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

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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 (Elvebakk, 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 nitrogen 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; Elvebakk, 2005; Cooper, 2011). Studies of cyanobacteria, on the other hand, were mostly focused on the biodiversity of phycoflora (Thomasson, 1958, 1961; Willen, 1980; Matuła, 1982; Plichta & Luścińska, 1988; Oleksowicz & Luścińska, 1992; Skulberg, 1996; Turicchia et al., 2005; Matuła 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 & Matuła, 2013; Richter et al., 2014a; Kvíderová et al., 2011; Komárek & Kovacik, 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 Ariekammen, 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 *Petalonema crustaceum*, *Tolypothrix tenuis*, *Microcoleus vaginatus*, *Stigonema* 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 coccoid 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. *lacustris* with *Petalonema crustaceum*, *Tolypothrix tenuis* and *Microcoleus vaginatus*. Within them there were also small colonies of *Symplocastrum* 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. *lacustris*, *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 *Gloeothece* 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 exannulata*, *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 habitates are also characterized by a large proportion of *Nostoc commune* (Fig. 3) and *N.* cf. *punctiform*e 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-

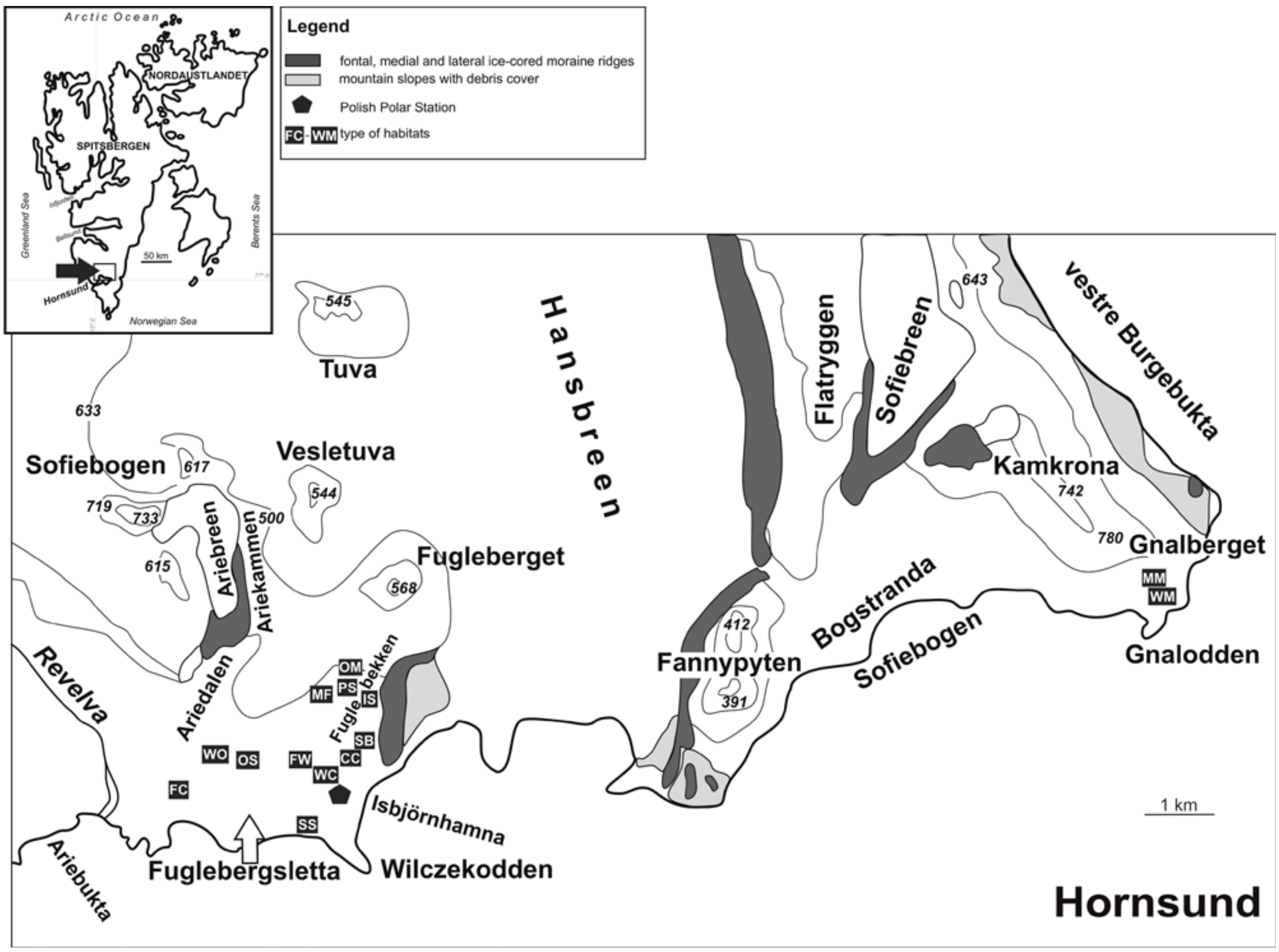

Figure 1. Location of the Svalbard, Spitsbergen – Hornsund fjord (Fuglebekken catchment, Fuglebergsletta marine terrace and Gnalberget slope, Gnolodden plain terrace)

Table 1. Relations between cyanobacterial assemblages and vegetation

Type of habitats	Symbols	Mosses and vascular plants-characteristic species	Cyanobacteria-characteristic species	Trophy	Moisture
The initial stage of cyanobacteria-moss habitat	IS	*Anthelia juratzkana* (Limpr.) Trevis., *Sanionia uncinata* (Hedw.) Loeske, *Saxifraga oppositifolia* (L.) and *S. cespitosa* (L.)	**aerophytic form of *Schizothrix* cf. *lacustris* A. Braun ex Gomont** and *Petalonema crustaceum* Agardh ex Kirchner, *Tolypothrix tenuis* Kützing ex Bornet et Flahault, *Microcoleus vaginatus* Gomont ex Gomont, *Sacconema* sp., *Stigonema* cf. *mamillosum* (Lyngbye) Agardh ex Bornet et Flahault and *Calothrix* cf. *parietina* Thuret ex Bornet et Flahault, *Gloeocapsa biformis* Ercegović, *G. punctata* Nägeli and *Chroococcus turgidus* (Kützing) Nägeli, *Nostoc commune* Vaucher ex Bornet et Flahault and *N.* cf. *paludosum* Kützing ex Bornet et Flahault	oligotrophic	wet
Polygonal soil	PS			oligotrophic	moderately wet
Cyanobacteria-moss snowbed	SB			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 tenuis* and *Microcoleus vaginatus*, *Symplocastrum* sp., *Dichothrix gypsophila* (Kützing) Bornet et Flahault, *Gloeocapsa punctata*, *G. sanguinea* (Agardh) Kützing, *G. biformis*	oligotrophic	damp
Cyanobacterial crust	CC	*Sanionia uncinata*, *Saxifraga oppositifolia* and *S. cespitosa*		oligotrophic	moderately wet
Oligotrophic flow water habitat	FW	*Barbula* sp. and *Sanonia uncinata*, *Straminergon stramineum* (Dicks. ex Brid.) Hedenas and other mosses	***Nostoc commune*, planctonic form of *Schizothrix* cf. *lacustris*,** *Petalonema crustaceum*, *Microcoleus vaginatus*, *Symplocastrum* sp., *Gloeocapsa kuetzingiana* Nägeli, *G. punctata*, *G. biformis*, *Aphanothece clathrata* W et G. S. West, *A. caldariorum* Richter, *A. microscopica* Nägeli, *Woronichinia* sp., *Gloeothece* sp. and *Aphanocapsa* sp.	oligotrophic	damp
Oligo-mesotrophic moss habitat	OM	*Sanionia uncina*, *Straminergon stramineum*, *Warnstorfia 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 habitat	WO			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 coccoid 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 coccoid 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, *Woronchinia* sp. *Nostoc commune*	oligotrophic	damp
Oligotrophic wet moss habitat	WM	*Saxifraga oppositifolia*, *Sanionia uncinata*, *Aulacomnium palustre* (Hedw.) Schwaegr., *Pohlia nutans* (Hedw.) Lindb.	***Nostoc punciforme*, *N.* cf. *palludosum* Kützing ex Bornet et Flahaolt,** *Gloeothece*cf. *incerta* Skuja	oligotrofphic	wet
Mesotrophic wet moss habitat	MM	*Saxifraga oppositifolia* and *Deschampsia borealis* (Traut.) Rosh. with *Plagiomnium ellipticum* (Brid.) T. Kop, *Pohlia nutans*	***Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky et al.,** *Pseudanabaena frigida* (Fritsch) Anagnostidis, *Phormidium uncinatum* 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. *lacustris* 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).

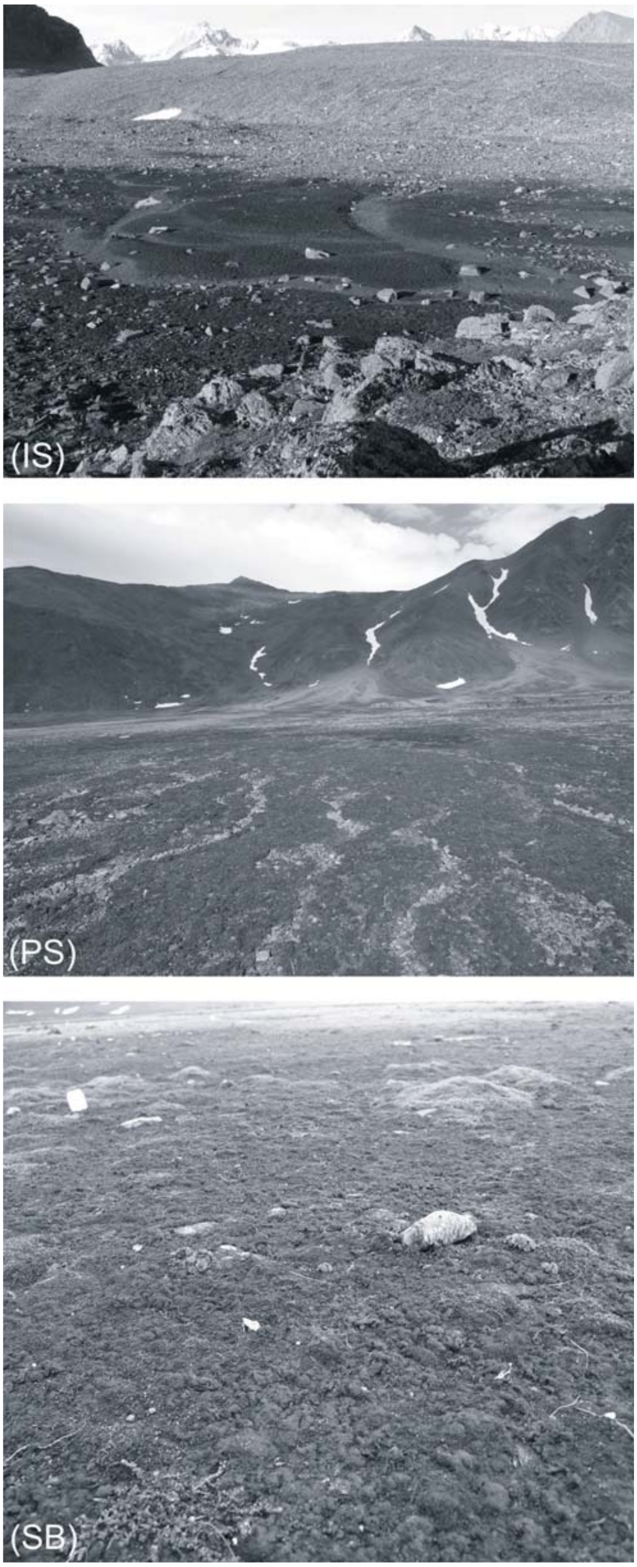

Figure 2. View of the initial stage of cyanobacteria-moss habitat (IS), polygonal soil (PS) and cyanobacteria-moss snowbed (SB)

Figure 3. Macroscopic view of *Nostoc commune* thallus

Figure 4. View of the wet oligotrophic cyanobacterial crust with *Saxifraga* spp. (OS)

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

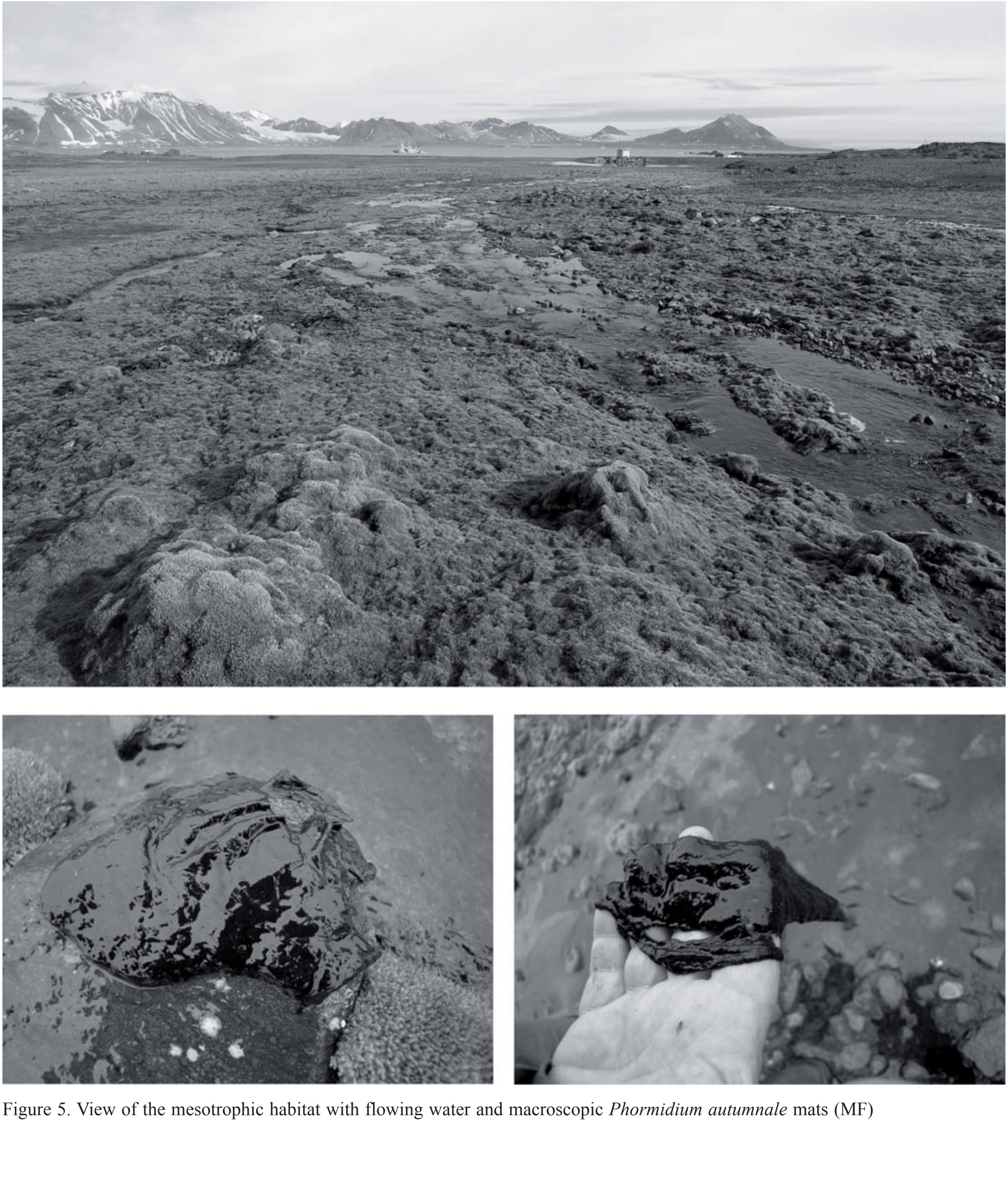

Figure 5. View of the mesotrophic habitat with flowing water and macroscopic *Phormidium autumnale* mats (MF)

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 *Plagomnium 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

Figure 6. View of the Gnalberget slope

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 & Kovacik, 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*, *Tolypothrix tenuis*, *Scytonema crustaceum* and species of the genera *Gloeocapsa*, *Chroococcus*. This results from the fact that filamentous sheath-forming species (e.g. *Schizothrix, 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, *Sanionia uncinata* has always been present in mosaic with other mosses, such as *Bryum* sp. or *Sanionia 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 (Matuła 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; Fukunda 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 recorded. 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 squarosa* dominance. Covering the habitats under sea spray *Paludella squarosa* 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 & Anagnostidis, 2005; Komárek, 2013).

Mesotrophic habitats are characterized by unusually rich bryophyte vegetation, vascular vegetation (*Saxifraga oppositifolia, 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; Matuła et al., 2007; Richter et al., 2009; Davydov, 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 assemblages 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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