Biodiversity and ecological classification of cryptogamic soil crusts in the vicinity of Petunia Bay, Svalbard

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Abstract
The objective of this study was to describe various types of Arctic soil crust that were collected in the vicinity of Petunia Bay, Svalbard in the 2012 summer season. The photosynthetically active area of different soil crust samples was estimated by a chlorophyll fluorescence imaging camera. Biodiversity of cyanobacteria and microalgae from the collected soil crusts was analyzed using a stereomicroscopy and light microscopy. In most cases, cryptogamic crusts were dominated by cyanobacteria such as *Gloeocapsa* sp., *Nostoc* sp., *Microcoleus* sp., *Scytonema* sp., and *Chroococcus* sp. The dominant green microalgae were *Coccomyxa* sp., *Hormotila* sp., and *Trebouxia* sp. which commonly occurred in a lichenised soil crust. Soil crusts that were located in conditions with high water content were dominated by *Nostoc* sp. Cryptogamic soil crusts from the studied area can be divided into three different types and classified: (1) black-brown soil crusts (with low diversity of cyanobacteria and microalgae), (2) brown soil crusts (with high diversity of cyanobacteria and microalgae) and (3) grey-brown soil crusts (with low diversity of cyanobacteria and algae). The occurrence of similar soil crust types were compared at different altitudes. Altitude does not affect the biodiversity of cyanobacteria and microalgae. However, cyanobacteria and microalgae abundance increases with altitude.

Key words: soil crust, microalgae, cyanobacteria, photosynthetic area, variable chlorophyll fluorescence, diversity.

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Introduction

In polar deserts, soil cyanobacteria and microalgae can form distinct visible biotic crust layers on the ground surface which are called cryptogamic crusts (Broady 1996, Elster et al. 1999). They consist of water-stable, surface soil aggregates held together by cyanobacteria, microalgae, fungi, lichens and mosses. These layers protect the soil from wind and water erosion (Leys et Eldrige 1998), and

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contribute to plant growth (Belnap et Lange 2001). In cold regions, the higher species diversity of biological crusts positively effects structural diversity of vascular vegetation. Soil crusts accumulate organic carbon and nutrients which are used by plants for their growth.

These communities influence key ecosystem processes and their characteristics such as water infiltration, moisture holding capacity, organic matter content, CO_2 fluxes, and nitrogen fixation and transformations (Bond et Harris 1964). Therefore, biological soil crusts are important in maintaining ecosystem structure and functioning in dry lands. However, biological soil crusts have only recently been recognized as having a major influence on terrestrial ecosystems (Belnap et Lange 2001).

Composition of biological soil crusts is very diverse. In many arid and semi-arid communities, there are often many more species associated with the biological soil crust at a given site than there are vascular plants (Ponzetti et al. 1998). As harsh environmental conditions limit vascular plant cover, a greater cover of crusts probably occurs at lower elevations in spite of, but not because of, these conditions (Belnap et al. 2001).

Soil cyanobacteria and microalgae play a major role in the initiation of crust development and the early stages of its growth. Algal components of cryptogamic crusts are found in the upper few centimeters of soil. The low biomass of cyanobacteria and microalgae is associated with a colourless soil surface. On the contrary, with higher cyanobacteria and microalgal biomass, the soil surface is usually covered by variously coloured patches, including lichenised communities and mosses (Lange et al. 1992, Zaady et al. 2000). Such types of crusts have a higher photosynthetic activity, because of high pigment content (Housman et al. 2006).

Crusts are formed by living organisms and their by-products, creating a surface crust of soil particles bound together by organic material. Surface crust thickness can reach up to 10 cm (Belnap et Lange 2003). The general appearance of the crusts in terms of color, surface topography, and surficial cover varies.

Biological soil crusts have considerable photosynthetic potential (Evans et Johansen 1999). Water content and temperature can influence their photosynthetic activity (Yoshitake et al. 2010). Cyanobacteria, together with some green algae, are the most conspicuous elements of cryptogamic crusts (Elster et al. 1999). *Nostoc* sp. is widely found in all types of soil crusts and usually located on the surface (Belnap et Lange 2001). In most cases, cryptogamic crusts are also dominated by filamentous cyanobacteria. *Microcoleus* sp., *Phormidium* sp., *Plectonema* sp., *Schizothrix* sp., *Tolypothrix* sp. and *Scytonema* sp. are the most common genera found in both hot and cold deserts worldwide (Johansen 1993). They particularly have been shown to be important in binding surface soil particles (Anantani et Marathe 1974). Cyanobacteria and microalgae appear to play important roles in the northern and southern polar ecosystems, including the nitrogen economy of certain environments (Dickson 2000).

The objective of this study was to describe different types of Arctic soil crusts that were collected in the Petunia Bay, central Svalbard using various methods. We hypothesized that there would be crust type- and altitude-dependent differences in their biodiversity and photosynthetic capacity.

Material and Methods

Crust samples were collected during August 2012 in various sites across the vicinity of the Petunia Bay (78°40'60" N, 16°33'0" E), the northwestern branch of Billefjorden, Dickson Land, Svalbard. Each site contained different types of soil crust that were selected by ocular observation using visible features of the crusts. Three soil subsamples were taken in each site by a corer (diameter of 5 cm) with a depth of 2-3 cm.

The same types of soil crust were taken from various altitudes and compared. Soil crusts from four different areas were studied: 350, 500, 700, and 800 m a.s.l.

The photosynthetic area of different samples was estimated using 2D epifluorescence images of the visible crust using a FluorCam 700MF fluorescence imaging camera (Photon Systems Instruments, Czech Republic). Circles of soil crusts were put into the dark adaptation compartment of the device to allow photosynthetic organisms, their reaction centers of photosystem II (RCs PS II), to open. Then, using the measurements of single Kautsky kinetics, images of the photosynthetic area were obtained.

The diversity of cyanobacteria and microalgae from collected soil crusts was studied using an Olympus SZX-ZB7 stereomicroscope and Olympus BX-51 light microscope (Olympus C&S, Japan). By using the stereomicroscope, various parts of each soil crust were chosen for measuring of several parameters, including morphological characteristics of the soil, photosynthetic area, the presence of lichens, and *Nostoc* colonies on the crust surface.

Using light microscopy, the diversity of cyanobacteria and microalgae was observed in the chosen parts of the soil crusts. Dominant species were identified by morphological characteristics such as colony or cell habitats, size, colour, shape of colonies and cells, presence of akinetes, heterocysts and sheath (Komárek et Anagnostidis 1999, Komárek et Anagnostidis 2005, Ettl et Gartner 1995). Microphotographs of samples were taken using an Olympus DP71 digital camera (Olympus C&S, Japan) and processed using the Quick Photo Camera 2.3 software (Promicra, Czech Republic).

Results and Discussion

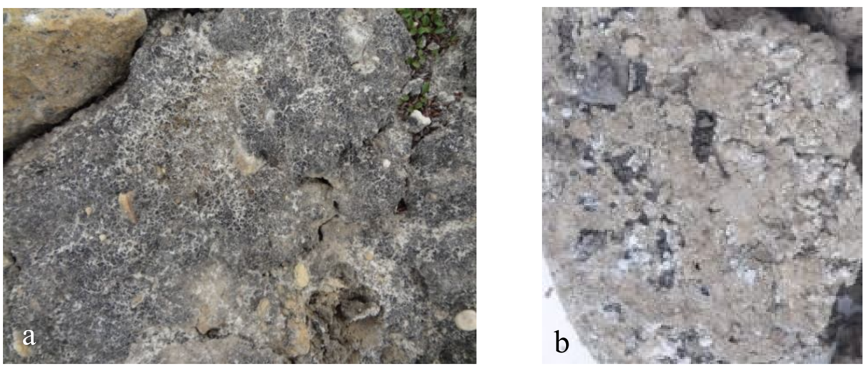


Fig. 1. Dark (a) and light (b) types of soil crust.

Based on data from the literature (Dunne 1989), our study has confirmed that the dark colour of soil crusts is due to the density of the organisms and their dark colour: cyanobacteria, lichens, and mosses (Fig. 1a). Soil crusts that contain a low amount of these organisms usually have a light colour (Fig. 1b). Crusts generally cover all soil spaces which are not occupied by vascular plants. They may account for 70% or more of the ground cover (Belnap et Lange 2003).

Chlorophyll fluorescence analysis

The study of the fluorescent area showed the parts of soil crust that contained photosynthetic organisms (Fig 2). The higher intensity of colour (*i.e.* Chl. fluorescence signal) shows higher concentration of photosynthetic pigments. This method allows for determining the location of organisms such as microalgae, cyanobacteria, mosses and lichens that are capable to photosynthesize. Lichens and mosses have a higher intensity of color such as the light blue (marked on a Fig. 2 by green circles). It can be considered that higher absolute values of chlorophyll fluorescence come from lichens and mosses rather than from free-living microalgae and cyanobacteria. On this base, *i.e.* when substracting lichens and mosses, we can estimate the approximate area of free microalgae and cyanobacteria over the sample area measured by chlorophyll fluorescence.

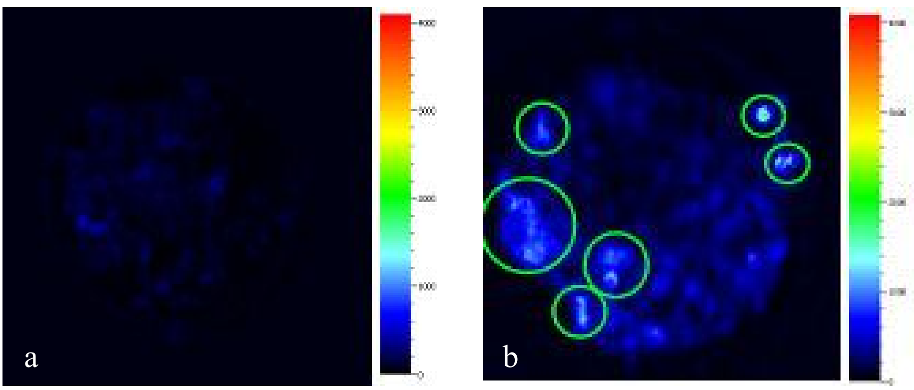


Fig. 2. Soil crusts with low (a) and high (b) variable chlorophyll fluorescence (F_V)

On the base of visual observation, the soil crusts from the studied area can be divided into three types: (1) black-brown soil crusts with low diversity of cyanobacteria and microalgae, (2) brown soil crusts with a high diversity of cyanobacteria and microalgae, and (3) gray-brown soil crusts with a low diversity of cyanobacteria and microalgae (Fig. 3).

Microscopic analyses

The most common species of cyanobacteria and microalgae are presented in Fig. 4, 5, 6.

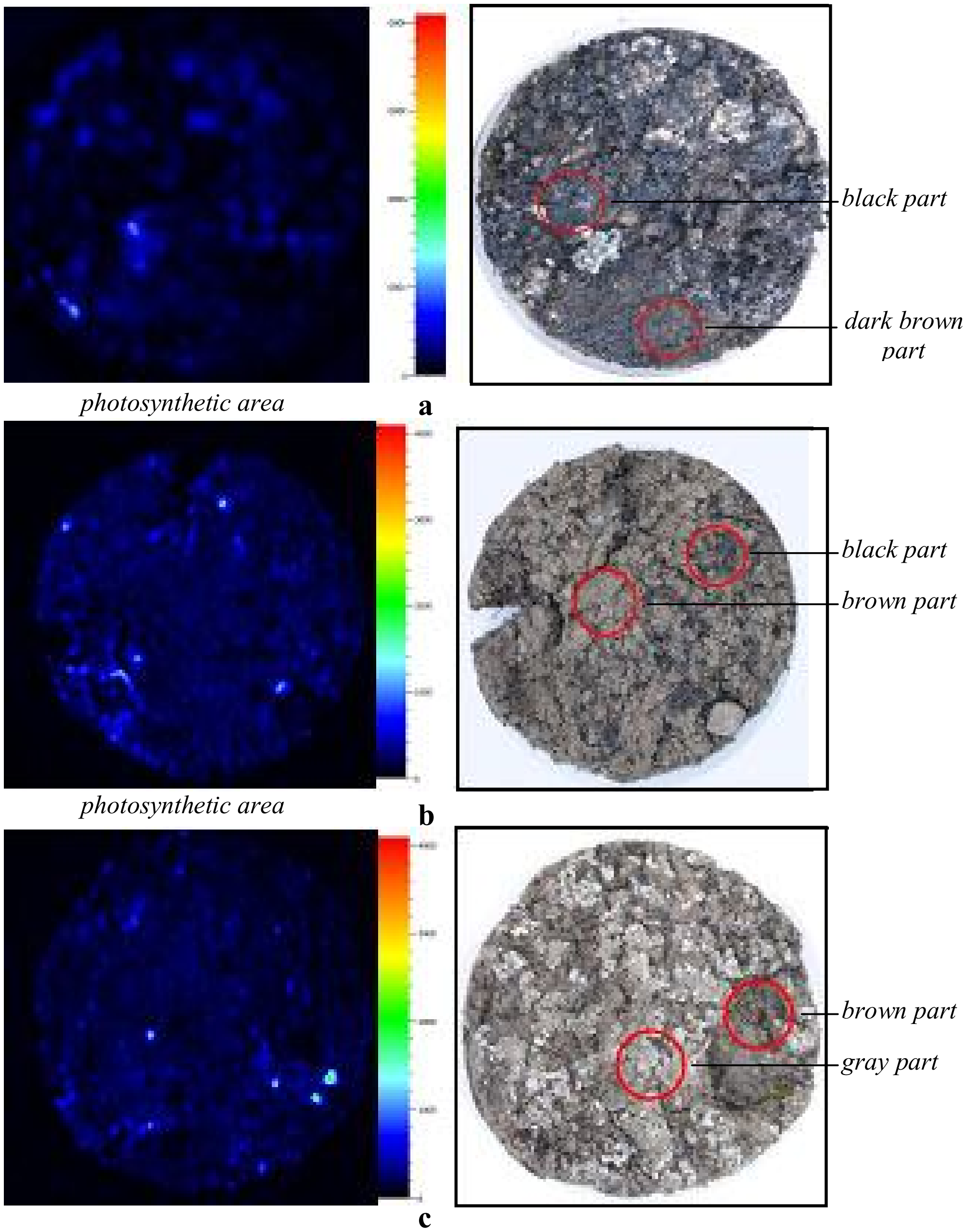


Fig. 3. Classification of soil crust types from the Petuniabukta, Svalbard: black-brown soil crust (a), brown soil crust (b) and gray-brown soil crust (c). Bright light blue spots on pictures with photosynthetically active areas indicate the presence of lichens or mosses.

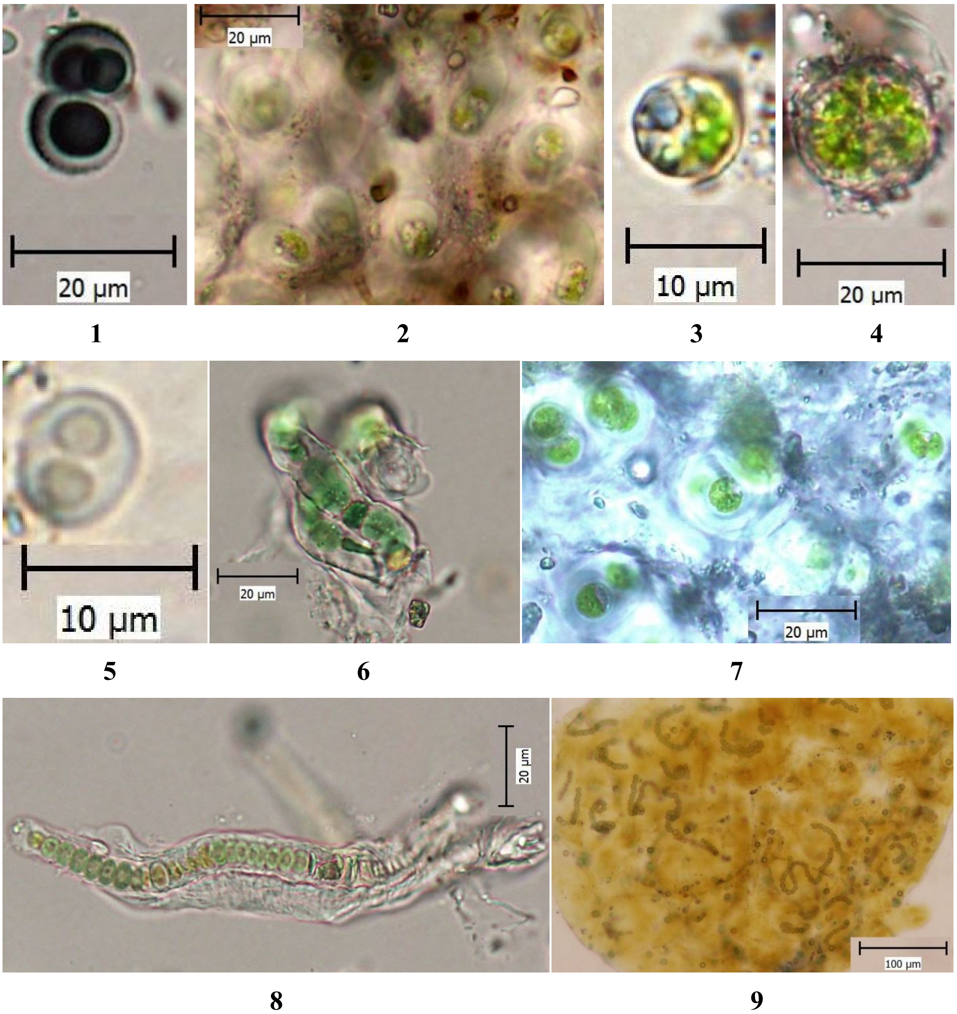
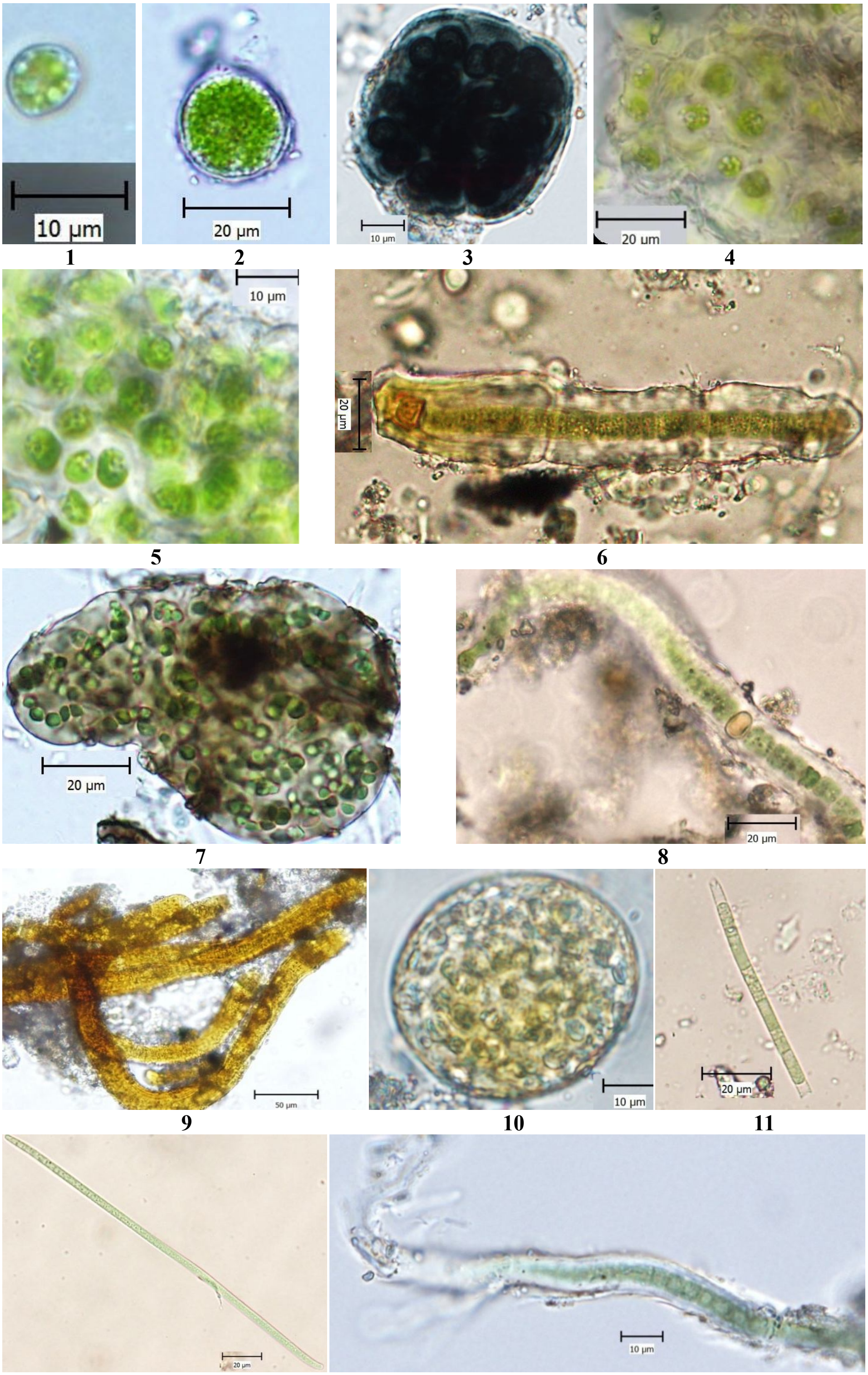


Fig. 4. ↑ Microalgae and cyanobacteria diversity of black-brown soil crusts. Dominant species: 1 - *Chroococcus* sp., 2 - *Hormotila* sp., 3, 4 - Unidentified green balls, 5 - *Gloeocapsa* sp., 6 - *Tolypothrix* sp., 7 - *Myrmecia* sp., 8 - *Nodularia* sp., 9 - *Nostoc* sp.

Fig. 5. → Microalgae and cyanobacteria diversity of brown soil crusts. Dominant species: 1, 2 - Unidentified green balls, 3 - *Gloeocapsa* sp., 4 - *Hormotila* sp., 5 - *Myrmecia* sp., 6 - *Scytonema* sp. (initial stage), 7 - *Nostoc* sp., 8 - *Nodularia* sp., 9 - *Scytonema* sp., 10 - *Asterocapsa* sp., 11 - *Geitlerinema* sp., 12 - *Phormidesmis* sp., 13 - *Calothrix* sp.



1 2 3 4 5 6 7 8 9 10 11 12 13

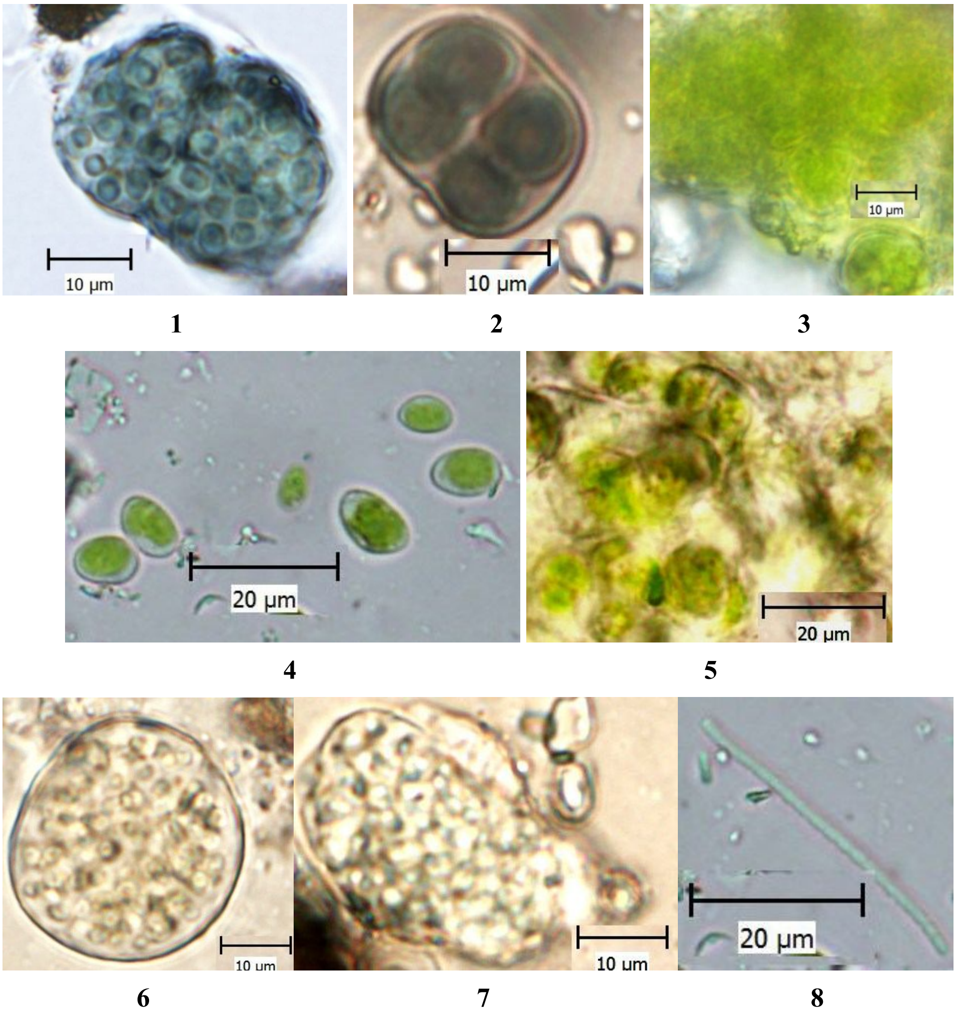


Fig. 6. Microalgae and cyanobacteria diversity of grey-brown soil crusts. Dominant species: 1, 2 - *Gloeocapsa* sp., 3 - *Trebouxia* sp., 4 - *Coccomyxa* sp. 5 - Unidentified green balls, 6 - *Asterocapsa* sp., 7 - *Chlorogloea* sp., 8 - *Pseudanabaena* sp.

Fig. 7. The initial phase of lichenization.

In most cases, cryptogamic crusts were dominated by cyanobacteria such as *Gloeocapsa* sp., *Nostoc* sp., green algae such as *Hormotila* sp. and *Trebouxia* sp. Green microalgae are usually present as the photobionts of lichens (Fig. 7) (Nash 1987). In three types of soil crusts, the green microalgae, which are very difficult to identify by morphological analysis, were found as dominant species.

Also, we observed soil crusts that were located in the places with high water content, including areas near shallow wetlands or in the places with melting snowfields. The stereomicroscope analysis showed that these areas were usually covered by *Nostoc* sp. (Fig. 8a). These areas had also a high potential of photosynthetic activity (Fig. 8b). The presence of a high amount of *Nostoc* sp. might also be explained by an increased nitrogen demand of the soil crust (Lan et al. 2012).

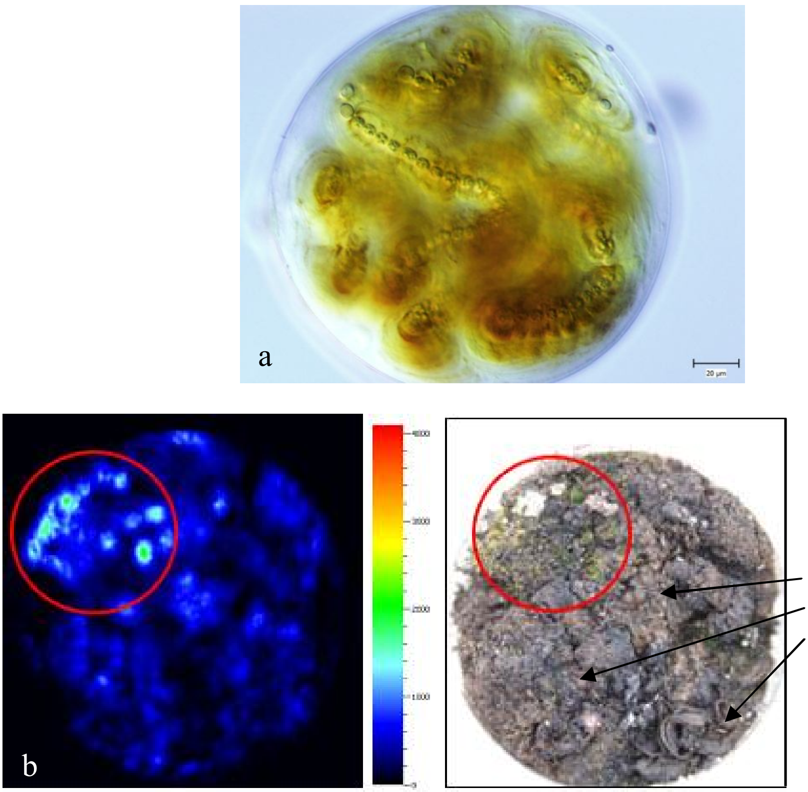


Fig. 8. *Nostoc* sp. (a) from a soil crust, (b) in an area with high humidity. Red circles show the area covered by mosses.

Altitude effect

The same types of soil crust were compared from different altitudes. *Microcoleus* sp. was the most dominant species among the microalgae and cyanobacteria at all studied altitudes (Fig. 9-1). When it is wet, the filaments glide out of their sheaths and, in a phototactic response, move towards the soil surface (Belnap et Lange 2001). Other common species are presented in Fig. 9. Differences in altitude do not affect the biodiversity of cyanobacteria and microalgae. However, their amount increases with increasing altitude. This is probably connected with the soil water content on mountain upper parts and presence of melting snowfields.

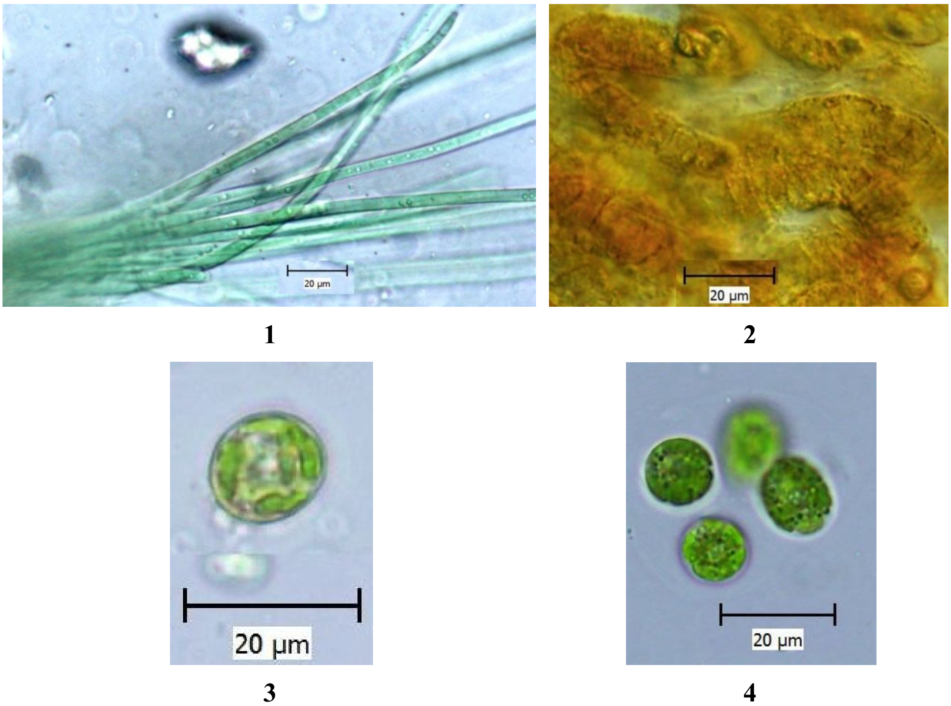


Fig. 9. Common dominant microalgae and cyanobacteria species at different altitudes. 1 - *Microcoleus* sp., 2 - *Nostoc* sp., 3 - *Bracteacoccus* sp., 4 - *Gloeocystis* sp.

Concluding remarks

Different types of soil crusts are presented in the studied area. The presence of a high diversity of cyanobacteria and microalgae allows photosynthetic activity the potential of which was indicated by chlorophyll fluorescence measurements. While the diversity of cyanobacteria and microalgae differs among the various types, there are some common species for all types of soil crust. Water content is important ecological parameter influencing abundance, diversity and photosynthetic performance of cryptogamic soil crusts ecosystem.

Chlorophyll fluorescence measurements of soil crust ecosystem are effective and promising tool for ecological and ecophysiological studies of soil crust ecosystem. Further study of the soil crust should be focused on detailed chlorophyll fluorescence parameters measurements, potential and effective quantum yields in particular, followed by proper taxonomical and ecological studies of soil crust ecosystem.

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