctona* (Palice & Soldán, 2004; unfortunately I did not find the patches of basic soils during the study of biological soil crusts).

Apart from naked soil, small debris of herbs and wood can be also overgrown by biological crusts. Especially microlichens like *Micarea denigrata*, *Steinia geophana* and *Vezdaea* spp. grow on rotting leaves, together with some *Cladonia* species.

The border area (dam) of the ore-washery basin in Měděnec is formed by mixture of acidic soil and waste material as bricks, concrete, etc. Twelve terricolous lichens including acidophilic (*Baeomyces rufus*, *C. coniocraea*, *C. fimbriata*) as well as basiphilic species (*P. rufescens*, *Verrucaria bryoctona*) were recorded on these substrates. The deposition of a dust from toxic sediment on the dam implicates the occurence of heavy-metal-tolerant species like *Sarcosagium campestre* and *Vezdaea leprosa*.

The ore-washery basin in Radvanice has a very specific lichen flora due to universally high pH of the sediment and also specific microclimatic conditions. The basin is located in a deep valley of the Jívka brook with cold inversion clima. The major part of the basin is covered by birch-alder and Scots pine wood. Basiphilic pyrenocarpous microlichens *Atla wheldonii*, *Placidiopsis oreades*, *Staurothele geioca*, *Verrucaria bryoctona* and cyanolichen *Collema tenax* grow on naked toxic soil in the rests of opened sites. Only one representative of the genera *Cladonia* – *C. rei* grows directly on the sediment in this locality.

As well as the terricolous species, some primary epiphytic lichens can sometimes grow on soil within the biological soil crust. In well-developed moss-lichen crust near the access road to the Chvaletice sedimentation basin, a prosperous thallus of *Evernia prunastri* was observed.

### *Noteworthy lichen species*

***Atla wheldonii*** (Travis) Savić & Tibell
(syn. ***Polyblastia wheldonii***)

Poorly known and probably overlooked inconspicuous pyrenocarpous species collected only in several localities in Europe. Based on molecular phylogeny it was recently transfered to genus *Atla* (Savić & Tibell, 2007). The authors described it as typical for damp, basic and unstable soils colonized by cyanobacteria and mosses in anthropogenic habitats as ditches along the roads, etc. The character of the Radvanice ore-washery basin agrees with this description very well.

***Placidiopsis oreades*** Breuss

The majority of representatives of pyrenocarpous genera *Placidiopsis* are known as terricolous or muscicolous species. *P. oreades* distinguished from other related species by squamules with distinct brown paraplectenchymatous lower cortex, closely adjacent to the substrate. This species has been collected only in high mountains (Alps, Carpathian Mountains and Central Tjan Shan) often on marly substrates (Breuss, 1996). Radvanice ore-washery basin with an altitude of 500 m represents the lowest locality of the species (the second is from Belianske Tatry Mts, 1620 m). Its appearence is probably caused by cold inversion clima together with very specific substrate.

*P. oreades* is new to the Czech Republic (concurrently a first record of the genera *Placidiopsis* to the CR).

***Staurothele geoica*** Zschacke

Sparsely collected pyrenocarpous species known only from Europe (Anonymus, 1991; Tretiach & Castello, 1992; Zschacke, 1918) is very exceptional within the genus *Staurothele* due to its terricolous growth (majority of species are saxicolous). Its blackish thallus with black perithecia forms a quiet extensive crust on the slag soil in opened parts of Radvanice ore-washery basin together with *Placidiopsis oreades*. Unfortunately, the relative fast invasion of the forest can danger the occurrence of the species in this unique locality.

First record to the Czech Republic.

## CONCLUSIONS

Terricolous lichens of biological soil crusts were studied in specific antropogenous habitats – the sedimentation basins near Chvaletice, Měděnec and Radvanice. A total of 33 taxa of terricolous lichens were recorded during the investigation of biological soil crusts. The highest diversity of lichens (26 taxa recently; 37 including records of Z. Palice in Palice & Soldán, 2004) was detected in the Chvaletice sedimentation basin, probably due to broad range of pH of local soils and diversity of habitats. The ore-washery basin in Radvanice is specific by universally high pH of the slag and cold microclima, which provide suitable conditions for occurrence of rare species – *Atla wheldonii*, *Placidiopsis oreades* and *Staurothele geoica*, which are new to the Czech Republic.

The major part of the records belongs to the pioneer lichens characteristic for antropogenic habitats and man-made substrates including toxitolerant species characteristic for heavy-metal-rich substrates, e.g. short-living lichen species of the genera *Sarcosagium*, *Steinia* and *Vezdaea*.

## ACKNOWLEDGMENT

My sincere thanks are due to prof. Othmar Breuss especially for determination of specimens *Atla wheldonii*, *Placidiopsis oreades*, *Staurothele geoica* and to Zdeněk Palice for valuable comments and kind providing of literature sources.

# 3.6. Fungi – species composition and diversity

ALENA KUBÁTOVÁ & KAREL PRÁŠIL

## INTRODUCTION

Fungi are dominating organisms of soil ecosystems and it is known for a long time, that they form also an integral part of biological soil crusts (Fletcher & Martin 1948). Unfortunately, the fungi in crusts were, as yet, studied only marginally. The most substantial is the survey of fungi associated with biological soil crusts in desert grasslands by States & Christensen (2001) and Grishkan et al. (2006). In semiarid or even arid regions, the biological soil crusts are known for a long time. In some respects, abandoned ore sedimentation basins in our country represent somewhat similar habitats. However, the limiting factor for growth of plants and other organisms on these anthropogenic habitats is not precipitation but the high amount of metal compounds and other associated factors (e.g. low pH and high salinity).

In this chapter, results of two-year study of microfungal communities in surface biological soil crusts or surface layer on four sedimentation basins (Měděnec, Radvanice, Ostrov, Dvůr Králové) compared with an agricultural locality (all in the Czech Republic) are given.

## MATERIALS AND METHODS

Localities (see Figs 3.1.1, 3.1.2) and sampling of surface biological soil crusts or surface layer: Měděnec, abandoned ore sedimentation area (sampling in May 2005 and May 2006), Radvanice, abondoned ore sedimentation basin (July 2005 and June 2006), Ostrov II, active ash-sedimentation basin (June 2005 and June 2006), Dvůr Králové I, active ash-sedimentation basin (July 2005 and June 2006) and pasture near Netluky (November 2005 and August 2006). Characteristics of the studied localities are given in the Chapter 2.1. and 3.1. On the two mentioned abandoned ore sedimentation basins (Měděnec and Radvanice), biological soil crusts were well developed in contrast to active ash-sedimentation basins (Ostrov II and Dvůr Králové I). From each locality, two composed samples of biological soil crust or surface layer (of ca 0.5 cm thickness) were taken into sterile plastic bags. For the mycological analysis the same material of biological soil crusts was used as for study of algae and cyanobacteria. Altogether, 10 samples of biological soil crusts were processed during this study.

Cultivation and identification: Microscopic fungi on biological soil crusts were studied by the same cultivation methods as described in the Chapter 2.4.

Identification of soil micromycetes was made according to the literature cited in Chapter 2.4. and according to Samson & Frisvad (2004). Several fungal strains were deposited at Culture Collection of Fungi (CCF), Department of Botany, Charles University, Prague, Czech Republic (see in Table 3.6.1).

Statistical methods: Detrended Correspondence Analysis (DCA) was performed using Canoco 4.5 (Ter Braak & Šmilauer 1998) to ordinate localities based on their microfungal composition.

## RESULTS AND DISCUSSION

In Table 3.6.1, a list of fungi isolated from biological soil crusts or surface layer during 2005–06 on four sedimentation basins comparing with an agricultural locality is given. Altogether 124 taxa (species, forms, and undetermined isolates) of microscopic fungi belonging to at least 50 genera were recorded (examples see on Figs 3.6.1a–d).

The majority of the fungi isolated are anamorphs of *Ascomycota* (110 taxa, 89%); fourteen taxa (11%) belong to *Zygomycota*. The most frequent genera were *Penicillium* (15 species), *Phoma* (10 species including undetermined isolates), *Mucor* (8 species including undetermined isolates), and sterile dark mycelia.

The most frequent fungus was *Cladosporium herbarum* dominating on three localities. Other fungi were frequent only on two or one of five localities: *Alternaria alternata*, *Aureobasidium* sp., *Botrytis cinerea*, *Cladosporium cladosporioides*, *Clonostachys rosea* f. *rosea*, *Emericellopsis minima*, *Fusarium* sp., *Geomyces pannorum*, *Mucor* spp., *Phoma* sp., *Trichoderma harzianum*, and *T. virens*. The majority of recorded fungi were isolated only rarely. The major part of the fungi found during this study is known as soil saprotrophs (Domsch et al. 1993). Among them, several are also plant pathogens (*Acremonium*, *Clonostachys*, *Fusarium*, *Phoma*), food-borne fungi (*Eurotium amstelodami*, *Aspergillus terreus*, *Penicillium brevicompactum*, *P. carneum*, *P. crustosum*, *P. echinulatum*, and *P. griseofulvum*), coprophiles (*Mucor*, *Sporormiella*), entomopathogens (*Beauveria bassiana*), opportunistic human pathogens (*Aspergillus fumigatus*), or freshwater hyphomycetes (Heliscus lugdunensis).

**Table 3.6.1.** Microscopic fungi isolated from biological soil crusts or surface layer of four sedimentation basins and one agricultural site in 2005 and 2006.

| Microscopic fungi | Locality, year of sampling | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ME 2005 | ME 2006 | RA 2005 | RA 2006 | OS 2005 | OS 2006 | DK 2005 | DK 2006 | NE 2005 | NE 2006 |
| *Absidia spinosa* | | | | | | | | | 1 | |
| *Acremonium strictum* | | | | 1 | | | | | | |
| *Acremonium* spp. (3 spp.) | | | 1 | | 1 | | 1 | | | |
| *Alternaria alternata* | | 1 | 1 | | 2 | | 1 | 1 | | 2 |
| *Alternaria* sp. | 1 | | | | | | | | | |
| *Arthrinium arundinis* | 1 | | 1 | | 1 | | | | | |
| *Aspergillus fumigatus* | 1 | | | | 1 | | | | | |
| *Aspergillus sydowii* | | | | | 1 | | | | | |
| *Aspergillus terreus* | | | | | | | 1 | 1 | | |
| *Aureobasidium* sp. | | | | | 2 | 1 | | | | |
| *Beauveria bassiana* | | | | | 1 | | | | | |
| *Botrytis cinerea* | | | | | 2 | 1 | | | | 1 |
| *Chaetomium* sp. | | | | | | 1 | | | | |
| *Cladosporium cladosporioides* | | | | 1 | 1 | | | | 2 | |
| *Cladosporium herbarum* | 2 | 1 | 2 | | 1 | 1 | 2 | 1 | | 2 |
| *Clonostachys rosea* f. *catenulata* | | | | 1 | | | | | 1 | |
| *Clonostachys rosea* f. *rosea* | | | | 1 | | | | | 2 | |
| *Clonostachys* sp. | | | | | | 1 | | | | |
| *Emericellopsis minima* ***CCF 3729*** | | | | | | | 2 | | | |
| *Epicoccum nigrum* | | 1 | | | | | | 1 | | 1 |
| *Eurotium amstelodami* | | | | | 1 | | | | | |
| *Fusarium avenaceum* | 1 | 1 | | | | | | | | |
| *Fusarium culmorum* | 1 | | | | | | | | 1 | |
| *Fusarium lateritium* | | | | | 1 | | | | | |
| *Fusarium tricinctum* | | | | | | | | | 1 | |
| *Fusarium* spp. (3) | | | | | | | 1 | | 1 | 2 |
| *Geomyces pannorum* | | | | | 1 | | | 2 | | |
| *Heliscus lugdunensis* | | | | | | 1 | | | | |
| *Mortierella* sp. | | | | | | | | | 1 | |
| *Mortierella* spp. (2) | | 1 | | | | | | | | |
| *Mucor hiemalis* f. *hiemalis* | 1 | | | | | | | | | |
| *Mucor* spp. (7) | 2 | 1 | 1 | | 1 | | 1 | 1 | 2 | |
| *Paecilomyces* sp. | | | | | 1 | | | | | |
| *Penicillium brasilianum* | | | | | | | | | | 1 |
| *Penicillium brevicompactum* | 1 | | | | 1 | | | | | |
| *Penicillium carneum* ***CCF 3719*** | | | | | | 1 | | | | |
| *Penicillium chrysogenum* | | | | | | | | | | 1 |
| *Penicillium crustosum* | | | | | 1 | | | | | |
| *Penicillium echinulatum* ***CCF 3719*** | | | | | 1 | | | | | |
| *Penicillium griseofulvum* | | | | | 1 | | | | | |
| *Penicillium purpurogenum* | | | 1 | | | | | | | |
| *Penicillium scabrosum* | | | | | | | | | | 1 |
| *Penicillium smithii* | | | | | 1 | | | | | |
| *Penicillium* spp. (2) | | | | | 1 | | | | | |
| *Penicillium* spp. (3) | | 1 | | | 1 | | | 1 | | |
| *Phialophora* sp. (2) | | 1 | | | 1 | | | | | |
| *Phoma* cf. *eupyrena* | | 1 | | | | | | | 1 | |
| *Phoma* sp. (2) | 1 | | | | | | | | | |
| *Phoma* sp. (3) | | 1 | | | | | | | | |
| *Phoma* sp. (2) | | | 1 | | | | | | | |

| Microscopic fungi | Locality, year of sampling | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ME 2005 | ME 2006 | RA 2005 | RA 2006 | OS 2005 | OS 2006 | DK 2005 | DK 2006 | NE 2005 | NE 2006 |
| *Phoma* sp. (2) | | | | | 1 | | | 1 | | |
| *Rhinocladiella* sp. | | | 1 | | | | | | | |
| *Rhizopus arrhizus* | | | | | | | | | 1 | |
| *Rhizopus microsporus* var. *rhizopodiformis* | | | | | | | 1 | | | |
| *Sordaria fimicola* | | | | | | | | | | 1 |
| *Sporormiella* sp. | | 1 | | | | | | | | |
| *Stemphylium sp.* | | | | | 1 | | | | | |
| sterile dark mycelia (2) | 1 | | | | | | | | | |
| sterile dark mycelia (3) | | 1 | | | | | | | | |
| sterile dark mycelia (3) | | | 1 | | | | | | | |
| sterile dark mycelia (3) | | | | 1 | | | 1 | 1 | | |
| sterile dark mycelia (2) | | | | | 1 | | | | | |
| sterile dark mycelia (2) | | | | | | 1 | | | | |
| sterile grey mycelium | 1 | | | | | | | | | |
| sterile light mycelia (2) | | | | | 1 | | | | | |
| *Trichoderma harzianum* | | | 2 | 1 | | | | | | |
| *Trichoderma virens* | | | 1 | 2 | | | | | | |
| *Trichoderma viride* | | | | | | | | 1 | | |
| *Trichoderma* spp. (3) | 1 | | | | | 1 | | | 1 | |
| *Truncatella angustata* | | 1 | | | | | | | | |
| *Ulocladium botrytis* | | | | | | | | | | 1 |
| *Ulocladium* sp. | 1 | | | | | | | | | |
| *Umbelopsis angularis* | | | | | | | | | | 1 |
| undetermined arthrosporic fungus | | | | | | 1 | | | | |
| undetermined ascomycetes (2) | | | | | 1 | | | 1 | | |
| undetermined basidiomycete | | | | 1 | | | | | | |
| undetermined coelomycete | | | | 1 | | | | | | |
| undetermined dark fungus | | | | | 1 | | | | | |
| undetermined filamentous yeast | | | | | | | 1 | | | |
| undetermined fungi (2) | | | 1 | | 1 | | | | | |
| undetermined fungi (3) | | | | | | | 1 | | | |
| undetermined light fungi (3) | | | | | 1 | | | 1 | | 1 |
| undetermined pycnidial fungi (2) | | 1 | 1 | | | | | | | |
| undetermined sporodochial fungi (2) | 1 | | | 1 | | | | | | |
| **No. of taxa:** | **17** | **19** | **16** | **10** | **34** | **11** | **13** | **13** | **12** | **12** |
| **Total No. of taxa: 124** | **33** | | **24** | | **42** | | **23** | | **24** | |

*Notes:* CCF = Culture Collection of Fungi, Prague, CZ; Localities: **OS** = Ostrov, **ME** = Měděnec, **RA** = Radvanice, **DK** = Dvůr Králové, **NE** = Netluky; Occurrence: **1** = rarely isolated species, **2** = frequent species.

The localities differed in species richness (Table 3.6.1). The richest spectrum of fungi was found at the active sedimentation pond at Ostrov, 42 species (including undetermined isolates). On locality Měděnec we discovered 33 species, on Radvanice 24 species, and on Dvůr Králové 23 species. On Netluky (agricultural site) 24 species of fungi were isolated also.

The biological soil crusts on sedimentation basins differed also by fungal spectrum (Table 3.6.1). On the active sedimentation basin, Ostrov, *Alternaria alternata*, *Aureobasidium* sp. and *Botrytis cinerea* dominated. They are typical decomposers of litter. In 2005, many food-borne contaminants were found on this locality (*Eurotium amstelodami*, *Penicillium brevicompactum*, *Penicillium crustosum*, *P. echinulatum*, and *P. griseofulvum*). These r-strategs probably occurred with accidental waste pollution. Freshwater hyphomycete *Heliscus lugdunensis* represent an interesting record on this locality (Fig. 3.6.1a). It was found only once, however this fungus is known to grow also in waters contaminated by heavy metals (Braha et al. 2007). On the other active sedimentation basin, Dvůr Králové, different fungi were frequently isolated: *Cladosporium herbarum*, *Emericellopsis minima* and *Geomyces pannorum*. Whilst *C. herbarum* and *G. pannorum* are typical litter and soil fungi, respectively, *Emericellopsis minima* is a somewhat rare fungus. On the locality Měděnec *Cladosporium herbarum*, *Mucor* sp., *Phoma* sp. and sterile dark mycelia, i.e. typical soil and litter fungi dominated. On the Radvanice locality, we frequently recorded *Cladosporium herbarum*, *Trichoderma harzianum*, *T. virens* and sterile dark mycelium. Among them, *T. virens* and sterile dark mycelia were formerly found as abundant on another abandoned ore-sedimentation basin at Chvaletice (Kubátová et al. 2002). On agricultural locality (pasture Netluky) *Alternaria alternata*, *Cladosporium cladosporioides*, *C. herbarum*, *Clonostachys rosea* f. *rosea*, *Fusarium* sp., and *Mucor* sp. dominated.

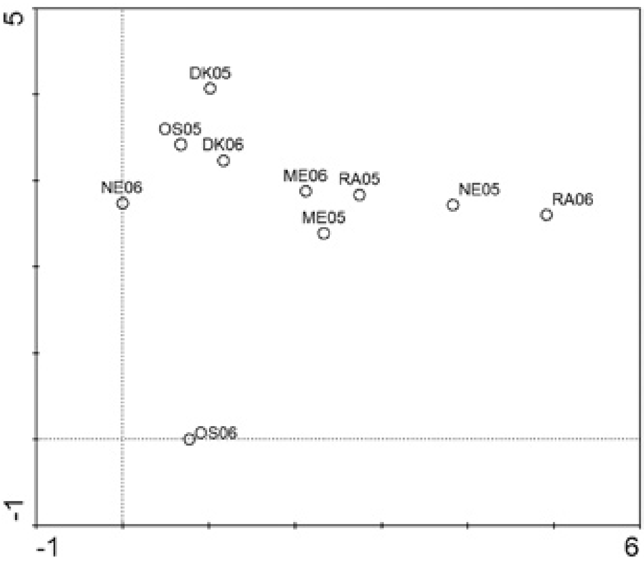



**Fig. 3.6.2.** Testing the differences in fungal species richness and composition of biological soil crusts on four ore-sedimentation basins and one agricultural site. DCA ordination diagram showing the position of samples in the range of the first two ordination axes (**ME** = Měděnec, **RA** = Radvanice, **OS** = Ostrov, **DK** = Dvůr Králové, **NE** = Netluky, 05 = 2005, 06 = 2006).

The sampling on studied sites was made twice, in 2005 and 2006. Using DCA, we tested changes of species composition during this period (see Fig. 3.6.2). From this ordination diagram great differences are obvious not only among localities but also between the years on the same locality. The localities Měděnec and Dvůr Králové show the smallest differences between the years, while in Netluky the difference is the greatest. It corresponds with less or more different species composition recorded in relevant samples.

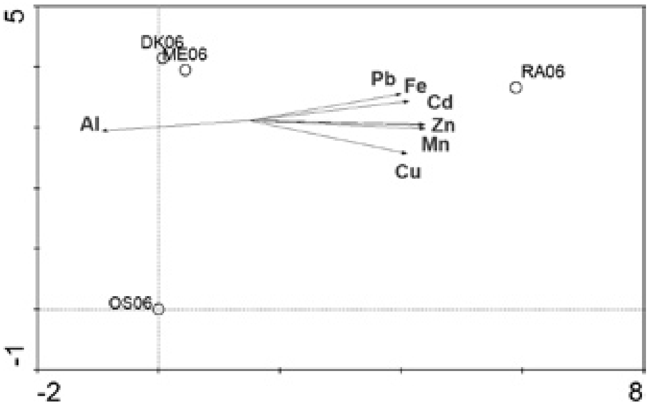



Fig. 3.6.3. Testing the differences in fungal species richness and composition of samples from 2006. DCA ordination diagram showing the position of samples in the range of the first two ordination axes (**ME** = Měděnec, **RA** = Radvanice, **OS** = Ostrov, **DK** = Dvůr Králové).

In 2006, the contents of heavy metals in biological soil crusts were measured on studied ore-sedimentation basins (see Chapter 3.2). The effect of heavy metals content on species composition is demonstrated on DCA ordination diagram (Fig. 3.6.3). The great distance of Radvanice site from other localities could correspond with the high content of different metals on this locality.

## CONCLUSIONS

Microfungi isolated from crusts or surface layer of sedimentation basins during the two-year study belong mostly to the known soil and litter fungi similarly to microfungi found on crusts on natural substrata. Only low number of fungal dominants were recorded on the studied localities. The majority of the fungi were isolated only once. Fungal species composition of the biological soil crusts on the localities studied was different probably due the different characteristics of localities. Moreover, the species composition differed on the same locality between the two years studied.

# 3.7. Bryophytes – species composition and diversity

ZDENĚK SOLDÁN

## INTRODUCTION

Anthropogenic habitats are not actually in the focus of bryological investigation. They are studied by bryologists occasionally, compared with natural habitats; such habitats as mountain regions, peat-bogs, virgin forests with their rich epiphytes, etc., predominantly in protected areas are much more interesting! If some studies are produced, their interest is concentrated on cities and their near surroundings (it is possible to mention – as an example – studies of Mišíková 2007 or Váňa 2004 from the territory of the former Czechoslovakia). In these cases historical data and data actual, recently obtained by field investigation are usually compared. Recently some interest has been also directed on diversity and biology of bryophytes forming so-called agrocenoses, it means bryophytes growing in fields, wastelands, etc. (e.g., Kresáňová 2006).

It is obvious, that bryological studies focused on abandoned sedimentation basins or similar habitats are absent and not only in the Czech Republic! The best documentation of this bad situation is the only (moreover, older) paper cited in aggregate study (Belnap and Lange 2001) which deals with disturbed habitats and the role of bryophytes (Mollenhauer 1970).

All data about diversity, ecology and biology of bryophytes in sedimentation basins in the Czech Republic are concentrated in Kovář's monograph (Kovář 2004): Palice & Soldán (2004), Hroudová & Zákravský (2004), Pohlová (2004).

It is obvious that bryophytes on habitats disturbed by mankind play a very important role as pioneer organisms and often form a dominant part of vegetation, especially in the early stages of succession. This dominant role is usually softened by the first successful planted wood plants. Recent activities in the study of biological soil crusts are, above all, focused on arid areas of the North America.

This chapter deals with bryophytes on such habitats like sedimentation basins in the Czech Republic.

## MATERIALS AND METHODS

Data used for this chapter are connected with the results formerly obtained about bryophytes in the sedimentation basin at Chvaletice (Palice & Soldán 2004), but they are predominantly based on concentrated field research in other sedimentation basins at Měděnec, Radvanice, Ostrov n. Ohří and Dvůr Králové in the years 2005–2007.

After field collection bryophytes were microscopically determined in a lab. The nomenclature follows the paper of Kučera & Váňa (2004); all specimens have been consecutively deposited in the herbarium of the Faculty of Natural Sciences of the Charles University in Prague (PRC).

A transect, with a direction approximately NNW from water level of central depression to man-made mound of sedimentation basin (inclusive) was arranged in the locality Měděnec. Permanently fixing plots were based in 2006 (November) according to following design: squares 1 x 1 m with a spin 3 m form a straight line in above mentioned direction. Repeated reading of the total cover of bryophytes (as well as vascular plants) was made in the following year (November 2007) and thanks to fixed points, it was naturally possible to repeat again. Apart of these plots, smaller plots were arranged in 2006 – 30 x 30 cm at a distance of 20 cm from relevant basic plots (upright to line of the transect). Surface soil cover, including vegetation of bryophytes and vascular plants to a depth of about 3 cm was removed and the natural reconstruction of vegetation (succession) was observed (described as "disturbed plots"). The plots are signed by symbols 0–20 (symbol 0 used for free water level of central depression with macrovegetation, where was not supposed occurrence of bryophytes). Following excursions in 2005–2007 it was obvious that water level of the central depression fluctuates according to actual precipitation in this region affecting plots No. 1–3(4). The value of soil of permanent plot No. 20 refers only to a man-made mound on a margin of the central depression.

The moisture gradient or the gravimetric delimitation of water in soil was made by the method mentioned in the paper of Suchara (2007): values of soil moisture of permanent plots were obtained by using Kopecký's cylinders for actual moisture (per cent) as well as using the method of Novák for maximal water capacity (again per cent).

Four permanent plots (30 x 30) cm were established in Radvanice locality during a study of biology of endangered liverwort *Moerckia hybernica*, and the occurrence of this species and other plants was consecutively precisely plotted on paper in all plots. The evaluation of changes was made during the years 2006 a 2007.

**Table 3.7.1.** The list of recorded species of bryophytes. (Used symbols: + = the species present, – = the species absent; localities: **DK** = Dvůr Králové, **CH** = Chvaletice, **ME** = Mědĕnec, **OS** = Ostrov, **RA** = Radvanice)

| Taxon | Locality | | | | |
|---|---|---|---|---|---|
| | DK | CH | ME | OS | RA |
| *Amblystegium humile* | – | – | – | – | + |
| *Aneura pinguis* | – | – | + | – | + |
| *Atrichum undulatum* | – | – | – | – | + |
| *Aulacomnium androgynum* | – | + | – | – | + |
| *Aulacomnium palustre* | – | + | + | – | + |
| *Barbula convoluta* | – | + | + | – | + |
| *Barbula unguiculata* | – | + | + | – | + |
| *Brachythecium albicans* | – | – | + | – | + |
| *Brachythecium mildeanum* | – | – | + | – | – |
| *Brachythecium plumosum* | – | – | + | – | – |
| *Brachythecium rivulare* | – | – | + | – | + |
| *Brachythecium rutabulum* | – | + | + | – | + |
| *Brachythecium salebrosum* | – | – | – | – | + |
| *Bryum argenteum* | + | + | + | + | + |
| *Bryum bicolor* | – | + | – | – | – |
| *Bryum caespiticium* | – | + | + | – | + |
| *Bryum capillare* | – | + | – | – | + |
| *Bryum pallens* | – | + | + | – | + |
| *Bryum ruderale* | – | + | – | – | – |
| *Calliergonella cuspidata* | – | + | + | – | + |
| *Campylium stellatum* | – | – | – | – | + |
| *Cephaloziella divaricata* | – | + | – | – | + |
| *Cephaloziella hampeana* | – | + | – | – | – |
| *Ceratodon purpureus* | + | + | + | + | + |
| *Chiloscyphus profundus* | – | + | – | – | + |
| *Climacium dendroides* | – | – | – | – | + |
| *Dicranella cerviculata* | – | + | + | – | – |
| *Dicranella heteromalla* | – | – | – | – | + |
| *Dicranella staphylina* | – | + | – | – | – |
| *Dicranella varia* | – | – | + | – | + |
| *Didymodon fallax* | – | – | + | – | + |
| *Ditrichum heteromallum* | – | + | – | – | – |
| *Drepanocladus aduncus* | – | + | + | – | – |
| *Encalypta streptocarpa* | – | – | – | – | + |
| *Eurhynchium hians* | – | – | – | – | + |
| *Fissidens taxifolius* | – | + | + | – | + |
| *Funaria hygrometrica* | + | + | + | + | + |
| *Hypnum cupressiforme* | – | + | – | – | + |
| *Leptobryum pyriforme* | – | + | – | – | + |
| *Leptodictyum riparium* | – | – | + | – | + |
| *Lophozia excisa* | – | + | – | – | – |
| *Marchantia polymorpha* | – | + | – | – | + |
| *Moerckia blyttii* | – | – | – | – | + |
| *Nardia scalaris* | – | – | – | – | + |
| *Pellia endiviifolia* | – | – | + | – | + |
| *Philonotis fontana* | – | – | + | – | + |
| *Pohlia nutans* | – | – | – | – | + |
| *Polytrichastrum commune* | – | + | – | – | – |
| *Polytrichastrum formosum* | – | + | + | – | + |
| *Polytrichum juniperinum* | – | + | + | – | + |
| *Polytrichum piliferum* | – | – | + | – | + |
| *Pogonatum urnigerum* | – | – | – | – | + |
| *Preissia quadrata* | – | – | + | – | + |
| *Ptilidium pulcherrimum* | – | – | – | – | + |
| *Rhizomnium punctatum* | – | – | – | – | + |
| *Rhytidiadelphus squarrosus* | – | – | – | – | + |
| *Scleropodium purum* | – | – | – | – | – |
| *Tortella tortuosa* | – | – | – | – | + |
| *Tortula inclinata* | – | – | – | – | + |
| *Tortula truncata* | – | + | – | – | + |
| *Trichodon cylindricus* | – | + | – | – | + |

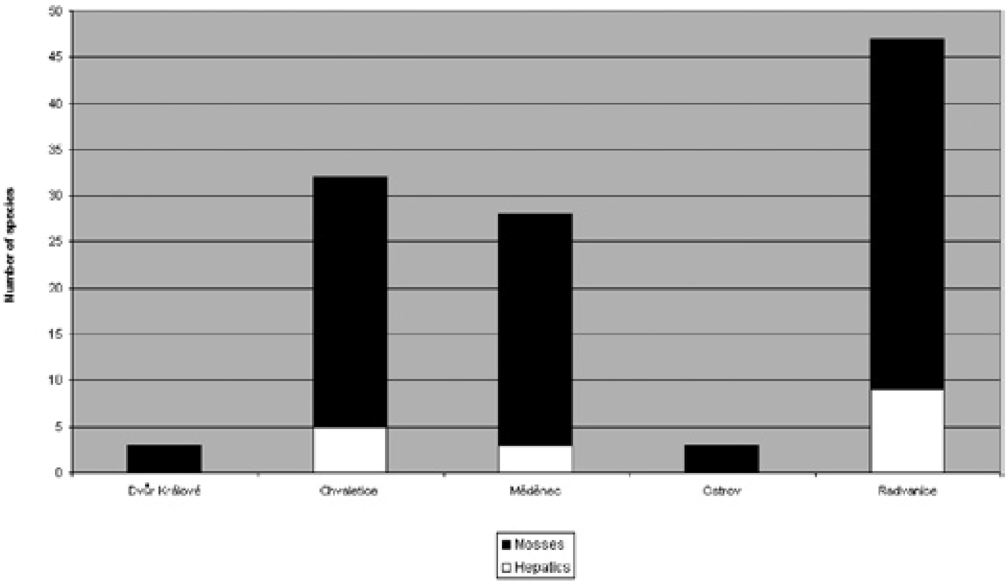



**Fig. 3.7.1.** Species diversity (ratio of mosses and liverworts) in the sedimentation basins.

## RESULTS AND DISCUSSION

Table 3.7.1. summarizes the species diversity or the occurrence of bryophytes on studied localities. The only terrestrial species of bryophytes of sedimentation basins were incorporated into this table (in some case also water or bank species of the central depression). The species of anthropogenic substrates (e.g., species of communal trash in the case of the locality Chvaletice, mounds of the sedimentation basin in the case of the locality Měděnec, epiphytes on bark of woods or epixyllic species of an old wood, etc.) were excluded.

In total, 60 species of bryophytes were collected in five sedimentation basins (52 mosses and 8 liverworts). The differences in species composition (mosses vs. liverworts) among individual localities are indicate by Fig. 3.7.1.

It is obvious, that the lowest (and identical) diversity occure at the localities Dvůr Králové and Ostrov n. Ohří. These localities represent still active sedimentation basins, which are periodically stocked by new sediments and moss layer which have no possibility to form compact cover here. But the same species diversity is not in accordance with the same production of biomass during the study period. A long-term pure cover of bryophytes in the locality Ostrov sharply contrasts with periods before and after replenishment by a new mixture of deposit material in the case of the locality lokality Dvůr Králové (at its most extreme, it is possible to speak about differences between 0–90% of the total cover!).

Similar species diversity is visible between the localities Chvaletice and Měděnec, where the number of species fluctuates about 30 and the ratio of mosses vs. liverworts is very similar; in addition, proportion between these groups is very close to the ration within the framework of the whole bryoflora of the Czech Republic.

The sedimentation basin at Radvanice represents a quite different locality. The highest number of bryophytes, in total, 47 species were discovered there, in spite of extreme toxicity of substrate. One interpretation of this fact can be explained from its topography: a relatively deep valley of brook and well developed forest in surroundings. This situation allows +/– constant humidity and it also restricts transport of surface material by wind (cf. the different situations in the open landscapes of Chvaletice and Měděnec). In addition, the soil is basic here and many obligate calciphytic species therefore have conditions for their successful growth (sensu Dierssen 2001); e.g., *Dicranella varia*, *Preissia quadrata*, *Tortella inclinata*, *T. tortuosa*.

The most interesting finding represents the liverwort *Moerckia hybernica*. Kučera et Váňa (2004) classify this hepatic in their Red List of bryophytes of the Czech Republic as endangered species. So far, only 8 historical localities have been known. But over 25 years this speies was not collected on places of their historical occurrence (negative result of the author of this paper in localities Hříběcí boudy in Krkonoše Mts and in Mramor Mt in Jeseníky Mts). Four permanent plots (30 x 30 cm) were established in the locality Radvanice during study of biology of endangered liverwort Moerckia hybernica and the occurrence of this species and other plants was consecutively exactly plotted on paper in all plots. An analysis of changes was made in the years 2006 and 2007. After one year, total destruction by wild animals of one plot was observed, this species completely disappeared from another plot and two remaining plots demonstrated decrease of about 1 in the original size of thallus (original thallus had size about 2 x 3 cm, the following year in both cases only about 1 x 1 cm). No traces were observed after two years (in 2007) in any plot. The species of other frondose liverwort (in sedimentation basin dominant) *Preissia quadrata* emerged in ever place where formely had the former occurrence of *Moerckia hybernica*. The interpretation to disapperance is in an anbility to compete with the species *Preissia quadrata*. Another explanation is also the fast proliferation of *Phragmites communis* vegetation (observed accumulation about 10–35% on permanent plots) and connected changes of microclimatic conditions. Some small plants (less than 1 cm$^2$) of this hepatic were observed in close vicinity of original occurrence in 2007 (in about 2 m distance)! Reproduction is possible, obviously, in the way of vegetation by vegetation way – by fragmentation of thallus (observed in only male gametangium, always without sporophytes).

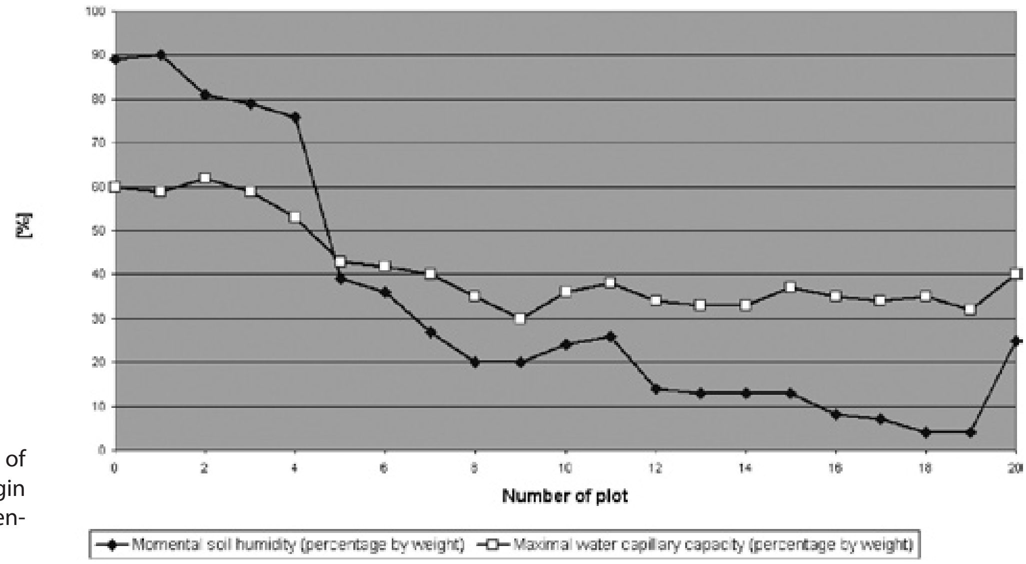



**Fig. 3.7.2.** Water condition of soil along the gradient margin of lake-mound of the sedimentation basin, Měděnec.

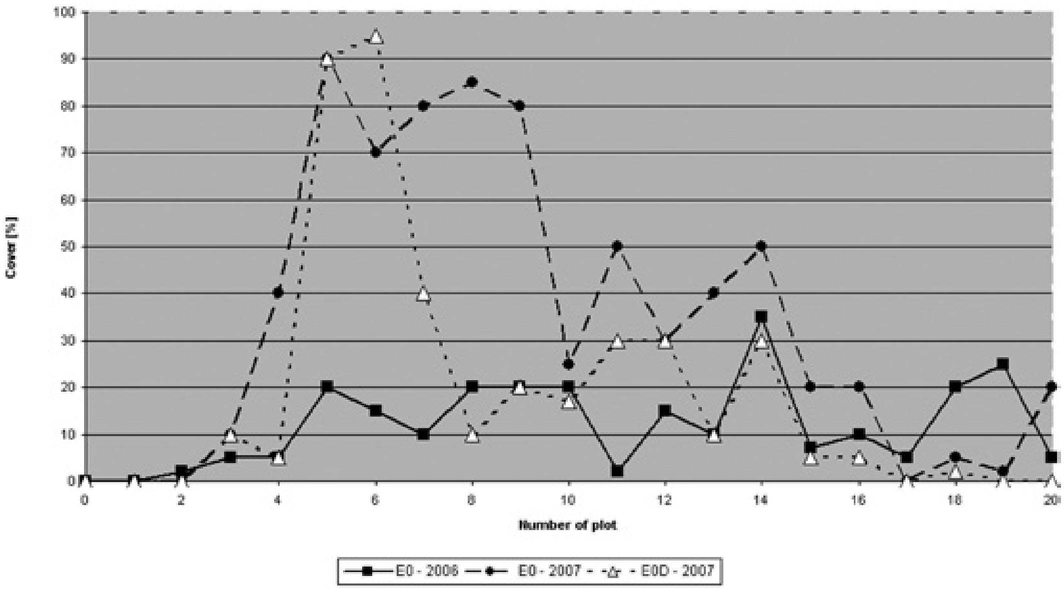



**Fig. 3.7.3.** The total cover of moss layer along a humidity gradient of the sedimentation basin, Měděnec. (Used symbols: E0 – 2006 = cover of E0 layer in 2006, E0 – 2007 = cover of E0 layer in 2007, E0D – 2007 = cover of E1 player of disturbed plot in 2007)

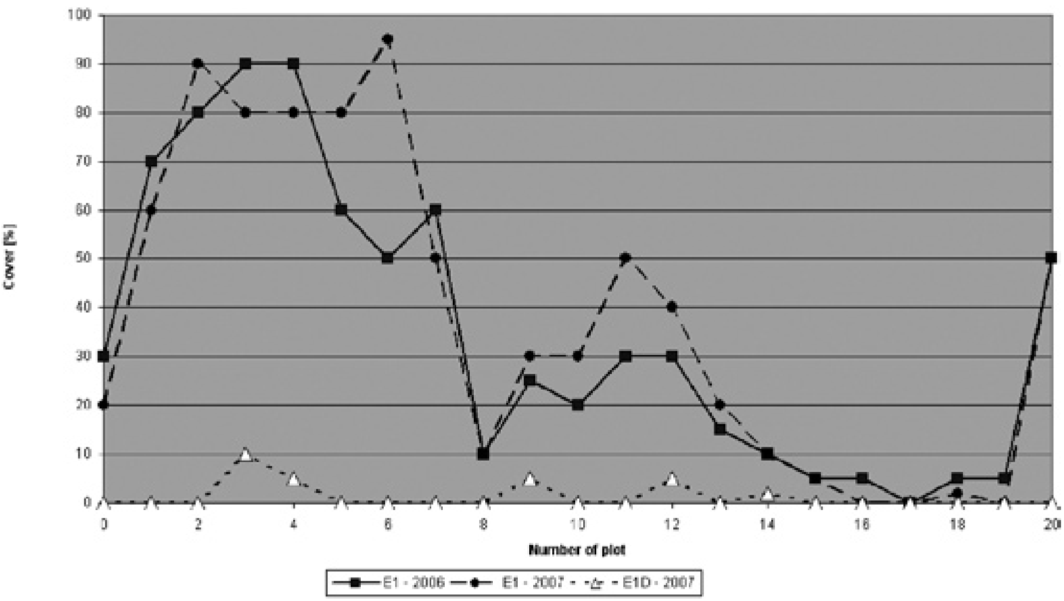



**Fig. 3.7.4.** The total cover of herb layer along a humidity gradient of the sedimentation basin, Měděnec. (Used symbols: E1 – 2006 = cover of E1 layer in 2006, E1 – 2007 = cover of E1 layer in 2007, E1D – 2007 = cover of E1 layer of disturbed plot in 2007).

The dynamics of moss layer were observed minutely in the case of the Měděnec locality. There is aclearly visible, gradual, decrease of water in soil from the central depression to the margin mould with the respect to distance from the central lake in depression (Fig. 3.7.2). The difference in elevation between the margin of the lake and the mould is relatively small – about 50–100 cm. It was observed (during 2005–2007), that there was fluctuation of water level among plots No. 1–3(4). The values of maximal water capillar capacity are therefore relatively well-rounded, higher values being explainable by deposits of clay particularly during inundation.

A comparison of the total cover of moss (Fig. 3.7.3.) and herb (Fig. 3.7.4) layers is also interesting. The moss layer is not successful in the zone of water fluctuation, but is at its maximum in a wet, relatively constant wet zone. The progress of the total cover is very different in the comparison of years 2006 a 2007.

Values of the total cover of herbs (= macrovegetation) are very similar in 2006–2007 (maximum between plots No. 1–7 and No. 9–13) and it was possible to establish only small differences during observation. The peak of macrovegetation cover (nearly 100%) was in the inundated zone. The total cover of disturbed plots is minimal, succession has obviously long-term character.

The quite different behaviour of 4 dominant bryophytes is surprising (see Fig. 3.7.5–3.7.8). It is noticeable, that these species have obviously different life strategies with accordance with their ecological valency. It is possible to

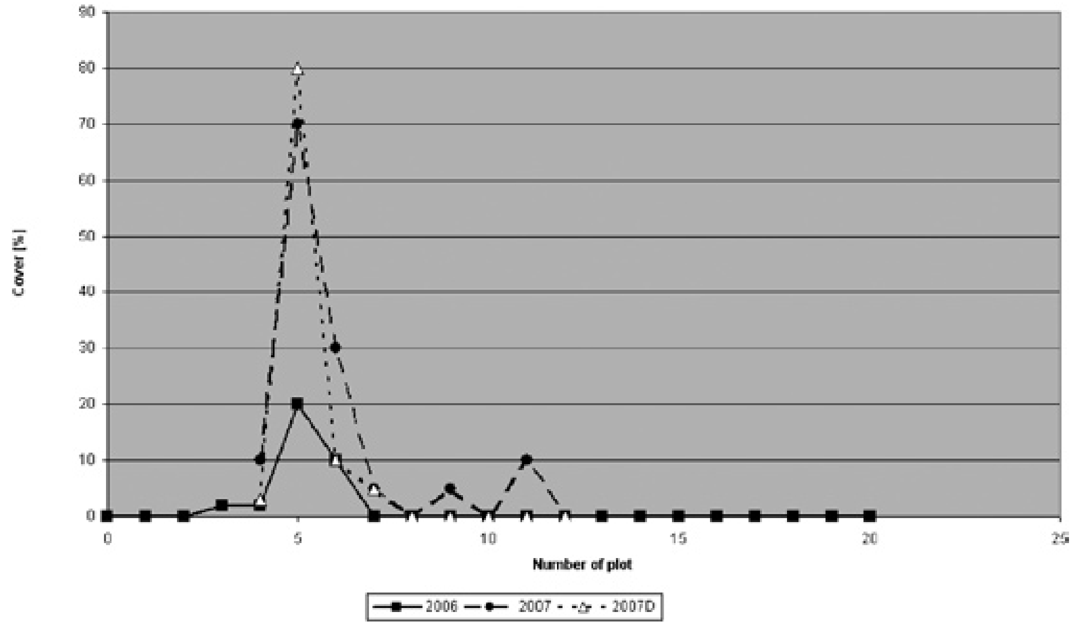



**Fig. 3.7.5.** The total cover of the liverwort *Pellia endiviifolia* along a transect in the sedimentation basin, Měděnec.

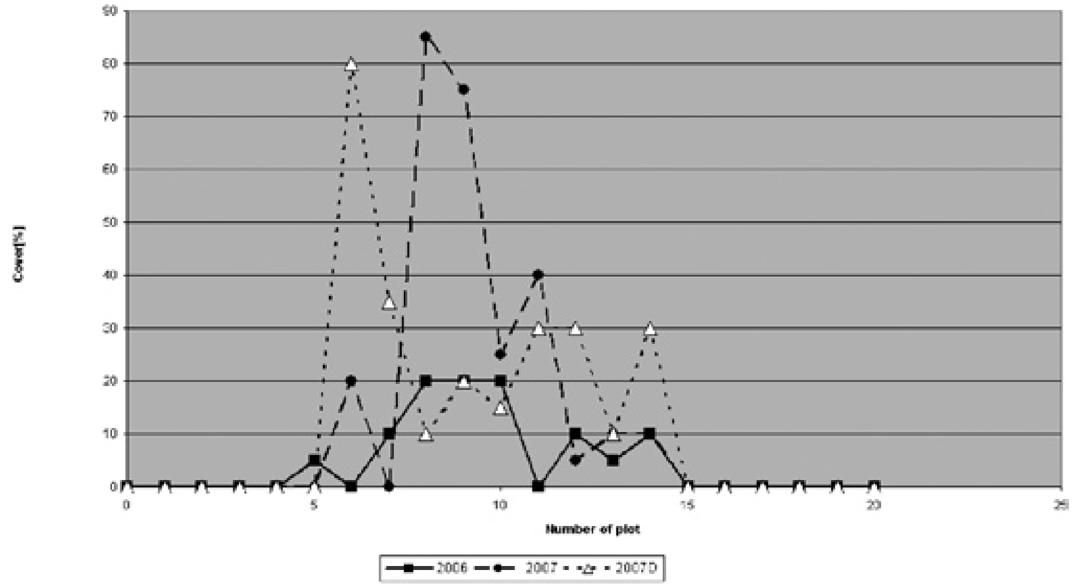



**Fig. 3.7.6.** The total cover of the moss *Dicranella varia* along a transect in the sedimentation basin, Měděnec.

postulate, that succession of moss layer is conspicuously dynamic, and it is possible to shaw prominent differences during only one year.

The frondose liverwort *Pellia endiviifolia* (Fig. 3.7.5) has a relatively well-rounded life cycle of cover within the line of gradient, maximum is near water fluctuation (plots No. 4–6) and it has obviously capability for fast settlement of open habitats (the total cover of disturbed plot No. 5 is actally the highest compared with with non-disturbed plots in the years 2006 a 2007). No sporophytes were observed, the reproduction is possible due to fragmentation, using small leafy lobs.

The moss species *Dicranella varia* (Fig. 3.7.6.) has a high potential to colonise, especially in the early stadium of succession, obviously on wet soil (plot No. 6), where strong movement of maximum is visible compared with previous years. It has also a very high production of sporophytes here.

Common, cosmopolitan moss *Ceratodon purpureus* (Fig. 3.7.7.) is a typical synantrophic species. It is successful in open habitats and usually becomes dominant during short period in different habitats. This species had quite considerable cover in 2006 (maximum on plots No. 12–19) in comparison with 2007 (maximum on plots No. 4–7), but, with low success in colonising disturbed plots. This fact can possibly be to explained by its affinity to acidic substrates (see dominance in Chvaletice). This species is known only sterile in the Měděnec locality, its reproduction obviously possible due to vegetative way or by transport of spores over longer distances.

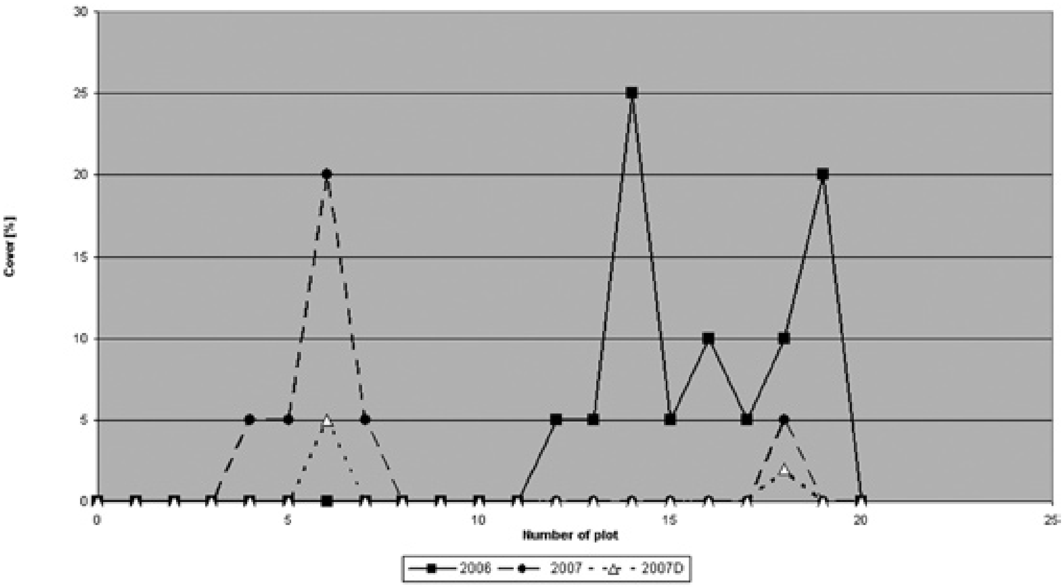



**Fig. 3.7.7.** The total cover of the moss *Ceratodon purpureus* along a transect in the sedimentation basin, Měděnec.

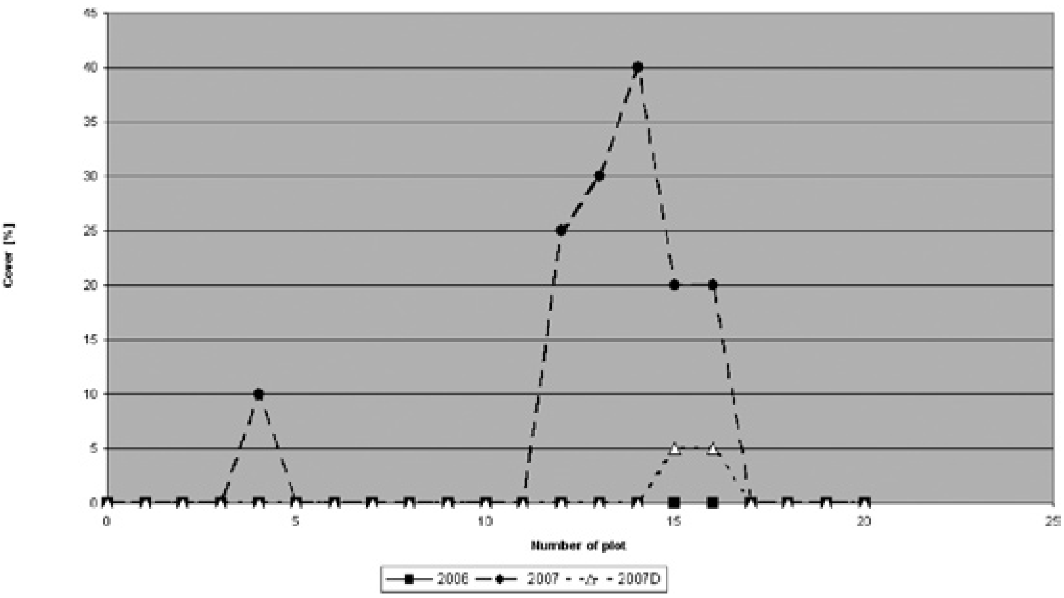



**Fig. 3.7.8.** The total cover of the moss *Barbula convoluta* along a transect in the sedimentation basin, Měděnec.

The moss species *Barbula convoluta*, (Fig. 3.7.8.) again has a quite different cover behaviour. It was not detected in plots in 2006, but it had high values of cover especially in dried sections of transect (maximum in plots No 12–16) in 2007 and its shows also a tendency to successful colonisation in this part of the transect. This species is often fruiting and it has the possibility of reproduction due to rich rhizoidal gemmae.

## CONCLUSIONS

In total, 60 species of bryophytes were collected (52 mosses and 8 liverworts) in studied localities. These represent about only 7% of the total number of the bryophytes of the Czech Republic. The sedimentation basins Dvůr Králové and Ostrov (still active!) have a very low, and moreover a similar, diversity of bryophytes. The sedimentation basins Chvaletice and Měděnec have a relatively analogous structure of bryophyte vegetation. The highest species diversity is in the locality, Radvanice, due to its topography and the basic pH soil, characteristic.

The occurrence of endangered liverwort *Moerckia hybernica* in Radvance shows a decline here. It is gradually replaced by the more agribusiness-dominant liverwort *Preissia quadrata*.

Data obtained from autecology of individual dominants along moisture gradient in the locality Měděnec contains interesting results.

# 4. Synanthropic biological soil crusts and the effect of disturbance; design of experiments

JIŘÍ NEUSTUPA & PAVEL ŠKALOUD

Mechanical disturbance is considered a key factor influencing ecological dynamics of biological soil crusts (Evans & Johansen 1999). Numerous studies demonstrated the vulnerability of crusts in semiarid ecosystems to disturbance. Johansen et al. (2001) described a significant negative correlation between autotrophic biomass and productivity of a crust and degree of disturbance. In heavily disturbed sites the autotrophic production almost ceased. In moderately disturbed localities, the negative effect on autotrophic microorganisms was still significant. Belnap (2002) revealed a conflicting response of biological soil crusts to mechanic disturbance with off-road vehicles. In her study, she detected a significant decrease of nitrogenase activity that indirectly measured biotic content and activity of *Nostoc*-bearing lichens in only about a half of her plots. Eldridge & Leys (2003) demonstrated the enhanced wind erosion on crusts after mechanic disturbance that leads to decreased productivity and total cover.

Apart from mechanic disturbance, several other potentially significant disturbing mechanisms were proposed and tested on crust localities of semiarid ecosystems. Considerable and long-term negative effects were demonstrated in studies investigating fire disturbance in semiarid crust localities (Johansen et al. 2001). The effect of grazing disturbance on crusts was tested in semiarid ecosystems of Utah, U.S.A. by Johansen & St. Clair (1986). Whereas the total cover and biomass of crusts was restored after 20 years, following disturbance, the authors revealed that a long-term negative effect of grazing on algal diversity remained even after a 20 year period of recovery. Negative effect of grazing on a diversity of algae in crusts was also ascertained by Hodgins & Rogers (1997) in the subtropical grasslands of Queensland, Australia.

In biological soil crusts of ore-sedimentation basins the disturbance effects were not previously investigated. However, off-road vehicles, motorbikes and other ways of mechanic disturbance evidently influence crust development and their physiognomy on most of our investigated sites. We investigated the effect of mechanic disturbance at two localities. Firstly, we chose Chvaletice ore-sedimentation basin as a typical surface crust site on toxic ore-rich substrate (50°2′28.577″N, 15°26′39.361″E, Fig. 4.1). Secondly, we investigated the locality close to the Ralsko former military airport (50°37′17.538″N, 14°42′49.296″E, Fig. 4.2).

The Chvaletice locality was located in an area of ore-sedimentation basin that was erected in 1952 in the vicinity of a pyrite mine. In 1975, mining activity ceased and in 1979, the ore-sedimentation basin was abandoned. In 1983, unsuccessful attempts to reforest the locality were conducted (Kovář 2004).

The Ralsko locality consists of sandstone-based tree-less habitats with well developed biological soil crust on a soil surface with low vascular plant cover. The sampling sites were situated in the immediate vicinity of a former Soviet military airport in the centre of a huge military area that ceased to exist after 1990. The area as a whole is heavily environmentally damaged. Contamination of soil and underground water by oil and other toxic substances in this area still represent one of the most significant environmental damaged in the Czech Republic.

In total, we established seven experimental plots (Fig. 4.3), three in Ralsko site and four in Chvaletice ore-sedimentation basin. In each plot, we delimited four 1m2 squares with different treatments: disturbed and undisturbed. Disturbance was done by mechanically scratching the surface crust layer (Figs 4.1d, 4.2d) immediately after the first set of samples was completed on $17^{th}$ November 2005. In 2006, we sampled both localities on $15^{th}$ November. As the investigation of lichens species composition did not involve culturing experiments, in this group additional data were determined in October 2007 and used in subsequent analyses. For abiotic factors measured on individual plots and for methodics see chapter 3.2.

Firstly, we investigated the species composition of experimental plots and we asked whether there was any change in crust diversity and species composition in response to disturbance significantly different from annual change of undisturbed control plots. In other words, we looked for whether the biological soil crusts on both localities were stable enough to sustain intensive nonrecurring disturbance. Secondly, we asked for changes in abiotic and ecophysiological factors in response to disturbance. Thirdly, we investigated possible correlations of abiotic factors and biotic data both within and between sets of disturbed and undisturbed plots.

The floristic results are presented separately for different major organismal groups as their biodiversity, the patterns of variation in species composition and, presumably, their different responses to disturbance stress. Then, we present results and interpretations of patterns of change in diversity and in abiotic data in response to experimental disturbance.

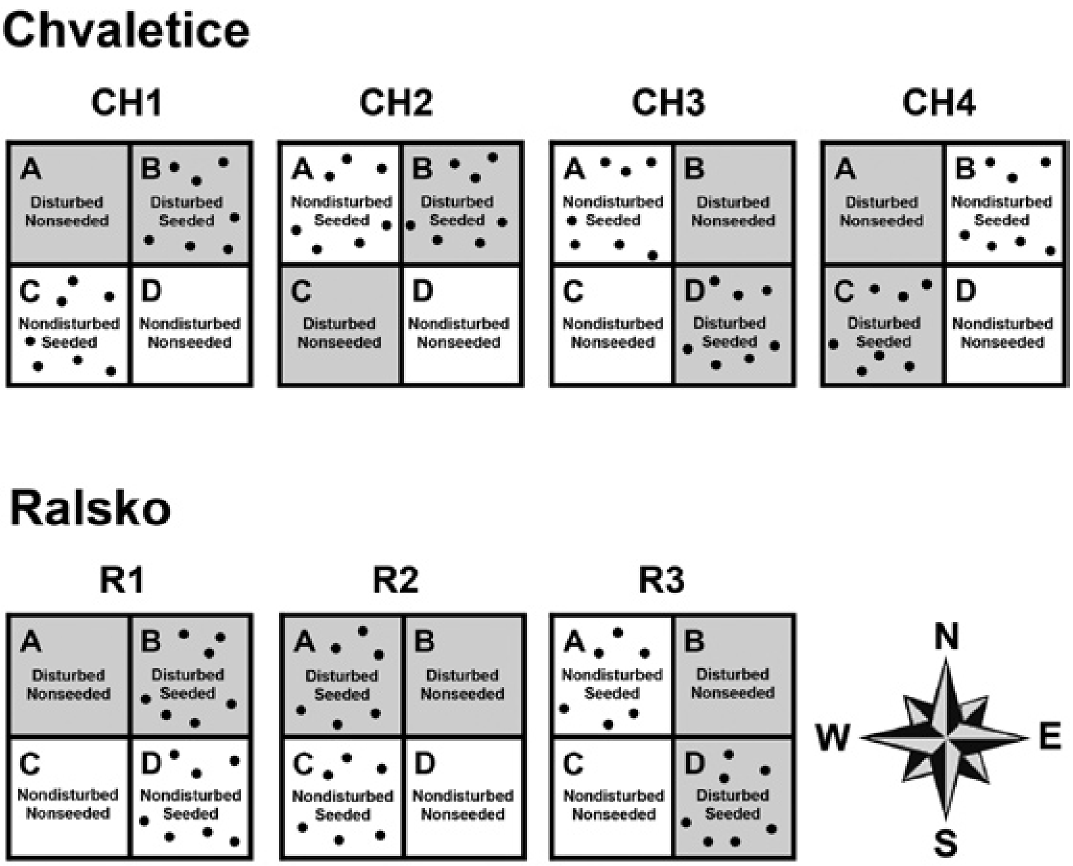



**Fig. 4.3.** Design of experimental plots. White – undisturbed, grey – disturbed.

# 4.1. Vegetation of the investigated plots at the Chvaletice and Ralsko localities

JAROSLAV VOJTA

The investigated plots in Chvaletice were nearly vegetation-free with the vegetation cover ranging from 0% to about 21% (median = 4.5%). The most frequent and most dominant species was *Calamagrostis epigeios*. Only two other species were present (seedlings of *Betula pendula* and *Pinus sylvestris*).

The vegetation on plots in Ralsko was significantly more species rich and also with more dense vegetation cover than the plots in Chvaletice. The total vegetation cover was 26–56% (median = 39%). Dominants were narrow-leaved grasses (*Festuca filiformis* and *Corynephorus canescens*) and *Pilosella officinalis* s.l. Further species present were: *Agrostis capillaris*, *Rumex acetosella*, *Scleranthus annuus*, *Jasione montana*, and *Vicia* sp.

# 4.2. Species composition and diversity of algae

PAVEL ŠKALOUD & JIŘÍ NEUSTUPA

## INTRODUCTION

This chapter provides comparison between the algal flora of ore-sedimentation sedimentation basin Chvaletice and natural forest-free area near Ralsko village. Beyond the general comparison of algal floras, we refer detailed descriptions of several taxa found in the investigated localities.

## MATERIALS AND METHODS

In each site, samples from the 0–3cm layer were taken randomly from several physiognomically uniform square areas (eight in Chvaletice – C1A, C1D, C2C, C2D, C3B, C3C, C4A, C4D and six in Ralsko – R1A, R1C, R2B, R2D, R3B, R3C). All samples were collected twice, in 2005 and 2006. The samples were placed into sterile bags and transported to the laboratory for analysis. The composite samples were crushed and mixed to produce a homogenouos sample. A 1-g aliquot was removed and added to 50 ml of distilled water. The soil suspension was mixed by a magnetic mixer for 15 minutes. Aliquots of 0.5 or 1 ml were spread in duplicate on agar solidified BBM and WC medium (Andersen 2005). Cultures were sealed with parafilm and incubated at 20–25 °C under daylight conditions (the plates were placed beside a north facing window) until good growth had been obtained (3–6 weeks). Algal microcolonies were examined directly from agarized plates using an Olympus BX 51 microscope with Nomarski DIC optics and photographed using Olympus Camedia digital camera C-5050 Zoom. Standard cytological stains (Lugol's solution, methylene blue, acetocarmine, chloraliode solution) were used for visualisation of pyrenoid, cell wall structures or mucilage. For detailed investigation of some strains, the algal colonies were transferred to agarized BBM culture tubes and then cultivated at 18 °C, under an illumination of 20–30 μmol $m^{-2} \cdot s^{-1}$ and 16:8 h light-dark cycle. Identification was made on the basis of life history and morphological criteria using standard authoritative references (Fott & Nováková 1969; Ettl 1978; Komárek & Fott 1983; Punčochářová 1992; Ettl & Gärtner 1995; Hindák 1996; Lokhorst 1996; Andreeva 1998). The quantities of algae on Petri dishes were evaluated as belonging to one of three classes: 1 – single algal colony found, 2 – rare species with several colonies on the dishes, 3 – dominant species in the sample. Following statistical methods were used to detect patterns in the data. Dice floristic similarities between selected sampling sites were counted in statistical program PAST 1.74 (Hammer et al. 2001). Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were performed using Canoco 4.5 (Ter Braak & Šmilauer 1998) to ordinate localities based on their algal composition. In CCA, 2000 permutations were performed to test the given hypotheses.

## RESULTS AND DISCUSSION

### *General conclusions*

A total of 34 algal species representing 25 genera were recovered during our investigation of several sampling areas in Chvaletice and Ralsko (Table 4.2.1). Six widespread taxa (coccal green algae *Watanabea* sp., *Pseudococcomyxa simplex* and *Radiococcus* sp.; and filamentous algae *Geminella terricola*, *Klebsormidium flaccidum* and *Stichococcus bacillaris*) were found in more than ten of 28 samples. We implied from this that green algae represented the most dominant algal group. In both localities, the members of Chlorophyta comprised 65% majority of all determined taxa (Fig. 4.2.1). Surprisingly, no diatoms and scarcely any cyanobacteria were determined during the investigation. That demonstrated a distinct difference when compared to the algal composition of biological soil crusts on natural substrata (see Chapter 2.2).

Comparing the species richness of both localities, Ralsko encompassed obviously more taxa than Chvaletice, even if fewer sampling sites were investigated there (Fig. 4.2.2). In spite of a similar proportion of algal groups determined in these localities, their species composition significantly differed. The CCA analysis significantly differentiated both localities on the basis of algal flora, whether it was tested separately for each year or for both years together (p-values invariably 0.0005). The distinct separation of Chvaletice and Ralsko samples is also well illustrated in the DCA ordination diagram (Fig. 4.2.3). It all corresponds with different dominant algal species for both localities. While *Radiococcus* sp., *Watanabea* sp. and *Pseudococcomyxa simplex* dominated in Chvaletice, Ralsko was characterized by the dominance of *Ulothrix tenerrima* and *Klebsormidium flaccidum* (see Table 4.2.1).

**Table 4.2.1.** Algal distribution in all investigated sampling sites (for explanation of the abbreviations see Materials and Methods).

| **Year of sampling** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** | **2005** | **2006** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sampling site** | **C1A** | | **C1D** | | **C2C** | | **C2D** | | **C3B** | | **C3C** | | **C4A** | | **C4D** | | **R1A** | | **R1C** | | **R2B** | | **R2D** | | **R3B** | | **R3C** | |
| ***Cyanobacteria*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Leptolyngbya* sp. | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nostoc* sp. | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Xanthophyceae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Botrydiopsis* cf. *arhiza* A. Borzi | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | |
| *Heterococcus* sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| ***Eustigmatophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eustigmatos magnus* (J. B. Petersen) Hibberd | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| *Eustigmatos vischeri* Hibberd | | | | | | | | | | | | | | | | | | | | | 3 | 1 | | 1 | | 2 | | |
| ***Chlorophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bracteacoccus* sp. | 2 | 2 | 2 | 1 | | | | | | | | | | | | | | | | 1 | | | | | | | 1 | |
| *Desmococcus* sp. | | | | | | | | | | | | | | | | | 3 | | 1 | | | 2 | | | | | | 1 |
| *Diplosphaera chodatii* Bialosuknia em. Vischer | 1 | 2 | | 3 | | 2 | | 1 | | 1 | | 1 | | | | | | | | | | | 2 | 2 | | | | |
| *Mychonastes homosphaera* (Skuja) Kalina et Puncocharova | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | 1 |
| *Radiococcus* sp. | 3 | 2 | 3 | 3 | | 1 | 2 | 3 | 2 | | | | | 3 | 3 | 2 | | | | | | | | | | | | |
| ***Trebouxiophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Asterochloris* sp. | | | | | | | 1 | 1 | | | | | | | 1 | 1 | | | | | | | | | | | | |
| *Chlorella mirabilis* Andreeva | | | | | 2 | 1 | | | | | | | | | | | | | | | | | | | | | | |
| *Chlorella* cf. *luteoviridis* Chodat | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | |
| *Chlorella* cf. *trebouxioides* Puncocharova | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | 2 | 2 | | | |
| *Chlorella* sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| *Choricystis chodatii* | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| *Coenocystis* cf. *oleifera* (Broady) Hindák | 1 | 2 | 3 | 1 | | | | | 1 | 3 | | 3 | | | | | | | | 1 | | | | 1 | | | | |
| *Leptosira erumpens* | | | | | 1 | 1 | 1 | | | | | | 2 | | 2 | | | | | | | | 1 | 1 | | | | |
| *Muriella zofingiensis* (Dönz) Hindák | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| *Myrmecia incisa* Reisigl | | | | | | | | | | | | | | | | | | 3 | | | | | | | | | | |
| *Myrmecia* sp. | 2 | 2 | 2 | | | 3 | 1 | 2 | | | | | 2 | | 2 | 2 | | | | 1 | | | | | | | | |
| *Pseudococcomyxa simplex* (Mainx) Fott | 1 | 1 | | 1 | 2 | 3 | 2 | | 3 | 3 | | 1 | 1 | 2 | | 1 | | 2 | | | 1 | | | | | | | |
| *Stichococcus allas* Reisigl | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | |
| *Stichococcus bacillaris* Nägeli | 2 | 3 | 3 | 2 | 3 | 2 | | | 1 | 3 | 2 | 3 | 1 | 1 | | 1 | | 1 | | | | 2 | | 2 | | | | 2 |
| *Watanabea* sp. | 3 | 3 | | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | | 1 | | | | 1 | 1 | | | | | |
| ***Ulvophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Kentrosphaera gibberosa* Vodenicarov et Benderliev | | | | | | | | | | | | | | | | | | | 2 | 2 | | | | | 2 | 1 | | |
| *Ulothrix tenerrima* Kützing | | | | | | | | | | | | | | | | | 2 | 2 | | | 2 | 3 | 2 | 2 | | | | |
| ***Klebsormidiophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Geminella terricola* Boye Petersen | 1 | 1 | 1 | 1 | 3 | 3 | 2 | 1 | 2 | | | | | | 2 | 2 | | | | 3 | | | 1 | | | | | |
| *Klebsormidium dissectum* (Gay) Ettl & Gärtner | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Klebsormidium flaccidum* (Kützing) Silva, Mattox et Blackwell | 1 | 1 | | 1 | | | | | 1 | | | | | | | | | 1 | 2 | 2 | | 2 | 3 | 2 | 2 | 2 | 3 | 3 |
| *Klebsormidium fluitans* (Gay) Lokhorst | | | | | | | | | | | | | | | | | | | 3 | | | | | | | | | |
| *Klebsormidium mucosum* (Boye Petersen) Lokhorst | | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | | | | |
| ***Zygnematophyceae*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Mesotaenium* sp. | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | |

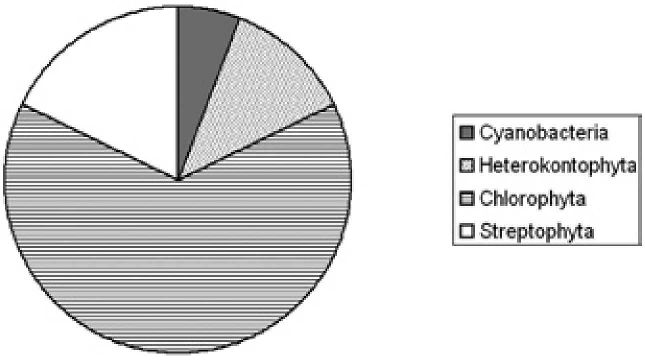



**Fig. 4.2.1.** Proportional occurrence of four algal groups, determined in all investigated localities.

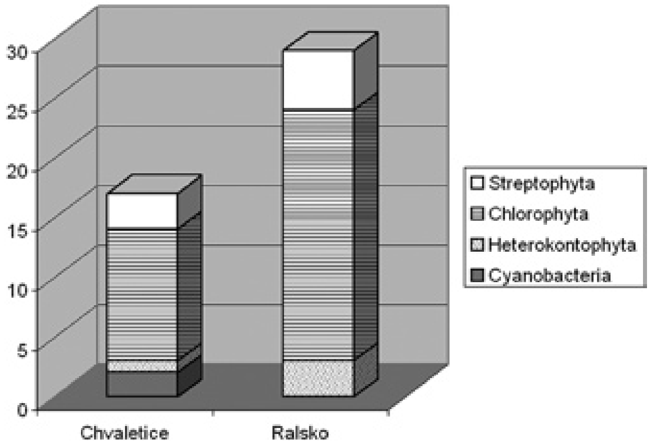



**Fig. 4.2.2.** Species richness expressed as the number of taxa found in each locality. Assignment of taxa to the four algal groups is displayed.

Since the same sampling sites were investigated in 2005 and 2006, the change of species composition during this period can be investigated. DCA ordination plot in Fig. 4.2.4 illustrates the pattern of these changes, connecting graphically the same sampling sites during two years. The diagram obviously indicates greater difference in species composition at Ralsko. The same result is obtained, comparing the average Dice coefficients of the species composition similarities counted for each couple of the samples from the same sampling site, but differing by the date (Chvaletice – 0.713, Ralsko – 0.398). Hence, Ralsko is characterized by a quite large transformation of species composition, which took place between 2005 and 2006. However, we did not determine any common pattern in the year-on-year shift in species composition, either in Ralsko (CCA analysis, p-value 0.83), nor in Chvaletice (CCA analysis, p-value 0.22). Therefore, even if some differences on species composition were observed in both localities, these have no common pattern and are caused rather by a unique, stochastic change within each sampling site.

Finally, the DCA ordination was performed to illustrate the correlation of measured physico-chemicals characteristics as well as their correlation with the observed differences in species composition of investigated samples (Fig. 4.2.5). Differences in the algal composition of Chvaletice and Ralsko well correspond to the diverse values of conductivity, phosphorus concentration (both higher in Chvaletice) and nitrogen concentration (higher in Ralsko). Further, the higher rates of nitrification, nitrate ammonification and chlorophyll a concentration advert to the accelerated biological activity in Ralsko.

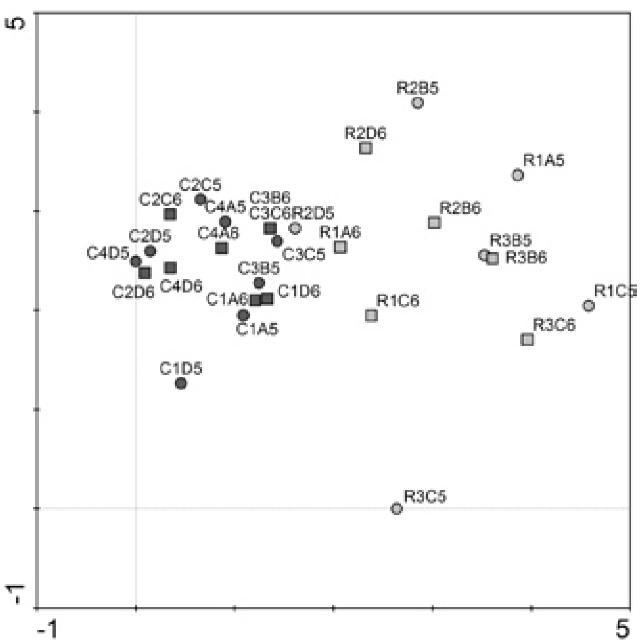



**Fig. 4.2.3.** DCA ordination diagram showing the position of samples in the range of the first two ordination axes (dark – Chvaletice, bright – Ralsko; circle – 2005, square – 2006).

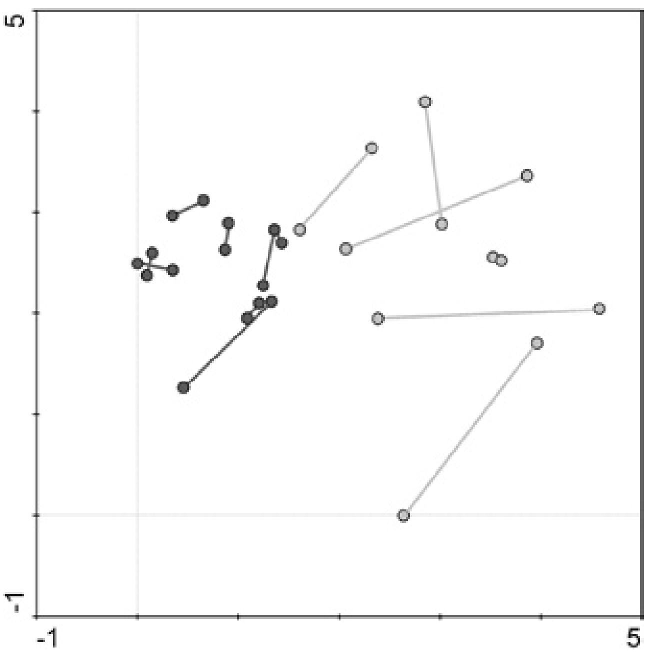



**Fig. 4.2.4.** DCA ordination diagram showing the position of samples in the range of the first two ordination axes (dark – Chvaletice, bright – Ralsko). The same sites sampled in 2005 and 2006 are connected to illustrate the year-on-year changes in the species composition.

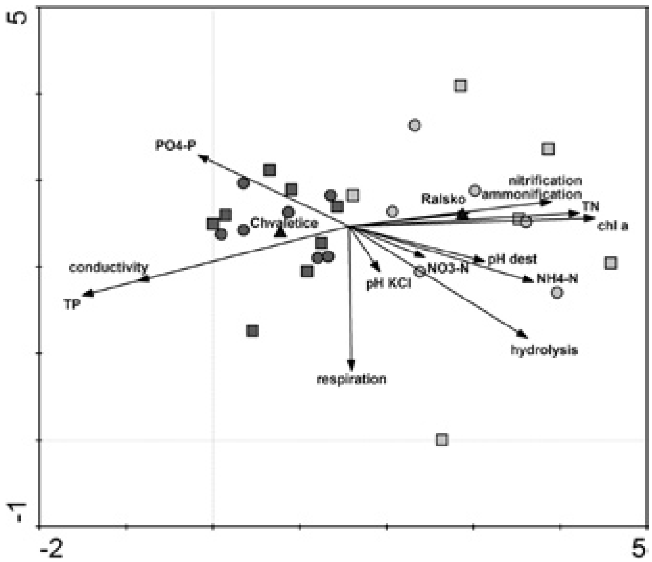



**Fig. 4.2.5.** DCA ordination diagram showing the position of samples and environmental characteristics in the range of the first two ordination axes (dark – Chvaletice, bright – Ralsko; circle – 2005, square – 2006).

### *Floristics*

The following pages provide detailed descriptions of several interesting taxa found in the investigated localities (see also Figs 4.2.6, 4.2.7).

***Myrmecia* sp.** (Figs 4.2.7a–c)

A very remarkable coccal green alga was determined in several sampling sites in Chvaletice. It was characterized by always spherical cells with smooth cell walls. The young cells contained one parietal incised chloroplast. In mature cells, the chloroplast divided into several flat parts, lying parietally beneath the cell wall. Occasionally, the flat chloroplasts forming the second layer below the first one could locally appear. The cells were uninucleate, with well visible nucleus and nucleolus. Almost always, a large distinct vacuole was situated near the cell centre and nucleus. The cells reached 15(–19) μm in diameter. The asexual reproduction took place by means of 8–32 spherical autospores. It is noteworthy that the cells were determined only from the agar plates with WC cultivation medium.

The taxonomic position of this organism is unclear. Cell dimensions and parietal position of chloroplast corresponds to the definition of *Myrmecia* (Ettl & Gärtner 1995). However, *Myrmecia* contains only one chloroplast, though distinctively incised in some species. The same could be stated to distinguish it from genus *Lobosphaera*. Possession of several chloroplasts per cell is typical for *Muriella* species. These, however, generally do not reach the dimensions of the observed alga. Moreover, in *Muriella* the distribution of chloroplasts is simpler than observed in investigated alga, constituting only one chloroplast layer beneath the cell wall. The genus *Bracteacoccus*, typical by large cells possessing many chloroplasts, is characterized by multinuclear cells. However, we always observed only single nucleus per cell.

Accordingly, we are not able to determine either the specific epithet or the generic name of observed alga. However, the characteristic morphology incongruent with any described algal species refers to the discovery of a still undescribed green algal genus.

***Watanabea* sp.** (Figs 4.2.7f–i)

In all but one sampling site in Chvaletice, we determined the distinct green coccal alga *Watanabea* sp. In 11 samples, it forms a dominant component of the algal community. The cells were characterized by spherical to oval shape; with dimensions varying in the range of 6–14 x 5–12 μm. Cell wall was smooth. Cells were uninucleate, possessing single chloroplast with distinct pyrenoid. Chloroplast was parietal, initially discoid, sometimes becoming band-shaped. At maturity, chloroplast developed into more complex stage, either parietal with the incisions and long sub-plasmatic chloroplast lobes or axial with short irregular lobes spreading the cell periphery. Asexual reproduction took place by autospores, two to four spherical spores or 8–32 ellipsoidal to cylindrical spores produced per sporangium.

The above-characterized organism corresponds morphologically well with the definition of *Watanabea*, the relatively recently described green algal genus of Trebouxiophyceae (Hanagata et al. 1998). In particular, the pattern of asexual reproduction is identical for both organisms. In *Watanabea*, cells are similarly reproduced by means of two types of aplanospores, the spherical S-form and elliptical E-form ones. However, the only described species of *Watanabea*, *W. reniformis*, is characterized by the chloroplast without pyrenoid. Since we observed a distinct pyrenoid within the chloroplast, investigated alga probably represent a new species of the genus *Watanabea*. However, a confident taxonomic position of this strain could be solved only with the appropriate aid of the molecular biology techniques.

***Kentrosphaera gibberosa*** Vodenicarov et Benderliev

*Kentrosphaera gibberosa* has been determined in two sampling sites in Ralsko, in both years of study. Large cells of linear, lanceolate, ovoid, globular or irregular shape contained one massive, axile chloroplast, which contained several pyrenoids. Pyrenoids were arranged in a row or equally distributed around the nucleus. Cells were always uninucleate, with the nucleus lying in the central area of the cell. Cell wall was thick, with characteristic lamellate thickenings of the cell wall. Asexual reproduction took place by numerous spherical autospores. This species is considered to be relatively rare, occurring sporadically in aquatic or terrestrial environments (Punčochářová 1992).

According to Wujek & Thompson (2005), *K. gibberosa* is not a valid name yet, since *Kentrosphaera* should be considered as a synonym of *Scotinosphaera*, a green alga described two years earlier (Klebs 1881). Hence, a new combination *Scotinosphaera gibberosa* should be used according to their opinion. However, we do not agree with the presented synonymisation of *Kentrosphaera* and *Scotinosphaera*, mainly because of some distinct incongruencies in the description of these two genera. For example, *Scotinosphaera* was described as having a parietal chromatophor forming a layer round the whole cell, containing many pyrenoids (Klebs 1881; Blackman & Tansley 1902). In *Kentrosphaera*, however, a single axial chloroplast with few to several pyrenoids was described. It is possible that Klebs (1881) coincidentally described „*Kentrosphaera*" in the stage of zoosporogenesis. This stage is characteristic in possessing many parietal chloroplasts with single pyrenoids. However, we cannot be sure about it and the above-mentioned synonymisation is therefore questionable. Instead, we rather use the generic concept of *Kentrosphaera* sensu Punčochářová (1992).

***Ulothrix tenerrima*** Kützing (Fig. 4.2.7j)

Long filaments of *Ulothrix tenerrima* were found in three sampling sites in Ralsko. In 2006, they even formed a dominant compound of algal flora in the sampling site R3B. The filaments consisted of cylindrical cells with ring-shaped chloroplast and one indistinct pyrenoid. The cell wall was rather thin locally, however, with dominant H-shaped cell wall thickenings. Cells were 7–8 µm wide and 2–7 µm long.

This predominantly freshwater species was rarely recorded from various terrestrial biotopes in Australia, England and USA (Cameron 1964; Ettl & Gärtner 1995). Interestingly, it was determined as a natural compound of desert biological soil crust communities at Camp Floyd State Park in Utah (Johansen et al. 1984).

## CONCLUSIONS

We compared algal communities between the biological soil crusts in Chvaletice ore-sedimentation basin and the former military airport near Ralsko. With 27 determined taxa, Ralsko was detected to be more species-rich than Chvaletice (only 17 species determined). Algal composition significantly differed between the localities, but some similarities could be found. In both localities, the members of Chlorophyta comprised a majority of all determined taxa, with no diatoms and scarcely any cyanobacteria found. In Ralsko, we noted large differences of species compositions, comparing the samples in 2005 and 2006. However, these differences do not show any common pattern on a scale of the whole locality; and are caused rather by a unique, stochastic change within each sampling site.

# 4.3. Species composition and diversity of lichens and bryophytes

ONDŘEJ PEKSA & ZDENĚK SOLDÁN

## INTRODUCTION

This chapter contains the results of repeated investigation of terricolous lichens growing in permanent sampling plots in sedimentation basin Chvaletice and in the area of former airport Ralsko. The comparison between lichen and bryophyte floras of these localities is provided.

## MATERIALS AND METHODS

Terricolous lichens and bryophytes associated with biological soil crusts (growing on soil and plant debris) were investigated in the years 2005–2007 on permanent sampling squares in localities of the Chvaletice sedimentation basin (16 squares grouped in 4 quaternion – CH1A to CH4D) and Ralsko airport (12 squares grouped in 3 quaternion – R1A to R3D). The lichens were determined in the field as well as in the laboratory using routine lichenological methods. Two related taxa *Cladonia rei* and *C. subulata* were not distinguished in this investigation, the designation *Cladonia subulata* s.l. was used. The cover was estimated more accurately only by the species with conspicious thallus (*Cladonia*, *Peltigera*, *Placynthiella*, etc.). The bryophytes were determined in the field only due to their low number and no problems with the determination.

For determination of collected specimens of lichens the works of Coppins (1983, 1987), Giralt et al. (1993), Purvis et al. (1992), Tønsberg (1992), Wirth (1995) and other taxonomic publications have been used. The nomenclature of lichens follows Santesson et al. (2004) or respective works included in references. The nomenclature of bryophytes follows Kučera & Váňa (2004). All collected specimens have been deposited in the PL (lichens and bryophytes) and PRC (bryophytes).

## RESULTS AND DISCUSSION

A total of 24 lichen taxa were recorded in sampling squares in two investigated localities (Table 4.3.1.). Comparing the species richness of both the localities, Ralsko has obviously less taxa than Chvaletice (40/22), however, in sampling sites similar number of species were found (13/16). (The number of lichens observed in 12 sampling squares in

**Table 4.3.1.** The list of species recorded in sampling squares during the years 2005–2007: Abb. – the abbreviations of species names, **1** – Chvaletice sedimentation basins, **2** – Ralsko airport.

| | Abb. | 1 | 2 |
|---|---|---|---|
| **lichens** | | | |
| *Bacidina* sp. | Bacsp | + | |
| *Cetraria aculeata* | Cetac | | + |
| *Cladonia cervicornis* | Clcer | | + |
| *Cladonia chlorophaea* | Clchl | + | + |
| *Cladonia coccifera* | Clcoc | + | + |
| *Cladonia coniocraea* | Clcon | + | |
| *Cladonia furcata* | Clfur | | + |
| *Cladonia gracilis* | Clgrac | | + |
| *Cladonia macilenta* | Clmac | + | + |
| *Cladonia pyxidata* | Clpyx | | + |
| *Cladonia ramulosa* | Clram | | + |
| *Cladonia subulata* s.l. | Clsub s.l. | + | + |
| *Diploschistes muscorum* | Dimus | + | |
| *Micarea denigrata* | Mic sp | + | |
| *Micarea* sp. | Micden | + | |
| *Peltigera didactyla* | Pedid | + | |
| *Placynthiella dasaea* | Pldas | | + |
| *Placynthiella icmalea* | Plicm | | + |
| *Placynthiella oligotropha* | Ploli | | + |
| *Placynthiella uliginosa* | Pluli | | + |
| *Thelocarppon* sp. | Thesp | + | |
| *Thrombium epigaeum* | Threp | + | |
| *Trapeliopsis granulosa* | Trgra | | + |
| *Vezdaea acicularis* | Vezac | + | + |
| **bryophytes** | | | |
| *Cephaloziella divaricata* | Cediv | | + |
| *Cephaloziella hampeana* | Ceham | + | |
| *Ceratodon purpureus* | Cerpur | + | |
| *Polytrichum juniperinum* | Pojun | | + |
| *Polytrichum piliferum* | Popil | | + |

Ralsko represents 69,5% of total lichen flora in the locality, however, in the Chvaletice sedimentation basin it is only 32.5% for 16 squares. Simultaneously, 9 species (from 16) were found in more then 75% of investigated squares in Ral-

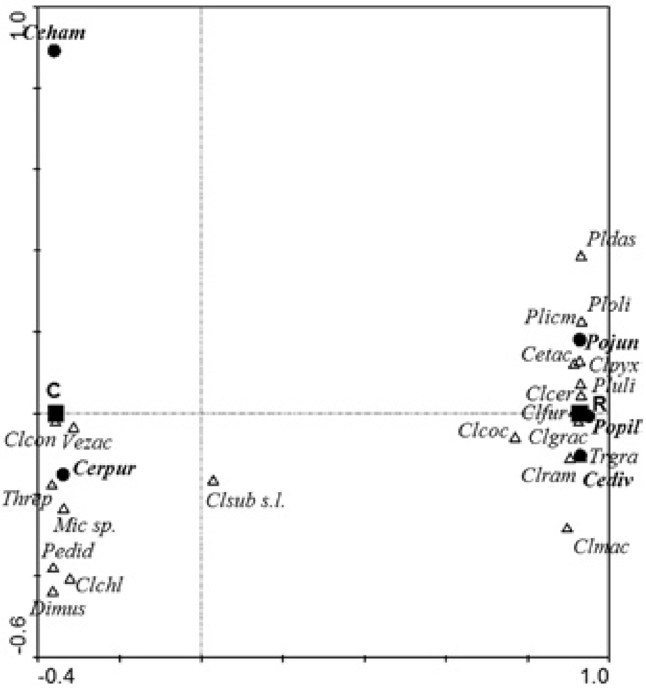



**Fig. 4.3.1.** CCA ordination diagram showing the relationship among species and localities (black square, **C** – Chvaletice, **R** – Ralsko; triangle, italic – lichens, black circle, bold italic – bryophytes; the abbreviations of species names are included in Table 4.3.1.).

sko, however, only 4 species (from 13) in Chvaletice. These divergences are probably related to the differences in character of each locality. The Chvaletice sedimentation basin is a larger and more diversified area compared with the smaller and relatively homogenous area in Ralsko (in Chvaletice, there occur more types of small-scale areas of different substrates and microclima).

The species diversity of bryophytes on permanent sampling squares – compared with lichens – is distinctly lower: only 3 bryophytes have been collected in Ralsko (2 mosses and 1 liverwort) and 2 bryophytes in Chvaletice (1 moss and 1 liverwort). Range of cover was very wide: between 0–90%!

Species composition of lichen and bryophyte flora in both the localities distinctly differed at first sight. This observation was confirmed by the CCA analysis, which significantly differentiated both localities on the basis of lichen flora (p-value 0.002, Fig. 4.3.1.).

The same sampling sites were investigated over three years (2005–2007) as was any change in species composition. The CCA analysis shows the distinct changes of species composition during the three years (with localities and effect of disturbance using as covariates: for lichens only p-value = 0.032, for bryophytes only p = 0.004, for lichens and bryophytes together p = 0.012). However, these changes are not related with the disturbance experiment done in 2005 in half the sampling squares (the CCA analysis did not confirm the effect of disturbance, p-value = 0.73). We did not observe any other influence except executed disturbance in sampling sites, which could induce the changes in species composition. Thus, the community of pioneer species occurring in both localities is evidently able to change itselfs relative quickly (during 2 years). Probably the changes could be influenced by a variety of enviromental factors, headed by climatical differences over separate years (e.g. increase of microlichens in more humid years). The ability of lichens and bryophytes to form on mechanically disturbed squares analogous with communities on natural squares over a relatively short time shows a very strong effort to regenerate from rests of thalluses as well as capabillity to spread from surroundings, especially by vegetative way.

## CONCLUSIONS

Lichen and bryophyte communities forming biological soil crusts were investigated in sampling squares delimited in the Chvaletice sedimentation basin and the former military airport near Ralsko. The lichen and bryophyte flora distinctly differ between the two localities. The sandy area near the runway in Ralsko airport was detected more homogenous in term of lichen species composition than the Chvaletice basin – in sampling squares (in total 12 $m^2$) was found almost 70% of total lichen flora in locality comparing with 32.5% in Chvaletice. This phenomenon is probably related with higher substrate and microclimatical diversity in the Chvaletice sedimentation basin. We observed distinct changes of species composition in the sampling sites during three years, which show the ability of pioneer cryptogamic community to change itself relatively fast without any apparent change of conditions in the habitat.

# 4.4. Species composition and diversity of fungi

ALENA KUBÁTOVÁ & KAREL PRÁŠIL

## INTRODUCTION

In this chapter we present results of a two-year study dealing with the effect of mechanical disturbance on species composition and diversity of fungi in biological soil crusts on two different localities, where a previous preliminary study of microfungal communities had been made, i.e. on the abandoned ore-washery sedimentation basin at Chvaletice and on an unforested area near the former military airport near Ralsko.

## MATERIALS AND METHODS

Localities and sampling of biological soil crusts: Sampling was made in November 2005 and November 2006 on Chvaletice and Ralsko localities (see Figs 4.1, 4.2). For the characteristics of the localities, see above in the Chapter 4. For the mycological analysis, the same material of biological soil crusts was used as for studying of algae and cyanobacteria. For the sampling pattern see Chapter 4. At Chvaletice and Ralsko, soil crust samples from four and three square plots were taken, respectively. One half of the samples originated from undisturbed nonseeded subplots and one half from disturbed nonseeded subplots. In total, 16 samples of crusts from Chvaletice locality and 12 samples from Ralsko were processed.

Cultivation and identification: Microscopic fungi in biological soil crusts were studied by the cultivation methods described in the Chapter 2.4. For isolation of fungi, three agar media were used: soil agar with rose Bengal and glucose (SEGA), wort agar (WA), and Sabouraud's agar (SAB), all with streptomycin (0.1 g/l) (Fassatiová 1986). Thus, one sample of biological soil crust was inoculated on 12 isolation Petri dishes.

Identification of soil micromycetes was made according to the literature cited in the Chapter 2.4. and according to Ellis (1971), Cannon & Hawksworth (1982), Ramírez (1982), and Arx et al. (1986). Several fungal strains were deposited at Culture Collection of Fungi (CCF), Department of Botany, Charles University, Prague, Czech Republic (see in Tab. 4.4.1).

Statistical methods: Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were performed using Canoco 4.5 (Ter Braak & Šmilauer 1998) to ordinate localities based on their microfungal composition.

## RESULTS AND DISCUSSION

In Tables 4.4.1 and 4.4.2, microfungi isolated during 2005–06 from disturbed and nondisturbed biological soil crusts on localities Chvaletice and Ralsko are listed. Altogether 46 and 31 taxa (species, forms, and undetermined isolates) of microscopic fungi were recorded from Chvaletice and Ralsko, respectively. The higher figure of microfungal species isolated at Chvaletice compared to Ralsko is probably due the higher number of samples processed (16 versus 12 samples). At Chvaletice, a survey of diversity of microfungi occurring on industrial deposit was made several years ago (Kubátová et al. 2002). During this study, 94 fungal species was recorded, based on 52 samples processed. The higher number of detected microfungi is again obviously due to the higher number of samples processed during the study published in 2002.

As concerns nondisturbed and disturbed subplots at Chvaletice and Ralsko (see Tables 4.4.1 and 4.4.2), overall species richness was similar (35 and 36 fungal taxa in Chvaletice, respectively, and 26 and 25 fungal taxa in Ralsko, respectively). Species richness on individual subplots was in the range of 4–16 fungi recorded.

The majority of the fungi isolated at Chvaletice are anamorphs of Ascomycota (38 taxa, 86%); six taxa (14%) belong to Zygomycota. The most frequent genus was *Penicillium* (10 species). At Ralsko anamorphs of Ascomycota were also prevailing (26 taxa, 90%); three taxa (10%) belonged to Zygomycota. The *Penicillium* again was the richest genus (12 taxa). Similar terms as concerns ascomycetes and zygomycetes we found on other localities studied (see Chapter 2.4. and 3.6.). They are similar to data cited in studies dealing with soil microfungi and using conventional isolation methods.

The most frequent fungi of biological soil crusts at Chvaletice were *Trichoderma* spp., *Trichoderma virens*, sterile dark mycelia, *Penicillium janthinellum* (Fig. 4.4.1a), *P. crustosum*, *P. pulvillorum* (Fig. 4.4.1b), *Polyscytalum* sp. (Fig. 4.4.1c), *Penicillium simplicissimum*, and *P.* cf. *coalescens* (Fig. 4.4.1e). A spectrum of these dominant fungi share four species (*Penicillium janthinellum*, *P. simplicissimum*, *Trichoderma* spp., and *T. virens*) with dominants found in substrate of this abandoned ore-washery basin several years ago (Kubátová et al. 2002). We consider these fungi as highly tolerant to stress factors on the studied localities. Among

**Table 4.4.1.** Chvaletice (**C1–C4**) – a list of microscopic fungi isolated from disturbed (**D**) and nondisturbed (**N**) biological soil crusts in 2005 and 2006.

| Microscopic fungus | C1N | | C2N | | C3N | | C4N | | CN | | C1D | | C2D | | C3D | | C4D | | CD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 | 05 | 06 |
| *Acremonium berkeleyanum* | 2 | | | | | | | | + | | 2 | | | | | | | | + | |
| *Acremonium* sp. | | | | 1 | | | | 1 | | + | | 1 | | | | | | | | + |
| *Alternaria* cf. *alternata* | | | | | | | | | | | | | | | | | 1 | | + | |
| *Arthrinium arundinis* | | | | | | | 1 | | + | | | | | | | | | | | |
| *Arthrinium phaeospermum* | | | 1 | | | | | | + | | | | | | | | 1 | | + | |
| *Aspergillus* section Fumigati | | | | | | | | | | | | 1 | | | | | | | | + |
| *Aureobasidium pullulans* | | | | | | | | | | | | | | | | | 1 | | + | |
| *Bipolaris sorokiniana* | 1 | | | | | | | | + | | | | | | | | | | | |
| *Cladosporium cladosporioides* | | 1 | 1 | 1 | | | | | + | + | | 1 | 1 | | | | | | + | + |
| *Cladosporium herbarum* | | | | | | | 1 | | + | | | 1 | | | | | | | | + |
| *Cladosporium sphaerospermum* | | | | 1 | | | | | | + | | | | | | | | | | |
| *Epicoccum nigrum* | | | | | | | | | | | 1 | 1 | | | | | 2 | | + | + |
| *Fusicladium* sp. | | | 1 | | | | | | + | | | | | | | | | | | |
| *Lecanicillium psalliotae* | | | | | | | | | | | | 1 | | | | | | | | + |
| *Lecanicillium* sp. | | 1 | | 1 | | 1 | | | | + | | | | 2 | | | | | | + |
| *Mortierella* sp. | | 1 | | 1 | | 1 | | | | + | | 1 | | | | | | | | + |
| *Mucor hiemalis* f. *hiemalis* | 1 | | | | | | | | + | | | | | | | | | | | |
| *Mucor* sp. | | 1 | | | | | | | | + | | 1 | | | | | | | | + |
| *Oidiodendron* sp. | | | | | 2 | | | | + | | | | 1 | | | | | | + | |
| *Paecilomyces inflatus* | | | 1 | | | | | | + | | | | | | | | | | | |
| *Paecilomyces lilacinus* | | | 2 | | | | | | + | | | | | | 1 | | | | + | |
| *Penicillium* cf. *coalescens* | | | | | 2 | | | 1 | + | + | 1 | | | | 1 | 2 | | | + | + |
| *Penicillium citreonigrum* | | | | | | | 1 | | + | | | | | | | | | | | |
| *Penicillium crustosum* | | 1 | | 1 | | 1 | | 2 | | + | 1 | 1 | | 1 | | 1 | | | + | + |
| *Penicillium chrysogenum* | | | 1 | | | | | | + | | | | | | | | | | | |
| *Penicillium janthinellum* | 1 | | 1 | 1 | 1 | 1 | | | + | + | 2 | | 1 | | 2 | 2 | 1 | | + | + |
| *Penicillium olsonii* | | | | | | | | | | | | | | 1 | | | | | | + |
| *Penicillium pulvillorum* | 1 | | | | 1 | 1 | | | + | + | 1 | 1 | | | 1 | 1 | | | + | + |
| *Penicillium sacculum* | | | | | | | | | | | | | | | | | 1 | | + | |
| *Penicillium simplicissimum* | | 2 | 1 | | 2 | | | | + | + | | | | | | | 2 | | + | |
| *Penicillium* spp. (2) | | 1 | | | | | | | | + | | | | | 1 | | | | + | |
| *Phoma* sp. | | 2 | | | | | | | | + | | 1 | | | | | 1 | | + | + |
| *Pithomyces chartarum* | | | | | | | | | | | | | | | | | 1 | | + | |
| *Polyscytalum* sp. | | 1 | 2 | 1 | 1 | 1 | | | + | + | | | | | | | | 1 | | + |
| *Sphaerodes fimicola* | | | | | | | 1 | | + | | | | | | | | | | | |
| *Sporormiella* sp. | | | | | | | | | | | | 1 | | | | | | | | + |
| sterile dark mycelia | | | 1 | 1 | 1 | 1 | | | + | + | | 1 | | | | | 1 | 1 | + | + |
| sterile light mycelia | | | | 1 | | | | | | + | 1 | | | | | | | | + | |
| *Trichoderma harzianum* | | 2 | | | | | | | | + | | 2 | | | | | 1 | | + | + |
| *Trichoderma virens* | 1 | 2 | | 2 | 1 | 2 | 1 | 2 | + | + | 2 | 2 | 2 | 2 | | 2 | | 2 | + | + |
| *Trichoderma* spp. (2) | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | + | + | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | + | + |
| *Umbelopsis angularis* | | | | | | | | | | | 1 | | | | | | | | + | |
| *Umbelopsis isabellina* | | | 1 | | | 1 | | | + | + | | | | | 1 | 1 | 1 | | + | + |
| *Umbelopsis ramanniana* | | | | | | | | | | | 1 | | | | | | | | + | |
| **No. of taxa on several subplots** | **7** | **12** | **12** | **12** | **9** | **10** | **6** | **5** | | | **11** | **16** | **5** | **5** | **7** | **7** | **13** | **4** | | |
| **Total No. of taxa: 46** | **34** | | | | | | | | **24** | **22** | **36** | | | | | | | | **26** | **23** |

*Note:* **1** = rarely isolated species, **2** = frequent species.

**Table 4.4.2.** Ralsko (**R1–R3**) – a list of microscopic fungi isolated from disturbed (**D**) and nondisturbed biological soil crust (**N**) in 2005 and 2006.

| **Microscopic fungus** | **R1N** | | **R2N** | | **R3N** | | **RN** | | **R1D** | | **R2D** | | **R3D** | | **RD** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **05** | **06** | **05** | **06** | **05** | **06** | **05** | **06** | **05** | **06** | **05** | **06** | **05** | **06** | **05** | **06** |
| *Acremonium berkeleyanum* | 1 | | | | | | + | | | | | | | | | |
| *Acremonium* cf. *strictum* | | | | | | | | | | 1 | | | | | | + |
| *Acremonium* sp. | | 1 | | | | | | + | 1 | | | | 1 | | + | |
| *Alternaria alternata* | | | | | | | | | | | | | 1 | 1 | + | + |
| *Aspergillus clavatus* | | | | | 1 | | + | | | | | | | | | |
| *Chaetomium aureum* | | 1 | | 1 | | 1 | | + | 1 | | | 2 | | | + | + |
| *Cladosporium cladosporioides* | | | 1 | | | | + | | | 1 | | | | | | + |
| *Epicoccum nigrum* | 1 | | 1 | | 1 | | + | | | | | | | | | |
| *Mucor* spp. (2) | 1 | | | | | 1 | + | + | 1 | | | | | 1 | + | + |
| *Penicillium aculeatum* | 1 | 1 | | 1 | 1 | 2 | + | + | 2 | 1 | 1 | 2 | | 2 | + | + |
| *Penicillium brasilianum* | | | 1 | | | | + | | | | | | | | | |
| *Penicillium canescens* | | | | 1 | | | | + | | | | 1 | | | | + |
| *Penicillium chrysogenum* | | | 1 | | | | + | | | | 1 | | | | + | |
| *Penicillium janthinellum* | 1 | 2 | 1 | 2 | 1 | 2 | + | + | | 1 | | 1 | 1 | 1 | + | + |
| *Penicillium miczynskii* | | | | | | | | | | 2 | | | | | | + |
| *Penicillium pulvillorum* | | | 1 | | | | + | | | | | 2 | 1 | | + | + |
| *Penicillium purpurogenum* | | | | | | 1 | | + | | | | | | | | |
| *Penicillium purpurogenum* var. *rubrisclerotium* | | | | | | | | | 1 | | | | | | + | |
| *Penicillium smithii* | 1 | 1 | 1 | 2 | | 1 | + | + | 2 | | | | 1 | 1 | + | + |
| *Penicillium spinulosum* | | | | 1 | | 1 | | + | | 1 | | 1 | | 1 | | + |
| *Penicillium* spp. | 1 | 1 | 2 | 1 | 1 | | + | + | | 1 | 1 | 1 | 1 | | + | + |
| *Pochonia bulbilosa* | | | | 1 | | | | + | 1 | | | | | 1 | + | + |
| *Polyscytalum* sp. | | | 1 | | | | + | | | | | | | | | |
| *Sphaerodes fimicola* | | | | | | | | | | 1 | | | | 1 | | + |
| sterile dark mycelia | | 1 | 1 | 1 | | | + | + | 1 | | 1 | | | | + | |
| *Trichoderma viride* | | 1 | | | | | | + | | 1 | | | 1 | | + | + |
| *Trichoderma spp. (2)* | 2 | 1 | 2 | 2 | 2 | 2 | + | + | 1 | 2 | 2 | 1 | 2 | 2 | + | + |
| *Umbelopsis angularis* | 2 | 2 | 2 | 2 | 1 | 2 | + | + | 1 | 2 | 1 | 2 | 1 | 2 | + | + |
| *Umbelopsis isabellina* | 1 | 2 | | 2 | 1 | 2 | + | + | 2 | 2 | 1 | 2 | | 2 | + | + |
| **No. of taxa on several subplots** | **10** | **11** | **12** | **12** | **8** | **10** | | | **11** | **12** | **7** | **10** | **9** | **11** | | |
| **Total No. of taxa: 31** | **26** | | | | | | **19** | **18** | **25** | | | | | | **19** | **21** |

*Note:* **1** = rarely isolated species, **2** = frequent species.

the above cited frequent fungi, *P. crustosum*, *Polyscytalum* sp., and *P.* cf. *coalescens* fall into unexpected findings. *Penicillium crustosum* is a typical food-borne species; however, though laboratory contamination was excluded, it was found in both studied years. *Polyscytalum* sp., and *P.* cf. *coalescens* belong to a somewhat rare soil and litter fungi. The number of fungi recorded at Chvaletice only sporadically was lower then on other localities studied (see Chapt. 2.4 and 3.6); the majority of them belong to micromycetes known from soil and plant remains (Domsch et al. 1993). Noteworthy among them are *Aspergillus* section Fumigati and *Cladosporium* sp. Isolate of *Aspergillus* section Fumigati probably presents one of the most newly described species in the section Fumigati (Hong et al. 2005), not yet known from the Czech Republic. Isolate of *Cladosporium* sp. is obviously a lesser known species of this common genus. Both isolates will be analyzed by molecular methods.

The dominant microfungi of biological soil crusts at Ralsko appeared to be *Trichoderma* spp., *Umbelopsis angularis*, *U. isabellina*, *Penicillium aculeatum*, *P. janthinellum*, *P. smithii* (Fig. 4.4.1d), *Penicillium* spp., and *Chaetomium aureum*. Compared with the Chvaletice locality, it is a different spectrum of fungi, sharing only one species, *Penicillium janthinellum*. The high occurrence of this species is considered as evidence of some stressing factors at this site. Other species like *Umbelopsis angularis*, *U. isabelina* or *P. smithii* were found often on natural localities (e.g. Šumava Mts., Kubátová et al. 1998). On the other hand, *P. aculeatum* is rather rare species (Pitt 1979) as well as *Chaetomium aureum*. This fungus is known from natural substrates. However, it was isolated also from soils and litter polluted with radionuclides near Chernobyl, Ukraine and is considered a bioindicator of radionuclide polluted soils (Zhdanova et al. 1995, 2001, 2005). In our country it was found for the first time (see Kubátová 2006). Looking at the microfungal community at Ralsko, we can consider this locality similar to natural localites, influenced some stress factors however.

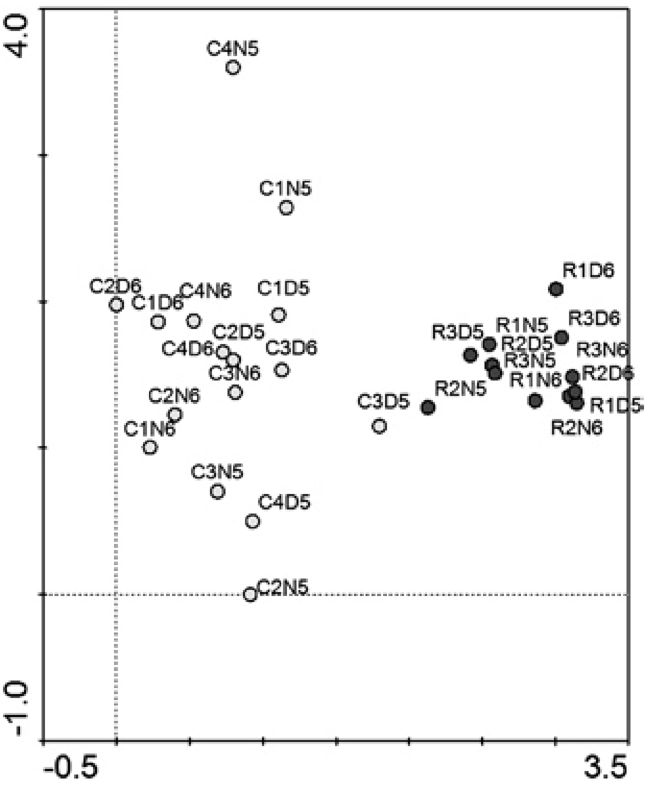



**Fig. 4.4.2.** Testing of differences in fungal species richness and composition of biological soil crusts on disturbed and nondisturbed subplots at Chvaletice and Ralsko during two years. DCA ordination diagram showing the position of samples in the range of the first two ordination axes (**C1–C4** = Chvaletice, **R1–R3** = Ralsko, **D** = disturbed subplots, **N** = nondisturbed subplots, **5** = 2005, **6** = 2006).

Species composition of fungal communities recorded at Chvaletice and Ralsko is generally very different. From 16 sharing species, only one species is dominant for both sites (*Penicillium janthinellum*). The CCA analysis of species richness and composition significantly differentiated both sites (p-values 0.0005). For comparison of species richness and composition using DCA, see diagram (Fig. 4.4.2). The CCA analysis testing difference in species composition during two years of sampling (2005 and 2006) significiantly confirmed great differences in species composition between samples processed in the different years, although the p-values were higher than in the case of locality effect testing (p-values 0,001). The effect of disturbance on species composition tested by paired T-test proved to be not significant (0.72).

## CONCLUSIONS

Microfungi isolated from biological soil crusts of the abandoned ore-washery basin at Chvaletice and from an unforested site near former military airport Ralsko, belong mostly to the soil and litter fungi similarly as in previous studies. On both localities, only small differences were found in fungal species richness recorded on disturbed and nondisturbed subplots. Species composition of fungal communities recorded at Chvaletice and Ralsko proved to be very different. On both localities, more dominant species of fungi were recorded than on localities in previous studies. Among the dominant fungi of biological soil crusts at Chvaletice are fungi considered as stress tolerant. The fungal species composition of biological soil crusts in Ralsko is closer to that of natural forested habitats.

Significant differences in fungal species composition were proved among biological soil crusts sampled in different years. In Ralsko, the interesting radionuclide tolerant fungus *Chaetomium aureum* was found. It is the first report of this fungus for the Czech Republic.

# 4.5. Ecology of biological soil crusts in relation to mechanical disturbance

JIŘÍ NEUSTUPA & KATEŘINA ČERNÁ

## INTRODUCTION

In this chapter, we discuss the effects of disturbance treatments (conducted on localities at Ralsko and Chvaletice) on both biotic and abiotic data of biological soil crusts. We report patterns of response to disturbance in individual organismal groups and, finally, we discuss results of this experiment as a whole.

## MATERIAL AND METHODS

The localities, design of an experiment and sampling details are included in the previous chapters. The lichen quantities were counted as a percentage of surface cover that was subsequently divided into four semiquantitative categories. Methods of measuring the abiotic data and ecophysiological characteristics can be found in Chapter 3.2. Statistical analyses of species data involved the significance testing of differences in species composition following the disturbance using Manhattan distances by non-parametric two-group ANOSIM permutation tests with 10 000 permutations (Clarke 1993; Hammer et al. 2001). The differences in species diversity between disturbed and non-disturbed samples in 2006 were evaluated using permutation tests (with 10 000 permutations) on Menhinick diversity index of data sets using a script written in R 2.3.1. (R Core Development Team, 2006). Two-matrices Mantel tests of matrix correlations were used to test for higher similarity in species composition on identical squares between seasons (Mantel 1967). Matrices of Manhattan distances were used to indicate dissimilarity in species composition and they were correlated with matrices of identity (0)/difference (1) in squares assignment. Significance was assessed by 10 000 permutations of original matrices. Ordination plots and graphs were created using SigmaPlot, ver. 9.01, and PAST, ver. 1.74.

The pattern of abiotic and ecophysiological data was illustrated using PCA. The significance of changes in abiotic and ecophysiological data following disturbance was evaluated using pairwise t-tests of 2005/2006 difference in individual factors.

## RESULTS

Species composition of algae and cyanobacteria did not differ significantly between 2005 and 2006 samples in both Chvaletice (ANOSIM p-value = 0.584) and Ralsko localities (ANOSIM p-value = 0.549). At the same time, the 2006 samples did not differ significantly in its algal and cyanobacterial species composition with regard to disturbance effect both in Chvaletice (ANOSIM p-value = 0.656) and Ralsko samples (ANOSIM p-value = 0.399). When looking at diversity indices, we see that average diversity in disturbed plots in 2006 was slightly higher in comparison to undisturbed sites in the Chvaletice locality (Menhinick index for disturbed sites was 3.65, for undisturbed sites 3.16). However, this difference was not significantly different in permutation test on Menhinick index (difference between Menhinick indices of disturbed and undisturbed 2006 sites was 0.486, permutation p-value 0.55). In Ralsko, disturbed plots had lower average biodiversity (Menhinick index for disturbed sites 3.54, for undisturbed sites 5.13). A permutation test demonstrated weak statistical significance of this difference (difference between Menhinick indices of disturbed and undisturbed 2006 sites was 1.587, permutation p-value 0.0347). Species composition in both Chvaletice and Ralsko was highly dependent on square identity (Mantel tests permutation p-values: 0.0003 and 0.0018 respectively), which indicates relative stability of algal and cyanobacterial species composition between seasons – with no regard to disturbance treatment.

When looking at lichen diversity dynamics, we encountered stable species composition in comparison of 2005 and 2006 samples in both Chvaletice (ANOSIM p-value = 0.0707) and Ralsko localities (ANOSIM p-value = 0.072) when using Manhattan distances that took into account quantitative differences in total cover of individual species. However, Dice index that does not take into account the quantitative changes and counts only presences or absences of individual species revealed a significant change between 2005 and 2006 (Chvaletice: ANOSIM p-value = 0.0044, Ralsko: ANOSIM p-value = 0.0191). The 2006 lichen samples did not differ significantly in species composition with regard to disturbance both in Chvaletice (ANOSIM p-value = 0.63) and Ralsko samples (ANOSIM p-value = 0.698). Average lichen diversity in disturbed plots in 2006 was not significantly different from undisturbed sites in both localities (Chvale-

**chybí obrázek 4.5.1**
**Fig. 4.5.1.** The PCA ordination diagram of abiotic data.
**Dodáte, nebo přečíslovat???**

tice: permutation p-value on Menhinick index = 0.8485, Ralsko: permutation p-value on Menhinick index = 0.6712).

The microscopic fungi species composition changed highly significantly between 2005 and 2006 samples in Chvaletice (ANOSIM p-value = 0.003) and in Ralsko (ANOSIM p-value = 0.009). The 2006 samples did not differ in their species composition with regard to disturbance effect in Chvaletice (ANOSIM p-value = 0.83) and in Ralsko (ANOSIM p-value = 0.189). Fungi diversity in disturbed plots in 2006 was not significantly different from undisturbed sites in both localities (Chvaletice: permutation p-value on Menhinick index = 0.565, Ralsko: permutation p-value on Menhinick index = 0.421).

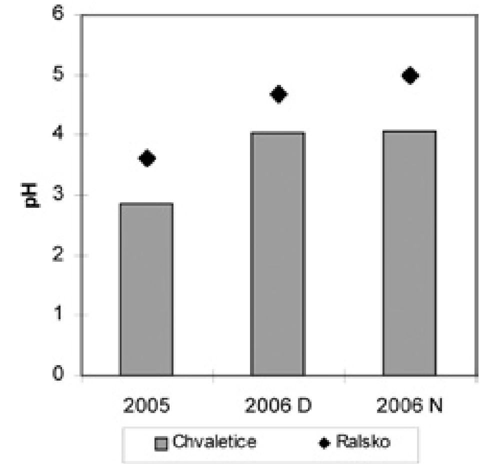



**Fig. 4.5.2.** The pH values at the Chvaletice and Ralsko localities in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

The principal component analysis of abiotic data demonstrated profound change in parameters of the Chvaletice locality between 2005 and 2006 samples (Fig. 4.5.1). On the other hand, Ralsko samples were much more homogenous across seasons (Figs 4.5.2–4.5.7). The Chvaletice samples consistently had more total phosporus concentrations, whereas in Ralsko, most quantitative parameters of biotic activity had higher values, which were reflected by the position of individual localities along the first PC axis. The pairwise t-tests of individual parameters revealed significant difference in change of chlorophyll *a* concentrations at the Ralsko locality, where disturbance lowered increase in this parameter (p-value = 0.011). In addition, hydrolysis activity decreased more distinctly on disturbed sites at Ralsko (p-value = 0.038). The differences in changes of other parameters were not significant.

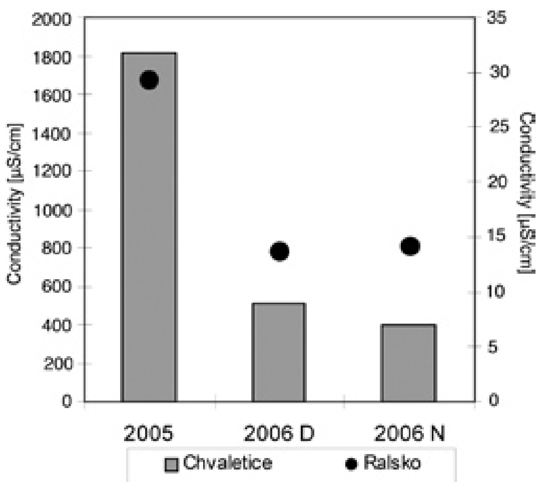



**Fig. 4.5.3.** The values of conductivity in Chvaletice and Ralsko in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

## DISCUSSION

We have detected profound differences in seasonal stability of species composition between individual major organismal groups. Algae and cyanobacteria largely had a very stable composition at both localities and lichens were relatively stable, too. However, species of microscopic fungi changed profoundly in 2006, when compared with the year 2005. This pattern nicely corresponds with the assumption that cyanobacteria, algae and lichens are the major constituents of biological soil crusts (Evans & Johansen 1999; Belnap & Lange 2001), whereas microscopic fungi form a more or less random and very fluctuating part of crust ecosystems with a significant proportion of allochthonous species.

In their review, Evans and Johansen (1999) illustrated importance of algae and cyanobacteria for biological soil crusts in semiarid ecosystems. They noted the effect of algal

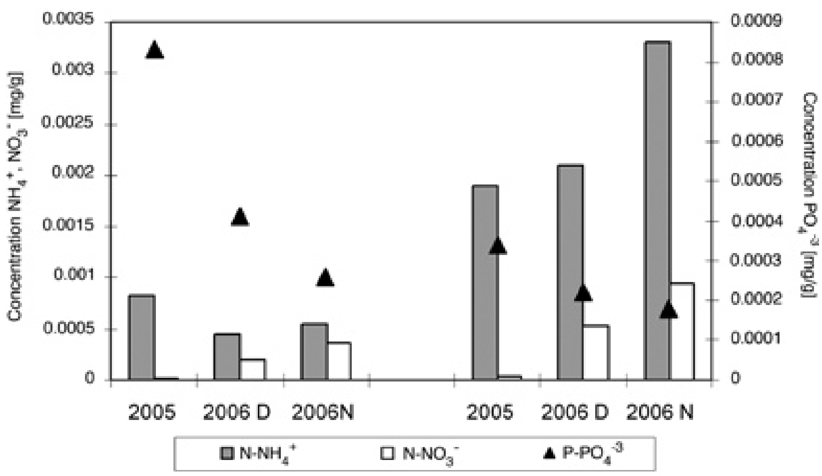



**Fig. 4.5.4.** Concentrations of N-$NH_4^+$, N-$NO_3^-$, P-$PO_4^-$ ions in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

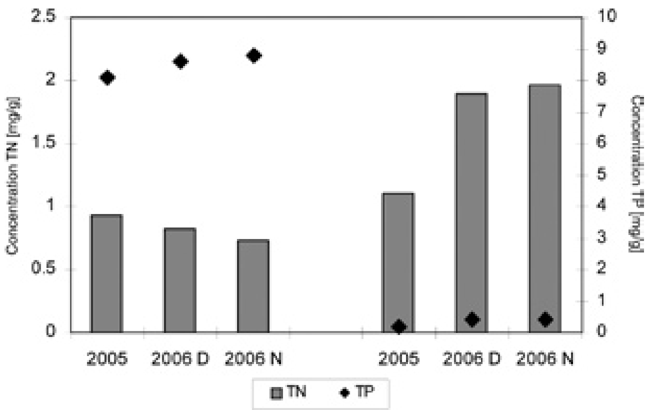



**Fig. 4.5.5.** TN and TP values measured in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

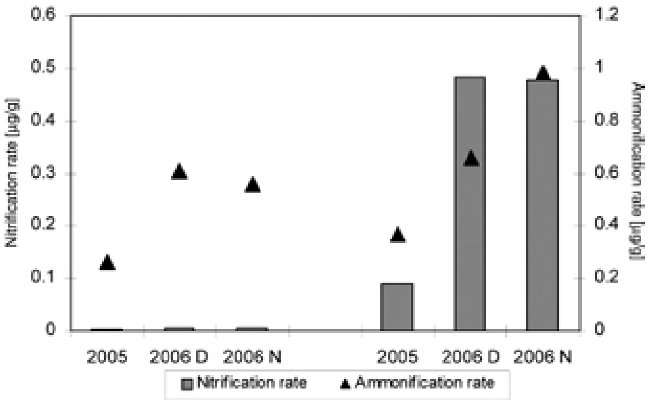



**Fig. 4.5.6.** The ammonification and nitrification rates detected after incubation of soil samples from investigated Ralsko and Chvaletice localities in 2005 and 2006 on disturbed (**D**) and non-disturbed (**N**) experimental plots.

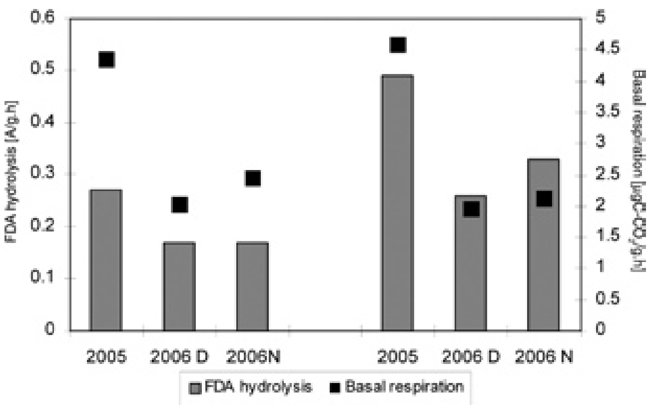



**Fig. 4.5.7.** Basal respiration and FDA hydrolysis of microbial communities measured in Ralsko and Chvaletice in 2005 and 2006 on disturbed (**D**) and non-disturbed **(N)** experimental plots.

mucilaginous sheath for stabilization of a crust and the role of nitrogen-fixing cyanobacteria in increasing trophic level of the substrate. Negative effect of mechanic disturbance on productivity and taxonomic structure of natural desert crusts was several times demonstrated (Hodgins & Rogers 1997; Johnston 1997; Eldridge & Koen 1998; Belnap 2002; 2003). However, in our study one year after disturbance we did not encounter any significant effects of mechanical destruction of the crust cover on diversity. The profound disturbance effect on desert crusts has mainly been related to wind and water erosion that increased in generally arid environment after the compact crust cover was destructed (Eldridge & Leys 2003; Belnap et al. 2007). In addition, drought stress hampers development of vascular plant cover at such localities. On the other hand, the crusts of industrial sedimentation basins are determined rather by toxicity of the substrate which limits vascular plant vegetation. Most of the investigated localities exceeded the permissible toxicity levels for non-agricultural soils in many toxic elements (Czech Ministry of Environment 1994). The cadmium levels were generally higher than 0.001 $mg \cdot g^{-1}$ of a substrate, delimited as the maximum permissible level for non-agricultural soils in Czech Republic. The cadmium concentrations were considerably higher than the comparable levels of natural European soils (Chlopecka et al. 1996; Abollino et al. 2002; Gil et al. 2004; Papadopoulos et al. 2007). In addition, the low organic matter and high clay content (Rauch 2004) of sedimentation basin substrates facilitate cadmium bioavailability (Prokop et al. 2003). Concentrations of copper exceeded the 0.1 $mg \cdot g^{-1}$ maximum level for non-agricultural soils in the Czech Republic in both the ash sedimentation localities and in the Radvanice ore sedimentation basin site, where, in addition, the Pb-levels reached the maximum permissible level. The manganese levels were rather low in comparison with Mn-loaded sites (Paschke et al. 2005; Li et al. 2007) with the exception of Radvanice locality which contained levels comparable with those of waste soils of Mn-ore mines (Li et al. 2007). Thus, we believe that toxicity of industrial substrates is crucial in development of biological soil crust instead of vascular plant communities. In such conditions, one-time mechanical disturbance does probably not necessarily lead to change of the algal and lichen community as competition of vascular plants is low. However, our disturbance experiments were conducted on a limited set of plots and on a single locality (Chvaletice ore sedimentation basin) so that we cannot preclude significant disturbance effects in differently composed crusts of other sedimentation basin localities.

Biological soil crusts of industrial sedimentation basins consist of relatively stable algal, cyanobacterial, fungal and, in some cases, lichen assemblages that experience little variation of species composition between seasons. In addition, they resisted one-time mechanical destruction of the crust cover which does not lead to change in their taxonomic composition or eco-physiological parameters. The biological soil crusts dominate large areas of the abandoned sedimentation basins even more than 20 years after industrial activity ceased and, in many cases, there is no indication that vascular plants could successfully colonise these habitats. On the other hand, we believe that – even in temperate conditions of Central Europe – biological soil crusts, similar to those of semiarid ecosystems, possibly represent the stable stage of ecosystem development at these man-made localities.

The semiarid biological soil crusts are usually quite susceptible to even unrepeated mechanical disturbance with long-term effects on diversity, productivity and physiognomy of the micro-ecosystem (Belnap 2002; Belnap 2003). Most importantly, the intense wind and water-overflow effects quickly erode exposed surfaces with disturbed crust cover. However, these factors are obviously not so intense in the investigated temperate crust localities. In this respect, we propose that unfavourable abiotic factors (i.e. extremely low pH values, substrate toxicity or high salinity) effectively hamper vascular plant succession leading to their rather low competition with crust microorganisms. In addition, wind erosion is of less effect in more humid temperate conditions, compared with to semiarid ecosystems. Crust microorganisms with relatively short life cycles are thus able to sustain unrepeated disturbance events and quickly restore the crust cover. This stability of species composition and ecological parameters of investigated crusts we consider as a rather remarkable result of our investigation.

On the other hand, looking at the physiognomy of exposed vegetation-less parts of sedimentation basins with high level of disturbance by off-road vehicles (e.g. at the Radvanice and Měděnec localities), we are convinced that repeated disturbance leads to effective destruction of crusts and results in an decrease of diversity, primary production and increase of erosion. However, we detected that these negative changes cannot be ascribed to single, unrepeated destructive disturbing events. However, this presumption should be specifically investigated in future research.

**Fig. 4.5.1.** The PCA ordination diagram of abiotic data.

# 5. Decomposition of birch foliar litter and model cellulose at sites with the synanthropic biological soil crusts

PETRA BUKOVSKÁ

## INTRODUCTION

As a part of the biological soil crusts investigation a decomposition study in Chvaletice and Ralsko stands was performed. Decomposition of organic matter is a fundamental process in ecosystem carbon flux and nutrient cycling. The investigation of decomposition is therefore an important aspect of the analysis of ecosystem function.

Decomposition is one of the main factors influencing plant succession through soil formation and there is evidence that decay rates co-vary with productivity of sites (Swift et al. 1979). Hence in human-affected stands – as the both studied stands are – decomposition of plant litter is a process of crucial importance with respect to their reclamation. However decomposition has been studied mostly in forest ecosystems (e.g. Witkamp 1963; McClaugherty et al. 1985; Bååth 1989; Albers et al. 2004; Osono & Takeda 2005) and there is still little information about it from such anthropogenic stands.

Both Chvaletice and Ralsko stands are of an early state of succession and provide harsh microclimatic conditions, which may become the main factor controlling the decay rate (Kurka et al. 2001; Sjögersten & Wookey 2004). Apart of this the "soil" substrate of the abandoned sedimentation basin Chvaletice is to be characterised by low pH, high salinity and high heavy metals content, which all are factors known individually to have negative effect on microbial communities and microbially mediated processes (Rühling & Tyler 1973; Freedman & Hutchinson 1980; Nordgren et al. 1984; Cotrufo et al. 1995; Ramsey et al. 2005; Rejmánková & Houdková 2006). However high manganese soil pollution – characteristic for the Chvaletice stand – is rare and there is no information about its effect on the decomposition process.

The present study aimed to reveal the decomposition rate of such stands in comparison with other ecosystems whether is any difference in decomposition rate between the toxic environment of the Chvaletice stand and the more natural stand of Ralsko.

## MATERIALS AND METHODS

As study localities abandoned ore-washery basin at Chvaletice and an unforested area near the former military airport Ralsko were chosen. The decomposition rate was studied both for *Betula pendula* leaf litter, as a natural organic substrate of both sites, and for filter paper which, as model cellulose, is widely used to compare decomposition activity among stands.

For both substrates the decomposition study litterbag method was used. In November 2005 freshly fallen birch foliar litter was collected in both stands. Litterbags (12 x 12 cm) of 1.5 mm and 0.042 mm mesh size were prepared and filled with 1.3 g of oven-dried (85°C) birch litter. Additionally, 1.5 mm mesh bags (12 x 12 cm) filled with 0.6 g oven-dried (85°C) filter papers (80 $g \cdot m^{-2}$) were prepared.

In each stand a plot of about 10 x 10 m was chosen with 12 subplots (50 x 50 cm) covered by the biological soil crust. The experiment started in May 2006 when six sets of 8 litterbags – 4 of coarse and 4 of fine mesh size – and one set of 4 cellulose bags were placed ca 3 cm under the soil biological soil crust, each set in one subplot. Bags were attached to the ground with metal pins to prevent movement. Every two months over a year sampling took place. On each sampling occasion a set of 8 litterbags from one subplot and a set of 4 cellulose bags were removed and another set of cellulose bags was placed for the next two-month interval.

Cellulose and litter samples were cleaned of soil particles and foreign plant remains and oven-dried at 85° C to constant weight. Mass loss of each sample was determined as the difference in dry weight before and after exposition. K-value (the annual decomposition rate constant) of birch litter was determined and the results were comparable with that of other studies. The calculation used the Olson's single exponential decay model (Olson 1963): $x_t = x_0 \cdot e^{-kt}$, where $x_t$ is mass of litter in time $t$, $x_0$ is original mass and t is time in years. For studies where only mass loss values were given k-values were assigned according this equation.

For statistical analysis of cellulose and litter mass loss values two-sample t-test, one-way ANOVA and Tukey-Kramer multiple comparison test were used. For all analyses, differences were considered to be significant when $P \leq 0.05$.

## RESULTS

*Birch litter decomposition*

The course of litter decomposition throughout the one year study was similar in both stands and under both treatments. It was relatively rapid in the first four months of the litter exposition (mean mass loss values reached 8–14% for the two-month interval) thereafter, it considerably decelerated (mean mass loss values were 0–8%).

Using coarse mesh litterbags, no significant difference in decomposition rate between stands was detected. Mean mass loss values after twelve months of experiment were 28.9% and 31.7% for Chvaletice and Ralsko stands, respectively. K-values reached 0.34 and 0.38 for Chvaletice and Ralsko stands, respectively (Fig. 5.1a).

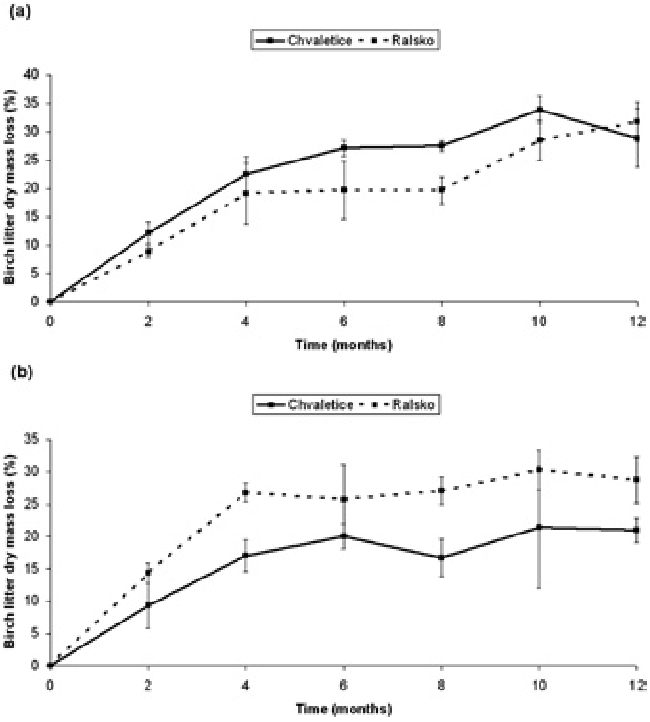



**Fig. 5.1. (a–b)** Accumulated dry mass losses (% ± SD) of birch litter exposed in (**a**) coarse mesh litterbags and (**b**) fine mesh litterbags in Chvaletice and Ralsko.

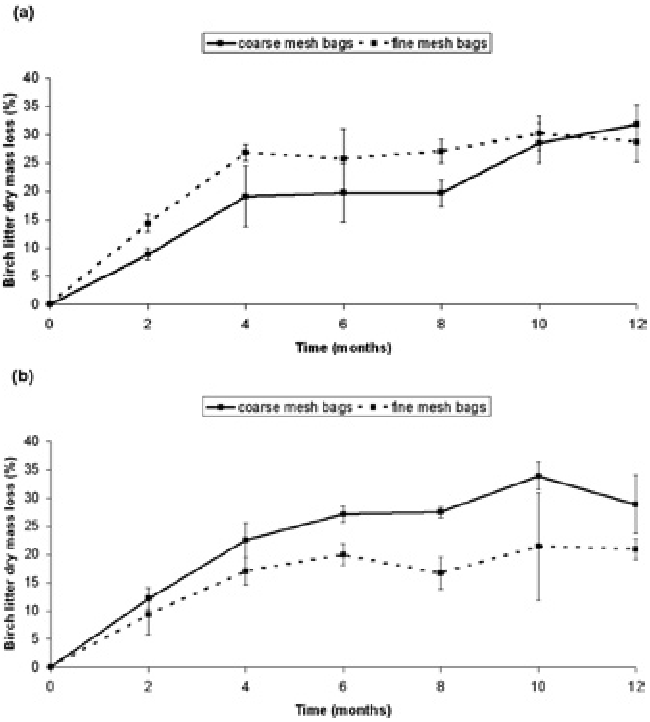



**Fig. 5.2. (a–b)** Accumulated dry mass losses (% ± SD) of birch litter exposed in two types of litterbags in (**a**) Ralsko and (**b**) Chvaletice.

Using fine mesh litterbags there was significantly higher mass loss in Ralsko (28.8%) than in Chvaletice (20.9%) at the end of the experiment. K-value reached 0.34 and 0.23 for Ralsko and Chvaletice, respectively (Fig. 5.1b).

No significant differences were found in decomposition rate between litter deposed in coarse and fine mesh bags in Ralsko. However, after the first four months mass loss was significantly higher in fine mesh bags (Fig. 5.2a).

In Chvaletice the litter deposed in coarse mesh litterbags was significantly more decomposed at the end of experiment (Fig. 5.2b).

*Cellulose decomposition*

In the first study period (May–July) there was no significant difference in mass loss between stands. In the second and third study period (July–September, September–November) mass loss was significantly higher in Ralsko (56.9% and 30.2%) than in Chvaletice (9.8% and 5.7%). In the fourth study period (November–January) mass loss was higher for cellulose exposed in Chvaletice (Fig. 5.3). In the two last study periods there was no significant mass loss on either of the stands and these values are not given in the graph. The exception was the January–March period in Chvaletice when the mean weight of cellulose after exposition was even higher than before it.

In Ralsko, mean mass loss values differed significantly between individual intervals of the experiment. Only between the two last periods was no difference found. The only significant difference in cellulose decay rate in Chvaletice was found between the fourth and fifth interval.

## DISCUSSION

*Birch litter decomposition*

The course of decomposition throughout the one year experiment followed the same pattern described in many other litter decomposition studies (e.g. Parsons et al. 2004; Johnson & Hale 2004; Fioretto et al. 2005; Jirout et al. 2005; Quideau et al. 2005) although they were performed in different ecosystems and for different litter types. Changes in the decay rate observed during the experiment period reflect both direct chemical changes in the substrate itself and the succession in microorganisms able to compete for substrate with a given chemical composition. Mass loss is relatively rapid in the early phase due to decomposition of soluble compounds such as polyphenols and soluble carbohydrates and non-lignified holocellulose. Later, it is slowed down due to the exhaustion of these compounds and the slow decomposition of lignified holocellulose and lignin (Berg et al. 1984; Aber et al. 1990).

The birch litter decay rate was rather slow in both stands. A *Betula pendula* leaf litter decomposition study performed in central Finland over three vegetation seasons resulted in k-values of 0.43, 0.56 and 0.45 year$^{-1}$ (Kasurinen et al. 2006). Parsons et al. (2004) revealed the k-value of 0.89 year$^{-1}$

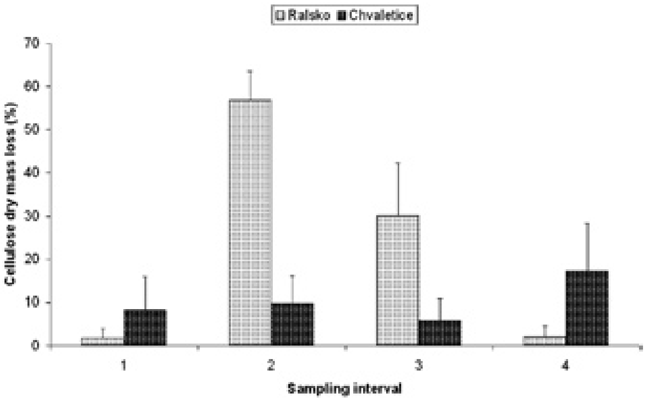



**Fig. 5.3.** Dry mass losses (% + SD) of model cellulose in individual intervals of the experiment (**1** – May–July, **2** – July–Sep, **3** – Sep–Nov, **4** – Nov–Jan).

evaluation of the role of different decomposer groups in the process. In addition it can also indicate the main factors influencing decay rate in a stand. Lower mass loss of litter confined in fine mesh bags observed in Chvaletice is a quite common phenomenon mainly explained as a direct result of soil mesofauna exclusion. The trend of more rapid decomposition in fine mesh litterbags in Ralsko can be explained as a microclimatic artefact. Where soil moisture content is limited the more convenient moisture conditions in fine mesh bags (Jirout et al. 2005) can accelerate the decomposition process even when some groups of decomposers are excluded. It is likely that even under comparable climatic conditions in both stands there is a higher probability of soil moisture deficit in the sandy soil substrate of the Hradčany stand than in sediments of the Chvaletice stand which are of rather fine texture.

for *Betula papyrifera* leaf litter in forest site of northern Wisconsin, USA. There were gained k-values of 0.63 and 0.97 for the same litter type under laboratory conditions at temperature of 10°C and 25°C, respectively (Daubenmire & Prusso 1963). *Betula pubescens* leaf litter decomposed in birch forest in Scottish Highlands with k=0.94 year$^{-1}$ (King et al. 2002). A three-year decomposition experiment in subalpine coniferous forest in Japan resulted in k=0.43 year$^{-1}$ for *Betula* sp. litter (Tian et al. 2000). K-values revealed in the present study were very similar to that found by Johnson & Hale (2004) for white birch foliar litter at seriously heavy metal contaminated forest sites near Sudbury, Ontario and Rouyn-Noranda, Quebec. These were 0.24 and 0.36 year$^{-1}$, respectively in comparison with 0.56 and 0.51 year$^{-1}$ at control sites.

The result of the intersite decomposition rate comparison was different, depending on the type of litterbag used. Using fine mesh bags decomposition rate was slower in the toxic environment of Chvaletice stand as expected but there was no significant difference when coarse mesh bags were used. This corresponds with Hopkins et al. (1990), Koide & Shumway (2000) or Jirout et al. (2005) who also found litter decay rate to be affected by litterbag mesh size used. With the coarser mesh size there is a lower probability that decomposition rate will be affected either through modification of microclimatic conditions of the enclosed litter or through exclusion colonization by invertebrates. Too coarse mesh, on the other hand, can cause overestimation of the decomposition rate because particles of decomposing litter fall through the mesh or are removed by soil fauna. Litterbags of 1–2 mm mesh size are an acceptable compromise and therefore they are most frequently used in decomposition studies. The decomposition rate of litter confined in such litterbags is supposed to be rather similar to that of unconfined litter. That is why for assessment of the litter decomposition rate of the study sites, and for the intersite comparison higher importance should be attached to the result gained using coarse mesh bags, from which there was found no difference in litter decomposition rate between study sites.

The decay rate comparison between litter confined in two types of litterbags in one stand is commonly used for

*Cellulose decomposition*

The cellulose decomposition rate was extremely slow in both stands. According to Školek's scale for cellulose decay rate evaluation (Školek 1980) the mass loss in Chvaletice should be classified as very poor decomposition, and in Ralsko as very poor to poor decomposition (July–September).

Except the November–January study period, the decay rate in Ralsko was always higher or the same as in Chvaletice and the total mass loss after the experiment was more than two times higher in Ralsko than in Chvaletice (90.3% and 41.2%, respectively). Thus, one can say that cellulose decomposition proceeded more rapidly in Ralsko.

Significant differences in mass loss among specific periods of the experiment in Ralsko reflect a determining effect of climatic conditions upon the decay rate. The highest cellulolytic activity was found in July–November period which corresponds with Šimonovičová (1986) who also found the highest cellulolytic activity at the end of the vegetation season. The unusually stable decomposition rate throughout the season together with extremely low mass loss values in Chvaletice suggest that cellulolytic activity in this stand is limited more by the "soil" substrate quality.

Negative mass loss values found in the January–May period is the result of a not overcome lag-phase. In this phase, preceeding the phase of exponential decay, substrate is beeing colonised and its mass is often observed to increase. The length of the lag-phase can differ, and is mainly moisture limited. Low cellulolytic activity in spring is usual (Suchara 1987) but when the lag-phase is not overcome even after two months it provides evidence of the very extreme conditions of the study sites in regard to decomposition.

It is interesting that results of the intersite decomposition rate comparison were different for litter and for model cellulose (using the same litterbag type). It suggests that results of experiments based on model cellulose decomposition commonly used for different sites comparison may not reflect real differences in decomposition rate of natural litter, and that any extrapolation of such model cellulose based information linked to the ecosystem function is questionable.

## CONCLUSIONS

Throughout one year, the decomposition of birch foliar litter and model cellulose was studied using the litterbag method in two anthropogenic stands with occurrence of biological soil crust. Birch litter decomposition in both stands followed the common pattern but was rather slow when compared to data known from another ecosystems for this litter type. Cellulolytic activity expressed as dry mass loss of filter paper was very slow in both stands as well.

Different results there were gained when the decay rate of cellulose and litter in the two stands were compared. Although cellulose decomposition proceeded more slowly in the toxic environment of the Chvaletice stand, as expected, there was no significant difference in the litter decomposition rate between stands.

Site specific litterbag effect and seasonal variability in cellulolytic activity suggest that the decay rate in Chvaletice was limited by toxic parametres of the soil substrate while in Ralsko it was limited by soil moisture content.

# 6. Summary and the conservational management proposals

JIŘÍ NEUSTUPA

A) Biological soil crusts represent relatively rare and mostly small-scaled micro-ecosystems in the Central European landscape. Vascular plant competition excludes crust cryptogamic and micro-organismal communities from most soil surfaces. The only exceptions in non-synantropic conditions are represented by localities of high level disturbance (erosion gorges, bases of sandstone cliffs, etc.). In samples from these localities, we encountered species typical for semiarid crusts (e.g. nostocalean filamentous Cyanobacteria). However, pH obviously is a limiting factor for development of cyanobacteria-dominated crusts on natural localities, as on acidic, sandstone-based localities Cyanobacteria were almost absent and crusts were dominated by green algae and lichens.

B) The biological soil crusts of ore and ash sedimentation basins appeared as species-rich, surprisingly stable and with abundant micro-communities on most of the investigated localities. Profound seasonal stability and resistance to disturbance of their species composition was detected mostly for groups that actually compose and dominate the crust biomass (algae, cyanobacteria, lichens).

C) The effect of unrepeated disturbance was detected neither in species composition, nor in diversity values and in ecophysiological parameters. We propose that crust micro-ecosystems represent later succession, or near-climax stage, of biotic communities on toxic anthropogenic substrates as vascular plants are hampered by toxicity and extreme physico-chemical parameters (pH, conductivity). In the places that were represented e.g. by cca 100 ha of the ore sedimentation basin area at the Chvaletice locality or by the Radvanice ore sedimentation basin, biological soil crusts should be considered as principle contributors to primary production and stability of the ecosystem as a whole.

At these localities, we propose passive management, consisting of monitoring activities and of conservation of crust cover from repeated mechanical disturbance. Our management recommendations consist of following points:

1) As examples of near-climax type of biological soil crust on a sedimentation basin, we consider localities:
   a) that have at least five years freedom from industrial activity;
   b) whose physico-chemical parameters and concentrations of toxic elements exceed the risk values for non-agricultural soils (public notice no. 13/94 of Czech Environment Ministry);
   c) the crust cover is in at least 25% composed of later colonizers – lichens or mosses;
   d) vascular plant cover does not exceed 10% of the total area.
2) In such places we do not recommend planting vascular plants species as a part of any restoration attempt.
3) In these localities we recommend passive management concentrated on stabilization of crust cover, i.e. by prevention of repeated disturbance effects mainly caused by the off-road vehicles.

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# COLOUR PLATES

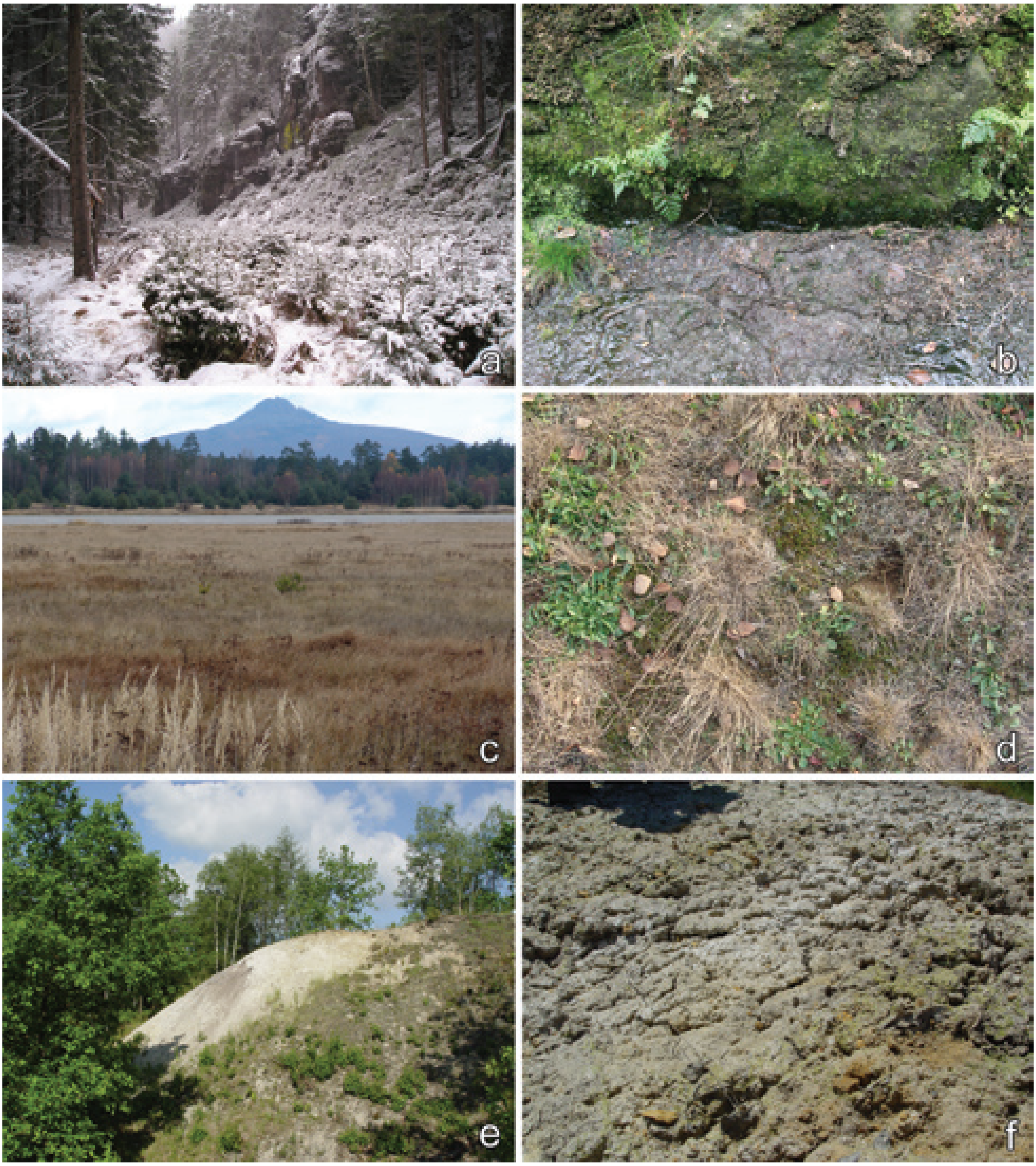


**Fig. 2.1.2.** Investigated natural localities. General views and detail of sampling sites. **a, b** – České Švýcarsko National Park; **c, d** – former military airport Ralsko; **e, f** – Střezovská rokle Natural Monument.

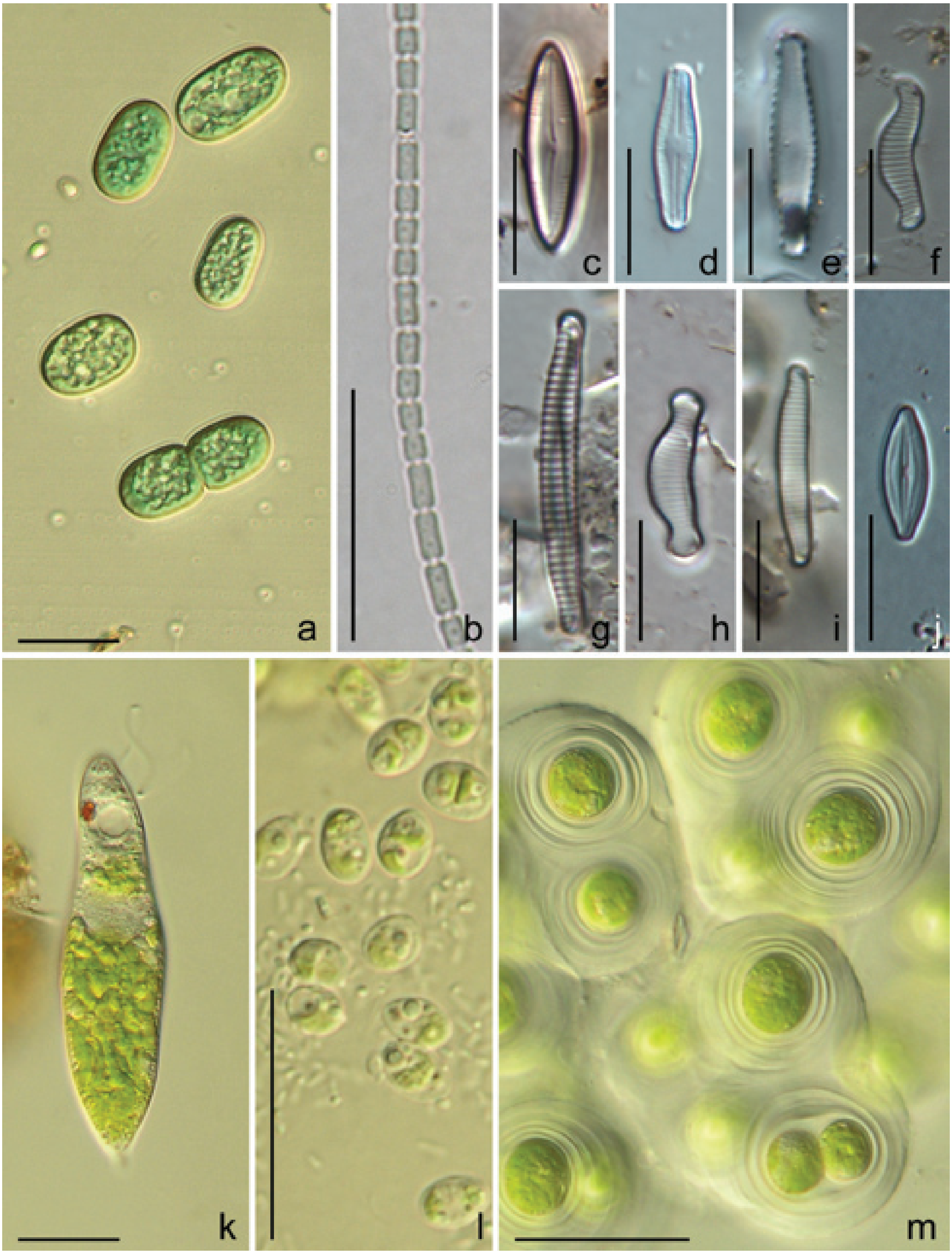


**Fig. 2.2.4.** Microphotographs of determined species. **a** – *Cyanothece aeruginosa*; **b** – *Pseudanabaena catenata*; **c** – *Caloneis aerophila*; **d, e** – *Diadesmis laevissima*; **f** – *Eunotia exigua*; **g** – *Eunotia fallax*; **h** – *Eunotia meisterii;* **i** – *Eunotia paludosa*; **j** – *Microcostatus krasskei*; **k** – *Euglena geniculata*; **l** – *Neodesmus* sp.; **m** – *Gloeocystis* sp. Scale bars: µm (a, b, k–m), 10 µm (c–j).

**Fig. 2.3.1.** Babylon Nature Reserve – communities of terricolous species headed by reindeer lichens occur often at sun exposed sandstone plateau rims (foto F. Bouda).

**Fig. 2.3.2.** Ralsko airport – well developed lichen crusts in the heather moor with predominant *Cladonia macilenta* (whitish podetia) (foto O. Peksa).

**Fig. 2.3.3.** Střezovská rokle – the cup lichen *Cladonia foliacea* (foto O. Peksa).

**Fig. 2.3.4.** Střezovská rokle – biological soil crusts with high participation of terricolous lichens. The predominant whitish shrub lichen is *Cladonia mitis* (foto O. Peksa).

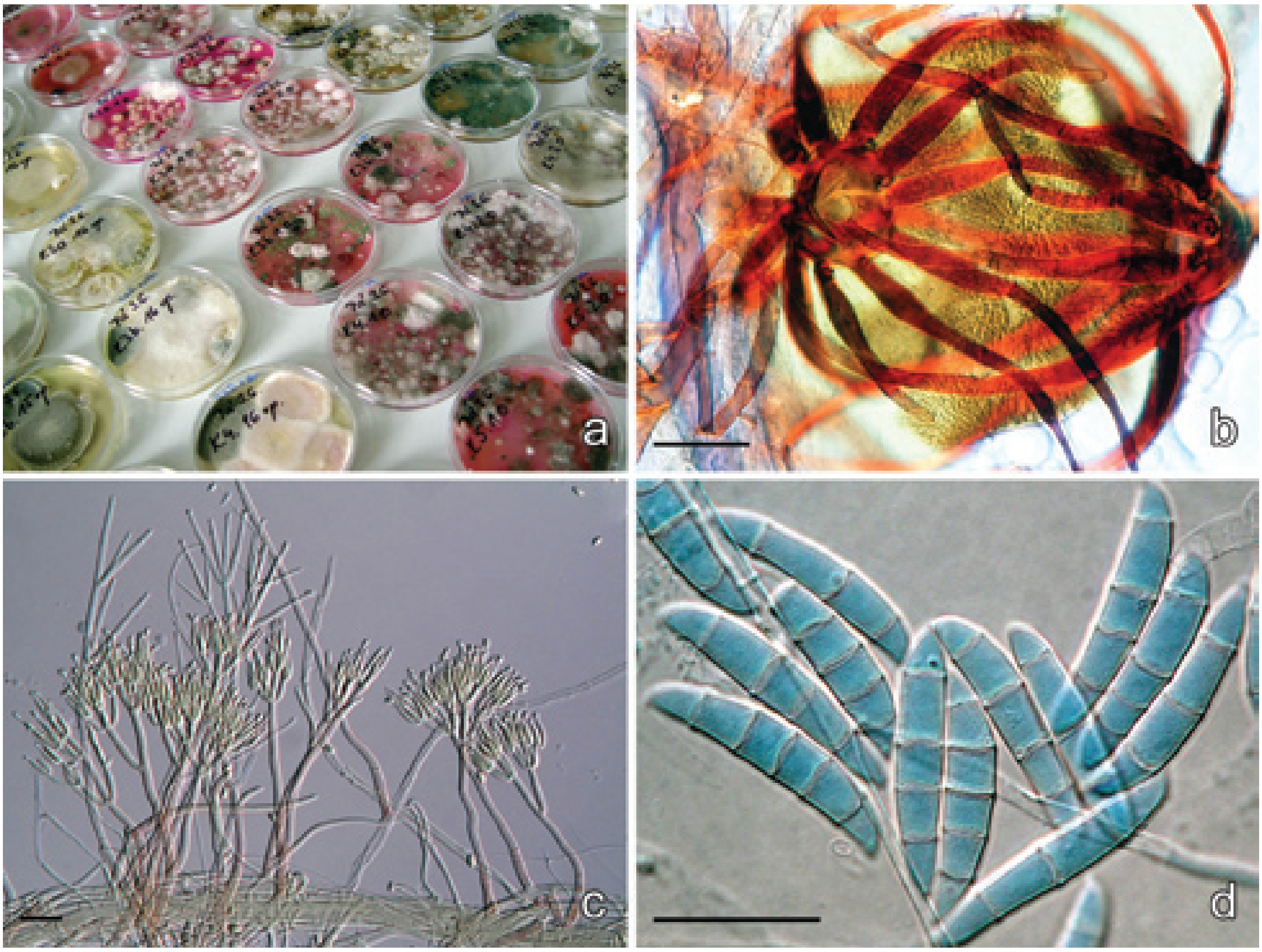


**Fig. 2.4.1. a** – Petri dishes with fungal colonies on different isolation media; **b** – *Absidia spinosa*, zygosporangium; **c** – *Clonostachys rosea* f. *rosea*, penicillate and verticillate conidiophores; **d** – *Fusarium culmorum*, macroconidia. Bars = 20 µm.


**Fig. 3.1.1.** Investigated sedimentation basins. **a**–**c** – Měděnec ore sedimentation basin (**a** – general view; **b, c** – details of the crust cover); **d**–**f** – Radvanice ore sedimentation basin (**d** – general view; **e, f** – details of the crust cover).

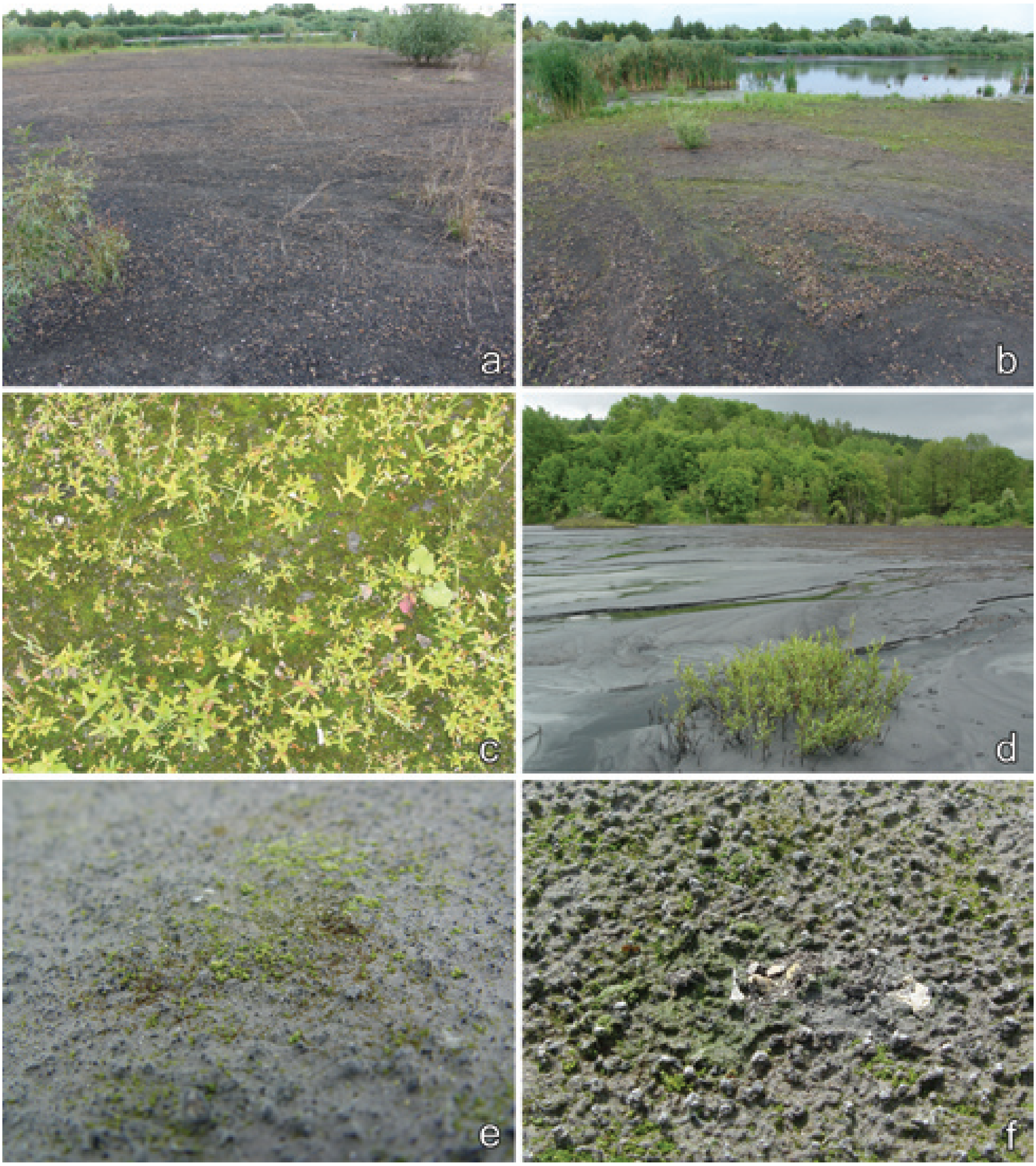


**Fig. 3.1.2.** Investigated sedimentation basins. **a–c** – Dvůr Králové I ash sedimentation basin (**a, b** – general view; **c** – detail of the crust cover); **d–f** – Ostrov II ash sedimentation basin (**d** – General view; **e, f** – details of the crust cover).

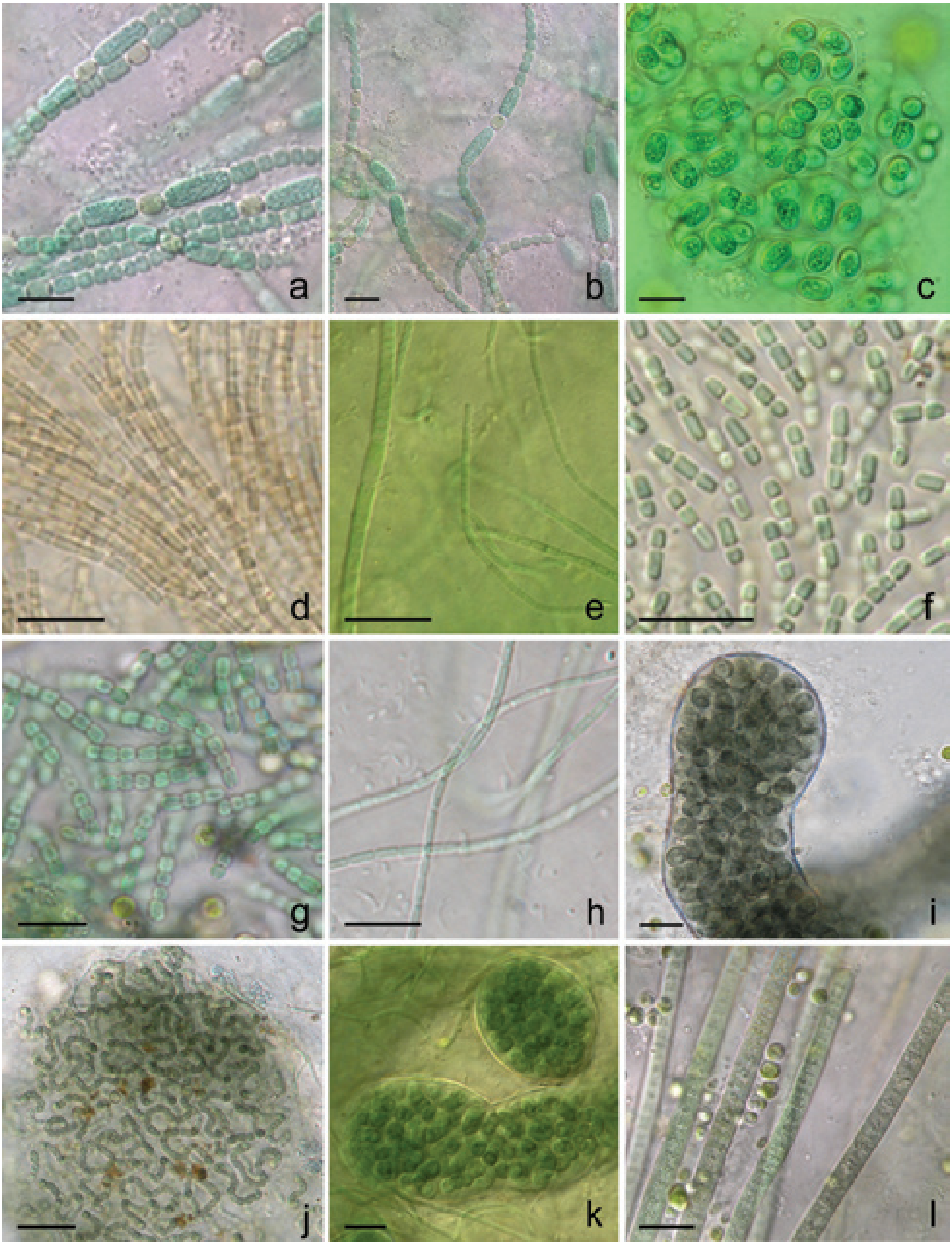


**Fig. 3.4.5.** Microphotographs of determined species. **a, b** – *Anabaena* cf. *cylindrica*; **c** – *Gloeothece* cf. *tepidariorum*; **d** – *Leptolyngbya* sp. 1; **e** – *Leptolyngbya* sp. 2; **f** – *Leptolyngbya* sp. 3; **g** – *Leptolyngbya* sp. 4; **h** – *Leptolyngbya* sp. 5; **i** – *Nostoc* cf. *calcicola*; **j** – *Nostoc* cf. *edaphicum*; **k** – *Nostoc* sp. 1; **l** – *Phormidium* cf. *autumnale*. Scale bar: 10 µm.

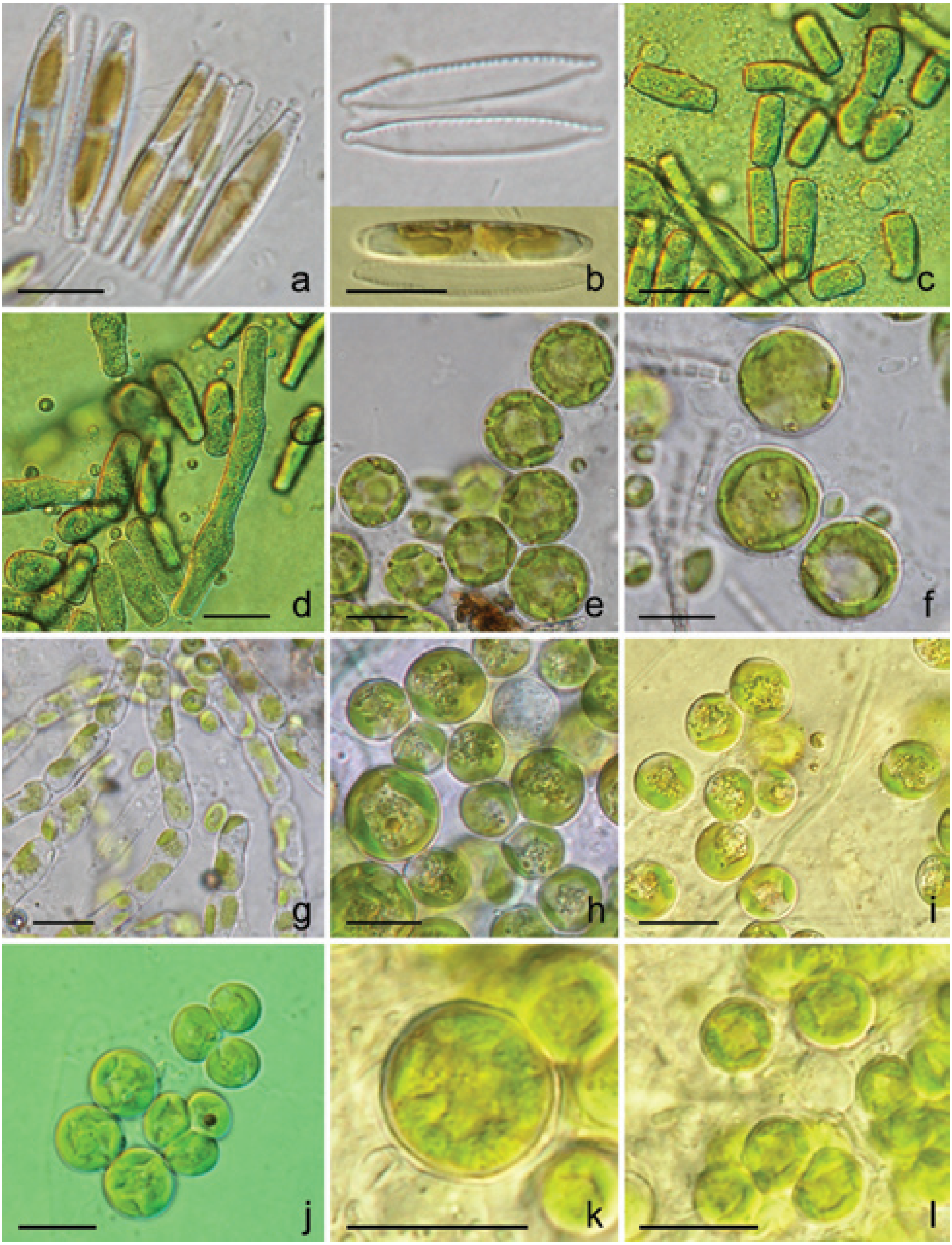


**Fig. 3.4.6.** Microphotographs of determined species. **a, b** – *Nitzschia* sp.; **c, d** – *Bumilleriopsis filiformis*; **e, f** – *Pleurochloris polychloris*; **g** – *Xanthonema* cf. *montanum*; **h** – *Eustigmatos polyphem*; **i, j** – *Eustigmatos vischerii*; **k, l** – *Bracteacoccus* cf. *aggregatus*. Scale bar: 10 µm.

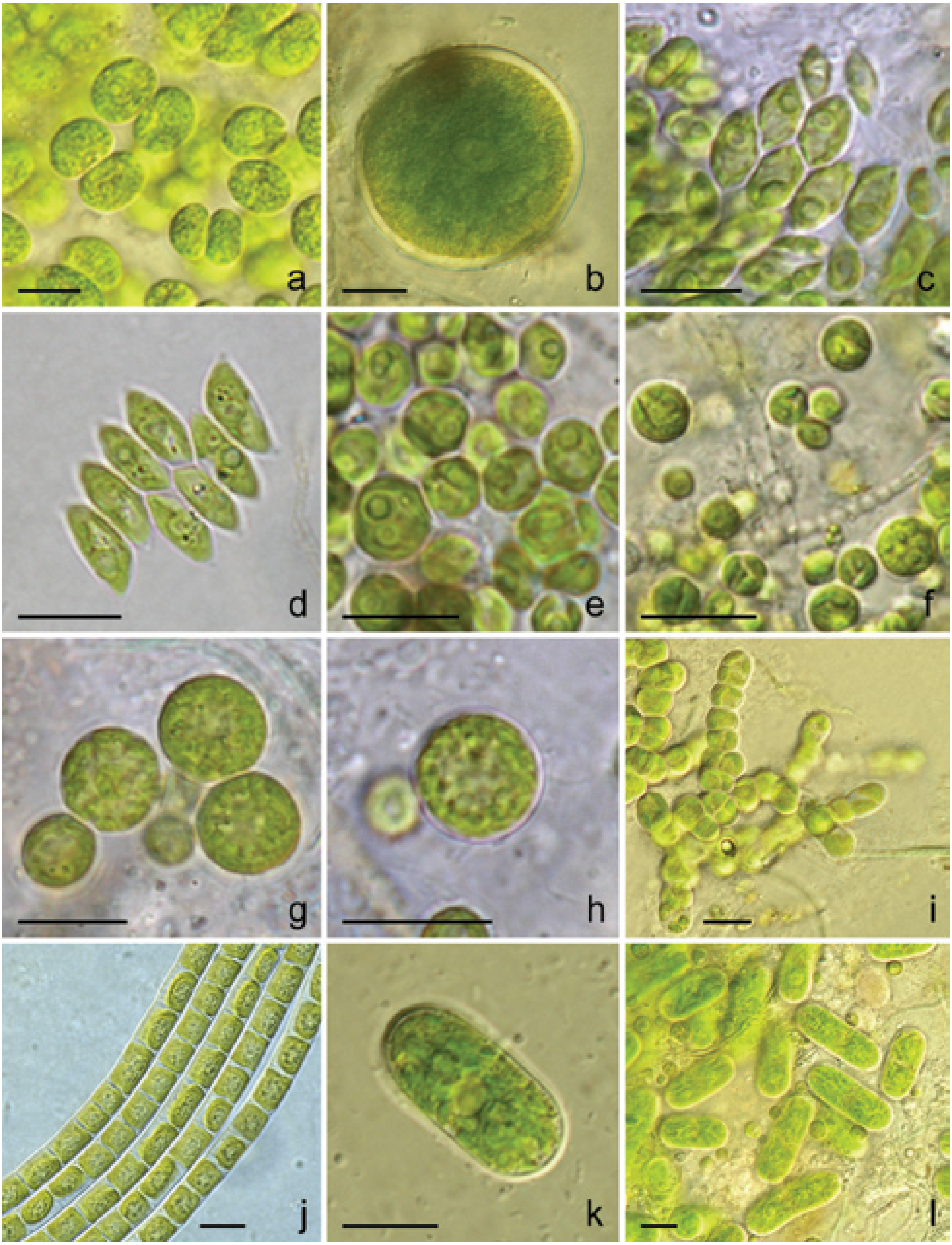


**Fig. 3.4.7.** Microphotographs of determined species. **a** – *Chlamydomonas* sp. 1; **b** – *Deasonia multinucleata*; **c–e** – *Scenedesmus* cf. *obtusiusculus* (note two pyrenoids per cell in **e**); **f** – *Chlorella lobophora*; **g, h** – *Dictyochloropsis* sp.; **i** – *Jaagiella* sp.; **j** – *Klebsormidium flaccidum*; **k, l** – *Cylindrocystis brebissonii* var. *desertii*. Scale bar: 10 µm.

**Fig 3.5.1.** Well developed biological soil crust with predominance of lichens (*Cladonia coccifera*, *C. macilenta*) alongside the access road to Chvaletice sedimentation basin (foto O. Peksa).

**Fig 3.5.2.** Cup lichens (*Cladonia* spp.) are often invaded by parasitic species *Diploschistes muscorum* in Chvaletice sedimentation basin (foto O. Peksa).

**Fig 3.5.3.** *Peltigera didactyla* – pioneer cyanophilous lichen characteristic for antropogenic habitats (Měděnec ore-washery basin) (foto O. Peksa).

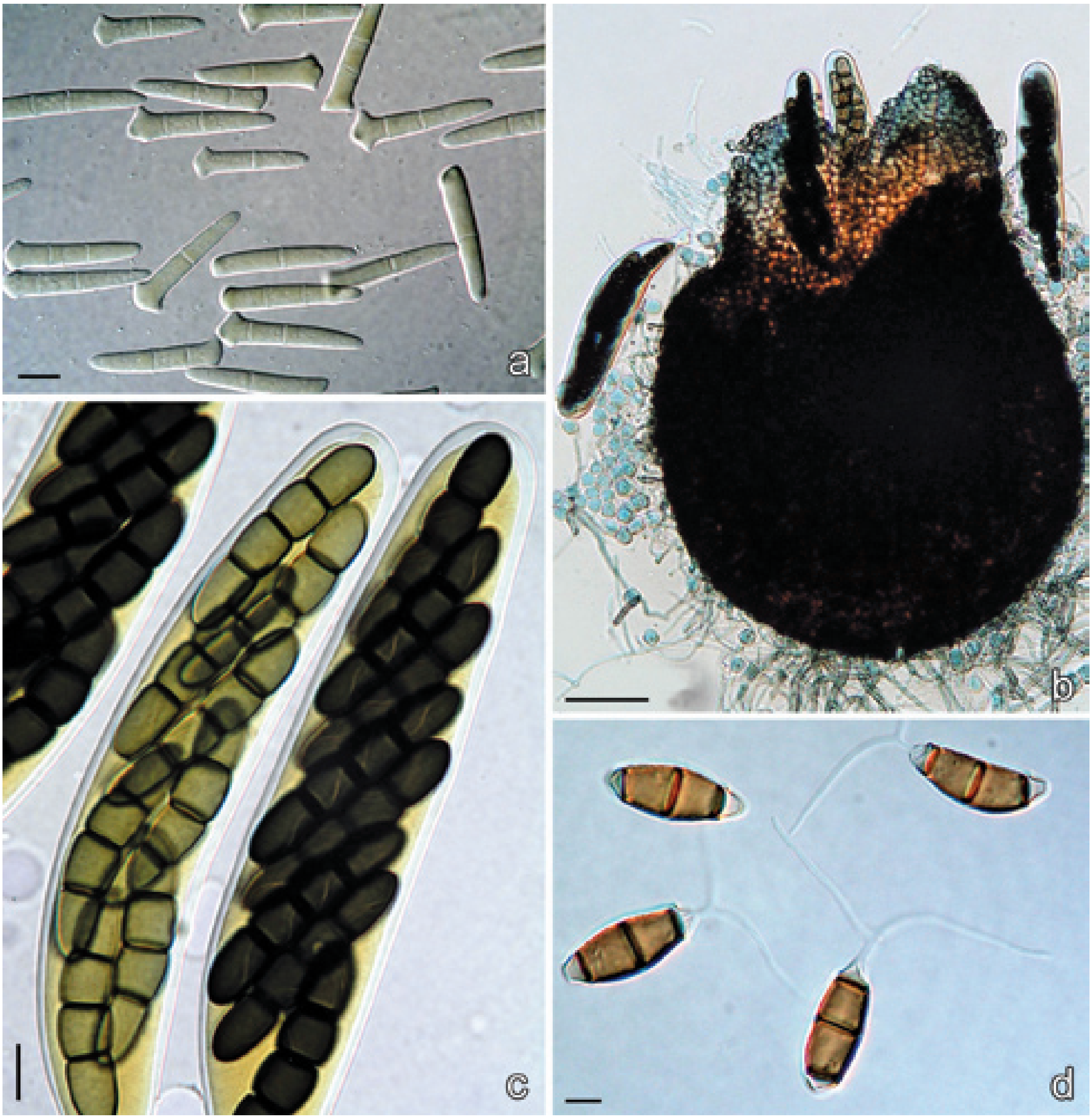


**Fig. 3.6.1. a** – *Heliscus lugdunensis*, aquatic hyphomycete. Conidia. Bar = 10 µm. **b** – *Sporormiella* sp., coprophilous fungus. Perithecium with asci. Bar = 50 µm. **c** – *Sporormiella* sp. Asci with ascospores. Bar = 10 µm. **d** – *Truncatella angustata*. Conidia with appendages. Bar = 5 µm.


**Fig. 4.1.** Chvaletice ore-sedimentation basin. **a** – general view; **b** – plotting the species composition and abundance of cryptogams; **c** – detail of the crust cover; **d** – the experimental plots with mechanically disturbed crust cover; **e** – undisturbed experimental plot; **f** – disturbed experimental plot, 1 year after the disturbance.

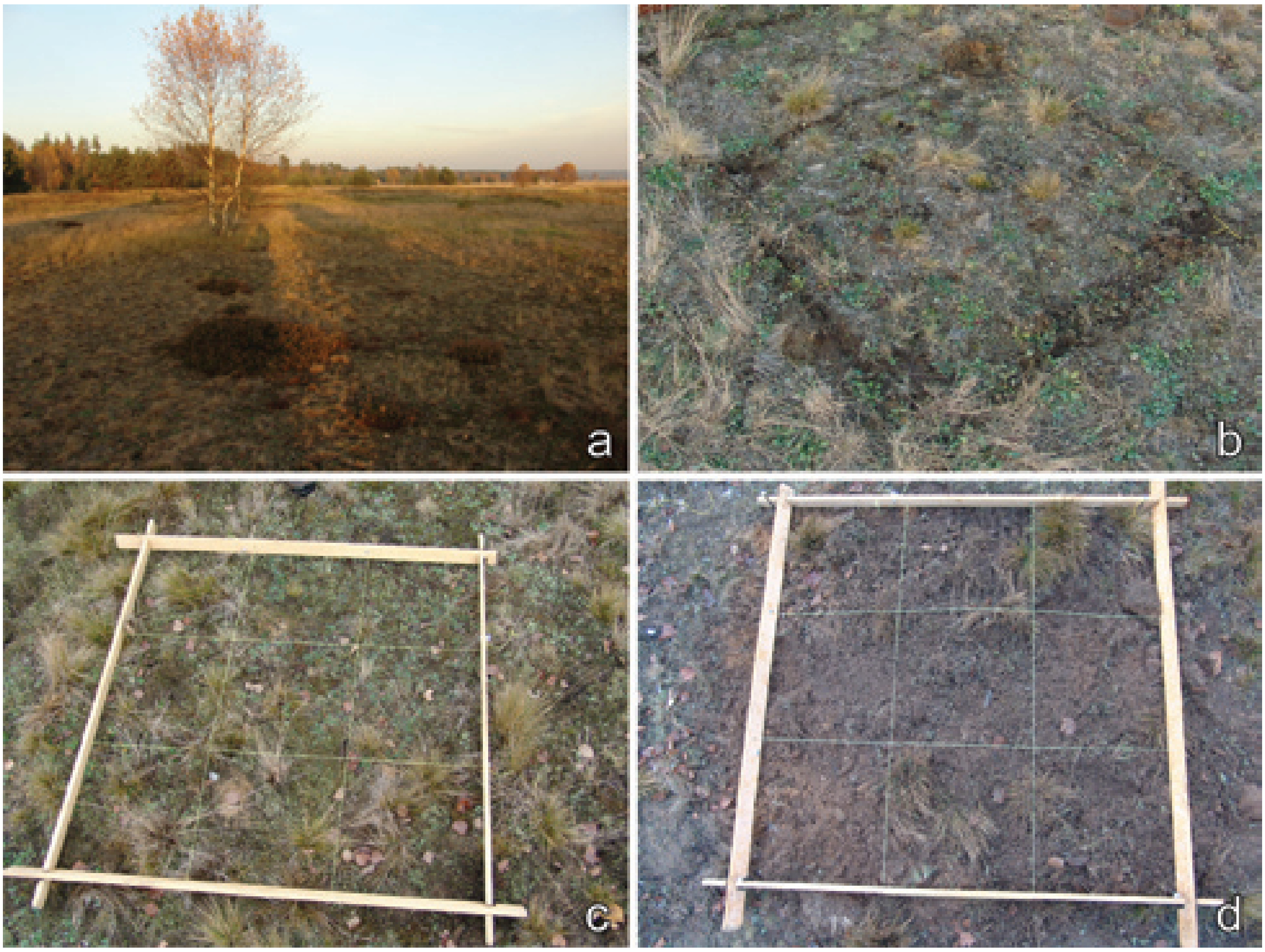


**Fig. 4.2.** Ralsko former military airport. **a** – general view; **b** – establishing the experimental plots; **c** – undisturbed experimental plot; **d** – disturbed experimental plot.

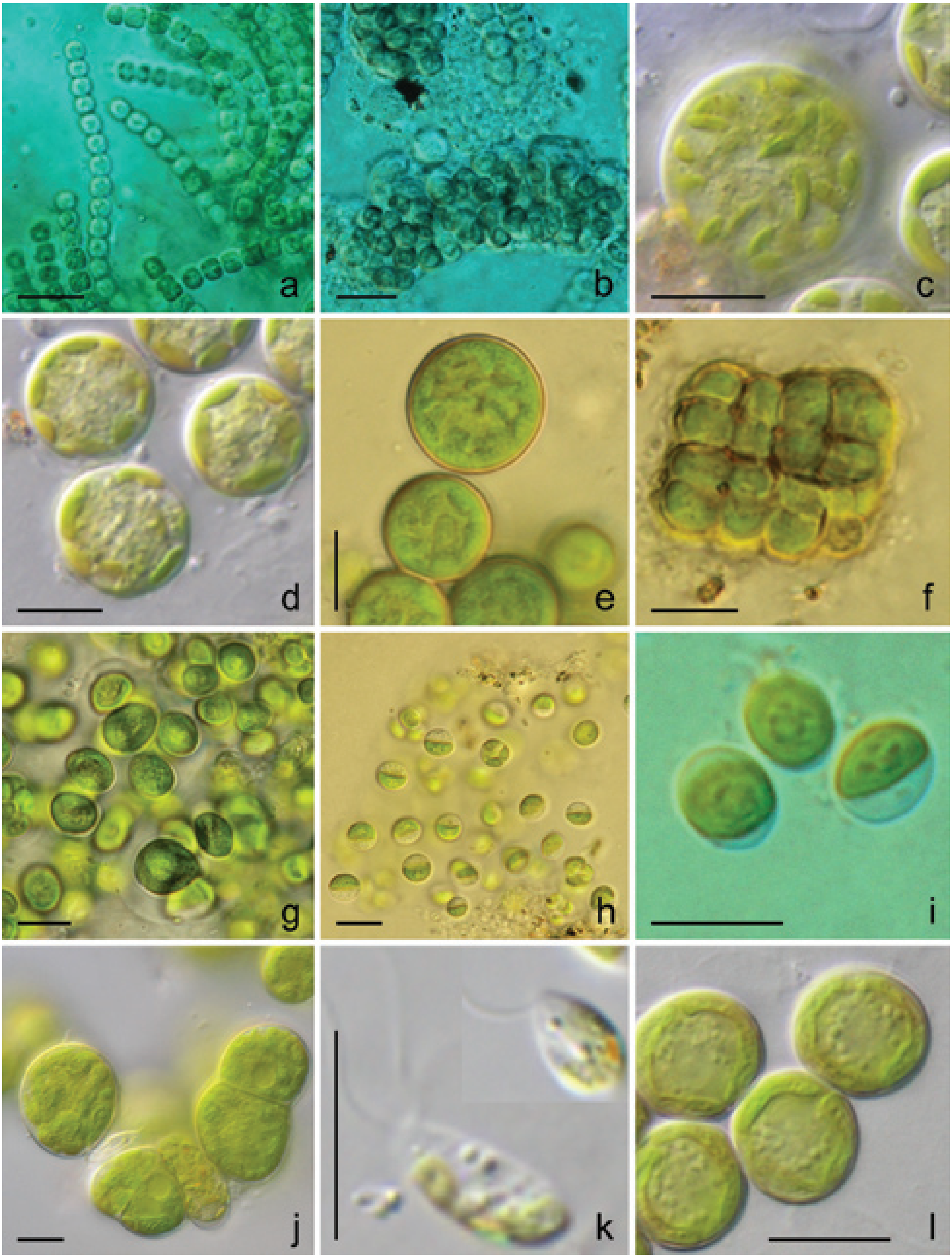


**Fig. 4.2.6.** Microphotographs of determined species. **a, b** – *Nostoc* sp.; **c, d** – *Botrydiopsis* cf. *arhiza*; **e** – *Bracteacoccus* sp.; **f** – *Desmococcus* sp.; **g, h** – *Radiococcus* sp.; **i** – *Chlorella mirabilis*; **j, k** – *Leptosira erumpens* (note zoospores in **k**); **l** – *Myrmecia incisa*. Scale bar: 10 µm.

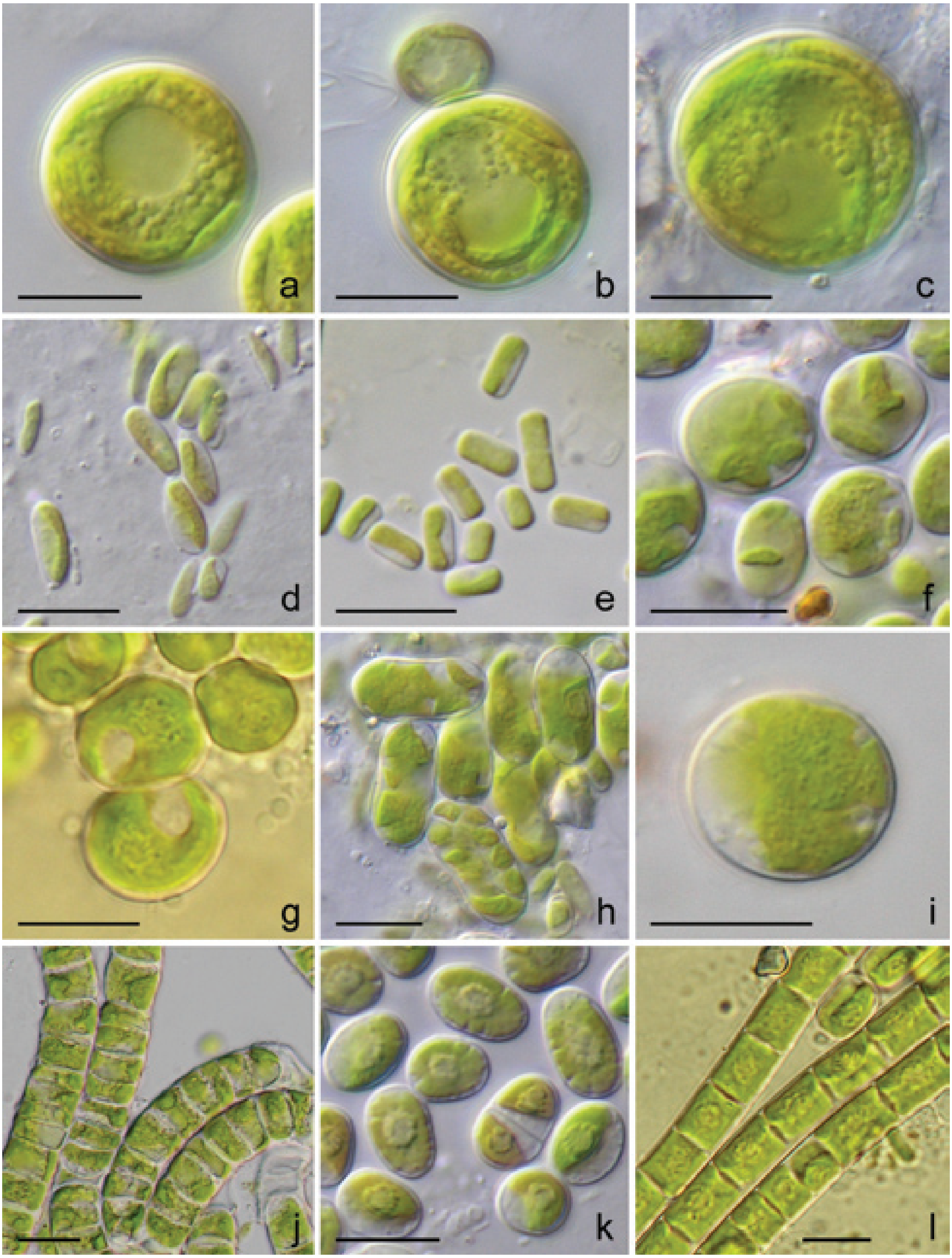


**Fig. 4.2.7.** Microphotographs of determined species. **a–c** – *Myrmecia* sp.; **d** – *Pseudococcomyxa simplex*; **e** – *Stichococcus bacillaris*; **f–i** – *Watanabea* sp.; **j** – *Ulothrix tenerrima*; **k** – *Geminella terricola*; **l** – *Klebsormidium flaccidum*. Scale bar: 10 µm.

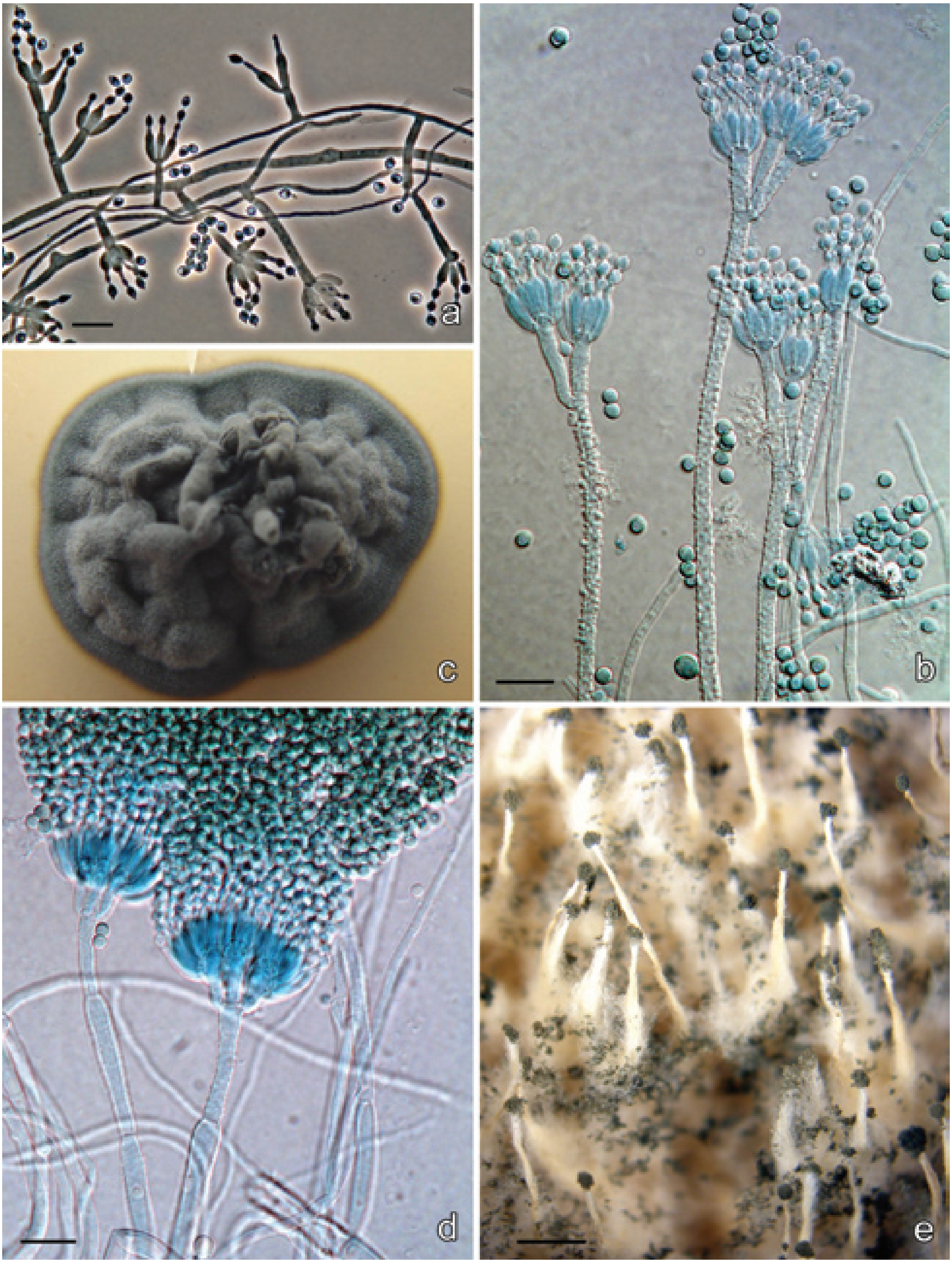


**Fig. 4.4.1. a** – *Penicillium janthinellum*, divaricate conidiophores, phialides with long neck, conidia. Bar = 10 µm. **b** – *Penicillium pulvillorum*, conidiophores with rough wall. Bar = 10 µm. **c** – *Polyscytalum* sp., slowly growing colonies on wort agar (after three weeks). **d** – *Penicillium smithii*, terminally branched conidiophores with swollen metulae. Bar = 10 µm. **e** – *Penicillium* cf. *coalescens*, colonies with synnemata on wort agar.