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Lichen diversity on glacier moraines in Svalbard

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Abstract – This paper contributes to studies on the lichen biota of Arctic glacier forelands. The research was carried out in the moraines of three different glaciers in Svalbard: Longyearbreen, Irenebreen and Rieperbreen. In total, 132 lichen taxa and three lichenicolous lichens were recorded. Eight species were recorded for the first time in the Svalbard archipelago: *Arthonia gelidae, Buellia elegans, Caloplaca lactea, Cryptodiscus pallidus, Fuscidea kochiana, Merismatium deminutum, Physconia distorta*, and *Polyblastia schaereriana*. One species, *Staurothele arctica*, was observed for the first time in Spitsbergen (previously recorded only on Hopen island). All the studied glaciers lie in Spitsbergen's warm region. However, Kaffiøyra Plain, where Irenebreen is located, is characterized by higher levels of humidity, which may explain its different lichen composition compared to that of the other two moraines. The forelands of Rieperbreen and Longyearbreen are located in the same area of Svalbard, which is also the warmest and the driest and where high species diversity is expected. This proved to be true for the Rieperbreen moraine, but not for the Longyearbreen moraine, where species diversity was lowest. The expansion of tourism along Longyearbyen appears to be a major factor behind the poor development of lichen biota on the Longyearbreen moraine.

Arctic / Irenebreen / Rieperbreen / Longyearbreen / species richness

INTRODUCTION

Ongoing studies on glacier forelands are necessary due to the rapid increase in ice-free areas as a consequence of melting glaciers resulting from climate change (Zemp *et al.* 2008; Nuth *et al.* 2013; Laspoumaderes *et al.* 2013; Grémillet *et al.* 2015). In Svalbard, progressive glacial recession has been observed since the end of the Little Ice Age (Błaszczyk *et al.* 2009). Areas exposed as a result of the retreating glaciers have been successively colonised by different groups of organisms, in particular cryptogams, which are represented by lichens in large numbers. Lichens are, among other cryptogams, one of the main components of Arctic vegetation. There are around 1750 species of lichen in the Arctic (Dahlberg & Bültmann 2013; Walker *et al.* 2013) while there are 742 in Svalbard (Øvstedal *et al.* 2009). Their participation in the formation of plant communities as a result of the primary succession process in deglaciated forelands of Arctic glaciers is also significant

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(Walker *et al.* 2013; Wietrzyk *et al.* 2016). However, because of their small size, lichens are often overlooked during research, while much attention is paid to vascular plants (Pirożnikow & Górniak 1992; Nakatsubo *et al.* 2010; Prach & Rachlewicz 2012).

Only a few studies include data on the lichens of glacier moraines in Svalbard (Kuc 1996; Hodkinson *et al.* 2003; Moreau *et al.* 2005; Moreau *et al.* 2009; Jones & Henry 2003). More specifically, only large fruticolous terrestrial species, such as *Cetrariella delisei* (Bory ex Schaer.) Kärnefelt & A. Thell, *Cladonia mitis* Sandst., *Cetraria* sp. and *Stereocaulon alpinum* Laurer are usually taken into account, e. g. in studies conducted near Ny-Ålesund (Hodkinson *et al.* 2003; Moreau *et al.* 2005; Moreau *et al.* 2009).

The aim of this study is to 1) investigate lichen diversity in the forelands of three Spitsbergen glaciers: Longyearbreen, Rieperbreen and Irenebreen; 2) compare lichen composition and richness between the studied moraines; and 3) investigate the impact of human trampling on lichens growing on glacier forelands. The lichens of the above-mentioned glacier moraines have not been studied before. Thus, we hope that the results will fill in some of the gaps in our knowledge regarding non-vascular tundra vegetation.

MATERIAL AND METHODS

Study area

Longyearbreen: Longyearbreen is located in Nordenskiöld Land in central Spitsbergen (Fig. 1). It is a rather small valley glacier, which flows northeast from the accumulation zone located at approx. 1000 m above sea level (a.s.l.) and ends at approx. 250 m a.s.l. (Hagen *et al.* 1993). The glacier is 3.6 km in length (Etzelmüller *et al.* 2000). The glacier area is 2.52 km^2 with a mean width of approx. 500 m and an average ice depth of 53 m (Etzelmüller *et al.* 2000, Langford *et al.* 2014). Due to its location near Longyearbyen, the main settlement in Svalbard, the glacier and its foreland are frequently visited by tourists. In recent decades, a coal mine operated on the eastern slope of the glacier valley, and at that time the intensity of people and vehicle traffic was high. Currently, there is a popular hiking route running through the glacier and its moraine.

Rieperbreen: Similarly to Longyearbreen, Rieperbreen is also located in Nordenskiöld Land (Fig. 1). It is a valley-confined glacier approx. 2 km in length and connected to the Foxfonna glacier complex (Lyså & Lønne 2001). The elevation of the glacier outlet varies from 200 to 500 m a.s.l. and it is less than 400 m wide (Lyså & Lønne 2001). In comparison with Longyearbreen, the glacier is much less often visited by tourists because of its location at the end of Bolterdalen (approx. 14 km from Longyearbreen).

Irenebreen: Irenebreen is located in Oscar II Land, NW Spitsbergen (Fig. 1). It is one of seven glaciers surrounding the Kaffiøyra Plain. It is a valley glacier approx. 4 km in length and between 1 km and 1.5 km in width, bordered by Grafjellet and Kristinefjella in the north, and by Prinsesserygen in the south, Prins Heinrichfjella in the east, and Waldemarbreen in the west (Sobota & Lankauf 2010; Sobota 2011). The elevation of the glacier outlet varies from approx. 150 to 600 m a.s.l. (Sobota 2011). This glacier covers a total area of about 4.1 km^2 (Sobota & Lankauf 2010; Sobota 2011).

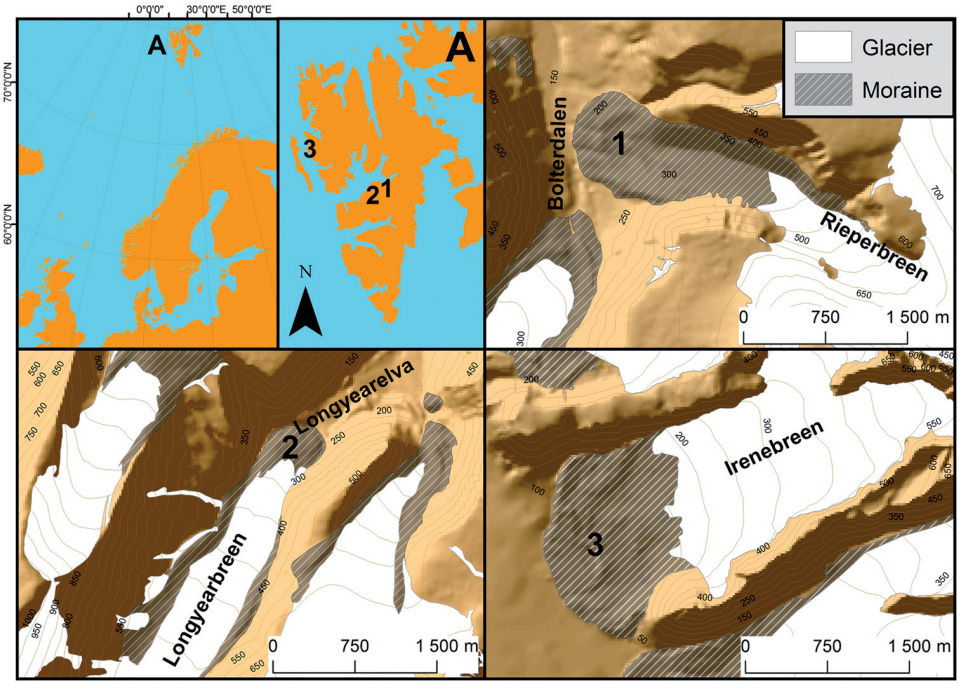

Fig. 1. The location of the study areas: A – Svalbard Archipelago; 1 – Rieperbreen foreland; 2 – Longyearbreen foreland; 3 – Irenebreen foreland (© Norwegian Polar Institute 2016).

Fieldwork and data analysis

Fieldwork was carried out in the summers of 2009, 2012 and 2015, in the moraines of Longyearbreen, Irenebreen and Rieperbreen, respectively (Fig. 1). Lichen biota was studied throughout the entire area of the forelands. Additionally, in each moraine 1 × 1 m sampling plots were marked out with a frame where the lichen presence was recorded so as to compare the lichen biota. In total, 250 plots were studied: 50 plots in the Longyearbreen foreland, 100 plots in the Irenebreen moraine and 100 plots in the Rieperbreen foreland. Lichen samples were collected for later identification.

Traditional taxonomical methods were employed to identify species and the following publications were used: Thomson (1984, 1997), Brodo *et al.* (2001), Smith *et al.* (2009), and Wirth (2013). Furthermore, in the case of sterile taxa, chemotaxonomical analyses were performed (Orange *et al.* 2001). Lists of recorded lichens were prepared on the basis of the collected data. The taxonomical nomenclature followed the Index Fungorum (MycoBank 2016). The distribution of taxa in Svalbard was checked according to Elvebakk & Hertel (1996), Øvstedal *et al.* (2009), Redchenko *et al.* (2010), Kristinsson *et al.* (2010), Zhurbenko & Brackel (2013), and Svalbard Lichen Database (2016). Herbarium materials were deposited in the Herbarium of the Institute of Botany, Jagiellonian University in Kraków (KRA).

Non-metric multidimensional scaling (NMDS) and species indicator analysis measured with Pearson's phi coefficient were performed to determine similarities in lichen composition between the studied glacier moraines. The analyses covered fifty plots from each moraine. The 50 plots from the Irenebreen and Rieperbreen forelands were chosen randomly from all the datasets. Species richness across moraines was estimated using the Kruskal-Wallis test. In addition, the U Mann-Whitney test was used to investigate the human impact on lichens growing on the Longyearbreen moraine. The analysis focused on 50 plots from Longyearbreen and 50 plots from Rieperbreen, owing to the location of these glaciers in similar climate conditions (Kostrzewski *et al.* 1989; Przybylak *et al.* 2007). The analyses were carried out using the following software: Statistica 12.5, PAST 3.10 and R-Cran 3.1.1.

RESULTS AND DISCUSSION

Lichen diversity

The lichens colonising the glacier moraines were observed at different stages of development. In the majority of cases, the thalli were found during the initial stage of their development (Sancho & Valladares 1993), but some were identified in medium-advanced stages, usually in more stable substrata. The taxa recorded near the glacier foreheads and in strongly eroded areas had poorly developed thalli. The different stages observed in thalli development were due to the habitat conditions, substratum stability and the time since deglaciation (Węgrzyn & Wietrzyk 2015).

Overall, a total of 135 lichen species were recorded in the forelands of the three glaciers (Table 1). The greatest species diversity was observed in the Rieperbreen moraine – 88 species; the lowest in the Longyearbreen foreland – 43 taxa; while in the Irenebreen foreland the number of species reached 60 (Table 1).

Eight species were recorded for the first time in the Svalbard archipelago: *Arthonia gelidae, Buellia elegans, Caloplaca lactea, Cryptodiscus pallidus, Fuscidea kochiana, Merismatium deminutum, Physconia distorta*, and *Polyblastia schaereriana.* One species, *Staurothele arctica*, was observed for the first time in Spitsbergen (it had previously only been found in Hopen island). Data on the new citations to Svalbard are presented below:

Arthonia gelidae R. Sant. (Santesson 1986)

Specimens examined: Rieperbreen, 78°07'39.05"N/16°01'16.21"E, alt. 225 m, July 2015, leg. M. Węgrzyn and P. Wietrzyk.

Notes: This species is poorly known in the Arctic region. In the Arctic, this taxon was recorded only from Iceland, on thallus of *Placopsis gelida* (Smith *et al.* 2009). It is a lichenicolous species noted on thallus of *Placopsis gelida* in Rieperbreen moraine.

Buellia elegans Poelt (Poelt & Sulzer 1974)

Specimens examined: Rieperbreen, 78°07'39.27"N/16°01'02.95"E, alt. 208 m; July 2015, leg. M. Węgrzyn and P. Wietrzyk.

Notes: *B. elegans* was recorded in other Arctic regions as North America, on soil in dry open areas (Thomson 1997). On Rieperbreen moraine, this species was collected from soil.

Table 1. A list of the lichen taxa recorded in the moraine of the studied glaciers: Rieperbreen, Irenebreen and Longyearbreen. A star (*) indicates lichenicolous lichens. Species new to Svalbard are in **bold**

No.	*Species name*	*Glacier*		
		Rieperbreen	*Irenebreen*	*Longyearbreen*
1	*Acarospora fuscata* (Nyl.) Th. Fr.	X	X	
2	*Acarospora molybdina* (Ach.) Trevis.	X	X	
3	*Acarospora sinopica* (Wahlenb.) Körb.			X
4	*Amandinea punctata* (Hoffm.) Coppins & Scheid.			X
5	*Amundsenia approximata* (Lynge) Søchting, Arup & Frödén		X	
6	***Arthonia gelidae** R. Sant.	X		
7	*Arthrorhaphis citrinella* (Ach.) Poelt	X		
8	*Aspicilia disserpens* (Zahlbr.) Räsänen			X
9	*Aspicilia fimbriata* (H. Magn.) Oxner	X	X	
10	*Aspicilia mashiginensis* (Zahlbr.) Oxner			X
11	*Aspicilia melanaspis* (Ach.) Poelt & Leuckert		X	
12	*Athallia holocarpa* (Hoffm.) Arup, Frödén & Søchting	X		
13	*Athallia pyracea* (Ach.) Arup, Frödén & Søchting	X		
14	*Bacidia bagliettoana* (A. Massal. & De Not.) Jatta		X	
15	*Bacidia illudens* (Nyl.) H. Olivier		X	
16	*Bellemerea alpina* (Sommerf.) Clauzade & Cl. Roux	X		
17	*Biatora subduplex* (Nyl.) Printzen	X		
18	*Bilimbia sabuletorum* (Schreb.) Arnold		X	
19	*Blastenia ammiospila* (Ach.) Arup, Søchting & Frödén	X	X	
20	*Bryobilimbia hypnorum* (Lib.) Fryday, Printzen & S. Ekman		X	
21	*Bryonora castanea* (Hepp) Poelt	X		
22	*Buellia aethalea* (Ach.) Th. Fr.			X
23	*Buellia badia* (Fr.) A. Massal.			X
24	***Buellia elegans*** Poelt	X		
25	*Buellia insignis* (Nägeli ex Hepp) Th. Fr.	X		
26	*Buellia papillata* (Sommerf.) Tuck.	X		
27	*Calogaya pusilla* (A. Massal.) Arup, Frödén & Søchting		X	
28	*Caloplaca caesiorufella* (Nyl.) Zahlbr.	X		
29	*Caloplaca cerina* (Hedw.) Th. Fr.	X		
30	***Caloplaca lactea*** (A. Massal.) Zahlbr.	X		
31	*Caloplaca nivalis* (Körb.) Th. Fr.		X	
32	*Candelariella aurella* (Hoffm.) Zahlbr.			X
33	*Candelariella vitellina* (Hoffm.) Müll. Arg.	X	X	X
34	*Carbonea vorticosa* (Flörke) Hertel	X	X	X
35	*Catillaria chalybeia* (Borrer) A. Massal.	X	X	
36	*Catillaria contristans* (Nyl.) Zahlbr.	X	X	
37	*Cetraria ericetorum* Opiz			X
38	*Cetrariella delisei* (Bory ex Schaer.) Kärnefelt & A. Thell	X	X	
39	*Circinaria caesiocinerea* (Nyl. ex Malbr.) A. Nordin, Savić & Tibell		X	X
40	*Cladona gracilis* (L.) Willd.			X
41	*Cladonia amaurocraea* (Flörke) Schaer.			X
42	*Cladonia arbuscula* (Wallr.) Flot.			X
43	*Cladonia coccifera* (L.) Willd.	X		
44	*Cladonia cornuta* (L.) Hoffm.	X		

Table 1. A list of the lichen taxa recorded in the moraine of the studied glaciers: Rieperbreen, Irenebreen and Longyearbreen. A star (*) indicates lichenicolous lichens. Species new to Svalbard are in **bold** *(continued)*

No.	*Species name*	*Glacier*		
		Rieperbreen	*Irenebreen*	*Longyearbreen*
45	*Cladonia macroceras* (Delise) Ahti	X		
46	*Cladonia mitis* Sandst.	X		
47	*Cladonia pleurota* (Flörke) Schaer.	X		
48	*Cladonia pyxidata* (L.) Hoffm.	X	X	X
49	***Cryptodiscus pallidus*** (Pers.) Corda	X		
50	*Eiglera flavida* (Hepp ex Kremp.) Hafellner	X	X	X
51	*Flavocetraria nivalis* (L.) Kärnefelt & A. Thell		X	X
52	*Frigidopyrenia bryospila* (Nyl.) Grube	X		
53	*Frutidella caesioatra* (Schaer.) Kalb	X		
54	***Fuscidea kochiana*** (Hepp) V. Wirth & Vězda		X	
55	*Henrica melaspora* (Taylor) Savić & Tibell	X	X	
56	*Henrica theleodes* (Sommerf.) Savić, Tibell & Nav.-Ros.		X	X
57	*Lecanora alpigena* (Ach.) Cl. Roux	X	X	X
58	*Lecanora atromarginata* (H. Magn.) Hertel & Rambold			X
59	*Lecanora epibryon* (Ach.) Ach.	X	X	
60	*Lecidea auriculata* Th. Fr.	X		X
61	*Lecidea lapicida* (Ach.) Ach.	X	X	
62	*Lecidea lithophila* (Ach.) Ach.	X		
63	*Lecidea ramulosa* Th. Fr.	X	X	
64	*Lecidella stigmatea* (Ach.) Hertel & Leuckert	X	X	
65	*Lecidella wulfenii* (Ach.) Körb.		X	
66	*Megaspora verrucosa* (Ach.) Hafellner & V. Wirth	X		
67	*Melanelia stygia* (L.) Essl.		X	
68	****Merismatium deminutum*** (Arnold) Cl. Roux & Nav.-Ros.	X		
69	**Merismatium nigritellum* (Nyl.) Vouaux	X		
70	*Micarea crassipes* (Th. Fr.) Coppins	X		
71	*Micarea incrassata* Hedl.	X		
72	*Nephroma arcticum* (L.) Torss.	X		
73	*Ochrolechia androgyna* (Hoffm.) Arnold	X	X	X
74	*Ochrolechia frigida* (Sw.) Lynge	X	X	X
75	*Parvoplaca tiroliensis* (Zahlbr.) Arup, Søchting & Frödén	X		
76	*Peltigera didactyla* (With.) J.R. Laundon	X		
77	*Peltigera leucophlebia* (Nyl.) Gyeln.	X		
78	*Peltigera malacea* (Ach.) Funck	X		
79	*Pertusaria oculata* (Dicks.) Th. Fr.			X
80	*Physcia caesia* (Hoffm.) Hampe ex Fürnr.	X		X
81	***Physconia distorta*** (With.) J.R. Laundon		X	
82	*Pilophorus cereolus* (Ach.) Th. Fr.	X		
83	*Placopsis gelida* (L.) Linds.	X		
84	*Polyblastia cupularis* A. Massal.	X	X	X
85	*Polyblastia gothica* Th. Fr.	X		
86	*Polyblastia hyperborea* Th. Fr.		X	
87	***Polyblastia schaereriana*** (A. Massal.) Müll. Arg.	X	X	
88	*Polyblastia sendtneri* Kremp.	X	X	

No.	Species name	Glacier		
		Rieperbreen	*Irenebreen*	*Longyearbreen*
89	*Polysporina simplex* (Taylor) Vězda	X	X	
90	*Porina chlorotica* (Ach.) Müll. Arg.	X	X	
91	*Porpidia crustulata* (Ach.) Hertel & Knoph	X		
92	*Porpidia macrocarpa* (DC.) Hertel & A.J. Schwab	X		
93	*Porpidia soredizodes* (Lamy) J.R. Laundon	X	X	
94	*Porpidia thomsonii* Gowan	X		
95	*Porpidia tuberculosa* (Sm.) Hertel & Knoph			X
96	*Protomicarea limosa* (Ach.) Hafellner	X		
97	*Protopannaria pezizoides* (Weber) P.M. Jørg. & S. Ekman	X		
98	*Protoparmelia badia* (Hoffm.) Hafellner			X
99	*Protothelenella sphinctrinoidella* (Nyl.) H. Mayrhofer & Poelt	X		
100	*Pseudephebe minuscula* (Arnold) Brodo & D. Hawksw.		X	
101	*Pseudephebe pubescens* (L.) M. Choisy	X	X	X
102	*Psoroma hypnorum* (Vahl) Gray	X		
103	*Rhizocarpon geographicum* (L.) DC.	X	X	X
104	*Rhizocarpon grande* (Flörke ex Flot.) Arnold			X
105	*Rhizocarpon hochstetteri* (Körb.) Vain.	X	X	
106	*Rhizocarpon intermediellum* Räsänen		X	
107	*Rhizocarpon reductum* Th. Fr.	X	X	
108	*Rhizocarpon submodestum* (Vain.) Vain.	X		
109	*Rinodina turfacea* (Wahlenb.) Körb.	X		
110	*Rostania ceranisca* (Nyl.) Otálora, P.M. Jørg. & Wedin	X	X	X
111	*Sarcogyne privigna* (Ach.) A. Massal.			X
112	*Solorina bispora* Nyl.	X		
113	*Solorina crocea* (L.) Ach.	X		
114	*Sporodictyon terrestre* (Th. Fr.) Savić & Tibell		X	
115	***Staurothele arctica*** Lynge		X	
116	*Stereocaulon alpinum* Laurer	X	X	
117	*Stereocaulon condensatum* Hoffm.	X		
118	*Stereocaulon rivulorum* H. Magn.			X
119	*Thelidium papulare* (Fr.) Arnold		X	
120	*Thelidium pyrenophorum* (Ach.) Körb.		X	X
121	*Trapeliopsis granulosa* (Hoffm.) Lumbsch	X		
122	*Tremolecia atrata* (Ach.) Hertel	X	X	X
123	*Umbilicaria arctica* (Ach.) Nyl.			X
124	*Umbilicaria cylindrica* (L.) Delise	X	X	X
125	*Umbilicaria decussata* (Vill.) Zahlbr.	X		X
126	*Umbilicaria deusta* (L.) Baumg.	X		
127	*Umbilicaria hyperborea* (Ach.) Hoffm.	X	X	X
128	*Umbilicaria proboscidea* (L.) Schrad.		X	
129	*Umbilicaria torrefacta* (Lightf.) Schrad.			X
130	*Usnea sphacelata* R. Br.	X		
131	*Verrucaria aethiobola* Wahlenb.		X	
132	*Verrucaria deversa* Vain.			X
133	*Verrucaria nigrescens* Pers.		X	
134	*Verrucaria obsoleta* Lynge			X
135	*Xanthoria elegans* (Link) Th. Fr.	X	X	
	Sum of species	**88**	**60**	**43**

Caloplaca lactea (A. Massal.) Zahlbruckner (Zahlbruckner 1901)

Specimens examined: Rieperbreen, 78°07'43.13"N/16°00'59.84"E, alt. 190 m; July 2015, leg. M. Węgrzyn and P. Wietrzyk.

Notes: This species was in the Arctic previously observed in West Greenland, Anabar (northern Russia) and North America, on pebbles and shells on the seashore (Søchting & Olech 1995; Smith *et al.* 2009; Zhurbenko *et al.* 2010). On Rieperbreen moraine, *C. lactea* was recorded on small pebbles.

Cryptodiscus pallidus (Pers.) Corda (Corda 1838)

Specimens examined: Rieperbreen, 78°07'36.09"N/16°01'31.72"E, alt. 231 m; July 2015, leg. M. Węgrzyn and P. Wietrzyk.

Notes: *C. pallidus* was also recorded for North America, Greenland and Iceland (Thomson 1997), on soil. It is a circumpolar arctic-alpine species, found on soil of Rieperbreen foreland.

Fuscidea kochiana (Hepp) V. Wirth & Vězda (Wirth & Vězda 1972)

Specimens examined: Irenebreen, 78°39'34.10"N/12°02'23.18"E, alt. 120 m; July 2012, leg. M. Węgrzyn.

Notes: In other Arctic regions, this species was observed in the Arctic coast of East Finnmark and in North America, on rocks and boulders (Smith *et al.* 2009; Zhurbenko *et al.* 2010). On Irenebreen moraine, *F. kochiana* was recorded on rock.

Merismatium deminutum (Arnold) Cl. Roux & Nav.-Ros. (Roux *et al.* 2002)

Specimens examined: Rieperbreen, 78°07'39.27"N/16°01'02.95"E, alt. 208 m; July 2015, leg. M. Węgrzyn and P. Wietrzyk.

Notes: This species was not previously observed in Arctic regions. On Rieperbreen moraine it was recorded on the thallus of *Polyblastia* sp. Smith *et al.* (2009) indicate that it is a lichenicolous taxon.

Physconia distorta (With.) J.R. Laundon (Laundon 1984)

Specimens examined: Irenebreen, 78°39'36.29"N/12°02'14.90"E, alt. 130 m; July 2012, leg. M. Węgrzyn.

Notes: In the Arctic, this species was noted in Polar Ural Mountains, Beringian Islands (Zhurbenko *et al.* 2010). In warmer regions, it inhabits tree barks and rocks (Smith *et al.* 2009). However, on Irenebreen moraine it was recorded on plant debris.

Polyblastia schaereriana (A. Massal.) Müll. Arg. (Müller 1862)

Specimens examined: Rieperbreen, 78°07'38.32"N/16°01'28.59"E, alt. 208 m; July 2015, leg. M. Węgrzyn and P. Wietrzyk; Irenebreen, 78°39'35.03"N/12°02'03.01"E, alt. 115 m; July 2012, leg. M. Węgrzyn.

Notes: *P. schaereriana* was in the Arctic previously observed in Greenland and North America, on rocks (Smith *et al.* 2009). On Irenebreen and Rieperbreen moraines, the species was recorded both on rocks and on soil.

Staurothele arctica Lynge (Lynge 1937)

Specimens examined: Irenebreen, 78°39'36.66"N/12°02'26.38"E, alt. 128 m; July 2012, leg. M. Węgrzyn.

Notes: In the Arctic, this species was found in Greenland, Ellesmere Island, Arctic Iceland and North America, on rocks (Thomson 1997; Smith *et al.* 2009; Zhurbenko *et al.* 2010). In Svalbard this species was observed only in Hopen Island (Svalbard Lichen Database 2016). On Irenebreen foreland, it was recorded on rocks.

A comparison of lichen biota in the studied moraines

According to the NMDS ordination, the lichen composition of the Longyearbreen foreland differs greatly when compared with the other two glacier moraines (Fig. 2). Minor differences can be also seen among plots from the Irenebreen and Rieperbreen moraines (Fig. 2; Fig. 3). Although the forelands of Rieperbreen and Longyearbreen are located in the warmest and driest area of Svalbard (Kostrzewski *et al.* 1989; Przybylak *et al.* 2007; Rachlewicz & Szczuciński 2008), which directly contributes to their high species diversity, the lichen composition of the Longyearbreen moraine exhibited the lowest species diversity in comparison with the Rieperbreen foreland which had the highest number of species (Table 1). The difference was clearly visible in the case of both lichens growing directly on soil and rocks, which were much less numerous in the Longyearbreen foreland (Fig. 4). This seems to be caused mainly by tourists trampling on the moraine as a result of a significant increase in tourism, which has expanded along Longyearbyen (Kaltenborn 1998, Kaltenborn 2000). Such trampling greatly inhibits or even prevents the development of terrestrial lichens. Bayfield *et al.* (1981) and Grabherr (1982) claim that terrestrial fruticose species are especially sensitive to human trampling.

The distribution of certain species is correlated with a particular glacier (Table 2), e.g. *Aspicilia mashiginensis*, *Cladona gracilis*, *Buellia aethalea, Rhizocarpon grande* for Longyearbreen; *Porpidia soredizodes, Placopsis gelida, Usnea sphacelata, Polyblastia schaereriana* for Rieperbreen; and *Acarospora molybdina, Polyblastia sendtneri, Aspicilia fimbriata* for Irenebreen. However, the presence of several species is related to more than one foreland. Such species as *Stereocaulon alpinum* (0.661; $p \leq 0.001$), *Rostania ceranisca* (0.640; $p \leq 0.001$), *Polyblastia cupularis* (0.606; $p \leq 0.001$), *Lecanora alpigena* (0.578; $p \leq 0.001$), *Polysporina simplex* (0.554; $p \leq 0.001$), *Rhizocarpon hochstetteri* (0.419; $p \leq 0.001$), *Rhizocarpon reductum* (0.397; $p \leq 0.001$), *Rhizocarpon geographicum* (0.346; $p \leq 0.001$) and *Lecidella stigmatea* (0.218; $0.017 \leq p \leq 0.049$) are common on both

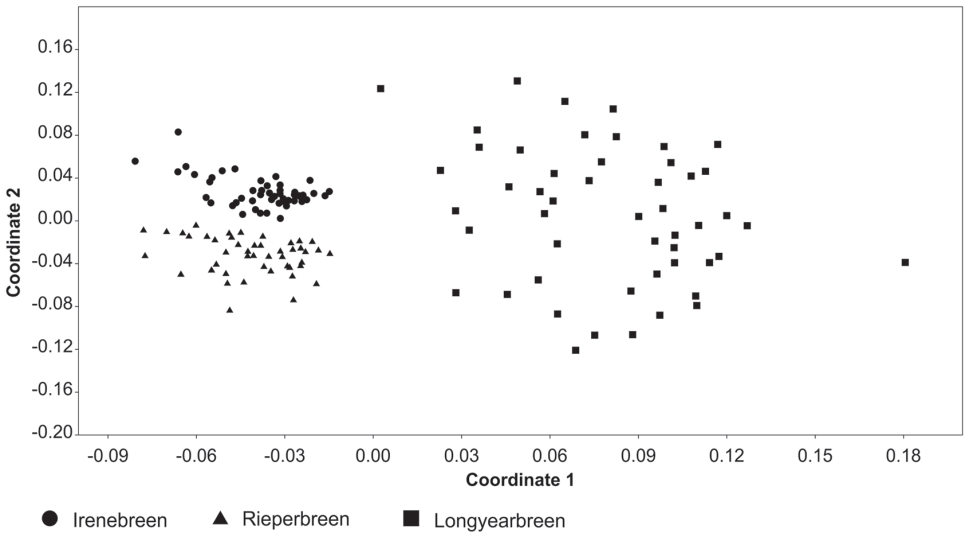

Fig. 2. Non-metric multidimensional scaling (NMDS) analysis of 150 plots (with the Bray-Curtis distance as a dissimilarity measure). The first axis explains 51% of the variability and the second 27%.

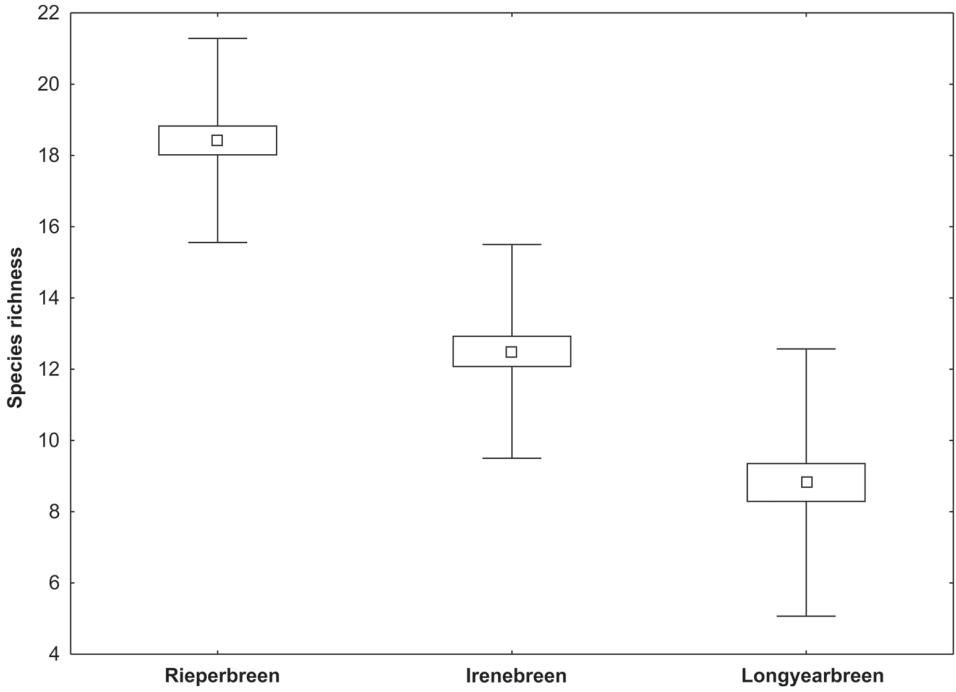

Fig. 3. The results of the Kruskal-Wallis analysis ($p < 0.05$). The difference between the species richness of Rieperbreen, Irenebreen and Longyearbreen moraines ($chi^2 = 88.30451$; $p = 0.0001$) are shown by boxplots. The z and p values for Kruskal-Wallis multiple comparisons: Rieperbreen – Irenebreen: $z = 5.9419453$, $p = 0.000000$; Rieperbreen – Longyearbreen: $z = 9.50849352$, $p = 0.000000$; Irenebreen – Longyearbreen: $z = 3.56654822$, $p = 0.001085$.

the Rieperbreen and Irenebreen forelands. There is also one species, *Umbilicaria decussata* (0.227; $0.017 \leq p \leq 0.049$), which is strongly associated with both the Rieperbreen and Irenebreen forelands.

Nevertheless, the majority of recorded taxa are associated only with the foreland of a particular glacier (Table 2). The main differences seem to stem from the different climatic aspects connected with the locations of glaciers. All glaciers lie in the warm region of Spitsbergen, but the area of Oscar II Land is characterized by higher humidity (Przybylak & Araźny 2005) which can influence the species composition of lichens. It seems that the specific microclimate of the Rieperbreen foreland connected with the absence of human trampling results in the increased presence of species producing cephalodia, such as *Polyblastia schaereriana, Micarea crassipes, Micarea incrassata, Placopsis gelida* and *Stereocaulon condensatum.* It can be assumed that cephalodia facilitate the colonization process because of the cyanobiont's ability to ensure enhanced rates of nitrogen fixation (Hill 2009).

The results of our study underlined the lichen diversity in Svalbard's glacier moraines. A comparison between Longyearbreen and Rieperbreen forelands suggests a major negative anthropogenic impact on lichen biota. Due to essential differences in the lichen composition of the studied moraines, further research is needed to be able to assess the lichen richness of glacier moraines throughout Svalbard as well as in the Arctic as a whole.

Table 2. Results of species indicator analysis (Pearson's phi coefficient). The 'phi' indicates the Pearson's phi coefficient value

	Rieperbreen	*phi*	*Irenebreen*	*phi*	*Longyearbreen*	*phi*
	Protopannaria pezizoides	0.955	*Acarospora molybdina*	0.842	*Cladona gracilis*	0.522
	Porpidia soredizodes	0.837	*Polyblastia sendtneri*	0.732	*Cladonia arbuscula*	0.522
	Cladonia coccifera	0.736	*Aspicilia fimbriata*	0.709	*Protoparmelia badia*	0.506
	Cladonia pyxidata	0.687	*Xanthoria elegans*	0.629	*Sarcogyne privigna*	0.506
	Acarospora fuscata	0.678	*Henrica melaspora*	0.479	*Verrucaria deversa*	0.489
	Ochrolechia frigida	0.619	*Umbilicaria hyperborea*	0.401	*Cetraria ericetorum*	0.471
	Ochrolechia androgyna	0.578	*Bilimbia sabuletorum*	0.357	*Lecidea auriculata*	0.461
	Cladonia macroceras	0.506	*Umbilicaria cylindrica*	0.315	*Buellia aethalea*	0.454
***** p ≤ 0.001**	*Umbilicaria deusta*	0.506			*Stereocaulon rivulorum*	0.454
	Eiglera flavida	0.487			*Candelariella aurella*	0.398
	Pseudephebe pubescens	0.446			*Rhizocarpon grande*	0.398
	Carbonea vorticosa	0.434			*Aspicilia disserpens*	0.378
	Peltigera malacea	0.417			*Aspicilia mashiginensis*	0.378
	Psoroma hypnorum	0.417			*Physcia caesia*	0.344
	Placopsis gelida	0.398			*Buellia badia*	0.336
	Usnea sphacelata	0.357			*Cladonia amaurocraea*	0.336
	Polyblastia schaereriana	0.336			*Thelidium pyrenophorum*	0.321
	Buellia insignis	0.289	*Aspicilia melanaspis*	0.289	*Acarospora sinopica*	0.313
	Micarea incrassata	0.289			*Lecanora atromarginata*	0.289
**** 0.002 ≤ p ≤ 0.010**	*Solorina crocea*	0.289			*Umbilicaria arctica*	0.289
	Peltigera didactyla	0.263			*Umbilicaria torrefacta*	0.289
	Protomicarea limosa	0.263			*Flavocetraria nivalis*	0.261
	Stereocaulon condensatum	0.263	*Staurothele arctica*	0.234	*Porpidia tuberculosa*	0.234
*** 0.017 ≤ p ≤ 0.049**	*Cetrariella delisei*	0.234	*Lecidea lapicida*	0.217	*Circinaria caesiocinerea*	0.217
			Lecidea ramulosa	0.217		

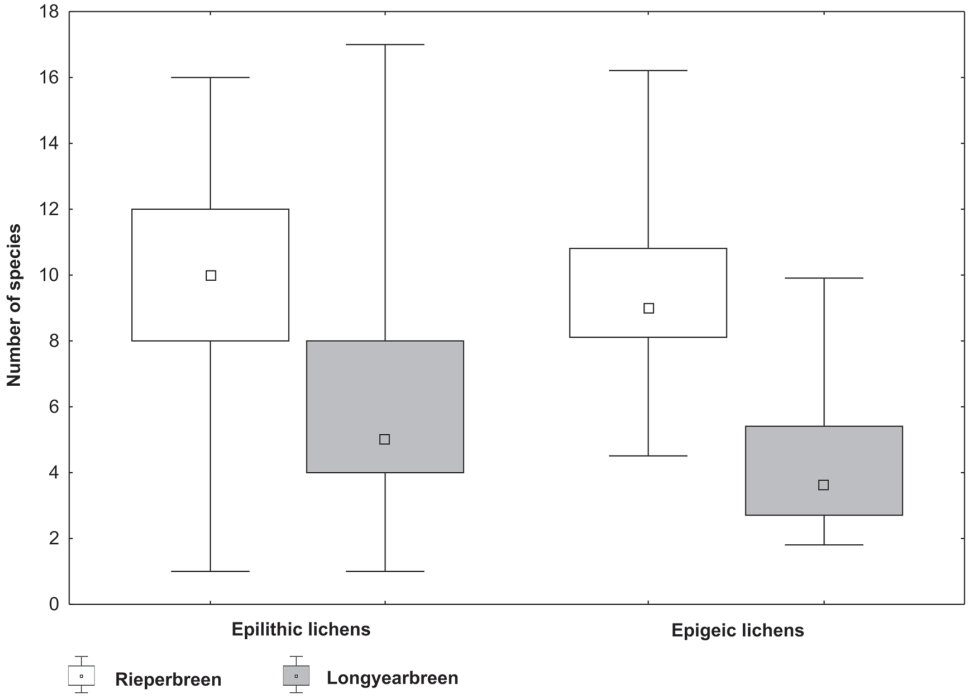

Fig. 4. The results of U Mann-Whitney analysis ($p < 0.05$). The difference between Rieperbreen and Longyearbreen in terms of epigeic species ($Z = 7.95823894$; $p = 0.0000001$) and epilithic species ($Z = 5.10298209$ $p = 0.0000001$) are shown by the boxplots.

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