Arctic ecosystems – relations between cyanobacterial assemblages and vegetation (Spitsbergen)

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Received: 20 September 2017 / Accepted: 30 November 2017

Abstract. The paper describes cyanobacterial assemblages in relation to mosses and vascular plants forming mosaic communities in Arctic tundra. The study area is located in the north of the Hornsund fjord. In the selected 14 type of habitats, the study analyzed the quantitative and qualitative share of cyanobacteria, mosses and vascular plants. Due to their similarity in cyanobacterial assemblages and their relations to vegetation, they were divided into 10 groups. Each group was characterized by a particular combination of species with a distinguishing cyanobacteria dominant species and mosses and vascular plants. The significant role of cyanobacteria crusts and mats in the formation of the Spitsbergen tundra suggests they should be included in the descriptions of communities present in the region.

Key words: ecology of cyanobacteria, Svalbard’s vascular plants and mosses, blue-green algae, Hornsund.

1. Introduction

In the vast terrains of the Arctic severe climatic conditions and specific habitat conditions determine the processes of colonization and succession of vegetation, especially on particularly on initial grounds, on surfaces uncovered as a result of the recession of the glaciers. These areas are characterized by low amounts of nutrients, especially nitrogen and phosphorus, which inhibits and narrows the vegetation. In such conditions biological crusts of cyanobacteria microalgae, mosses and lichens are most successful and play a dominant role in the majority of polar ecosystems (Elvebak, 1994; Kanda & Inoue, 1994; Turetsky et al., 2012). The characteristic crusts and mats are built of cyanobacteria and are often responsible for the whole production of biomass in the area (Dickson, 2000; Hu & Liu, 2003; Elster & Benson, 2004; Kaštovská et al., 2005; Thomas et al., 2008; Pócs, 2009). Ecophysiological characteristics of cyanobacteria include the ability to grow in a large spectrum of temperatures, a tolerance to desiccation, freezing and salinity stress, and adaptive strategies to high levels of solar radiation. These features contribute to their success and dominance in regions lacking other vegetation (Warwick, 2002). By stabilizing soil surfaces and providing nutrients they prepare the habitat for further stages of growth. Such surfaces are gradually inhabited by dominant mosses and lichens and a few vascular plants.

The superiority of mosses in extreme habitats is a result of their associations with epiphytic cyanobacteria. Associations between bryophytes and cyanobacteria have been a subject of research for a long time (Solheim & Zielke, 2002; Zielke et al., 2002; Lindo et. al., 2013; Zhang et. al., 2014). The mutualistic relations between the organisms are the benefits resulting from cyanobacteria ability to nitrogen fixation. It is particularly important in environments lacking in nutrients (especially in polar regions), where nitro-
gen shortages result in lasting associations between these organisms. In such a case the bryophyte receives nitrogen from the cyanobacteria, providing carbohydrates, shelter and protection in return (Steinberg & Meeks, 1991; Rai et al., 2000; Turetsky, 2003; Gavazov et al., 2010; Rousk et al., 2013). Research conducted in the Arctic and the Antarctic has shown that nitrogen fixing through cyanobacteria and mosses associations constitutes a significant part of nitrogen export in terrestrial polar ecosystems (Chapin & Bledsoe, 1992; Steward et al., 2011).

Despite detailed studies regarding the roles of cyanobacterial crusts and associations between cyanobacteria and mosses, so far the relation between cyanobacteria assemblages and mosses and vascular plants has not been studied. Many years phytosociological research conducted in Spitsbergen only studied mosses and vascular plants (Dubiel & Olech, 1990; Olech, 1990, 2008; Cooper et al., 2004; Elvebak, 2005; Cooper, 2011). Studies of cyanobacteria, on the other hand, were mostly focused on the biodiversity of phycocflora (Thomasson, 1958, 1961; Willen, 1980; Matula, 1982; Plichta & Łuścinska, 1988; Oleksowicz & Łuścinska, 1992; Skulberg, 1996; Turicchia et al., 2005; Matula et al., 2007; Kim et al., 2008, 2011; Richter et al., 2009; Komárek et al., 2012; Davydov, 2013, 2014, 2016, 2017; Raabová et al., 2016; Davydov & Patova, 2017) or on the morphological and ecological characteristics of individual species (Strunecký et al., 2012; Richter & Matula, 2013; Richter et al., 2014a; Kviderová et al., 2011; Komárek & Kovacík, 2013). Only recently have there been whole some studies of habitats, where cyanobacteria, algae, lichens, mosses and vascular plants are equal components of tundra habitats (Richter et al., 2014b, 2015). Because the important role of cyanobacteria and algae in the formation of Spitsbergen community tundra should they find out in the description of plant communities. This study is focused on the summary of research into the interdependence between assemblages cyanobacteria and vegetation of the tundra in the Hornsund fjord.

2. Study area

The study area is located in the Hornsund fjord of West Spitsbergen. Hornsund fjord is spread in a latitudinal way, and from is from both sides approached by meridional mountain ranges. Studies have been conducted for several years near the Polish Polar Station, north of the Hornsund fjord, in the area covering the Revdalen valley with the Revelva River, the plain of raised marine terrace Fuglebergsletta and Gnalodden, Fuglebekken catchment, as well as the Arikammen, Fugleberget and Gnalberget slopes.

The following study is a summary of years of research carried out during the Arctic summer in July and August in the years 2011-2013. It presents research results from 14 habitat types, differing in moisture, trophy and existing communities of mosses and vascular plants. A detailed characteristics and location of particular habitats is presented in Figure 1 and Table 1.

3. Material and methods

Sample material was collected from the surface of soil and mosses. 14 ecologically different habitats were selected for the studies and 5 representative samples were collected from each. 70 samples were analyzed in total.

In the field, habitats were studied for percentage coverage of cyanobacteria thalli, mats and crusts. Microscopically, the quantitative of particular species was estimated on scale of 1-5, were 1 means sporadic occurrence and 5 means dominant species.

Species observations were conducted with a digital microscope Nikon Eclipse TE2000-S light. The taxa were digitally archived using the NIS image analysis program, which enables saving the images with a proper scale of objects. The identification was performed live and also on material preserved. Cyanobacteria were identified according to the following monographs: Komárek and Anagnostidis (1999, 2005), Komárek (2013), Strunecky et al. 2013.

4. Results

Cyanobacteria in relation to habitats types (Table 1)

The initial stage of cyanobacteria-moss habitat (IS) and surface of polygonal soil (PS) and cyanobacteria-moss snowbed (SB), (Fig. 2) are covered mainly by Anthelia juratzkana, Sanionia uncinata, Saxifraga oppositifolia and S. cespitosa. Among the mentioned mosses and vascular plants, on the surface there are also dirty-gray, elastic cyanobacterial crusts built of the aerophytic form of Schizothrix cf. lacustris. Among them the study also recorded brown thalli formed by Petalonia crustaceum, Tolypothrix tenuis, Microcoleus vaginatus, Siganema cf. mamillosum, Calothrix cf. parietina and Saccoconema sp. Within crusts built of the Schizothrix cf. lacustris (aerophytic form) there are also numerous other species: Gloeocapsa biformis, G. punctata and Chroococcus turgidus. Among cyanobacterial crusts the study also observed large quantities of free-living, spherical olive-green colonies of Nostoc commune and less numerous accompanying N. cf. paludosum.

Habitats with the dominance of cyanobacterial crusts (wet cyanobacterial crust (WC) and cyanobacterial crust (CC)) with a large proportion of Sanionia uncinata were characterized by the greatest variety of cyanobacteria, especially with respect to heterocytous and coccolid types. On such terrain, there was a dominance of macroscopic,
spherical or spread, olive-green colonies of *Nostoc commune* and cyanobacterial crusts. Thalli of *Nostoc commune* covered up to 50% of uncovered, moist soil in the analyzed habitats. Elastic and gray cyanobacterial crusts were formed of the subaerophytic form of *Schizothrix cf. lacuadrivis* with *Petalonema crustaceum, Tolypothrix tenuis* and *Microcoleus vaginatus*. Within them there were also small colonies of *Symplocastrium* sp., and, in large quantities, coccoid species: *Gloeocapsa punctata, G. biformis, Chroococcus turgidus*.

Oligotrophic flow water habitat (FW) with *Barbula* sp. (dominant) and other mosses was characterized by the presence of cyanobacterial crust, which, in shape of dirty greenish, hard thalli, covered branches and leaves of mosses and the long cell form of *Nostoc commune* in the form of vast, lobular, olive thalli. Cyanobacterial crusts formed mostly of the plankton form of *Schizothrix cf. lacuadrivis, Petalonema crustaceum, Microcoleus vaginatus, Symplocastrum* sp. In the crusts the study recorded many coccoid species, such as *Gloeocapsa kuetzingiana, G. punctata, Aphanothece clathrata, A. caldariorum*, the aerotope form of *Woronichinia sp.*, the granular form of *Gloeothecae* sp. and the dark mucilaginous form of *Aphanocapsa* sp.

In oligo-mesotrophic moss habitat (OM) and wet oligotrophic moss habitat (WO) covered with a mosaic of mosses (*Sanionia uncinata, Straminergon stramineum, Warnstorfia examulata, Bryum pseudotriquetrum*) on the branches and leaves of mosses and between them there were dirty green and gray cyanobacteria crusts formed of granular form of *Leptolyngbya* sp. (dominant) and *Petalonema crustaceum, Microcoleus vaginatus, Gloeocapsa punctata* and *G. tornensis*. The studied habitats are also characterized by a large proportion of *Nostoc commune* (Fig. 3) and *N. cf. punctiforme* which formed macroscopic leathery lobes of olive-green thallus on soil surface and between mosses. *Oscillatoria* cf. *ornata* was characteristic for these habitats.

Wet oligotrophic cyanobacterial crust with *Saxifraga* spp. (OS), (Fig. 4) covered with a *Saxifraga oppositifolia* community with *S. cespitosa, Salix polaris* was domi-

Figure 1. Location of the Svalbard, Spitsbergen – Hornsund fjord (Fuglebekken catchment, Fuglebergsletta marine terrace and Gnalberget slope, Gnalodden plain terrace)
| Type of habitats            | Symbols | Mosses and vascular plants-characteristic species | Cyanobacteria-characteristic species                                                                 | Trophy | Moisture     |
|----------------------------|---------|--------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------|--------------|
| The initial stage          | IS      |                                                  | aerophytic form of *Schizothrix cf. lacustris* A. Braun ex Gomont and *Petalonema crustaceum* Agardh ex Kirchner, *Tolypothrix tenax* Kützing ex Bomet et Flahault, *Microcoleus vaginatus* Gomont ex Gomont, *Sacconema* sp., *Stigonema* cf. *mamillosum* (Lyngbye) Agardh ex Bomet et Flahault and *Calothrix* cf. *parietina* Thuret ex Bomet et Flahault, *Gloeocapsa biformis* Erengović, *G. punctata* Nägeli and *Chroococcus turgidus* (Kützing) Nägeli, *Nostoc commune* Vaucher ex Bomet et Flahault and *N. cf. paludosum* Kützing ex Bomet et Flahault | oligotrophic | wet          |
| Polygonal soil             | PS      | *Anthelia juratzkana* (Limpr.) Trevis., *Sanionia uncinata* (Hedw.) Loeske, *Saxifraga oppositifolia* (L.) and *S. cespitosa* (L.) |                                                                                                         | oligotrophic | moderately wet |
| Cyanobacteria-moss         | SB      | snowbed                                          |                                                                                                         | oligotrophic | damp         |
| Wet cyanobacterial crust   | WC      | *Sanionia uncinata*                              | macroscopic thalli of *Nostoc commune* and cyanobacterial crusts – subaerophytic form of *Schizothrix cf. lacustris* with *Petalonema crustaceum* Agardh ex Kirchner, *Tolypothrix tenax* and *Microcoleus vaginatus*, *Symphocapsa* sp., *Dichothrix gypsophila* (Kützing) Bomet et Flahault, *Gloeocapsa biformis* and *Nostoc commune* | oligotrophic | damp         |
| Cyanobacterial crust       | CC      | *Sanionia uncinata, Saxifraga oppositifolia* and *S. cespitosa* |                                                                                                         | oligotrophic | moderately wet |
| Oligotrophic flow water    | FW      | *Barbula* sp. and *Sanionia uncinata*, *Straminergon stramineum* (Dicks. ex Brid.) Hederas and other mosses | *Nostoc commune, planctonic form of *Schizothrix cf. lacustris*, *Petalonema crustaceum*, *Microcoleus vaginatus*, *Symphocapsa* sp., *Gloeocapsa ketzingiana* Nägeli, *G. punctata*, *G. biformis*, *Aphanathece clathrata* W et G. S. West, A. caldariorum Richter, A. microscopica Nägeli, *Woronichinia* sp., *Gloeocapsa* sp. and *Aphanocapsa* sp. | oligotrophic | damp         |
| Oligo-mesotrophic moss     | OM      | *Sanionia uncina, Straminergon stramineum*, *Warnstorffia exannulata* (Schimp.) Loeske, *Bryum pseudotriquetrum* (Hedw.) Gaertn., Meyer & Scherb. | cyanobacteria crusts formed of granular form of *Leptolyngbya* sp.(dominant) and. *Petalonema crustaceum*, *Microcoleus vaginatus*, *Gloeocapsa* punctata and *G. tornensis* Skuja, *Nostoc commune*, *Nostoc punctiforme* (Kützing ex Hariot) Hariot, *Oscillatoria cf. ornata* Kützing ex Gomont | oligo-mesotrophic | damp         |
| Wet oligotrophic moss      | WO      | habit                                           |                                                                                                         | oligotrophic | damp         |
| Wet oligotrophic cyanobacterial crust with Saxifraga spp. | OS | Saxifraga oppositifolia community with Saxifraga cespitosa, Salix polaris Walenb. | thalli of Nostoc commune, and aerophytic form of Schizothrix cf. lacustris A. and filaments of Microcoleus vaginatus, Tolypothrix tenuis and coccolid cyanobacteria: Chroococcus turgidus (Kützing) Nägeli, Gloeocapsa punctata, G. compacta Kützing, G. biformis, G. alpina (Nägeli) Brand, G. kuetzingiana | oligotrophic permanent supply of water |
| Flow water habitat with cyanobacterial crust | FC | Paludella squarrosa (Hedw.) Brid and Sanionia uncinata | Nostoc commune, forming widespread lobular thalli, Schizothrix cf. calcicola Gomont forming crust with coccolid species: Gloeocapsa compacta, G. punctata, Chroococcus turgidus, Ch. minutus (Kützing) Nägeli and filamentous, heterocytous species: Dichothrix gypsophila, Scytonema sp. | oligotrophic permanent supply of water |
| Flow water moss habitat under sea spray | SS | Paludella squarrosa | Lyngbya aestuarii Liebman ex Gomont with Geitlerinema acutissimum (Kufferath) Anagnostidis, Leptolyngbya valderiana (Gomont) Anagnostidis et Komárek, Woronichinia sp. Nostoc commune | oligotrophic damp |
| Oligotrophic wet moss habitat | WM | Saxifraga oppositifolia, Sanionia uncinata, Aulacomnium palustre (Hedw.) Schwaegr., Pohlia nutans (Hedw.) Lindb. | Nostoc punctiforme, N. cf. palludosum Kützing ex Bornet et Flahault, Gloeothececf. incerta Skuja | oligotrophic wet |
| Mesotrophic wet moss habitat | MM | Saxifraga oppositifolia and Deschampsia borealis (Traut.) Rosch. with Plagiomnium ellipticum (Brid.) T. Kop., Pohlia nutans | Microcoleus autumnalis (Trevisan ex Gomont) Struneycky et al., Pseudanabaena frigida (Fritsch) Anagnostidis, Phormidium uncinitum Gomont ex Gomont, Woronichinia compacta (Lemmerman) Komárek et Hindák, Merismopedia sp., N. punctiforme | mesotrophic wet |
| Mesotrophic habitat with flowing water | MF | Sanionia uncinata, Polytrichum sp., Warnstorfia sarmentosa (Wahlenb.), Straminergon stramineum, Tetraplodon mnioides (Hedw.) Bruch & Schimp. | Microcoleus autumnalis, Leptolyngbya sp., Schizothrix cf. facilis (Skuja) Anagnostidis, Geitlerinema acutissimum Anagnostidis, Pseudanabaena catenata Lauterborn, Leptolyngbya valderiana (Gomont) Anagnostidis et Komárek, Oscillatoria fracta Carlson | mesotrophic damp |
nated by the thallus of *Nostoc commune*. It formed a vast, leathery thallus on the surface. The sub-dominant species was cyanobacterial soil crust formed of elastic, dirty-gray filaments of the aerophytic form of *Schizothrix cf. lacus-tris* and filaments of *Microcoleus vaginatus, Tolypothrix tenuis* and numerous coccoid cyanobacteria: *Chroococcus turgidus, Gloeocapsa punctata, G. compacta, G. biformis, G. alpine, G. kuetzingiana*.

Flow water habitat with cyanobacterial crust (FC) with a large share *Palludella squarosa* and *Sanionia uncinata* was characterized by the dominance of *Nostoc commune* forming widespread lobular thalli covering up to 50% of the tundra surface. At the bottom of the flows the study recorded white, gray and green from the bottom cyanobacterial crusts formed of *Schizothrix cf. calcicola*. In the upper parts of the mats there were numerous nodular brown and orange thalli of *Dichothrix gypsophila* and long, dark olive and black filaments of *Scytonema* sp. (brown sheath).
This species was characteristic for this habitat and didn’t occur in any other studied tundra. Among the filaments of *Sch. calcicola* the study recorded coccoid species *Gloeocapsa compacta*, *G. punctata*, *Chroococcus turgidus*, *Ch. minutus*.

In the broad stream flowing through the oligotrophic moss habitat with *Palludella squarosa* (flow water habitat with cyanobacterial crust-SS) *Lyngbya aestuarii* was the dominant. Despite the presence of a similar mosses community as in the previous habitat the local community of cyanobacteria was very different. The dominance of *Lyngbya aestuarii* results from special habitat conditions in the area. It is a seaside habitat, under the influence of sea spray. Distinctive habitat conditions shaped its dominance and the species was accompanied by *Geitlerinema acutissimum* (sub-dominant), *Leptolyngbya valderiana*, small cells

Figure 5. View of the mesotrophic habitat with flowing water and macroscopic *Phormidium autumnale* mats (MF)
of Woronichinia sp. In uncovered locations on the soil the study also recorded patches of Nostoc commune thalli.

In oligotrophic wet moss habitat (WM), (Fig. 6) covered by a mosaic of mosses (Saxifraga oppositifolia, Sanionia uncinata, Aulacomnium palustre, Pohlia nutans) on the soil surface, between the mosses the dominant was Nostoc punciforme and N. cf. palludosum (subdominant), creating clearly visible, black or dark blue spherical thallus. Among them there were Gloeothece cf. incerta.

Mesotrophic wet moss habitat (MM), (Fig. 6) was covered by Saxifraga oppositifolia and Deschampsia borealis with Plagmnmium ellipticum, Pohlia nutans. Between bare patches of soil and between the mosses Microcoleus autumnalis was the dominant species, creating large spread thallus. Among the filaments there were also the thalli of Pseudanabaena frigida, Phormidium uncinatum, Woronichinia compacta, Merismopedia sp. There was also a small share thalli of N. cf. punctiforme.

Mesotrophic habitat with flowing water (MF), (Fig. 5) was also characterized by the dominance of Microcoleus autumnalis (forming mats), whose proportion in the community was between 40 and 60%. It occurred as dark brown, thin thalli on mosses, rocks and wet soil. Between the leaves of mosses there were also lobular thalli of the thin form of Leptolyngbya sp. The species distinctive for this tundra was Schizothrix cf. facilis occurring as long filaments in the water and at the bottom of streams. A lot of species of non-heterocytous types of cyanobacteria (Geitlerinema acutissimum, Pseudanabaena catenata, Leptolyngbya valderiana, Oscillatoria fracta) were also noted.

5. Discussion

Studies conducted over several years in the Hornsund area allowed us to distinguish several types habitats characterized by particular kinds of mosses, vascular plants and phycoflora (Richter et al., 2014b; Richter et al., 2015). In each of the analyzed habitats cyanobacteria had an important role, especially in initial habitats. They occupied vast surfaces of the analyzed area and were often essential in the production of biomass.

During research in oligotrophic habitats it was noted that uncovered soil was visibly dominated by cyanobacterial crusts, and by Nostoc commune thalli. In these difficult conditions they occupied vast areas of the mosses surface, creating visible black or dark blue thalli.
conditions the colonization success of cyanobacteria assemblages in the form of crusts results from their accommodation to environmental stresses, such as drastic fluctuations in temperature and drying and radiation (Oleksowicz & Luścińska, 1992; Hu et al., 2012; Komárek & Kovacík, 2013).

In the majority of the studied oligotrophic habitats in the Hornsund region cyanobacteria crusts are formed by *Schizotrix* cf. *lacustris* and the accompanying species such as *Microcoleus vaginatus*, *Tolyphothrix tenuis*, *Scytonema crustaceum* and species of the genera *Gloeocapsa*, *Chroococcus*. This results from the fact that filamentous sheath-forming species (e.g. *Schizotrix*, *Microcoleus*) are best adapted to the tundra conditions because the presence of a sheath and mucilage can help protect cells against physical desiccation (Friedmann et al., 1988; Mazor et al., 1996; Gupta & Agrawal, 2008). In habitats of this type, in mosses communities, *Sanonia uncinata* has always been present in mosaic with other mosses, such as *Bryum* sp. or *Sanonia uncinata* is one of the dominating species of mosses in the Arctic because it is adapted to extreme conditions. The dominance of mosses in the region derives from the fact that many of them are able to use nitrogen due to high activity of epiphytic cyanobacteria cooperating with them. The research by Karagatzides et al. (1985) and Solheim et al. (1996) describe *Sanionia* sp. and *Bryum* sp. as the most popular host plants for cyanobacteria.

During the Hornsund research conducted in low nutrient oligotrophic habitats it was observed that there is a connection between the presence of *Sanonia uncinata* and the occurrence of heterocytous cyanobacteria. It was particularly visible in case of *Nostoc commune* and *Nostoc* cf. *punctiforme*. In polar regions habitats low in nutrients have a big share of heterocytous species (Matula et al., 2007; Richter et al., 2009; Komárek & Elster, 2008; Komárek & Komárek, 2010; Richter et al., 2014b, 2015). The accompanying vegetation, mostly bryophytes, often forms strict associations with cyanobacteria. These may include *Anabaena* and *Calothrix* sp., but most often the genus *Nostoc* (Nakatsubo & Ino, 1986, 1987), which is the most commonly spread species from the Antarctic, especially in surface habitats, where it may reach macroscopic sizes (Vincent et al., 1986; Fumanti et al., 1995; Cavacini, 2001; Hirai et al., 2004; Fukuda et al., 2008; Komárek & Elster, 2008; Komárek & Komárek, 2010). The dominance of *Nostoc commune* thalli was also observed in oligotrophic habitats, where *Bryum pseudotriquetrum* was record-ed. Othani’s research (1986) confirmed this and proved that *Nostoc commune* often occurs in leaves and branches of the moss, forming an association.

Another interdependency was observed in habitats with *Paludella squarrosa* dominance. Covering the habitats under sea spray *Paludella squarrosa* co-created a community with a dominance of cyanobacterial mats with *Geitlerinema acutissimum* and *Lyngbya aestuarii*. This resulted from the particular habitat conditions in the coastal area. *Lyngbya aestuarii* is a species with a large spectrum of occurrence in salty environments (Silva et al., 1996; Galil et al., 2011; Kothari et al., 2013). On the other hand, in the conditions of an oligotrophic habitat *Paludella squarrosa* was characteristic of habitats on lime soils (Dierssen, 2001), which was reflected in the presence of blue green algae. Cyanobacterial crusts were formed of *Schizothrix* cf. *calcicola* and *Dichothrix gypsophila*, species, whose sheaths are richly incrusted with calcium carbonate (Komárek & Anagnostidís, 2005; Komárek, 2013).

Mesotrophic habitats are characterized by unusually rich bryophyte vegetation, vascular vegetation (*Saxifraga oppositofolia*, *Tetraplodon mnioides*, *Straminergon stramineum*) and phycoflora richness. Cyanobacterial crusts and mats are of lesser importance. Filamentous cyanobacteria are present, non-heterocytous of the *Oscillatoria*, *Pseudanabaena*, *Phormidium* genera *Microcoleus autumnalis* is observed in mesotrophic habitats in Hornsund forming dark brown, flat wide-spread mats attached to mosses, rock and ground, and constituting as much as 70% of cyanobacterial and algal community. In polar regions *Microcoleus autumnalis* is characteristic of humid subaerophytic habitats (Vincent, 2000; Komárek & Elster, 2008; Strunecký et al., 2013). The analyzed habitats also had numerous occurrences of *Pseudanabaena frigida*. It has a broad spectrum occurrence in relation to trophy and surface (Fumanti et al., 1995, 1997; Matula et al., 2007; Richter et al., 2009; Davydyov, 2014), but occurs most often in mesotrophic moss tundra.

The large share of cyanobacteria in the habitats structure confirms their important role in creating the mosaic communities of Arctic tundra. The conducted research indicates correlation between the occurrence of particular cyanobacteria species and mosses or vascular plants in habitats diverse in trophy and moisture.

### 6. Conclusions

The paper is concerned with the relations between cyanobacterial assemblages and vegetation in Arctic ecosystems. The studies were conducted in the area of Hornsund fjord in 14 types of habitats diversified in humidity and trophy. In the habitats, qualitative and quantitative analyses of phycoflora were conducted along with floristic analyses of mosses and vascular plants. The study distinguished plant assemblages and cyanobacterial assemblages forming cyanobacterial thalli and crusts characteristic of particular habitats. As a result, the habitats were grouped into 10 categories with a specific combinations of species and clear relations between cyanobacteria and mosses or vascular plants. The observed relations between cyanobacterial as-
semblages and vegetation and the often dominating role of cyanobacteria in Arctic ecosystems indicate their significant role in the formation of the Arctic ecosystem and suggest they should be included in the descriptions of communities present in the region.

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