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Biodiversity of freshwater algae and cyanobacteria on deglaciated northern part of James Ross Island, Antarctica. A preliminary study.

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Abstract

Freshwater algae and cyanobacteria have been studied at the James Ross Island (Antarctica) since the first Czech expedition to the James Ross Island area in austral summer of 2004. Main emphasis, however, has been devoted to cyanobacteria and diatoms. Therefore, recent knowledge on biodiversity of freshwater species of green algae is fragmentary. The main aim of presented study was to contribute to species list of green algae and cyanobacteria from James Ross Island. To evaluate species richness of algae and cyanobacteria, samples of water/mats from 6 different lakes, shallow ponds, and seepages located in northern deglaciated part of the James Ross Island were collected in austral summers 2012 and 2013, respectively. The samples were analysed using optical microscopy approach after transport to Czech laboratories. Algal and cyanobacterial taxa were determined according to morphological characteristics. Frequencies of individual taxa occurrence in samples were evaluated. Species richness differences between sampling sites was found. Dominating taxa differed between collection sites as well. Altogether, 41 algal and cyanobacterial taxa were found. Some species and genera: *Cosmarium* sp., *Actinotaenium curtum*, *Staurastrum punctulatum* and *Chlorobotrys regularis* are reported for James Ross Island for the first time. In some samples, there were some species that remained undetermined due to limitations of light microscopy and morphological approach. We plan to sample those locations of the James Ross Island that have never been investigated before for future studies

Key words: polar lakes, ponds, seepages, freshwater ecosystems

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Introduction

Freshwater algae and cyanobacteria are quite abundant in Maritime Antarctica, especially along the Trinity Peninsula. They occur in a wide variety of ecosystems ranging from bare rock and soils/ regolith, soil crusts and microbiological mats, moss cushions, streams, seepages, lakes and wet bottom of glaciers, snow and ice. Since the pioneering study of Cameron (1970), who reported microbes and algae from Deception Island, there have been more than 50 studies devoted to a variety of biological/ecological aspects of algae thriving in such ecotopes. From a bibliographic survey (Skácelová et Barták, MS in prep.), it follows that majority of algal and cyanobacterial samples have been collected from Western side of the Trinity Peninsula, the South Shetlands and Argentinian Islands in particular (*see* e.g. Zidarova 2008, Temniskova-Topalova et Kirjakov 2002). The islands east of the Trinity Peninsula have been sampled much less frequently and thus information on biodiversity of green algae (excluding diatoms – *see* details below) is still at the beginning. However, in spite of the fact that the first report on freshwater ecosystems of the James Ross Island (East of the Antarctic Peninsula) dates back to the early 90-ies of the last century (Hawes et Brazier 1991), numerous cyanobacterial species and their more than 70 morphotypes are reported from the James Ross Island (Komárek et Elster 2008, Komárek et al. 2008) indicating potentially large cyanobacterial biodiversity of the island (Vincent et Quesada 2012). *Chroococcus* sp., *Leptolyngbya fritschiana*, *L. vincentii*, *L. borchgrevinkii*, *Phormidium priestleyi* and *Microcoleus autumnalis* (former name *Phormidium autumnale*) are the most reported cyanobacterial species. Green algal species, although reported for the James Ross Island in the studies focused on the effects of abiotic factors on autotrophic communities (*e.g.* Nedbalová et al. 2013), have not yet been studied systematically. Only 6 freshwater algal species are reported by Elster et al. (2013) from James Ross Island and 3 algal species are cultivated in CCALA collection in Třeboň: *Zygnema* sp., *Klebsormidium* sp. and *Heterococcus* sp.

Thanks to facilities of J. G. Mendel Station (Prošek et al. 2013), a long-term research on physical (*e.g.* Váczi et Barták 2011), chemical and ecological characteristics (Nedbalová et al. 2013) of lakes of the James Ross Island has been conducted since 2006. In these studies, mineral ions contents in lakes and long-term water temperature courses are reported. Moreover, initial part of geochemical mapping based on strontium isotope ratio was done for some lakes, such as Phormidium Lake (Míková 2012). Autotrophic organisms associated with wet habitats of the James Ross Island have been studied with the main focus on diatoms (*e.g.* Esposito et al. 2008, Van de Vijver et al. 2011, Kopalová et al. 2011a, 2011b, 2012, 2013) and cyanobacteria (*e.g.* Komárek 2007, Komárek et al. 2012). Some specific aspects of cyanobacteria occurrence in lake ecosystems, such as formation of mineral structures similar to stromatolites (Elster et al. 2009) has been in focus as well. Algae have been studied less frequently, only 5 genera (*Klebsormidium*, *Prasiola*, *Ulothrix*, *Tribonema* and *Hazenia*) are reported for James Ross Island (Veselá 2007, Prošek et al. 2013, Škaloud et al. 2013). In our study, we therefore focus on preliminary report of algae and cyanobacteria from lakes and seepages of the northern ice-free area of James Ross Island. For sampling, several sites have been selected in respect to different lake and pond types, their freezing/thawing cycles and geographical location on the island.

Material and Methods

Sampling sites description

Locations of 6 sampling sites are indicated in Fig. 1 and basic geographic information are given in Table 1. Detailed description of sampling site is given for each of them.

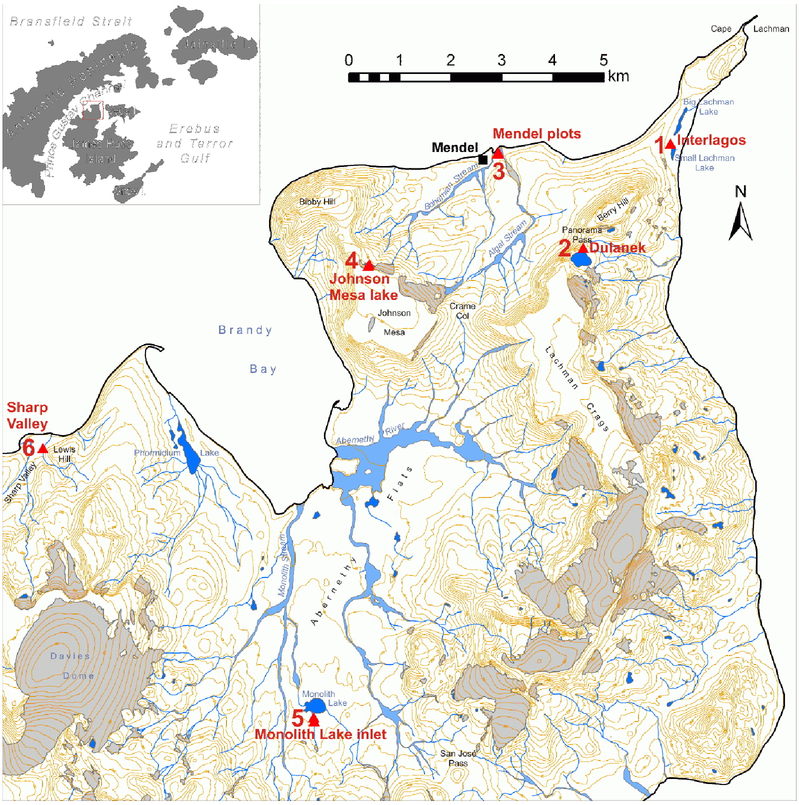

Fig. 1. Sampling sites located at the northern part of the James Ross Island – Ulu Peninsula: (1) Interlagos, (2) Dulanek Pond, (3) Mendel plots (Long-term experimental plots close to Mendel Station), (4) Johnson Mesa Lake, (5) Monolith Lake inlet, (6) Sharp Valley. Topographic base of Czech Geological Survey (2009).

1. *Interlagos ponds*

These are very shallow small ponds located in between Big and Small Lachman Lakes at the altitude of ~10 m a.s.l. The Big and Small Lachman Lakes are typical shallow coastal lakes, which evolved after the retreat of the ice in the early Holocene time (Nedbalová et al. 2013) and are located in sedimentary rocks. In spite of the fact that Big and Small Lachman lakes are typical of high content of fine-grained clayey to silty particles originating from underlying Neogene glacigenic and glaciomarine sediments of the Mendel Formation (Nývlt et al. 2011) resulting in greyish-brown colour of turbulent water column, water in the Interlagos ponds is clear and rich in benthic microbial mats. For sampling of microbiological mats, the southern pond (Interlago 2) was used. Mean water temperature in the Interlago 2 for January is 7.2°C (Váczi et Barták 2011). Both the

Interlagos ponds and Big and Small Lachman Lakes are affected by the sea proximity. Therefore, nutrient input from a sea-spray took place during windy days. Main source of water for the ponds and lakes are snowfields formed annually during austral winter thanks to local topography (*see* Fig. 2B in Nedbalová et al. 2013). If snow accumulation is not sufficient, lakes may dry out during summer season (Váczi et al. 2011).

2. *Dulanek Pond*

The Dulanek Pond is a typical small-area pool formed in a shallow depression on the surface of a left lateral glacier moraine made of large stones of hyaloclastite breccias with present ice core (*e.g.* Davies et al. 2013). Main source of water are snowfields formed annually in a neighbourhood of the pond during austral winter. The pond is located close to Panorama Pass at the altitude of ~220 m a.s.l. about 2 km from coast. Typical pond area is of ~25 m^2. Maximum depth reaches 0.8 m. Average annual and summer season temperature (December–February) is -4.6 and 2.1°C, respectively (Váczi et al. 2011).

3. *Mendel plots* (*Long-term experimental plots close to Mendel Station*)

The plot is located in coastal area on the upper inactive part of Algal Stream delta only 80 m from the Mendel Station. The area is therefore supplied by water mainly from neighbouring snowfield that may remain for whole summer season. Occasionally, the snowfield may melt out in extremely hot and windy summer, which results in drying-out of the seepage and consequent full inhibition of photosynthetic activity of the autotrophs forming the community for several weeks (Barták, unpublished data from February 2009). The seepage is rich in moss and lichen flora. Therefore, a long-term research plot was established here in 2007 to study the probable effects of atmospheric warming on vegetation of Antarctic coastal oases using an open top chambers approach (Barták et al. 2009). An automatic weather station has recorded microclimate data here since 2007. The plot is characterized by annual mean air temperature -4.6°C (Láska et al. 2011). In austral summers (November to February) mean temperature above the surface of moss cushion forming patchy vegetation cover of the long-term research plot is 4.1°C (recalculated from Láska et al. 2011).

4. *Johnson Mesa Lake*

The lake was formed after the glacier retreat from the cirque area on the northern slope of the Johnson Mesa at the altitude of ~255 m a.s.l. (it is named Bibby Lake in Nedbalová et al. 2013). Recently, the lake is delimited by perpendicular rock wall from S–SW and dammed by a frontal moraine in the NE. The area of the lake is estimated to 7 439 m^2 (Nedbalová et al. 2013). Typically, the lake remains partly frozen during austral summer seasons. The recent main water source is the snow accumulation located on the NE slopes of Johnson Mesa formed thanks to prevailing SW winds during austral winters.

5. *Monolith Lake*

The lake is located in an inland area of the Ulu Peninsula, northern James Ross Island in the altitude of 67 m a.s.l., ~6 km from the Brandy Bay seashore (*see* Fig. 1). It is a typical representative of stable lakes formed in old moraines, in this case after the mid-Holocene retreat of Whisky Glacier (Hjort et al. 1997, Nedbalová et al. 2013). It represents the second largest lake (~93 000 m^2) in the ice-free area of northern Ulu Peninsula. The lake and two main inlets are rich in freshwater autotrophs. The surrounding of the two inlets is covered by well-developed patterned moss and lichen communities as well as microbial mats.

6. *Sharp Valley*

The samples were collected from one of the seepages formed along the sides of a stream close to Lewis Hill at the altitude of 10 m a.s.l. The site of collection was located ~200 m from the coast. Stony substrate forming valley floor originated from sedimentary rocks of the Bibby Point and Lewis Hill Members of the Whisky Bay Formation (Crame et al. 2006) rich in weathered dark green chloritic rocks originating from the rafts of the Nordenskjöld Formation. Therefore, the studied mineral formed a greenish inorganic layer, on which soil crust and seepages vegetation was formed.

Locality No.	**Sampling site**	**Geographic coordinates**	**Habitat**	**Date of collection**	**pH, water temperature**
1.	Interlagos ponds (Interlago 2)	63°47’56” S 57°48’38” W	Small-area ponds in sediments (10 m a.s.l.)	6. 2. 2013	pH = 9.4 t = 7.5°C
2.	Dulanek Pond		Small-area pond rich in mats (220 m a.s.l.)	2011	
3.	Mendel plots (Long-term experimental plots close to Mendel Station – seepage)	63°48’01” S 57°52’46” W Site A	Coastal vegetation oasis with moss and lichen cover (5 m a.s.l.)	14. 2. 2013	pH = 8.2 t = 3.5°C
		63°48’01” S 57°52’45” W Site B	Vegetation oasis with formed moss and lichen cover	14. 2. 2013	pH = 8.2 t = 3.5°C
		63°48’00” S 57°52’45” W Site C	Vegetation oasis with formed moss and lichen cover	14. 2. 2013	pH = 8.2 t = 3.5°C
4.	Johnson Mesa Lake	63°49’11” S 57°55’54” W Site A	Moraine lake (250 m a.s.l.)	29. 1. 2013	pH = 9.8 t = 4.0°C
		63°49’10” S 57°55’52” W Site B	Moraine lake (250 m a.s.l.)	29. 1. 2013	pH = 9.8 t = 4.0°C
5.	Monolith Lake - inlet	63°53’56” S 57°57’21” W Site A	Inland lake (67 m a.s.l.)	3. 2. 2013	pH = 8.3 t = 2.2°C
		63°53’59” S 57°57’21” W Site B	Inland lake (67 m a.s.l.)	3. 2. 2013	pH = 8.3 t = 2.2°C
6.	Sharp Valley (seepage)		Soil crust close to the Sharp Valley stream (10 m a.s.l.)	2011	

Table 1. General characteristics of sampling sites at the James Ross Island, Antarctica.

Sampling

The communities of freshwater algae and cyanobacteria were sampled on the James Ross Island (64°10' S, 57°45' W) in 2012/2013 austral summer season. The collections were done during the Czech Polar Expedition in the area of ice-free Ulu Peninsula. All samples were collected at air temperature of 1–3°C. Thus, the mats of algae and cyanobacteria exhibited physiological activity. Mat samples were collected into polyethylene vials of 50 ml volume with a sufficient amount of ambient water. After collecting, the samples were stored at the temperature of 4°C in a refrigerator. The transport of samples to laboratories in the Czech Republic was carried out using a cooling container at the temperature around 0°C.

Cyanobacterial communities of lakes in this area constitute a transitional zone between Maritime and Continental Antarctica (Komárek et Elster 2008). In this research, two samples from an inlet of old stable Monolith Lake were observed (*see* Fig. 1). Furthermore, two samples from the Johnson Mesa Lake floor are also involved here. Due to low water level, the lake was divided into two parts in this season. The sample A (*see* Table 1) was collected from an overflow among these parts. The sample B was collected from layers of a mat near a bank. However, the main part of lake surface remained under the ice even during the high summer season. Algae and cyanobacteria from the Interlago 2 (one of the two ponds forming the Interlagos, for details *see* Váczi et Barták 2011) on the Cape Lachman were also collected. This site has been intensively studied since 2006. Samples of microbiological mats were collected from Dulanek Pond, a small-area pond rich in algae and cyanobacteria. Limnological characteristics of selected lakes were described in detail by Nedbalová et al. (2013). Other samples were collected in the seepages - three samples in Mendel plots and one in Sharp Valley close to a stream.

Optical Microscopy

After transfer to Brno (Czech Republic), mat samples were analysed by an optical microscopy (Olympus BX50, Japan) and digital photograph of the species forming the mat were taken (Sony SLT-A35 (HD AVCHD). Throughout all samples, more than 1 000 photographs were taken and analysed, so that individual mat-forming species could be distinguished. Morphologic approach was used to determine particular algal and cyanobacterial species. Relative frequencies of species were calculated for each sample.

Results and Discussion

Total number of 41 algal and cyanobacterial taxa were found in ten samples from the material collected at 6 investigated sampling sites (*see* Fig. 1, Table 1). Biodiversity differed between sampling sites, however a large variation in species composition was found even within a single samples. It has been documented for the seepages close to the Mendel Station (Mendel plots, sampling site No. 3), where three samples were collected (A, B, and C). In two of them, different dominant taxa were found: alga *Zygnema* sp. (*see* Fig. 2D) and cyanobacterium *Nostoc* sp. (*see* Fig. 3F). In the third one, an unidentified species was dominant. This might be attributed to a high biodiversity of green algal and cyanobacterial species of sampling site No. 3 (seepages).

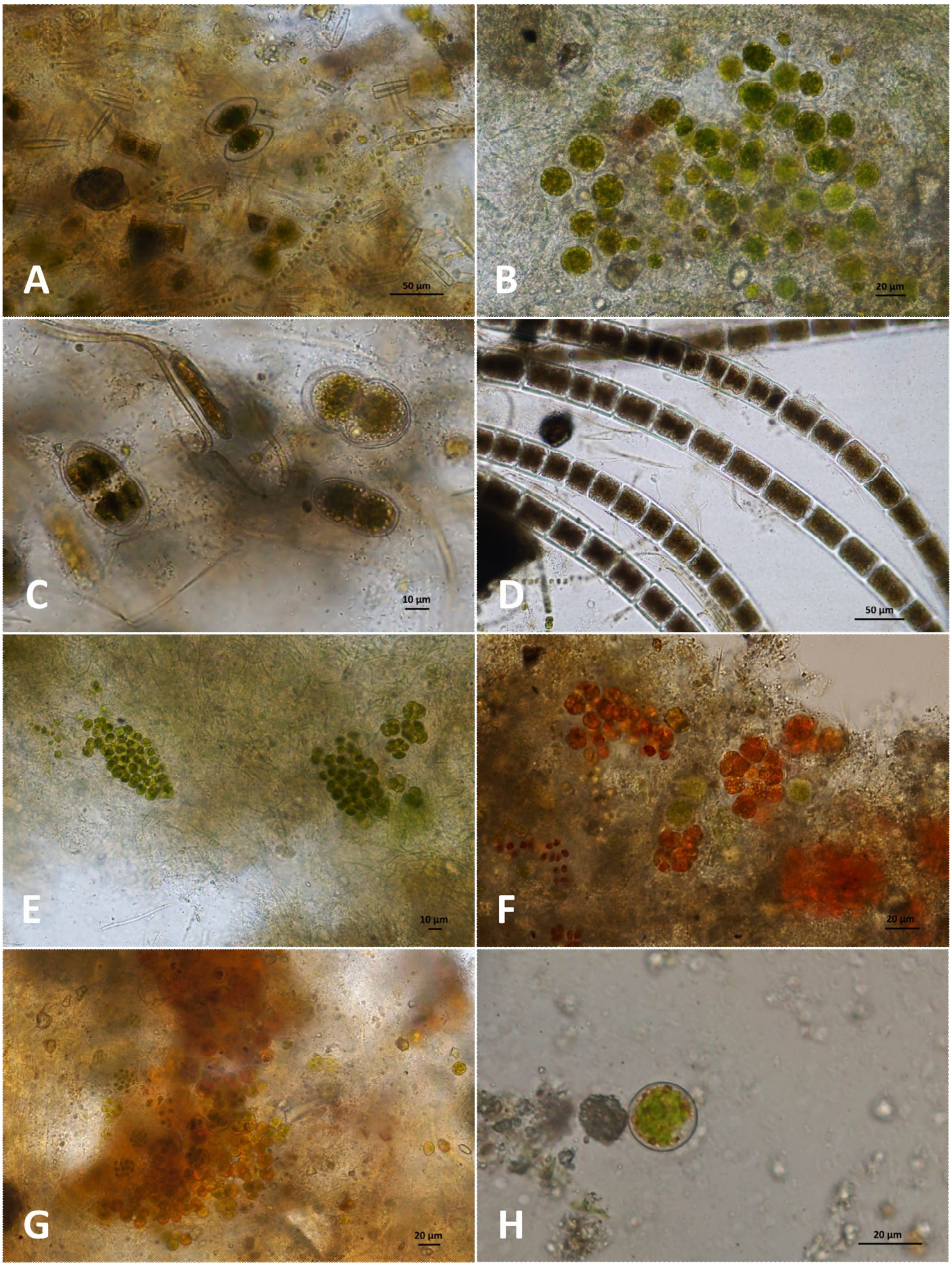

Fig. 2. Algae of James Ross Island – Ulu Peninsula. A – *Staurastrum punctulatum*, B – Chlorococcales (type 1), C – *Actinotaenium curtum*, D – *Zygnema* sp., E – Chlorococcales (type 2), F – Chlorococcales (type 3), G – unidentified algae, H – *Chlorobotrys regularis*. Photos: A-G by K. Skácelová, H by K. Trnková.

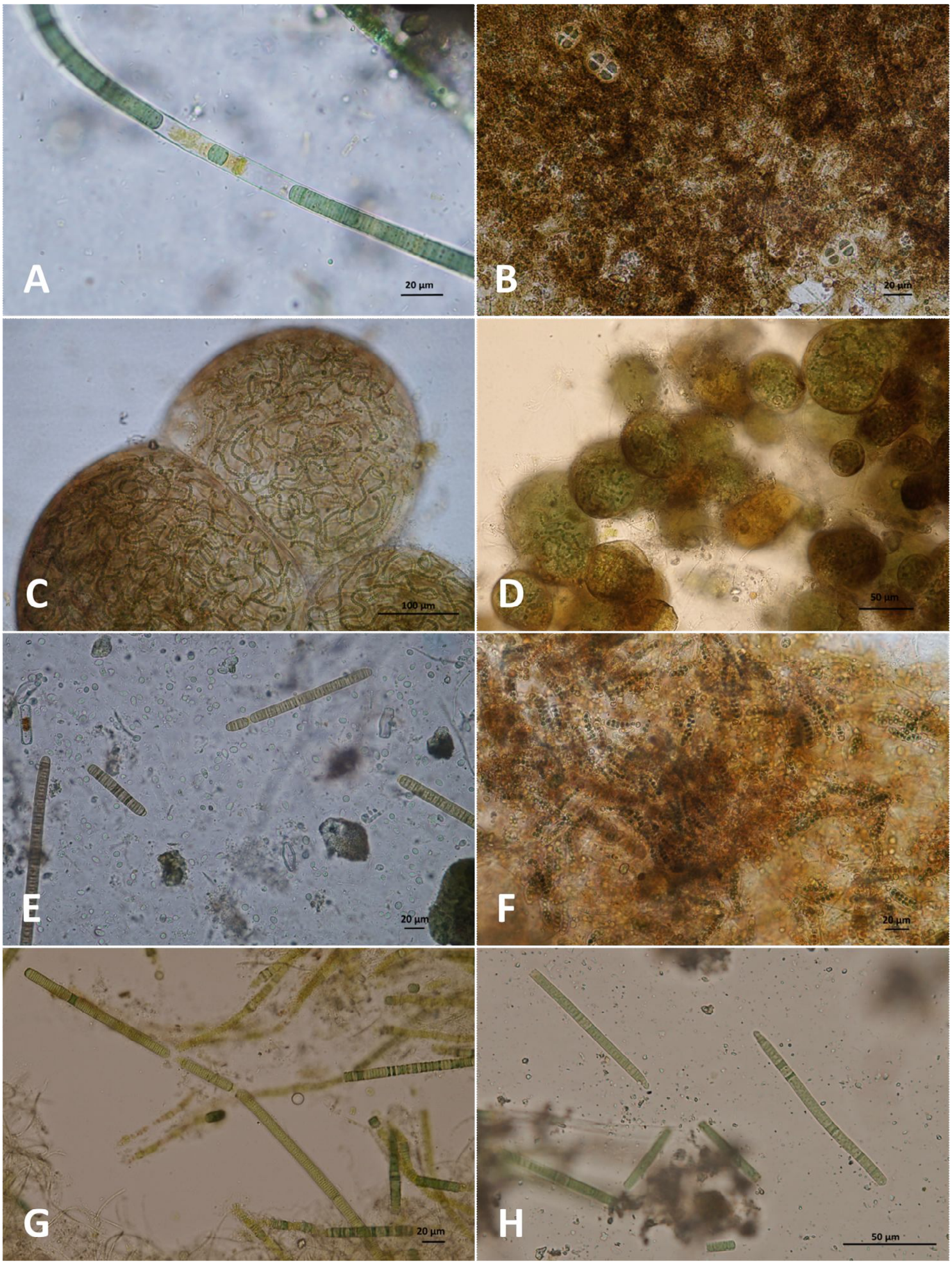

Fig. 3. Cyanobacteria of James Ross Island – Ulu Peninsula. A – *Lyngbya* sp., B – *Chroococcus* sp., C – *Nostoc* sp., D – *Nostoc* sp., E – *Oscillatoria* cf. *subproboscidea*, F – *Nostoc* sp., G – *Blennothrix* sp., H – *Microcoleus autumnalis*. Photos: A-G by K. Skácelová, H by K. Trnková.

The effect of microrelief and spatial patchiness in water availability might be considered possible cause of such difference between single samples from sampling site No. 3. Another seepage (Sharp Valley, sampling site No. 6) was dominated by *Microcoleus autumnalis* (*see* Fig. 3H). Total number of identified autotrophic microorganisms was 28, however some of them has not yet been determined. The number of taxa found in sampling sites No. 3 and 6 supports the idea that seepages represent an important biotope in Antarctic ecosystems. Filamentous cyanobacteria are considered first colonizers of Antarctic seepages (Komárek et Komárek 2010), in which rich communities of algae and cyanobacteria form mats covering soil and/or stony surfaces. It is believed that community structure of algal species forming planktonic communities is dependent on seasonality (Izaguirre et al. 2001). In cyanobacterial mats, zonation is another factor affecting community structure. At the James Ross Island, such dependence was documented for *e.g.* Green Lake (Strunecký et al. 2011, Škaloud et al. 2013). Therefore, our further study will be focused on species biodiversity of mats from the seepages located close to the localities No. 1, 3 and 6, as dependent on the distance from main water source. The study will focus not only on taxonomy of the mat-forming species, but also on their physiological properties, temperature and irradiation optima during controlled growth in photobioreactors in particular (*see* e.g. Balarinová et al. 2013).

Similarly to seepages, samples from lakes exhibited different dominating taxa. While *Nostoc* sp. (*see* Fig. 3C, D) and *Nitzschia* sp. were most abundant in small-area ponds (sampling sites No. 1 and 2), the two genera were missing in the Johnson Mesa Lake and Monolith Lake inlet, *i.e.* sampling sites No. 4 and 5. *Leptolyngbya erebi* was another dominant genus in small-area ponds (sites No. 1 and 2). In large-area lakes, no single dominant species was apparent. Further and more detailed sampling and consequent analyses of communities forming mats in large-area lakes are required in future studies, so that a presence or absence of the species typical for small-area pond such as *e.g. Nostoc* sp., *Nitzschia* sp., and *Leptolyngbya* sp. in large-area lakes of the James Ross Island could be evidenced. Generally, differences between small- and large-area ponds/lakes could be expected because of different water temperature courses during austral summer season (Váczi et Barták 2011). However, *Nostoc* sp. and *Leptolyngbya* sp. are reported to be frequent species at the James Ross Island (Komárek et Komárek 2010).

While colonies of *Klebsormidium* sp. followed by *Gloeocapsopsis*-like cyanobacterium dominated in the site B from the Johnson Mesa Lake, unidentified green alga (*see* Chlorococcales type 1 in Fig. 2B) was dominating in the site A. Sample rather than site-related community composition was found for autotrophs from the Monolith Lake (sampling site No. 5, *see* Fig. 1). While *Zygnema* sp. and *Gomphonema* sp. were most dominant in the site A, *Microcoleus* sp., *Nostoc* sp., and *Leptolyngbya vincentii* were the most frequent species/genera in the site B. However, when pooled, data showed relatively high number of 16 taxa found at the sampling site No. 5 (Monolith Lake). Therefore, the lake can be ranked as partially frozen inland lake with rich autotrophic flora in littoral zone (*see* e.g. Komárek 2007, Taton et al. 2011).

	Interlago 2	Dulanek	Mendel plots			Johnson Mesa Lake		Monolith Lake - inlet		Sharp Valley
			site A	site B	site C	site A	site B	site A	site B	
CYANOBACTERIA										
Blennothrix sp.		+ + +								+
Calothrix sp.	+	+							+ +	
Cyanothece ohtani Komárek		+		+						
Gloeocapsa sp.		+								
Hassalia sp.									+	+
Chroococcus sp.					+					+
Leptolyngbya cf. *borchgrevinkii* Komárek 2007			+							
Leptolyngbya erebi (West & G.S.West) Anagnostidis & Komárek 1988	+ + +	+ +	+ + +	+	+ +		+			
Leptolyngbya fritschiana Komárek 2007				+ + +						
Leptolyngbya vincentii Komárek 2006								+ +	+ + +	
Lyngbya sp.	+ +	+			+		+ +		+	
Microcoleus autumnalis (C.Agardh) Rabenhorst 1847		+		+	+					+ + +
Microcoleus sp.	+ +								+ + +	
Nodularia quadrata F.E.Fritsch 1912	+	+								
Nostoc sp.	+ + +	+ + +	+ +	+	+ + +				+ + +	
Oscillatoria cf. *fracta* Carlson 1913	+									
Oscillatoria cf. *subproboscidea* West & G.S.West 1911	+		+ +		+ +			+ +		
Oscillatoria sp.				+ +		+ +				+
Phormidesmis sp.	+ +									
Wilmottia murrayi (West & G.S.West) Strunecký, Elster & Komárek 2011			+ +							
Chroococcales (type 1)	+							+		
CHLOROPHYTA										
Actinotaenium curtum (Brébisson ex Ralfs) Teiling 1978				+ +						
Cosmarium sp.		+		+	+	+		+	+	
Klebsormidium sp.			+	+	+		+ + +	+		
Staurastrum punctulatum Brébisson, 1848								+		
Ulothrix sp.				+ +						
Zygnema sp.	+			+ + +	+			+ + +	+	
Chlorococcales (type 1)	+ +									
Chlorococcales (type 2)	+ +		+ +				+ +			
Chlorococcales (type 3)						+ + +				
Chlorococcales (type 4)							+ +	+ +		
BACILLARIOPHYCEAE										
Amphora sp.	+ +									
Eucocconeis sp.			+							
Fragillaria sp.	+									
Gomphonema sp.	+							+ + +	+	
Hantzschia sp.		+	+ +						+	
Luticola sp.							+ +			
Navicula sp.		+	+							
Nitzschia sp.	+ + +	+ +								

Pinnularia sp.			+			+		+		
EUSTIGMATOPHYCEAE										
Chlorobotrys regularis (West) Bohlin 1901		+								+

Table 2. Occurrence of algal and cyanobacterial taxa at single sampling sites on James Ross Island – Ulu Peninsula. + + + means frequent taxa, + + medium occurring taxa, + rare taxa.

In conclusion, diversity of algae and cyanobacteria was site-specific, however, may be ranked as generally high. When compared to the number of genera/species presented by Veselá (2007), who studied biodiversity in two coastal streams of the James Ross Island (*see* Bohemian and Algal Streams in Fig. 1), our data supports the conclusion of high biodiversity in freshwater ecosystems, lakes in particular, at the James Ross Island. Veselá (2007) reported 15 species of cyanobacteria and four genera of algae. Our study resulted in total of 41 freshwater autotrophs. Some taxa are reported for the first time for James Ross Island: *Cosmarium* sp., *Actinotaenium curtum* (*see* Fig. 2C), *Staurastrum punctulatum* (*see* Fig. 2A) and *Chlorobotrys regularis* (*see* Fig. 2H).

Concluding remarks

Antarctic lakes and water ponds differ in a biodiversity of their benthic mats. Some could be monospecific, formed typically by a single cyanobacterium, the others could be formed by several dominant species (Singh et Elster 2007). According to the scheme, the lakes and seepages investigated in our study might be classified as species-rich. Algal and cyanobacterial communities forming a mat of the Dulanek Pond consist of at least 15 species. Therefore, it can be ranked as a complex and species-rich microbial community. Similar classification could be done for Interlago 2 because at least 18 autotrophic organisms have been distinguished, although not completely determined.

In conclusion, the biodiversity of algal and cyanobacterial species in majority of the studied sites might be higher than reported in this study, because some species have not yet been determined (*see* Fig. 2B, E, F, G). Furthermore, future sampling of the sites at the James Ross Island will undoubtedly bring new species because there are numerous wet ecosystems varying in ecological conditions. This is promising for future studies on biodiversity of algae and cyanobacteria in ice-free part of the James Ross Island. Recently, microorganisms from extreme environments, including Polar Regions (*e.g.* Fernández-Valiente et al. 2007), represent a great potential for biotechnology since they may be used as a source of secondary compounds that exhibit biological activity. Therefore, the knowledge of biodiversity of freshwater algae and cyanobacteria of the James Ross Island may help bioprospection of the island and future algal biotechnologies.

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