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The microorganisms of cryoconite holes (algae, Archaea, bacteria, cyanobacteria, fungi, and Protista): a review

Łukasz Kaczmarek
Department of Animal Taxonomy and Ecology, Adam Mickiewicz University in Poznań, Umultowska 89, 61–614 Poznań, Poland. (kaczmar@amu.edu.pl)

Natalia Jakubowska
Department of Water Protection, Faculty of Biology, Adam Mickiewicz University in Poznań, Umultowska 89, 61–614 Poznań, Poland.

Sofia Celewicz-Gołdyn
Department of Botany, Poznań University of Life Sciences, Wojska Polskiego 71c, 60–625 Poznań, Poland

Krzysztof Zawierucha
Department of Animal Taxonomy and Ecology, Adam Mickiewicz University in Poznań, Umultowska 89, 61–614 Poznań, Poland.

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ABSTRACT. We provide a comprehensive list of microorganisms (algae, Archaea, bacteria, cyanobacteria, fungi, and Protista) inhabiting cryoconite holes on glaciers throughout the world, giving an updated taxonomy accompanied by geographic coordinates and localities. The list consists of 370 taxa reported from cryoconite holes (mostly from Arctic and Antarctic regions and European Alps). However, most of the taxa were not identified to the species level. Until now only 39 identified species or subspecies of bacteria and Archaea, 11 fungi, 17 cyanobacteria, 62 algae, and 13 Protista are known from cryoconite holes, which are only about 38% of total number of taxa reported from these ephemeral environments. Almost 62% of the taxa were marked as *cf.* (*confer*) or were identified only to the genera or even to the higher taxonomic units (such as families or orders). This wide and detailed review assists other scientists to identify the gaps in our knowledge about cryobionts and indicates directions for further zoogeographical and taxonomical studies in this unique freshwater habitat.

Introduction

It is well known that microorganisms can survive in extreme environments such as the surface of glaciers or an ice sheet (for example Hodson and others 2008), or even directly in ice (Sheridan and others 2003). Many Archaea, bacteria, cyanobacteria, algae, fungi, ciliates and microinvertebrates (rotifers, tardigrades, arthropods etc.) have been reported from almost all investigated glaciers (for example Mieczan and others 2013a, 2013b; Sheridan and others 2003; Singh and others 2014b, 2014c; Takeuchi and Koshima 2004; Zawierucha and others 2015). These glaciers and ice sheets should be regarded as independent biomes due to truncated food webs and distinct biogeographical structure, with the cryoconite holes as autonomous microecosystems (Anesio and Laybourn-Parry 2012; Wharton and others 1985).

Cryoconite holes (Fig 1) are water-filled depressions situated in ablation zones on the glacier surfaces in polar and mountain regions (for example Gribbon 1979; Hodson and others 2008; Wharton and others 1985) and one of the most surveyed habitats in glacial ecosystems. The holes are formed due to the decrease of ice albedo in places where dark organic and inorganic debris are deposited on the glacier's surface and resultant localised melting (Gerdel and Drouet 1960; Hodson and others 2008; Wharton and others 1985). Other important factors influencing the formation of cryoconite holes are the microorganisms assemblages of these unique habitats. Combined activity of primary producers with algal mats and bacteria in cryoconite holes results in the accumulation of dark-coloured organic matter and the reduction of ice albedo (Anesio and others 2009; Takeuchi and others 2001a). Moreover, cryoconite granules are formed by cyanobacteria (Hodson and others 2010b) involved in the organic carbon cycles on the glaciers (Anesio and others 2009; Fig. 1).

Despite there being some inputs of microorganisms from non-glaciated habitats, cryoconite holes have distinct and independent microbial communities (Edwards and others 2013c). Many species are directly connected with glacial habitats (Dastych and others 2003; Edwards and others 2013c). But the impacts of local and regional conditions on the bacterial communities have been also observed (Edwards and others 2014). Despite the fact that glaciers and ice caps constitute 10% of the Earth's area and cryoconite holes cover approximately (*circa*) 10% of glaciers (in ablation zone) (Fountain and others 2004), the knowledge of organisms in glacial habitats is still poor. Scientific browsers such as Scopus or Web of Science reported only eight and nine papers, respectively, using the search term 'cryoconite holes' and 'organisms'

Table 1. The number of results using the key words connected with different groups of microorganisms and cryoconite holes, cryoconite and glacier. A comparison of results from three different scientific browsers (Scopus, Web of Science (WoS) and Google Scholar (GS)). Accessed 15 December 2014).

	Key words	Scopus	WoS	GS
Algae	Cryoconite holes/*Cryoconite*/glacier	12/*23*/211	20/*32*/148	720/*972*/18900
Archaea	Cryoconite holes/*Cryoconite*/glacier	1/*2*/34	1/*4*/36	232/*336*/8020
Bacteria	Cryoconite holes/*Cryoconite*/glacier	26/*49*/406	36/*62*/398	699/*1040*/18800
Cyanobacteria	Cryoconite holes/*Cryoconite*/glacier	12/*26*/94	22/*35*/95	496/*645*/17300
Fungi	Cryoconite holes/*Cryoconite*/glacier	5/*8*/128	5/*7*/170	397/*560*/11500
Protista	Cryoconite holes/*Cryoconite*/glacier	2/*3*/6	0/*0*/2	127/*145*/7010
Viruses	Cryoconite holes/*Cryoconite*/glacier	7/*7*/36	9/*10*/19	244/*245*/9020

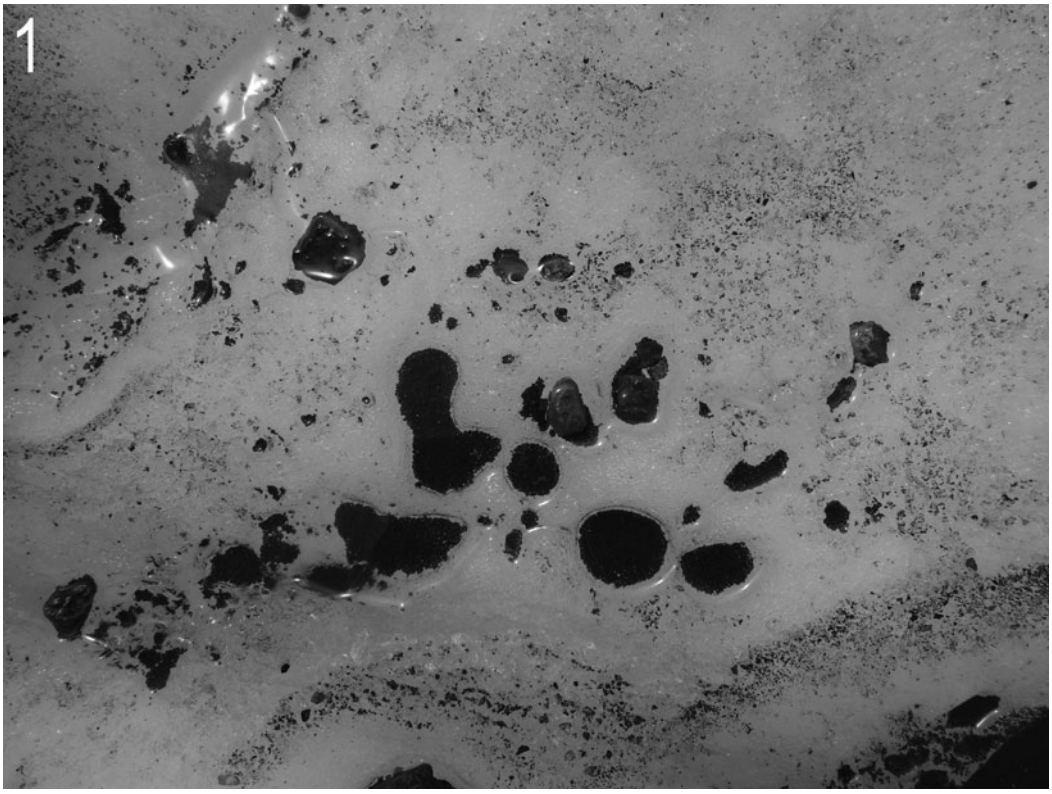

Fig. 1. Typical cryoconite holes in the ablation zone of the glacier.

and 26 and 36, respectively, using the terms 'cryoconite holes' and 'bacteria (Table 1).

Due to climate change, glaciers and ice sheets are among the most endangered habitats and vastly disappearing ecosystems (Hodson and others 2008; IPCC 2013). The first list of cryoconite hole organisms was presented as an MSc thesis by Mueller (2001) and later published by Mueller and others (2001). Although detailed, Mueller's list was not complete and now requires revising because many new taxa were reported from cryoconite holes in the past 14 years. Thus, in this paper an updated inventory of microorganisms (excluding data on micro-invertebrates, given in Zawierucha and others 2015) is presented with a detailed geographical distribution and discussion on the importance of studies conducted on glacial microorganisms.

Material and methods

Literature database

The literature database incorporates all published papers on organisms (excluding invertebrates, which were published in a separate paper by Zawierucha and others 2015) inhabiting cryoconite holes up to the end of November 2014. We are aware that it is possible we missed some papers so we ask all readers of this article to notify us about missing articles. We would be grateful for this and will add all subsequent papers and corrections to future editions of our database.

Format for presented records

All records are presented in the form of five tables: Archaea, bacteria, and viruses (Table 2), fungi

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Table. 2. Archaea, bacteria and viruses taxa (in alphabetic order) reported from cryoconite holes.

	Archaea, bacteria and viruses				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
1.	Phylum	Acidobacteria	2a-e; 3a-c; 53a-e, g; 66a-c	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 3; Edwards and others (2011): 53; Edwards and others (2014): 66; Edwards and others (2013c)
2.	Phylum	Actinobacteria/ Actinomycetales/ Actinomycetes	2a-f; 3a-c; 4b,e; 6a; 7a; 41a; 53a-f; 66a-c	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 3; Edwards and others (2011): 4; Lee and others (2011): 6; Zarsky and others (2013): 7; Kaštovská and others (2007): 41; Edwards and others (2013b): 53; Edwards and others (2014): 66; Edwards and others (2013c)
3.	Species	*Agreia pratensis*	35a	Arctic: Svalbard	35: Singh and others (2014a)
4.	Class	Alphaproteobacteria/ α proteobacteria	2a-f; 4b,d,f; 24a-c; 41a; 53a-f; 66a-c	Antarctica; Arctic: Greenland; Svalbard; Europe: Austria	2: Cameron and others (2012): 4; Lee and others (2011): 24; Foreman and others (2007): 41; Edwards and others (2013b): 53; Edwards and others (2014): 66; Edwards and others (2013c)
5.	Domain	Archaea	2(undefined)	Antarctica	2: Cameron and others (2012)
6.	Genus	*Arthrobacter* sp.	4b-c; 19a	Antarctica; Europe: Austria	19: Christner and others (2003): 4; Lee and others (2011)
7.	Species	*A. agilis*	19a	Antarctica	19: Christner and others (2003)
8.	Species	*A. sulfonivorans*	4b;	Europe: Austria	4: Lee and others (2011)
9.	Class	Bacilli	41a; 53a-d, f-g	Arctic: Greenland and Svalbard; Europe: Austria	41: Edwards and others (2013b): 53; Edwards and others (2014)
10.	Species	*Bacillus amyloliquefaciens*	4b	Europe: Austria	4: Lee and others (2011)
11.	Domain	Bacteria (heterotrophic)	12a-b; 27a-h; 52a-c	Antarctica; Arctic: Canada Greenland and Svalbard; Europe: Austria	12: Mueller and others (2001): 27; Anesio and others (2010): 52; Bellas (2013)
12.	Domain	Bacteria (undefined)	3a-c; 9a-b; 22a; 23a; 24a-c; 25a-i; 26a-b; 27a-d, 28a; 29a; 51a; 52a-c; 61a; 66a-c	Antarctica; Arctic: Canada, Greenland and Svalbard; Asia: China and Nepal; Europe: Austria	3: Edwards and others (2011): 9; Hodson and others (2010a): 22–23; Säwström and others (2002, 2007): 24; Foreman and others (2007): 25; Takeuchi (2002): 26–27; Anesio and others (2007, 2010): 28; Adams (1966): 29; Takeuchi and others (2001a): 51; Kohshima (1987): 52; Bellas (2013): 50; Telling and others (2014): 66; Edwards and others (2013c)
13.	Phylum	Bacteroidetes (undefined)	2a-f; 3a-c; 4b,d-f; 6a; 41a; 53a-f; 66a-c	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 3; Edwards and others (2011): 4; Lee and others (2011): 6; Zarsky and others (2013): 41; Edwards and others (2013b): 53; Edwards and others (2014): 66; Edwards and others (2013c)
14.	Class	Bacteroidia	41a	Europe: Austria	41: Edwards and others 2013b
15.	Class	Betaproteobacteria/ β proteobacteria	2a-f; 4b,d,f; 24a-c; 41a; 53a-f; 66a-c	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 4; Lee and others (2011): 24; Foreman and others (2007): 41; Edwards and others (2013b): 53; Edwards and others (2014): 66; Edwards and others (2013c)

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Table. 2. Continued.

	Archaea, bacteria and viruses				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
16.	Order	Burkholderiales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
17.	Species	*Carnobacterium maltaromaticum*	4a	Europe: Austria	4: Lee and others (2011)
18.	Order	Caulobacterales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
19.	Species	*Cellulomonas gelida*	19a	Antarctica	19: Christner and others (2003)
20.	Phylum	Chloroflexi	2a-f; 66c	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012): 66; Edwards and others (2013c)
21.	Genus	*Chloroflexus* sp.	3c	Arctic: Svalbard	3: Edwards and others (2011)
22.	Species	*Chryseobacterium balustinum*	19a	Antarctica	19: Christner and others (2003)
23.	Species	*Clavibacter michiganensis*	19a	Antarctica	19: Christner and others (2003)
24.	Class	Clostridia	41a, 53a-c, e-g	Arctic: Svalbard; Europe: Austria	41: Edwards and others (2013b): 53; Edwards and others (2014)
25.	Family	Comamonadaceae	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
26.	Genus	*Cryobacterium* sp.	57a	Arctic: Svalbard	57: Singh and others (2014b)
27.	Species	*C. psychrophilum*	19a; 35c; 57a	Antarctica; Arctic: Svalbard	19: Christner and others (2003): 35; Singh and others (2014a): 57; Singh and others (2014b)
28.	Species	*C. psychrotolerans*	35a-c; 57a	Arctic: Svalbard	35: Singh and others (2014a): 57; Singh and others (2014b)
29.	Genus/ species	*Cytophaga*-Flavobacteria/ Cytophaga [Cytophaga-Flavobacterium]	24a-c; 41a	Antarctica; Europe: Austria	24: Foreman and others (2007): 41; Edwards and others (2013b)
30.	Class	Deltaproteobacteria/ δ-proteobacteria	2a-f; 41a; 53a-f; 66a-c	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 41; Edwards and others (2013b): 53; Edwards and others (2014): 66); Edwards and others (2013c)
31.	Family	Enterobacteriaceae	4e-f		4: Lee and others (2011)
32.	Class	Epsilonproteobacteria/ ε-proteobacteria	2d-e; 41a; 53a-f	Arctic: Greenland and Svalbard Europe: Austria	2: Cameron and others (2012): 41; Edwards and others (2013b): 53; Edwards and others (2014)
33.	Class	Erysipelotrichi	41a	Europe: Austria	41: Edwards and others (2013b)
34.	Kingdom	Eubacteria	24a-c	Antarctica	24: Foreman and others (2007)
35.	Phylum	Euryarchaeota	2a-b	Antarctica	2: Cameron and others (2012)
36.	Phylum	Firmicutes	2b-c,e-f; 4b, 53a-f	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 4; Lee and others (2011): 53; Edwards and others (2014)
37.	Class	Flavobacteriia	41a; 53a-f	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	41: Edwards and others (2013b): 53; Edwards and others (2014)
38.	Species	*Flavobacterium degerlachei*	35c	Arctic: Svalbard	35: Singh and others (2014a)
39.	Species	*F. hydatis*	19a	Antarctica	19: Christner and others (2003)
40.	Species	*F. succinicans*	19a	Antarctica	19: Christner and others (2003)
41.	Species	*F. xinjiangense*	4a,c,e	Europe: Austria	4: Lee and others (2011)
42.	Genus	*Flectobacillus* sp.	19a	Antarctica	19: Christner and others (2003)

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Table. 2. Continued.

	Archaea, bacteria and viruses				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
43.	Species	*Flexibacter ruber*	19a	Antarctica	19: Christner and others (2003)
44.	Class	Gammaproteobacteria/ γ-proteobacteria	2a-e; 4b,d-f; 41a; 53a-b, d-f	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 4; Lee and others (2011): 41; Edwards and others (2013b): 53; Edwards and others (2014)
45.	Family	Gemmatimonadetes	2b	Antarctica	2: Cameron and others (2012)
46.	Species	*Gemmimonas aurantiaca*	19a	Antarctica	19: Christner and others (2003)
47.	Species	*Georgenia muralis*	19a	Antarctica	19: Christner and others (2003)
48.	Undefined	Gram- bacteria/ Gram positive bacteria	7a	Arctic: Svalbard	7: Kaštovská and others (2007)
49.	Species	*Haloanella gallinarum*	19a	Antarctica	19: Christner and others (2003)
50.	Species	*Janthinobacterium lividum/ Pseudomonas mephitica* [*Janthinobacterium lividum*]	4a-d,f; 19a	Antarctica; Europe: Austria	4: Lee and others (2011): 19; Christner and others (2003)
51.	Genus	*Leifsonia* sp.	57a	Arctic: Svalbard	57: Singh and others (2014b)
52.	Species	*Leifsonia antarctica*	35a; 57a	Arctic: Svalbard	35: Singh and others (2014a): 57; Singh and others (2014b)
53.	Species	*Matsuebacter chitosanotabidus*	19a	Antarctica	19: Christner and others (2003)
54.	Family	Methanobacteriaceae	2a	Antarctica	2: Cameron and others (2012)
55.	Class	Methanomicrobia	2a	Antarctica	2: Cameron and others (2012)
56.	Genus	*Methanosarcina* sp.	2a	Antarctica	2: Cameron and others (2012)
57.	Family	Methanosarcinaceae	2a	Antarctica	2: Cameron and others (2012)
58.	Order	Methanosarcinales	2a	Antarctica	2: Cameron and others (2012)
59.	Genus	*Methanosphaerula* sp.	2a	Antarctica	2: Cameron and others (2012)
60.	Species	*Methanosphaerula palustris*	2a	Antarctica	2: Cameron and others (2012)
61.	Species	*Micrococcus endophyticus*	35c	Arctic: Svalbard	35: Singh and others (2014a)
62.	Undefined	Microorganisms and Microbes	50a-c	Arctic: Svalbard	50: Telling and others (2010)
63.	Genus	*Mucilaginibacter* sp.	4b,d	Europe: Austria	4: Lee and others (2011);
64.	Class	Negativicutes	41a	Europe: Austria	41: Edwards and others (2013b)
65.	Genus	*Nocardioides* sp.	19a	Antarctica	19: Christner and others (2003)
66.	Genus	*Olleya* sp.	4a-d,f	Europe: Austria	4: Lee and others (2011)
67.	Family	Oxalobacteraceae	4f	Europe: Austria	4: Lee and others (2011)
68.	Species	*Pedobacter cryoconitis*	4f; 45a	Europe: Austria	4: Lee and others (2011): 45; Margesin and others (2003)
69.	Species	*Pseudomonas saccharophila* [*Pelomonas saccharophila*]	19a	Antarctica	19: Christner and others (2003)
70.	Phylum	Planctomycetes	2a-f; 3a,c; 66a	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012): 3; Edwards and others (2011): 66); Edwards and others (2013c)
71.	Species	*Polaromonas naphthalenivorans*	35c; 57a	Arctic: Svalbard	35: Singh and others (2014a): 57; Singh and others (2014b)
72.	Genus	*Prosthecobacter* sp.	19a	Antarctica	19: Christner and others (2003)
73.	Phylum	Proteobacteria (heterothropic)	6a	Arctic: Svalbard	6: Zarsky and others (2013)
74.	Phylum	Proteobacteria	3a-c; 41a; 53a-f	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	3: Edwards and others (2011): 41; Edwards and others (2013b): 53; Edwards and others (2014)
75.	Genus	*Pseudomonas* sp.	4a	Europe: Austria	4: Lee and others (2011)

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Table. 2. Continued.

	Archaea, bacteria and viruses				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
76.	Species	*P. antarctica*	4e	Europe: Austria	4: Lee and others (2011)
77.	Species	*P. brenneri*	4c,f	Europe: Austria	4: Lee and others (2011)
78.	Species	*P. ficuserectae*	35a,c; 57a	Arctic: Svalbard	35: Singh and others (2014a): 57: Singh and others (2014b)
79.	Species	*P. fluorescens*	4a-c,f	Europe: Austria	4: Lee and others (2011)
80.	Species	*P. fragi*	4c	Europe: Austria	4: Lee and others (2011)
81.	Species	*P. frederiksbergensis*	4b-c,f	Europe: Austria	4: Lee and others (2011)
82.	Species	*P. orientalis*	4a,e-f	Europe: Austria	4: Lee and others (2011)
83.	Species	*P. psychrotolerans*	4b	Europe: Austria	4: Lee and others (2011)
84.	Species	*P. trivialis*	4e	Europe: Austria	4: Lee and others (2011)
85.	Species	*P. veronii*	4a-f	Europe: Austria	4: Lee and others (2011)
86.	Genus	*Pseudorhodobacter* sp.	4c	Europe: Austria	4: Lee and others (2011)
87.	Genus	*Pseudoxanthomonas* sp.	19a	Antarctica	19: Christner and others (2003)
88.	Order	Rhizobiales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
89.	Order	Rhodobacterales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
90.	Species	*Rhodococcus qingshengii*	4e	Europe: Austria	4: Lee and others (2011)
91.	Order	Rhodospirillales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
92.	Order	Sphingobacteriales	2a-f; 3b; 53a-f	Antarctica; Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012): 3; Edwards and others (2011): 53; Edwards and others (2014)
93.	Class	Sphingobacteriia	41a	Europe: Austria	41: Edwards and others (2013b)
94.	Family	Sphingomonadaceae	3a-c	Arctic: Svalbard	3: Edwards and others (2011)
95.	Order	Sphingomonadales	2a-f	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
96.	Genus	*Sphingomonas* sp.	3a-c; 4d,f	Arctic: Svalbard; Europe: Austria	3: Edwards and others (2011): 4; Lee and others (2011)
97.	Species	*Subtercola frigoramans*	35b; 57a	Arctic: Svalbard	35: Singh and others (2014a): 57; Singh and others (2014b)
98.	Species	*Flavobacterium ferrugineum* [*Terrimonas ferruginea*]	19a	Antarctica	19: Christner and others (2003)
99.	Phylum	Thaumarchaeota (Crenarchaeota and Euryarchaeota)	2a-b	Antarctica	2: Cameron and others (2012)
100.	Phylum	Verrucomicrobia	2a,c,f	Arctic: Greenland and Svalbard; Europe: Austria	2: Cameron and others (2012)
101.	Undefined	Viruses	26a-b; 52a-c	Arctic: Greenland and Svalbard	26: Anesio and others (2007): 52; Bellas (2013)
102.	Class	ζ-proteobacteria	41a	Europe: Austria	41: Edwards and others (2013b)

(Table 3), cyanobacteria (Table 4), algae (Table 5) and Protista (Table 6; see also Figs. 2–17). Taxa in the tables are listed in alphabetical, not taxonomical, order. Although taxonomic order is preferable, taxa presented in our tables have many different taxonomic ranks. Some taxa are lower or larger ranks of others also presented in the same table. Moreover, this presentation will be more understandable for non-biologists (for example climatologists, geochemists, glaciologists). In the tables we provide original names from the articles, even if the names were marked by question marks (?). However, if the name in the article was incorrect (for example as a

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Table. 3. Fungi taxa (in alphabetic order) reported from cryoconite holes.

	Fungi				
No	Taxon rank	Taxon Name	Localities	Distribution	Citations
1.	Genus	*Cephalothecium* sp. [*Acremonium* sp.]	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
2.	Genus	*Alternaria* sp.	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
3.	Genus	*Articulospora* sp.	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
4.	Species	*A. tetracladia*	20a	Arctic: Svalbard	20: Singh and Singh (2012)
5.	Phylum	Ascomycota (filamentous)	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
6.	Undefined	Basidiomycetous yeasts	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
7.	Species	*Choiromyces meandriformis*	19a	Antarctica	19: Christner and others (2003)
8.	Phylum	Chytridiomycota	5b	Arctic: Svalbard	5: Edwards and others (2013a)
9.	Genus	*Circinella* sp.	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
10.	Genus	*Hormodendrum* spp. [*Cladosporium* spp.]	28a	Arctic: Canada	28: Adams (1966)
11.	Genus	*Cryptococcus* sp.	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
12.	Species	*C. gilvescens*	20a	Arctic: Svalbard	20: Singh and Singh (2012)
13.	Kingdom	Fungi (undefined)	2a-e; 7a; 12a-b; 28a	Antarctica; Arctic: Canada, Greenland and Svalbard;	2: Cameron and others (2012): 7; Kaštovská and others (2007): 12; Mueller and others (2001): 28; Adams (1966);
14.	Species	*Hydnotrya tulasnei*	19a	Antarctica	19: Christner and others (2003)
15.	Genus	*Mrakia* sp.	20a	Arctic: Svalbard	20: Singh and Singh (2012)
16.	Species	*M. frigida*	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
17.	Species	*Mrakiella cryoconiti*	59a	Europe: Austria	59: Margesin and Fell (2008)
18.	Undefined	sterile mycelia [*mycelia sterilia*]	28a	Arctic: Canada	28: Adams (1966)
19.	Genus	*Penicillium* spp.	28a	Arctic: Canada	28: Adams (1966)
20.	Species	*P. terrestre*	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
21.	Genus	*Phialophora* sp.	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
22.	Species	*P. alba*	20a	Arctic: Svalbard	20: Singh and Singh (2012)
23.	Genus	*Rhodotorula* sp.	5b; 20a; 28a	Arctic: Canada and Svalbard	5: Edwards and others (2013a): 20; Singh and Singh (2012): 28; Adams (1966)
24.	Species	*R. glacialis*	58a	Europe: Austria	58: Margesin and others (2007)
25.	Species	*R. svalbardensis*	60a	Arctic: Svalbard	60: Singh and others (2014c)
26.	Species	*Varicosporium elodeae*	5a-c	Arctic: Svalbard	5: Edwards and others (2013a)
27.	Undefined	Yeasts (filamentous)	28a	Arctic: Canada	28: Adams (1966)
28.	Undefined	Yeasts (non-filamentous)	28a	Arctic: Canada	28: Adams (1966)

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Table. 4. Cyanobacteria taxa (in alphabetic order) reported from cryoconite holes.

	Cyanobacteria				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
1.	Genus	*Anabaena* sp.	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
2.	Genus	*Aphanocapsa* sp.	62a	Arctic: Greenland	62: Von Drygalski (1897)
3.	Species	*Aphanothece* cf. *nidulans*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
4.	Species	*Calothrix drygalskiana*	62a	Arctic: Greenland	62: Von Drygalski (1897)
5.	Species	*C. parietina*	10a; 16b-c	Arctic: Canada and Greenland	10: Gerdel and Drouet (1960): 16; Takeuchi and others (2001b)
6.	Genus	*Chamaesiphon* sp.	19a	Antarctica	19: Christner and others (2003)
7.	Genus	*Chlorogloea* sp.	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
8.	Order	Chroococcacan alga [Chroococcales]/ Chroococcales spp.	16a-b; 29a; 48a	Arctic: Canada and Svalbard; Asia: Nepal	16: Takeuchi and others (2001b): 29; Takeuchi and others (2001a): 48; Stibal and Tranter 2007
9.	Genus	*Chroococcus*/ *Chroococcus* spp.	12a-b; 13a-b; 46a-c	Antarctica; Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 46: Porazińska and others (2004)
10.	Genus	*Crinalium* spp.	46a-c,e	Antarctica	46: Porazińska and others (2004)
11.	Species	*Crinalium glaciale*	12a; 13a; 34a-c	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 34; Broady and Kibblewhite (1991)
12.	Species	*Crinalium glaciale* var. *helicoides* [*Crinalium helicoides*]/ *Crinalium helicoides*	12a; 13a; 34a-c; 46a-b,e	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 34; Broady and Kibblewhite (1991): 46; Porazińska and others (2004)
13.	Phylum	Cyanobacteria (cocoid and filamentous)/ filamentous blue-green algae	17a; 25a-i; 51a	Arctic: Canada and Svalbard; Asia: China and Nepal	17: Takeuchi and others (2000): 25; Takeuchi (2002): 51; Kohshima (1987)
14	Phylum	Cyanobacteria (unicellular)	12a-b; 13a-b; 43a-d	Antarctica; Arctic: Canada, Greenland and Svalbard	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 43; Langford and others (2010)
15.	Phylum	Cyanobacteria (unspecified)	2a-f; 3a-c; 6a; 7a; 9a-b; 21a-d; 32a-e; 37a; 38a; 39a; 41a; 48a; 53a-f; 66a-c	Antarctica; Arctica: Greenland and Svalbard; Asia: China; Europe: Austria	2: Cameron and others (2012): 3; Edwards and others (2011): 6; Zarsky and others (2013): 7; Kaštovská and others (2007): 9; Hodson and others (2010a): 21; Stibal and others (2006): 32; Kaštovská and others (2005): 37; Takeuchi and others (2010): 38; Takeuchi and others (2005): 39; Hodson and others (2010b): 41; Edwards and others (2013b): 48; Stibal and Tranter (2007): 53; Edwards and others (2014); 66) Edwards and others (2013c)
16.	Class	Gleobacteria	41a	Europe: Austria	41: Edwards and others (2013b)
17.	Genus	cf. *Gloeocapsa* spp.	12a; 13a; 62a	Antarctica; Arctic: Greenland	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 62; Von Drygalski (1897)
18.	Species	*G. kuetzingiana*	33a	Antarctica	33: Broady (1989a)
19.	Species	*Homoeothrix* cf. *rivularis*	33a	Antarctica	33: Broady (1989a)
20.	Genus	*Leptolyngbya* sp./ *Leptolyngbya* spp./ *Leptolyngbya* sp. (diameter 0.7–2 mm)/ *Leptolyngbya* sp. short cells/ long cells	19a; 21a-d; 32a-e; 42a; 43a-d; 48a	Antarctica; Arctic: Greenland and Svalbard	19: Christner and others (2003): 21; Stibal and others (2006): 32; Kaštovská and others (2005): 42; Stibal and others (2008): 43; Langford and others (2010): 48; Stibal and Tranter (2007)

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Table. 4. Continued.

	Cyanobacteria				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
21.	Species	*L. foveolarum*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
22.	Species	*L.* cf. *notata*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
23.	Genus	*Lyngbya* sp.	43a-d	Arctic: Greenland and Svalbard	43: Langford and others (2010)
24.	Species	*L. martensiana*	31a	Antarctica	31: Wharton and others (1981)
25.	Genus	cf. *Microcystis* spp.	12a-b; 13a-b	Antarctica; Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
26.	Species	*Microcoleus paludosus* var. *acuminatus*	31a	Antarctica	31: Wharton and others (1981)
27.	Species	*M. vaginatus*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
28.	Species	*Nodularia harveyana*	31a	Antarctica	31: Wharton and others (1981)
29.	Genus	*Nostoc* sp.	21a-d; 22a; 32a-e; 33b	Antarctica; Arctic: Svalbard	21: Stibal and others (2006): 22; Säwström and others (2002): 32; Kaštovská and others (2005): 33; Broady (1989a)
30.	Species	*N.* cf. *commune*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
31.	Species	*N. punctiforme*	31a	Antarctica	31: Wharton and others (1981)
32.	Species	*N.* cf. *punctiforme*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
33.	Order	Nostocales	2a-f; 32a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012): 32; Kaštovská and others (2005)
34.	Genus	*Oscillatoria* sp./ *Oscillatoria* 2 spp./ *Oscillatoria* sp. (diameter 4–11 mm)	34a-c; 40a-b; 43a-d	Antarctica; Arctic: Greenland and Svalbard; Asia: China	34: Broady and Kibblewhite (1991): 40; Kohshima (1989): 43; Langford and others (2010)
35.	Species	*O. limosa?*	46a-e	Antarctica	46: Porazińska and others (2004)
36.	Family	Oscillatoriaceae spp.	14a-b	Arctic: Greenland	14: Uetake and others (2010)
37.		Oscillatoriales (may include *Oscillatoria* spp., *Lyngbya* spp., *Phormidium* spp., *Leptolyngbya* spp., *Microcoleus* spp.)	12a-b; 13a-b; 68a	Antarctica; Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 68; Broady (1989b)
38.	Order	Oscillatoriales (filamentous)	7a	Arctic: Svalbard	7: Kaštovská and others (2007)
39.	Order	Oscillatoriales/ Oscillatoriaceaen 1 and 2/ Oscillatoriacean algae/ Oscillatoriacean	2a-f; 15a-b; 16a-c; 17a; 18a; 29a; 32a-e	Antarctic; Arctic Canada, Greenland and Svalbard; Asia: Nepal; North America: USA; South America: Chile	2: Cameron and others (2012): 15; Takeuchi and others (2003): 16; Takeuchi and others (2001b): 17; Takeuchi and others (2000): 18; Takeuchi and others (2001c): 29; Takeuchi and others (2001a): 32; Kaštovská and others (2005)
40.	Genus	*Phormidium* sp.	19a; 21a-d; 22a; 32a-e; 42a; 43a-d; 47a; 48a; 51a	Antarctica; Arctic: Greenland and Svalbard; Asia: Nepal	19: Christner and others (2003): 21; Stibal and others (2006): 22; Säwström and others (2002): 32; Kaštovská and others (2005): 42; Stibal and others (2008): 43; Langford and others (2010): 47; Kohshima (1984): 48; Stibal and Tranter (2007): 51; Kohshima (1987)
41.	Species	*P. amoenum*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)

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Table. 4. Continued.

	Cyanobacteria				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
42.	Species	*P. frigidum*	31a	Antarctica	31: Wharton and others (1981)
43.	Species	*P.* cf. *laminosum*	33a-b	Antarctica	33: Broady (1989a)
44.	Species	*Plectonema nostocorum*	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
45.	Genus	cf. *Pseudanabaena* sp.	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
46.	Genus	*Schizothrix* sp.	40a-b; 62a	Arctic: Greenland; Asia: China	40: Kohshima (1989): 62; Von Drygalski (1897)
47.	Species	*S. heufleri*	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
48.	Genus	cf. *Scytonema* sp.	12b; 13b	Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
49.	Species	*S. gracile*	69a	Arctic: Greenland	69: Berggren (1871)
50.	Genus	*Sphanocatsa* sp.	40a-b	Asia: China	40: Kohshima (1989)
51.	Genus	*Spirulina* sp.	46a-c,e	Antarctica	46: Porazińska and others (2004)
52.	Genus	cf. *Spirulina* spp.	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
53.	Species	*Synechococcus aeruginosus*	31a	Antarctica	31: Wharton and others (1981)
54.	Species	cf. *Synechococcus aeruginosa*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)

result of changes in taxonomic nomenclature), we added the currently accepted name in square brackets [] behind the name appearing in the cited publication. To verify the correct taxonomic names, we used internet databases and search engines such as AlgaeBase, World Register of Marine Species (WoRMS), Fungal Databases and Protist Information Server, WoS, Scopus and Google Scholar. In some cases, if the names used by different authors were presented in different ways but referred to the same taxon (for example *Chroococcus*/ *Chroococcus* spp., Betaproteobacteria/ β-proteobacteria), we used all the names and separated them by slashes (/). In Tables 2–6, taxa without 'scientific names' (for example Lake Bonney clone, Freshwater lake clone, Industrial gas filter clone in Christner and others (2003)) were deliberately omitted because they could lead to inaccurate estimates of biodiversity and confusion in future checklists and biogeographic studies.

In the list of localities the geographic co-ordinates and altitude are provided with some modifications according to Kaczmarek and others (2014; 2015) using different font formats depending on the data origin:

- Original data, where provided (also if they are presented only on the map), are in Roman and bold font.
- Where the original data were provided in decimal degrees and/or in imperial unit format, conversions to degree-minute and/or metric format are preceded by a slash (/) and in Roman and bold font.
- If the original data are inconsistent (for example co-ordinates or altitude do not correspond to the locality description or mismatched altitude for given co-ordinates), we offer values from the nearest probable site using Google Earth™ (ver. 6.2.2.6613), presented after a slash (/) and in Roman font.
- When original coordinates were not supplied, we provided estimated data in italics. In order to estimate coordinates and/or altitude, we used Google Earth™ (ver. 6.2.2.6613) and the following rules:
  - where a general locality, administrative unit, or specified location was provided (for example glacier, mountain range, region, province, country), the collection site was approximated to the centre of the smallest viable unit (assisted by additional data, for example altitude);
  - sample sites described as x distance in y direction from a named locality (for example a city), were approximated using Google™ Earth tools;
  - the midpoint between localities A and B for sample sites reported as, 'between locality A and B', was used.

All collecting places in the list of localities are arranged in the following way: sequence number, author/authors of the article, year of publication, geographic region, area, locality, coordinates, and altitude (both in square brackets []). (Note: separate localities of the same author/authors are presented as a), b), c) etc.) Later, the same numbers are used in Tables 2–6 for specific taxa reported from an exact locality.

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Table. 5. Algae taxa (in alphabetic order) reported from cryoconite holes.

	Algae				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
1.	Genus	*Achnanthes* sp.	56a, c-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
2.	Species	*A. flexella var. flexella*	1a	North America: Canada	1: Wharton and Vinyard (1983)
3.	Genus	*Achnanthidium* sp.	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
4.	Species	*A. minutissimum*	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
5.	Species	*Actinotaenium cucurbita* var. *attenuatum* [*Actinotaenium cucurbita*]	1a	North America: Canada	1: Wharton and Vinyard (1983)
6.	Undefined	Algae (unspecified)	8a; 9a-b; 14a-b; 63a; 64a, e; 69a	Arctic: Greenland	8: Cook and others (2012): 9; Hodson and others (2010b): 14; Uetake and others (2010): 63; Wittrock (1885): 64; Steinböck (1957): 69; Berggren (1871)
7.	Genus	*Ancylonema* sp.	17a; 18a	Asia: Nepal; South America: Chile	17: Takeuchi and others (2000): 18; Takeuchi and others (2001c)
8.	Species	*Ancylonema nordenskioeldii*	10a; 14a-b; 15a-b; 16a; 36a; 54a	Arctic: Canada and Greenland; North America: USA	10: Gerdel and Drouet (1960): 14; Uetake and others (2010): 15; Takeuchi and others (2003): 16; Takeuchi and others (2001b): 36; Steinböck (1936): 54; Lutz and others (2014)
9.	Class	Bacillariophyceae/ Diatoms	21a-d; 32a-e; 48a, 64a	Arctic: Greenland and Svalbard; Europe: Austria	21: Stibal and others (2006): 32; Kaštovská and others (2005): 48; Stibal and Tranter (2007): 64; Steinböck (1957)
10.	Genus	*Bracteacoccus* sp.	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
11.	Genus	*Caloneis* sp.	56b, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
12.	Species	*C. molaris*	56b, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
13.	Species	*C. ventricosa* var. *truncatula*	31a	Antarctica	31: Wharton and others (1981)
14.	Genus	*Cocconeis* sp.	56a, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
15.	Undefined	Coenobium	46d-e	Antarctica	46: Porazińska and others (2004)
16.	Genus	*Chlamydomonas* sp.	12a; 13a; 18a; 21a-d; 67a	Antarctica; Arctic: Greenland and Svalbard; South America: Chile	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 18; Takeuchi and others (2001c): 21; Stibal and others (2006): 67; Wilson (1955)
17.	Species	*C. nivalis*	1a; 15a-b; 21a-d; 22a, 36a; 48a; 49a; 54a; 64d	Arctic: Greenland and Svalbard; Europe: Austria; North America: Canada and USA	1: Wharton and Vinyard (1983): 15; Takeuchi and others (2003): 21; Stibal and others (2006): 22; Säwström and others (2002): 36; Steinböck (1936): 48; Stibal and Tranter (2007): 49; McIntyre (1984): 54; Lutz and others (2014): 64; Steinböck (1957)

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Table. 5. Continued.

	Algae				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
18.	Species	*C. subcaudata*	31a	Antarctica	31: Wharton and others (1981)
19.	Genus	*Chlorella* sp.	21a-d; 22a; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 22; Säwström and others (2002): 32; Kaštovská and others (2005)
20.	Species	*Chlorella homeosphaera*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
21.	Species	*C. minutissima*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
22.	Species	*C. vulgaris*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
23.	Order	Chlorococcales	32a-e	Arctic: Svalbard	32: Kaštovská and others (2005)
24.	Genus	cf. *Chlorococcum* sp.	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
25.	Genus	*Chlorococcus* sp.	46b,e	Antarctica	46: Porazińska and others (2004)
26.	Genus	*Chloromonas* sp.	14a	Arctic: Greenland	14: Uetake and others (2010)
27.	Genus	cf. *Chloromonas* sp.	12b	Arctic: Canada	12: Mueller and others (2001)
28.	Species	*C. nivalis*	1a	North America: Canada	1: Wharton and Vinyard (1983)
29.	Species	*C. perforata*	19a	Antarctica	19: Christner and others (2003)
30.	Class	*Chlorophyceae* spp.	21a-d	Arctic: Svalbard	21: Stibal and others. (2006)
31.	Division	Chlorophyta (unidentified)	12a-b; 13a-b	Antarctica; Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
32.	Kingdom	Chloroplastida	2a-e	Antarctic; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
33.	Species	*Coleochlamys cucummis*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
34.	Genus	*Cylindrocystis* sp.	16a-c; 18a; 21a-d; 32a-e; 40a-b; 48a	Arctic: Canada and Svalbard; Asia: China; South America: Chile	16: Takeuchi and others (2001b): 18; Takeuchi and others (2001c): 21; Stibal and others (2006): 32; Kaštovská and others (2005): 40; Kohshima (1989): 48; Stibal and Tranter (2007)
35.	Species	*C. brebissonii*	12b; 13b; 14a-b; 17a	Arctic: Canada and Greenland; Asia: Nepal	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 10; Gerdel and Drouet (1960): 14; Uetake and others (2010): 17; Takeuchi and others (2000)
36.	Species	*C. cylindrospora*	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
37.	Genus	*Cylindromonas* sp.	22a	Arctic: Svalbard	22: Säwström and others (2002)
38.	Order	Desmids	32a-e; 48a	Arctic: Svalbard	32: Kaštovská and others (2005): 48; Stibal and Tranter (2007)
39.	Genus	*Diadesmis* sp.	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
40.	Species	*D. contenta*	55a-c; 56d	Arctic: Greenland; Antarctica	55: Stanish and others (2013): 56; Yallop and Anesio (2010)
41.	Species	*D. contenta var. pararllela*	55a-c	Antarctica	55: Stanish and others (2013)
42.	Genus	*Diatoma* sp.	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
43.	Genus	cf. *Dictyochloropsis* sp.	33a-b	Antarctica	33: Broady (1989a)
44.	Genus	cf. *Dinobryon* sp.	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
45.	Genus	*Encyonema* sp.	56a-b	Arctic: Svalbard	56: Yallop and Anesio (2010)
46.	Species	*E. minutum*	56a-b	Arctic: Svalbard	56: Yallop and Anesio (2010)
47.	Species	*Achnanthes lapponica* [*Eucocconeis quadratarea*]	1a	North America: Canada	1: Wharton and Vinyard (1983)

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Table. 5. Continued.

	Algae				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
48.	Genus	*Eunotia* sp.	56c	Arctic: Greenland	56: Yallop and Anesio (2010)
49.	Species	*E. curvata* var. *curvata*	1a	North America: Canada	1: Wharton and Vinyard (1983)
50.	Genus	*Fragilaria* sp.	56a, c	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
51.	Species	*Synedra mazamaensis* [*F. mazamaensis*]	1a	North America: Canada	1: Wharton and Vinyard (1983)
52.	Genus	*Frustulia* sp.	56c	Arctic: Greenland	56: Yallop and Anesio (2010)
53.	Species	*Trochiscia aciculifera* [*Glochiococcus aciculiferus*]	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
54.	Genus	*Gomphonema* sp.	56a-b, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
55.	Species	*Gomphonema acuminatum*	1a	North America: Canada	1: Wharton and Vinyard (1983)
56.	Species	*G. angustatum*	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
57.	Species	*G. olivaceum*	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
58.	Species	*G. parvulum*	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
59.	Undefined	Green algae	17a	Asia: Nepal	17: Takeuchi and others (2000)
60.	Undefined	Green algae (unicellular)	25a-i	Arctic: Svalbard and Canada; Asia: China and Nepal	25: Takeuchi (2002)
61.	Undefined	Green coccoid algae/ green coccoid (unidentified)	32a-e; 48a	Arctic: Svalbard	32: Kaštovská and others (2005): 48; Stibal and Tranter (2007)
62.	Undefined	Green filamentous algae	32a-e	Arctic: Svalbard	32: Kaštovská and others (2005)
63.	Genus	*Hantzschia* sp.	56b,d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
64.	Species	*H. amphioxys*	56b,d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
65.	Genus	*Heterococcus* sp.	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
66.	Genus	*Klebsormidium* sp.	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
67.	Species	*K. flaccidum*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
68.	Genus	*Kolbesia* sp.	56b,d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
69.	Genus	*Luticola* sp.	56d	Arctic: Greenland	56: Yallop and Anesio (2010)
70.	Species	*L. gaussii*	55a-c	Antarctica	55: Stanish and others (2013)
71.	Species	*L.* cf. *gaussii*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
72.	Species	*L.* cf. *murrayi*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
73.	Species	*L.* cf. *mutica*	12a; 13a	Antarctica	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
74.	Species	*L. nivalis*	56d	Arctic: Greenland	56: Yallop and Anesio (2010)
75.	Species	*L. ventricosa*	56d	Arctic: Greenland	56: Yallop and Anesio (2010)
76.	Genus	*Mayamaea* sp.	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)

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Table. 5. Continued.

	Algae				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
77.	Species	*M. atomus var. permitis*	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
78.	Genus	*Meridion* sp.	56a, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
79.	Species	*M. circulare*	56a, d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
80.	Species	*Mesotaenium berggrenii*	12b; 13b; 14a-b; 15a-b; 17a; 54a	Arctic: Canada and Greenland; Asia: Nepal; North America: USA	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 14; Uetake and others (2010): 15; Takeuchi and others (2003): 17; Takeuchi and others (2000): 54; Lutz and others (2014)
81.	Genus	*Mesotaenium* sp.	18a	South America: Chile	18: Takeuchi and others (2001c)
82.	Undefined	Micro-plants	51a	Asia: Nepal	51: Kohshima (1987)
83.	Genus	*Muelleria* spp./ *Muriella* sp.	12a; 13a; 21a-d; 55a-c; 56d	Antarctica; Arctic: Greenland and Svalbard	12: Mueller and others (2001): 13; Mueller and Pollard (2004): 21; Stibal and others (2006): 55; Stanish and others (2013): 56; Yallop and Anesio (2010)
84.	Species	*M. cryoconicola*	44a-b; 55a-c	Antarctica	44: Van de Vijver and others (2010): 55; Stanish and others (2013)
85.	Species	*M. meridionalis*	44a-b; 55a-c	Antarctica	44: Van de Vijver and others (2010): 55; Stanish and others (2013)
86.	Species	*M. peraustralis*	55a-c	Antarctica	55: Stanish and others (2013)
87.	Species	*M. supra*	44a-b; 55a-c	Antarctica	44: Van de Vijver and others (2010): 55; Stanish and others (2013)
88.	Species	*M. terrestris*	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
89.	Species	*M. cf. terrestris*	56d	Arctic: Greenland	56: Yallop and Anesio (2010)
90.	Genus	*Navicula* sp.	56a-d; 67a	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010) 67: Wilson (1955)
91.	Species	*N. muticopsis*	68a	Antarctica	68: Broady (1989b)
92.	Genus	*Nitzschia* sp.	56a-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
93.	Species	*N. amphibia*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
94.	Species	*N. palea var. debilis*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
95.	Species	*N. paleacea*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
96.	Species	*N. paleaeformis*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
97.	Genus	*Palmella* sp.	62a	Arctic: Greenland	62: Von Drygalski (1897)
98.	Order	Pennate diatoms	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
99.	Genus	*Pinnularia* sp.	56b-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
100.	Species	*P. borealis*	56b-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
101.	Species	*P. cymatopleura*	68a	Antarctica	68: Broady (1989b)
102.	Species	*P. hilseana* var. *hilseana* [*P. subcapitata*]	1a	North America: Canada	1: Wharton and Vinyard (1983)

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Table. 5. Continued.

	Algae				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
103.	Genus	*Planothidium* sp.	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
104.	Species	*P. frequentissimum*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
105.	Species	*P. lanceolatum*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
106.	Species	*Pleurastrum insigne*	19a	Antarctica	19: Christner and others (2003)
107.	Genus	*Protococcus* sp.	40a-b	Asia: China	40: Kohshima (1989)
108.	Species	*P. nivalis*	10a; 69a	Arctic: Greenland	10: Gerdel and Drouet (1960): 69; Berggren (1871)
109.	Species	*P. vulgaris*	69a	Arctic: Greenland	69: Berggren (1871)
110.	Genus	*Psammothidium* sp.	55a-c; 56a-d	Arctic: Greenland and Svalbard; Antarctica	55: Stanish and others (2013): 56; Yallop and Anesio (2010)
111.	Species	*P. helveticum*	56b-c	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
112.	Species	*P. marginulata*	56b-c	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
113.	Species	*P. subatomoides*	56b-c	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
114.	Genus	cf. *Pseudococcomyxa* sp.	32a-e	Arctic: Svalbard	32: Kaštovská and others (2005)
115.	Species	*P. simplex*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
116.	Genus	*Raphidonema* sp.	17a	Asia: Nepal	17: Takeuchi and others (2000)
117.	Genus	*Reimeria* sp.	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
118.	Species	*R. sinuata*	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
119.	Genus	*Scotiella* sp.	49a	North America: Canada	49: McIntyre (1984)
120.	Genus	*Sellaphora* sp.	56b-d	Arctic: Greenland and Svalbard	56: Yallop and Anesio (2010)
121.	Genus	*Stauroneis* sp.	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
122.	Species	*S. anceps*	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
123.	Genus	*Staurosira* sp.	56a	Arctic: Svalbard	56: Yallop and Anesio (2010)
124.	Species	*Stichococcus bacillaris*	21a-d; 32a-e; 33a-b	Antarctica; Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005): 33; Broady (1989a)
125.	Species	*S.* cf. *chlorelloides*	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
126.	Genus	*Surirella* sp.	56b	Arctic: Svalbard	56: Yallop and Anesio (2010)
127.	Species	*Synedra tabulata var. acuminata* [*Tabularia affinis var. acuminata*]	1a	North America: Canada	1: Wharton and Vinyard (1983)
128.	Genus	*Tetracystis* sp.	31a	Antarctica	31: Wharton and others (1981)
129.	Class	Tribophyceae	21a-d	Arctic: Svalbard	21: Stibal and others (2006)
130.	Genus	*Trochiscia* sp.	16a-c; 40a-b; 62a	Arctic: Canada and Greenland; Asia: China	16: Takeuchi and others (2001b): 40; Kohshima (1989): 62; Von Drygalski (1897)
131.	Species	*T. hirta*	10a	Arctic: Greenland	10: Gerdel and Drouet (1960)
132.	Genus	cf. *Trochisciopsis* sp.	21a-d; 32a-e	Arctic: Svalbard	21: Stibal and others (2006): 32; Kaštovská and others (2005)
133.	Class	Zygnematophyceae	21a-d; 54a	Arctic: Greenland and Svalbard	21: Stibal and others (2006): 54; Lutz and others (2014)

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Table. 6. Protista taxa (in alphabetic order) reported from cryoconite holes.

	Protista				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
1.	Species	*Actinosphaerium sol* [*Actinosphaerium eichhornii*]	64a	Arctic: Greenland	64: Steinböck (1957)
2.	Superphylum	Alveolates [Alveolata]	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
3.	Species	*Amphileptus pleurosigma*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
4.	Undefined	Autotrophic flagellates	13b	Arctic: Canada	13: Mueller and others (2004)
5.	Genus	*Colpidium*	64a	Arctic: Greenland	64: Steinböck (1957)
6.	Class	Centrohelida	2a	Antarctica	2: Cameron and others (2012)
7.	Order	Cercomonadida	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
8.	Phylum	Cercozoa	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
9.	Class	Choanomonada [Choanoflagellatea]	2a	Antarctica	2: Cameron and others (2012)
10.	Phylum	Ciliates/ Ciliophora	2a-e; 12a-b; 13a-b; 36a; 46a-c,e; 64c-e	Antarctica; Arctic: Canada, Greenland and Svalbard; Europe: Norwegia (or Sweden?) and Austria	2: Cameron and others (2012): 12; Mueller and others (2001): 13; Mueller and Pollard (2004): 36; Steinböck (1936): 46; Porazińska and others (2004): 64; Steinböck (1957)
11.	Species	*Cinetochilum margaritaceum*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
12.	Species	*Codonella cratera*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
13.	Species	*Colpoda cucullus*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
14.	Class	Colpodea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
15.	Order	Cyrtophorida	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
16.	Genus	*Didinium*	64a-b	Arctic: Greenland	64: Steinböck (1957)
17.	Genus	*Dileptus* sp.?	64d	Europe: Austria	64: Steinböck (1957)
18.	Species	*Drepanomonas revoluta*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
19.	Genus	*Euplotes* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
20.	Species	*Gastronauta derouxi*	65a-b	Europe: Austria	65: Aescht (2005)
21.	Genus	*Glaucoma*	64a	Arctic: Greenland	64: Steinböck (1957)
22.	Genus	*Halteria* sp.	11a; 30a; 22a	Antarctica; Arctic: Svalbard	11: Mieczan and others (2013a): 22; Säwström and others (2002): 30; Mieczan and others (2013b)
23.	Species	*H. grandinella*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)

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Table 6. Continued.

		Protista			
No	Taxon rank	Taxon name	Localities	Distribution	Citations
24.	Division	Haptophyceae [Haptophyta]	2a	Antarctica	2: Cameron and others (2012)
25.	Undefined	Heterotrophic flagellates	12a-b; 13a-b	Antarctica; Arctic: Canada	12: Mueller and others (2001): 13; Mueller and Pollard (2004)
26.	Genus	*Holophrya* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
27.	Species	*Holosticha pullaster*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
28.	Class	Litostomatea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
29.	Genus	*Monodinium* sp.	22a	Arctic: Svalbard	Säwström and others (2002)
30.	Undefined	Nanoflagellates	22a	Arctic: Svalbard	Säwström and others (2002)
31.	Class	Nassophorea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
32.	Species	*Odontochlamys alpestris alpestris*	65a-b	Europe: Austria	65: Aescht (2005)
33.	Genus	*Oxytricha* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
34	Genus	*Paramaecium* [*Paramecium*]	64b	Arctic: Greenland	64: Steinböck (1957)
35.	Species	*P. putrinum*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
36.	Genus	*Paraphysomonas* sp.	22a	Arctic: Svalbard	Säwström and others (2002)
37.	Class	Phaeodarea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
38.	Class	Phyllopharyngea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
39.	Genus	*Prorodon* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
40.	Class	Prostomatea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
41.	Kingdom	Rhizaria	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
42.	Class	Silicofilosea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
43.	Genus	*Spathidium* sp.	19a	Antarctica	19: Christner and others (2003)
44.	Class	Spirotrichea	2a-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
45.	Phylum	Stramenopiles	2a,c-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
46.	Genus	*Strombidium* sp.	22a	Arctic: Svalbard	Säwström and others (2002)

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Table 6. Continued.

	Protista				
No	Taxon rank	Taxon name	Localities	Distribution	Citations
47.	Genus	*Stylonychia*	64b	Arctic: Greenland	64: Steinböck (1957)
48.	Species	*Stylonychia mytilus* complex	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
49.	Class	Tubulinea	2b-e	Antarctica; Arctic: Greenland and Svalbard	2: Cameron and others (2012)
50.	Genus	*Trachelomonas* sp.	67a	Arctic: Greenland	67: Wilson (1955)
51.	Genus	*Urotricha* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
52.	Species	*Vorticella campanula*	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)
53.	Genus	*Zosterodasys* sp.	11a; 30a	Antarctica	11: Mieczan and others (2013a): 30; Mieczan and others (2013b)

List of localities

1) Wharton and Vinyard (1983): North America: Canada: a) Alberta State, Athabasca Mt., North Glacier [*52°1′N, 117°13′W;* **2,743 m asl**].
2) Cameron and others (2012): Antarctica: Signy Island: a) Tuva Glacier [**60°41′S, 45°38′W;** *0 m asl*]; Vestfold Hills: b) Sørsdal Glacier [**68°39′S, 78°21′E;** *100 m asl*]; Arctic: Greenland: c) Kangerlussuaq [**67°09′N, 50°01′W;** *600 m asl*]; Svalbard: d) Midre Lovénbreen [**78°53′N, 12°03′E;** *250 m asl*], e) Longyearbreen [**78°10′N, 15°30′E;** *600 m asl*], f) Foxfonna [**78°08′N, 16°07′E;** *700 m asl*].
3) Edwards and others (2011): Arctic: Svalbard: a) Austre Brøggerbreen [**78°55′N, 11°56′E/** 78°54′N, 11°50′E; *200 m asl*], b) Midtre Lovénbreen [**78°55′N, 11°56′E/** 78°54′N, 12°04′E; *100 m asl*], c) Vestre Brøggerbreen [**78°55′N, 11°56′E/** 78°55′N, 11°46′E; *100 m asl*].
4) Lee and others (2011): Europe: Austria: a) Pasterze Glacier [*47°04′N, 12°45′E;* **2,200 m asl**] b) Bankerferner [*46°53′N, 11°05′E;* **2,820 m asl**], c) Pitztaler Jöchl Ferner [*46°56′N 10°55′E;* **2,875 m asl**] d) Tiefenbachferner [*46°55′N, 10°56′E;* **2,900 m asl**], **e)** Zugspitz Glacier [*47°25′N, 10°59′E;* **2,620 m asl**] f) Eisgratferner - Stubaier glacier [*46°59′N, 11°07′E;* **2,900 m asl**].
5) Edwards and others (2013a): Arctic: Svalbard: a) Austre Brøggerbreen [**78°55′N, 11°56′E/** 78°54′N, 11°50′E; *200 m asl*], b) Midtre Lovénbreen [**78°55′N, 11°56′E/** 78°54′N, 12°04′E; *100 m asl*], c) Vestre Brøggerbreen [**78°55′N, 11°56′E/** 78°55′N, 11°46′E; *100 m asl*].
6) Zarsky and others (2013): Arctic: Svalbard: a) Aldegondabreen [*77°59′N, 14°07′E; 200 m asl*].
7) Kaštovská and others (2007): Arctic: Svalbard: a) Werenskioldbreen [**77°05′N, 15°10′E/** 77°05′N, 15°20′E; *250 m asl*].
8) Cook and others (2012): Arctic: Greenland: a) Leverett Glacier [**67°04′17.1”N, 50°08′45.2”W-67°09′10.8”N, 48°22′14.6”W; 399–1,446 m asl**].
9) Hodson and others (2010a): Arctic: Greenland: a) Kronprins Christian Land, undefined glacier [*80°52′N 18°45′W*], b) Kangerlussuaq [*67°09′N, 50°01′W; 600 m asl*].
10) Gerdel and Drouet (1960): Arctic: Greenland: a) Thule area, undefined glacier [*76°24′N, 68°12′W*].
11) Mieczan and others (2013a): Antarctica: a) King George Island, Ecology Glacier [**62°10.226′S, 58°28.268′W/** 62°10′13”S, 58°28′16”W–**62°10.404′S, 58°28.546′W/** 62°10′24”S, 58°28′33”W; **40–145 m asl**].
12) Mueller and others (2001): Antarctica: Taylor Valley: a) Canada Glacier [**77°37′S, 162°55′E; 450–1,750 m asl**]; Arctic: Canada: b) Axel Heiberg Island, White Glacier [**79°27′N, 90°40′W; 75–800 m asl**].
13) Mueller and Pollard (2004): Antarctica: Taylor Valley: a) Canada Glacier [**77°37′S, 162°55′E;** *200 m asl*]; Arctic: Canada: b) Axel Heiberg Island, White Glacier [**79°27′N, 90°40′W;** *350 m asl*].
14) Uetake and others (2010): Arctic: Greenland: a) Qaanaaq Glacier [**77°29′N, 69°14′W/** 77°30′N, 69°10′W; **276–783 m asl**], b) Russel Glacier [**67°09′N, 50°01′W; 510–635 m asl**].
15) Takeuchi and others (2003): North America: USA: a) Alaska State, Worthington Glacier [*61°10′N, 145°46′W;* **550–1,110 m asl**],

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b) Alaska State, Matanuska Glacier [*61°44′N, 147°39′W;* **550–1,110 m asl**].

16) Takeuchi and others (2001b): Arctic: Canada: a) Buffin Island, Penny Ice Cap, G-H points, undefined glacier [*67°13′N, 65°59′W;* **450 and 660 m asl**], b) Devon Island, Devon Ice Cap, A-C points, undefined glacier [*75°21′N, 82°10′W;* **300–1,065 m asl**], c) Buffin Island, Penny Ice Cap, D-F points, undefined glacier [*67°13′N, 65°59′W;* **790–960 m asl**].
17) Takeuchi and others (2000): Asia: Nepal: a) Langtang Region, Yala Glacier [*28°14′N, 85°36′E;* **5,110–5,240 m asl**].
18) Takeuchi and others (2001c): South America: Chile: a) Patagonian Icefield, Tyndall Glacier [*51°15′S, 73°17′W; 150 m asl*].
19) Christner and others (2003): Antarctic: Taylor Valley: a) Canada Glacier [*77°37′S, 162°59′E; 200 m asl*].
20) Singh and Singh (2012): Arctic: Svalbard: a) Midre Lovénbreen [**78°55′N, 11°56′E/** 78°54′N, 12°04′E; *100 m asl*].
21) Stibal and others (2006): Arctic: Svalbard: a) Hansbreen [**77°05′N, 15°10′E/** 77°04′N, 15°39′E; *300 m asl*], b) Werenskioldbreen [**77°05′N, 15°10′E/** 77°05′N, 15°20′E; *250 m asl*], c) Nannbreen [**77°05′N, 15°10′E/** 77°08′N, 15°18′E; *400 m asl*], d) Austre Torellbreen [**77°05′N, 15°10′E/** 77°10′N, 15°10′E; *200 m asl*].
22) Säwström and others (2002): Arctic: Svalbard: a) Midre Lovénbreen [*78°54′N, 12°04′E; 100 m asl*].
23) Säwström and others (2007): Arctic: Svalbard: a) Midre Lovénbreen [**78°55′N, 11°56′E/** 78°54′N, 12°04′E; *100 m asl*].
24) Foreman and others (2007): Antarctica: Taylor Valley: a) Canada Glacier [**77°00′S, 162°52′E/** 77°37′S, 162°59′E; *200 m asl*], b) Commonwealth Glacier [**77°00′S, 162°52′E/** 77°35′S, 163°16′E; *200 m asl*], c) Hughes Glacier [**77°00′S, 162°52′E/** 77°44′S, 162°28′E; *400 m asl*].
25) Takeuchi (2002): Asia: Nepal: a) Langtang Region, Yala Glacier [**28°N, 86°E/** 28°14′N, 85°36′E; **5,150 m asl**], b) Shorong Region, AX010 Glacier [**28°N, 87°E/** 27°42′N, 86°34′E; **5,000 m asl**], c) Makut Region, RikhaSamba Glacier [**29°N, 83°E/** unknown locality; **5,350 m asl**]; China: d) Qinghai Province, Meikuang Glacier [**35°N, 93°E/** 35°41′N, 94°11′E; **4,900 m asl**], e) Tibet Autonomous Region, Gozha Glacier [**35°N, 81°E/** 35°14′N, 81°04′E; **5,800 m asl**], f) Qinghai Province, Xiao Dongkemadi Glacier [**33°N, 92°E/** 33°04′N, 92°05′E; **5,600 m asl**]; Arctic: Svalbard: g) Austre Brøggerbreen [**79°N, 12°E/** 78°54′N, 11°50′E; **200 m asl**]; Canada: h) Buffin Island, Penny Ice Cap, Greenshield Glacier [**67°N, 66°W/** 67°07′N, 67°05′W; **490 m asl**], i) Devon Island, Devon Ice Cap, Sverdrup Glacier [**76°N, 83°W/** 75°41′N, 83°15′W; **350 m asl**].
26) Anesio and others (2007): Arctic: Svalbard: a) Austre Brøggerbreen [**78°53′N, 12°04′E/** 78°54′N, 11°50′E; **50–600 m asl**], b) Midre Lovénbreen [**78°53′N, 12°04′E/** 78°54′N, 12°04′E; **50–600 m asl**].
27) Anesio and others (2010): Arctic: Svalbard: a) Austre Brøggerbreen [**78°53′N, 12°04′E/** 78°54′N, 11°50′E; **50–600 m asl**], b) Midre Lovénbreen [**78°53′N, 12°04′E/** 78°54′N, 12°04′E; **50–600 m asl**]; Europe, Austria: c) Rotmoosfermer [**46°50′N, 11°30′E/** 46°50′N, 11°03′E; **2,430 m asl**], d) Stubacher Sonnblickkees Glacier [**47°13′N, 12°60′E/** 47°08′N, 12°36′E; **2,500–3,050 m asl**]; Antarctica: Horseshoe Valley: e) Patriot Hills [**80°18′S, 81°21′W;** *1,000 m asl*]; Taylor Valley: f) Canada Glacier [**77°00′S, 162°52′E/** 77°37′S, 162°59′E; *200 m asl*], g) Commonwealth Glacier [**77°00′S, 162°52′E/** *77°35′S, 163°16′E; 200 m asl*], h) Taylor Glacier [**77°00′S, 162°52′E/** *77°43′S, 162°16′E; 200 m asl*].
28) Adams (1966): Arctic: Canada: a) Axel Heiberg Island, White Glacier. b) Axel Heiberg Island, White Glacier [*79°27′N, 90°40′W; 350 m asl*].
29) Takeuchi and others (2001a): Asia: Nepal: a) Langtang Region, Yala Glacier [*28°14′N, 85°36′E;* **5,100–5,750 m asl**].
30) Mieczan and others (2013b): Antarctica: a) King George Island, Ecology Glacier [**62°10.226′S, 58°28.268′W/** 62°10′13”S, 58°28’16”W– **62°10.404′S, 58°28.546′W/** 62°10′24”S, 58°28′33” W; **40–145 m asl**].
31) Wharton and others (1981): Anarctica: Taylor Valley: a) Canada Glacier [**77°38′S, 162°53′E;** *100 m asl*]
32) Kaštovská and others (2005): Arctic: Svalbard: a) Vestre Brøggerbreen [*78°55′N, 11°46′E; 100 m asl*], b) Austre Brøggerbreen [*78°54′N, 11°50′E; 200 m asl*], c) Vestre Lovénbreen [*78°54′N, 11°57′E; 200 m asl*], d) Midtre Lovénbreen [*78°54′N, 12°04′E; 100 m asl*], e) Austre Lovénbreen [*78°53′N, 12°09′E; 200 m asl*].
33) Broady (1989a): Antarctica: Marie Byrd Land: a) Washington Ridge [**77°00′–78°30′S, 152°–154°W/** 78°06′S 154°48′W; *450 m asl*], b) Mount Paterson [**77°00′–78°30′S, 152°–154°W/** 78°02′S, 154°37′E; *400 m asl*].
34) Broady and Kibblewhite (1991): Antarctica: Ganvood Valley: a) Joyce Glacier [**78°02′S, 163°46′E;** *550 m asl*], b) Garwood Glacier [**78°01′S, 163°56′E;** *550 m asl*]; Taylor Valley: c) Canada Glacier [**77°37′S, 163°02′E;** *50 m asl*].
35) Singh and others (2014a): Arctic: Svalbard: a) Midre Lovénbreen [**78°53′N, 12°04′E;** *100 m*

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asl], b) Austre Brøggerbreen [**78°53′N, 12°04′E/** 78°54′N, 11°50′E; *200 m asl*], c) Vestre Brøggerbreen [**78°53′N, 12°04′E/** 78°55′N, 11°46′E; *100 m asl*].

36) Steinböck (1936): Arctic: Greenland: a) Disko Island, ice highland near Godhaven [Qeqertarsuaq] [*69°18′N, 53°22′W; 700 m asl*].
37) Takeuchi and others (2010): Asia: China: a) Xinjiang Uyghur Autonomous Region, Ürümqi Glacier No. 1 [**43°06′N, 86°48′E; 3,765m asl, 3,820 m asl and 3,870 m asl**].
38) Takeuchi and others (2005): Asia: China: a) Gansu Province, 1st Glacier (Qiyi Glacier) [**39°15′N, 97°45′E; 4,305–5,159 m asl**].
39) Hodson and others (2010b): Arctic: Svalbard: a) Longyearbreen [**78°10′49”N, 15°30′21”E;** *500 m asl*].
40) Kohshima (1989): Asia: China: a) Tibet Autonomous Region, Chongce Ice Cap (Chongce Glacier) [**35°14′N, 81°07′E; 6,120–6,160 m asl**], b) Tibet Autonomous Region, Gozha Glacier [*35°14′N, 81°04′E*; **5,400–5,900 m asl**].
41) Edwards and others (2013b): Europe: Austria: a) Rotmoosferner [**46°50′N, 11°03′E; 2,450 m asl**].
42) Stibal and others (2008): Arctic: Svalbard: a) Werenskioldbreen [*77°05′N, 15°20′E; 250 m asl*].
43) Langford and others (2010): Arctic: Svalbard: a) Vestfonna, undefined glacier [*79°56′N, 20°11′E*], b) Midtre Lovénbreen [*78°54′N, 12°04′E; 100 m asl*], c) Longyearbreen [*78°11′N, 15°31′E; 500 m asl*]; Greenland: d) Kronprins Christian Land, undefined glacier [*80°52′N, 18°45′W*], d) Kangerlussuaq [*67°09′N, 50°01′W; 600 m asl*].
44) Van de Vijver and others (2010): Antarctica: Taylor Valley: a) Commonwealth Glacier [**77.57674°S, 163.27231°E/ 77°35′S, 163°16′E;** *200 m asl*], b) Canada Glacier [*77°37′S, 162°59′E; 200 m asl*].
45) Margesin and others (2003) Europe: Austria: a) Stubaier Glacier [*46°59′N, 11°07′E;* **3,000 m asl**].
46) Porazińska and others (2004): Antarctica: Taylor Valley: a) Commonwealth Glacier [*77°35′S, 163°16′E; 200 m asl*], b) Canada Glacier [*77°37′S, 162°59′E; 200 m asl*], c) Howard Glacier [*77°40′S, 163°05′E; 400 m asl*], d) Hughes Glacier [*77°44′S, 162°28′E; 400 m asl*], e) Taylor Glacier [*77°43′S, 162°16′E; 200 m asl*].
47) Kohshima (1984): Asia: Nepal: a) Langtang Region, Yala Glacier [*28°14′N, 85°36′E;* **5,100–5,600 m asl**].
48) Stibal and Tranter (2007): Arctic: Svalbard: a) Werenskioldbreen [**77°05′N, 15°15′E; 65–600 m asl**].
49) McIntyre (1984): North America: Canada: a) British Columbia, Manatee Glacier [**50°35′N, 123°40′W; 1,500–2,100 m asl**].
50) Teiling and others (2010): Arctic: Svalbard: a) Midtre Lovénbreen [**78°55′48”N, 11°56′59”E/** 78°54′N, 12°04′E; *100 m asl*], b) Vestre Brøggerbreen [**78°55′48”N, 11°56′59”E/** 78°55′N, 11°46′E; *100 m asl*], c) Austre Brøggerbreen [**78°55′48”N, 11°56′59”E/** 78°54′N, 11°50′E; *200 m asl*].
51) Kohshima (1987): Asia: Nepal: a) Langtang Region, Yala Glacier [*28°14′N, 85°36′E;* **5,100–5,700 m asl**].
52) Bellas and others (2013): Arctic: Svalbard: a) Austre Brøggerbreen [**78°55′N, 11°55′W/** 78°54′N, 11°50′E; *200 m asl*], b) Midre Lovénbreen [**78°55′N, 11°55′W/** 78°54′N, 12°04′E; *100 m asl*]; Greenland: c) Russell Glacier [**67°09′39.7”N, 50°00′52.7”W;** *650 m asl*].
53) Edwards and others (2014): Arctic: Svalbard: a) Austre Brøggerbreen [**78°53′54”N, 11°48′17”E; 190–310 m asl**], b) Midre Lovénbreen [**78°53′04”N, 12°02′17”E; 170–300 m asl**], c) Vestre Brøggerbreen [**78°54′45”N, 11°43′16”E; 140–270 m asl**]; Greenland: d) Leverett Glacier [**67°04′17”N–67°07′36”N, 49°00′36”W–50°08′45”W; 400–1,190 m asl**]; Europe: Austria: e) Rotmoosferner [**42°49′17”N, 11°02′47”E/** 46°49′N, 11°03′E; **2,620–2,660 m asl**], f) Gaisbergferner [**46°49′50”N, 11°03′59”E; 2,480–2,590 m asl**], g) Pfaffenferner [**46°57′42”N, 11°08′01”E; 2,780–2,880 m asl**].
54) Lutz and others (2014): Arctic: Greenland: a) Mittivakkat Glacier [**65.6848°N–37.8802°E/** 65°41′N, 37°53′W; **150–250 m asl**].
55) Stanish and others (2013): Antarctica: Taylor Valley: a) Canada Glacier [*77°37′S, 162°59′E; 200 m asl*], b) Commonwealth Glacier [*77°35′S, 163°16′E; 200 m asl*], c) Taylor Glacier [*77°43′S, 162°16′E; 200 m asl*]
56) Yallop and Anesio (2010): Arctic: Svalbard: a) Vestre Brøggerbreen [**78°53′N, 12°04′E/** 78°55′N, 11°46′E; *100 m asl*], b) Austre Brøggerbreen [**78°53′N, 12°04′E/** 78°54′N, 11°50′E; *200 m asl*]; Greenland: c) Frøya Glacier [**74°24′N, 20°50′W**; *800 m asl*], d) Cirque Gacier [**74°30′N, 20°46′W**; *950 m asl*]
57) Singh and others (2014b): Arctic: Svalbard: a) Midre Lovénbreen [*78°54′N, 12°04′E; 100 m asl*].
58) Margesin and others (2007): Europe: Austria: a) Stubaier Glacier [**46°59′12”N, 11°06′53”E; 2,900 m asl**].
59) Margesin and Fell (2008): Europe: Austria: a) Stubaier Glacier [*46°59′N, 11°07′E;* **2,900 m asl**].
60) Singh and others (2014c): Arctic: Svalbard: a) Midre Lovénbreen [**78°55′N, 11°56′E/** 78°54′N, 12°04′E; *100 m asl*].

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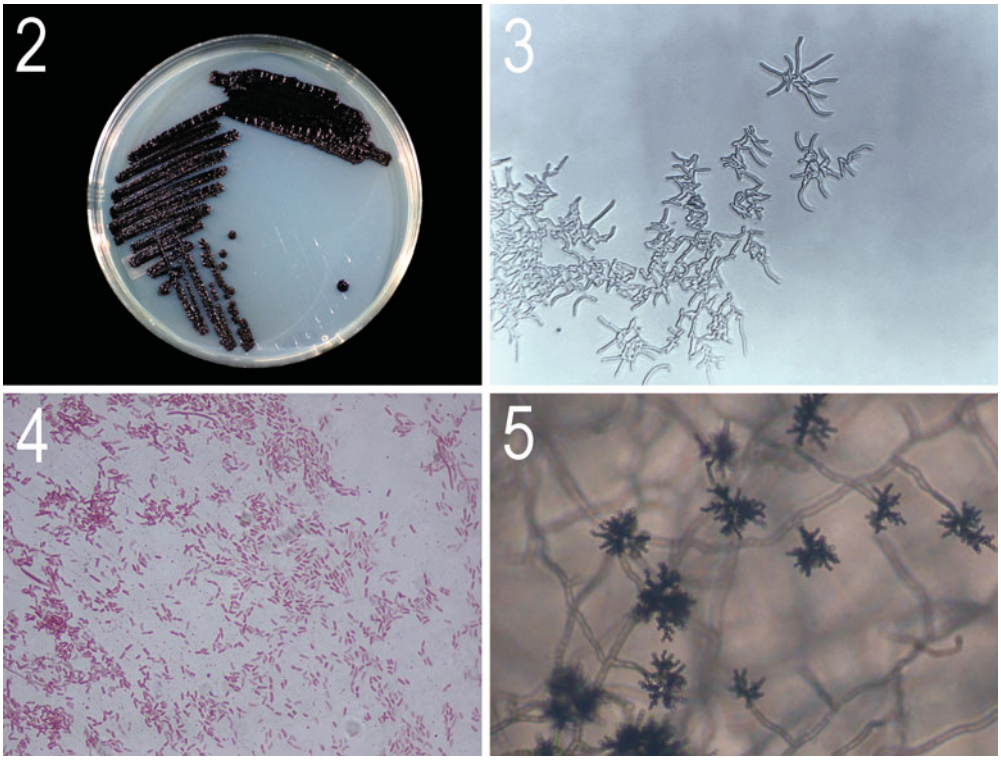

Figs. 2–5. Bacteria and Fungi. 2: *Janthinobacterium lividum*; 3: *Rhodococcus* sp.; 4: *Pseudomonas fluorescens*; 5: conidia of *Cladosporium* sp.
(**Sources. 2:** 'Janthinobacterium lividum on TY' by Ninjatacoshell - Own work. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Janthinobacterium_lividum_on_TY.png#/media/File:Janthinobacterium_lividum_on_TY.png; **3:** 'Rhodococcus species' by David Berd - This comes from the Centers for Disease Control and Prevention's Public Health Image Library (PHIL), with identification number #2981. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Rhodococcus_species.jpg#/media/File:Rhodococcus_species.jpg; **4:** 'Pseudomonas fluorescens' by Riraq25 - Own work. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Pseudomonas_fluorescens.jpg#/media/File:Pseudomonas_fluorescens.jpg; **5:** 'Cladosporium sp conidia'. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Cladosporium_sp_conidia.jpg#/media/File:Cladosporium_sp_conidia.jpg)

61) Telling and others (2014): Antarctica: Taylor Valley: a) Canada Glacier [*77°37′S, 162°59′E; 200 m asl*].
62) Von Drygalski (1897) according to Mueller and others (2001): Arctic: Greenland: a) undefined glacier [*71°42′N, 42°32′E*]*.
63) Wittrock (1885) according to Steinböck (1936): Arctic: Greenland: a) south Greenland, unspecified glacier [*78°00′N, 43°52′W*]*.
64) Steinböck (1957): Arctic: Greenland: a) Scoresbysund (Kangertittivaq), drift ice near Liverpool coast [*70°30′N, 25°01′W; 0 m asl*], b) undefined locality, Scoresbysundes Glacier [*70°30′N, 25°01′W*]; Europe: c) Norwegia (or Sweden?): undefined locality, S Abisko, Korsawagga Glacier [**68°N/** *68°20′N, 18°50′E*); Austria: d) Sulztalerferner [*47°01′N, 11°05′E;* **2,530 m asl**] e) Niederjochferner [*46°47′N, 10°52′E; 3,000 m asl*].
65) Aescht (2005): Europe: Austria: a) Rotmoosferner [**46°49′N, 11°02′E; circa 2,720 m asl**], b) Gaisbergferner [**46°50′N, 11°03′E; circa 2,600 m asl**].
66) Edwards and others (2013c): Arctic: Svalbard: a) Austre Brøggerbreen [**78°54′N, 11°50′E;** *200 m asl*], b) Midtre Lovénbreen [**78°54′N, 12°04′E;** *100 m asl*], c) Vestre Brøggerbreen [**78°55′N, 11°46′E**; *100 m asl*].
67) Wilson (1955) according to Mueller and others (2001): Arctic: Greenland: a) Thule Area, undefined glacier [*76°24′N, 68°12′W*]*.
68) Broady (1989b): Antarctica: Ross Island: a) Cape Bird, Mt. Bird Ice cap [**77°15′S, 166°27′E;** *400 m asl*].

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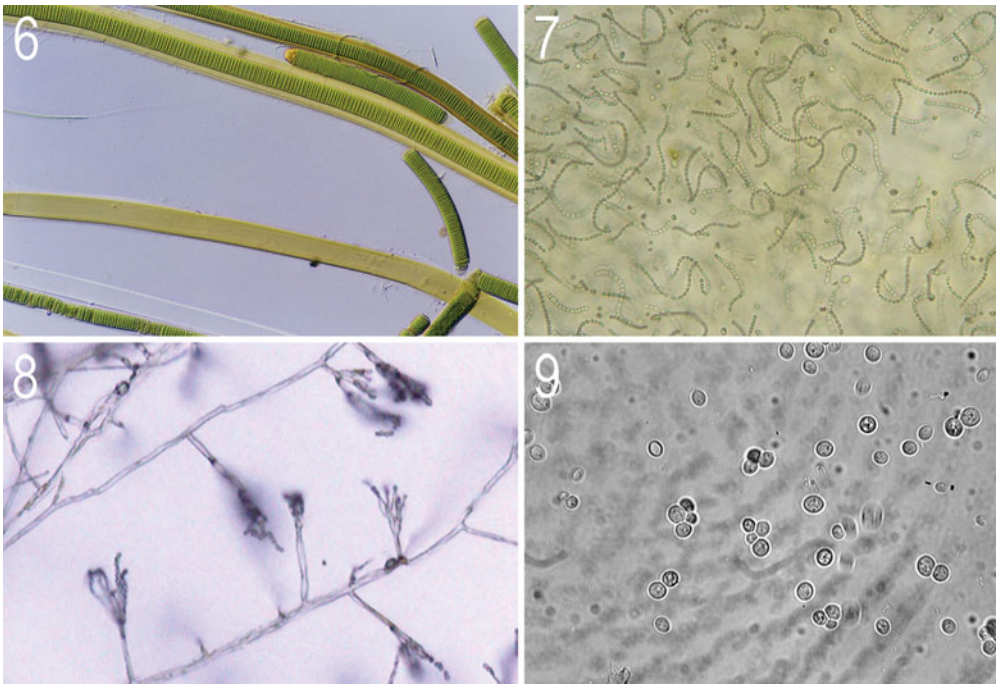

Figs. 6–9. Cyanobacteria and Fungi. 6: *Lyngbya* sp.; 7: *Nostoc* sp.; 8: *Penicillium*; 9: Yeasts (non-filamentous).
(**Sources. 6:** 'Lyngbya' by NASA - http://microbes.arc.nasa.gov/images/content/gallery/lightms/publication/lyngbya.jpg. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Lyngbya.jpg#/media/File:Lyngbya.jpg; **7:** 'Nostoc' by Original uploader was Gibon at cs.wikipedia - Transferred from cs.wikipedia; transfer was stated to be made by User: Vojtech.dostal.. Licensed under Copyrighted free use via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Nostoc.jpg#/media/File:Nostoc.jpg; **8:** 'Penicillium' by Y_tambe - Y_tambe's file. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Penicillium.jpg#/media/File:Penicillium.jpg; **9:** 'Levure' by Savantfou - Own work. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Levure.jpg#/media/File:Levure.jpg)

69) Berggren (1871): Arctic: Greenland: a) undefined glacier [*71°42′N, 42°32′E*].

* The authors have not had the possibility of examining these papers directly and we have only cited a list of taxa from them according to later authors.

Results and discussion

In total 370 taxa (excluding invertebrates which were listed in a previous paper by Zawierucha and others 2015) were reported from cryoconite holes throughout the world (mostly from polar regions and European Alps) (Tables 2–6). However, most of the taxa were not identified to the species level. Up to now only 39 species or subspecies of bacteria and Archaea, 11 fungi, 17 cyanobacteria, 62 algae, and 13 Protista are known from cryoconite holes, which is approximately 38% of all taxa reported from these environments. Almost 62% of the taxa were marked as *cf.* (*confer*) or were identified only to the genera or even to the higher taxonomic units (such as families or orders) (see Tables 2–6). Additionally, many taxa (often identified to the species level) reported in the older papers need a confirmation according to modern taxonomy or molecular methods (=integrative taxonomy) (for example Casamatta and others 2003; Fenchel and others 1997; Heger and others 2010, see also remarks in Zawierucha and others 2015).

Most 'cryoconite taxa' are known from polar glaciers in the Arctic (217, *circa* 60%) and Antarctic regions (156, *circa* 43%). Fewer taxa are known from mountain glaciers in Europe (52, *circa* 14%), Asia (19, *circa* 5%), North America (15, *circa* 4%), and South America (5, *circa* 1%). This is, of course, a result of 1) the distribution of glaciated areas, which are located mainly in the polar regions, and the large number of studies conducted in these regions (Antarctica, 14 papers, *circa* 20%; Arctic, 39 papers, *circa* 57%); 2) locations of research stations, and 3) accessibility of particular glaciers. However, a relatively large number of taxa have also been reported from small central European glaciers (mainly in Austria) (3,785 square kilometers, according to WGMS report: http://www.grid.unep.ch/glaciers/), which is definitively related to the large number of studies conducted in this area (eight papers, *circa* 12%). A low

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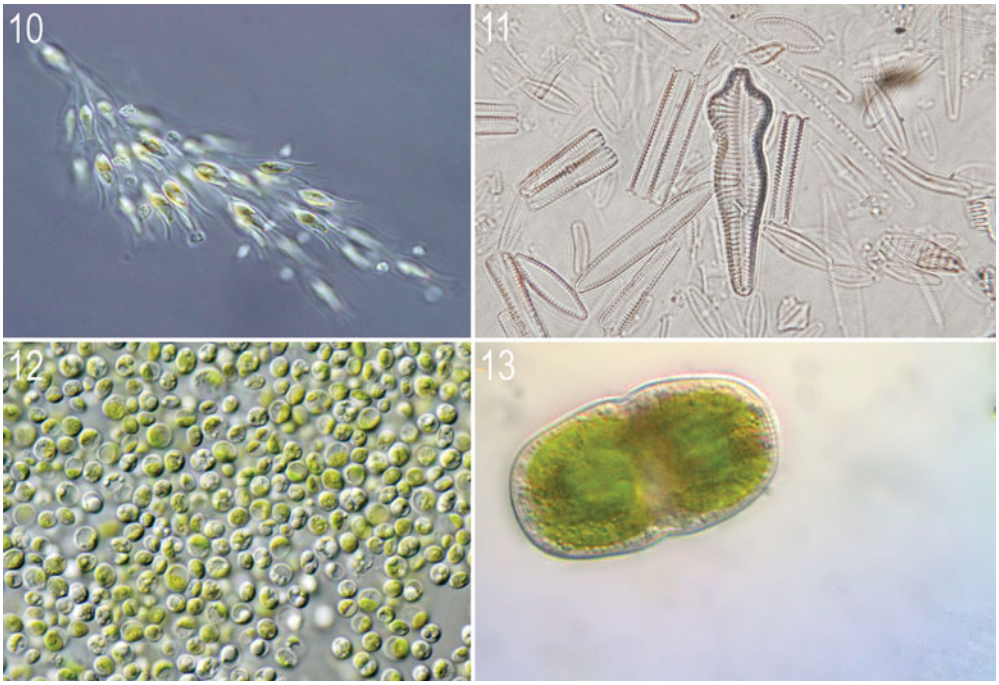

Figs. 10–13. Algae. 10: *Dinobryon* sp.; 11: *Gomphonema acuminatum*; 12: *Chlorella vulgaris*; 13: *Actinotaenium cucurbita*.
(**Sources. 10:** 'Dinobryon sp' by ja:User:NEON / commons:User:NEON_ja - Own work. Licensed under CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Dinobryon_sp.jpg#/media/File:Dinobryon_sp.jpg; **11:** 'Gomphonema acuminatum' by Philipp Gilbert (Muc) - Own work. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Gomphonema_acuminatum.jpg#/media/File:Gomphonema_acuminatum.jpg; **12:** 'Chlorella vulgaris NIES2170' by ja:User:NEON / User:NEON_ja – Own work. Licensed under CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Chlorella_vulgaris_NIES2170.jpg#/media/File:Chlorella_vulgaris_NIES2170.jpg; **13:** 'Actinotaenium cucurbita (BREB.)' by Oliver s. - Own work (Original text: eigene Arbeit). Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Actinotaenium_cucurbita_(BREB.).jpg#/media/File:Actinotaenium_cucurbita_(BREB.).jpg)

number of cryophilic taxa have been reported from North and South America where glaciers cover 124,000 and 25,500 square kilometers, respectively (WGMS report: http://www.grid.unep.ch/glaciers/). This is probably due to the low number of studies focused on cryoconite hole organisms in these regions (only four papers, *circa* 6%). Surprisingly, also in Asia, with 174,000 square kilometers of ice cover areas, the number of reported taxa is also very low, although the number of papers related to this region is relatively great (eight papers, *circa* 12%). Here, the small number of taxa is probably due to the fact that the papers are not focused on cryoconite hole organisms but on the morphology and functioning of the 'holes' themselves (for example Gribon 1979; Fountain and others 2004; MacDonell and Fitzsimons 2008). Until now, cryoconite hole microorganisms have not been reported from New Zealand and Scandinavian (excluding invertebrates and undefined Protista) glaciers which cover respectively 1,600 and 2,940 square kilometers. Similarly, no organisms were reported from African and New Guinean glaciers, but ice-covered areas in these regions are very small (6 and 3 square kilometers, respectively) (WGMS report: http://www.grid.unep.ch/glaciers/). Hence, cryoconite organisms are rather poorly known except for in a few well-studied small areas (Figs. 2–9).

Despite the fact that first studies on the organisms inhabiting glaciers took place towards the beginning of the twentieth century (Von Drygalski 1897), scientific and economic potential of this unique biota is still highly unexplored. In recent years only a few papers were focused on the importance of glaciers and the organisms inhabiting them, for the astrobiology, industry and biotechnology (for example Nisbet and Sleep 2001; Tranter and others 2004; Singh and others 2014a, 2014b). Organisms inhabiting both, cryoconite holes and glacier surfaces can be treated as extremophiles (for example Zawierucha and others 2015). As has been shown for other extremophiles (for example Singh and others 2014a, 2014b; Van den Burg 2003), organisms inhabiting cryoconite holes such

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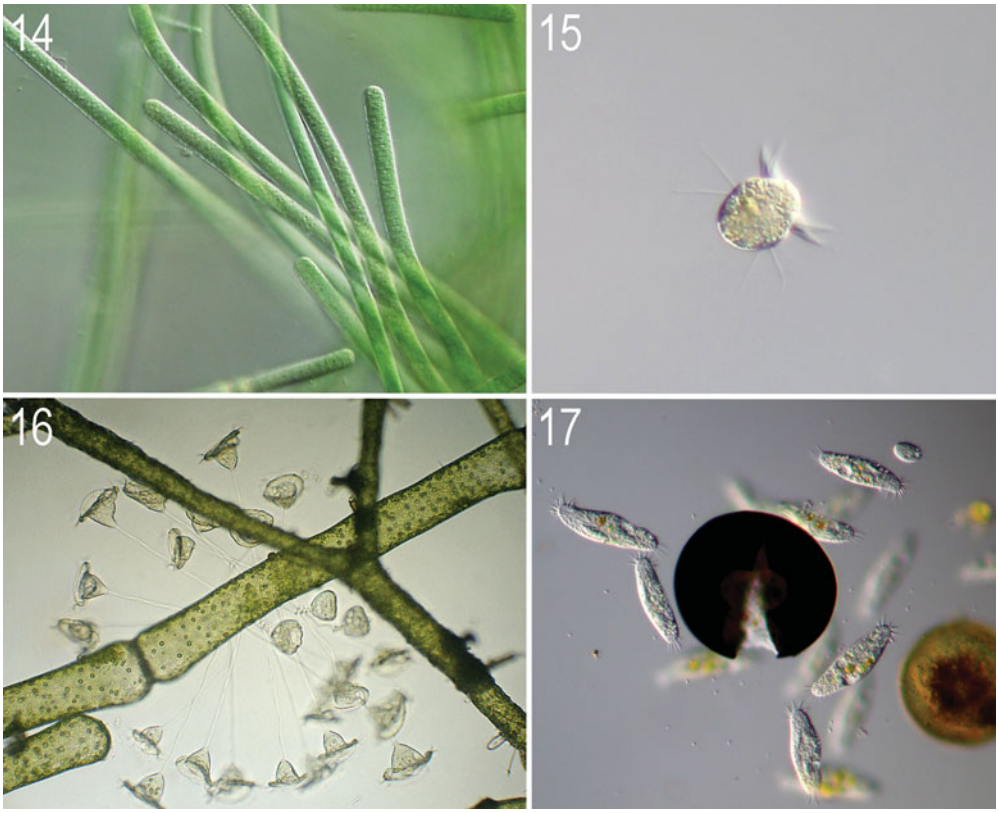

Figs. 14–17. Cyanobacteria and Protista. 14: *Oscillatoria* sp.; 15: *Halteria grandinella*; 16: *Vorticella campanula*; 17: *Holosticha pullaster*.
(**Sources. 14:** 'Oscillatoria sp' by ja:User:NEON / User:NEON_ja - Own work. Licensed under CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Oscillatoria_sp.jpg#/media/File:Oscillatoria_sp.jpg; **15:** 'Halteria grandinella - 160x (14069352174)' by Picturepest - Halteria grandinella - 160x. Licensed under CC BY 2.0 (http://creativecommons.org/licenses/by/2.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Halteria_grandinella_-_160x_(14069352174).jpg#/media/File:Halteria_grandinella_-_160x_(14069352174).jpg; **16:** 'Vorticella campanula' by Giuseppe Vago - http://www.flickr.com/photos/giuseppevago/4938691032/. Licensed under CC BY 2.0 (http://creativecommons.org/licenses/by/2.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Vorticella_campanula.jpg#/media/File:Vorticella_campanula.jpg; **17:** 'Holosticha pullaster und Zysten - 160x (13215619384)' by Picturepest - Holosticha pullaster und Zysten - 160x. Licensed under CC BY 2.0 (http://creativecommons.org/licenses/by/2.0/) via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Holosticha_pullaster_und_Zysten__160x_(13215619384).jpg#/media/File:Holosticha_pullaster_und_Zysten_-_160x_(13215619384).jpg)

as tardigrades could also be a source of novel enzymes or other useful molecules with applications in industry and medicine (for example Bradbury 2001; Shill and others 2009).

The earth is subject to cyclical glaciations and a significant part of its surface is covered by glaciers (Milankovitch 1941 and English translation 1998). However, at the same time, it could be concluded that at least some glaciated areas are covered by small seasonal reservoirs of liquid water. Cryoconite holes on the ice caps constitute a micrometeorite collector (Maurette and others 1987). Micrometeorites are sources of extraterrestrial carbonaceous material on Antarctic ice. These micrometeorities are carbonaceous chondrites, which include potential catalysts. They could be chemical reactors to form molecules on the early earth (Maurette 1996). It is appreciated that glaciers and water reservoirs within them could constitute a model for astrobiological research because these are habitats potentially suitable for life on planets or moons covered with ice (Nisbet and Sleep 2001; Tranter and others 2004). Thus, studies on the organisms inhabiting cryoconite holes could give new insights in some aspects of astrobiology studies, as well as origin and distribution of life.

Yallop and others (2012) have demonstrated that phototrophs growing on the ice absorb more light than dust particles, which means that organisms living on the ice have a great impact on the reducing of ice albedo. Additionally, these results, as well as previous studies (for example Takeuchi and others 2001a) indicated

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that various organisms inhabiting glaciers can influence the reduction of ice albedo and speed glacier melting. Pigmentation of cryoconite organisms protects them against high doses of ultraviolet radiation but the dark pigmentation also absorbs large amounts of heat leading to faster glacier melting (Zawierucha and others 2015). In the context of global warming and poor knowledge on the glacier organisms, it is very important to monitor diversity and the abundance of cryoconite and ice surface inhabitants. In particular, this is because of unexplored and endangered (by glacier retreat) biodiversity (Figs. 10–17).

In 1992, predictions of the effects of climate change mobilised world leaders and scientists to try to mitigate these effects. Thus, the United Nations (UN) on the earth summit in Rio de Janeiro prepared and signed a 'climate convention' (United Nations Framework Convention on Climate Change (UNFCCC)). Thereafter, many papers, reports, and websites focused on biodiversity loss, climate change, and glaciers melting. For instance, a CAFF website (Conservation of Arctic Flora and Fauna) focused entirely on the conservation of Arctic biota (http://www.caff.is/). In 2012, Cardinale and others published a detailed review in which they clearly indicated that biodiversity loss has a negative impact on humanity. Unfortunately, in many papers on biodiversity loss and its influence on human wellbeing, glaciers and ice sheets are most often omitted (for example Cardinale and others 2012; Diaz and others 2006). Partly as a result, the diversity of organisms inhabiting glacier ecosystems remains poorly known and their loss is difficult to estimate. We probably cannot protect glaciers against melting, but understanding glacier organisms' diversity is an urgent task. Thus, the first review published by Zawierucha and others (2015) (which was focused on invertebrates) together with this review are the first steps to summarize biodiversity of cryoconite holes. We hope that such wide and detailed reviews help other scientists find the gaps in our knowledge about cryobionts and indicate directions for further zoogeographical and taxonomical studies.

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