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Mosses (Bryophyta) and liverworts (Marchantiophyta) of the Zackenberg valley, northeast Greenland

Kristian Hassel, Harald Zechmeister and Tommy Prestø

K. Hassel (kristian.hassel@ntnu.no) and T. Prestø, The Natural History Dept, NTNU University Museum, Norwegian Univ. of Science and Technology, NO-7491 Trondheim, Norway. – H. Zechmeister, Dept of Botany and Biodiversity Research, Rennweg 14, AT-1030 Vienna, Austria.

The moss and liverwort flora of Zackenberg valley in the Northeast Greenland National Park has been studied based on field investigations and literature survey. Altogether 212 taxa are recorded in the area, with 43 liverworts and 169 mosses. Five taxa are reported as new to Greenland *Lophochaete fryei* (Perss.) R.M. Schust., *Sphagnum orientale* L.I. Savicz, *Orthothecium lapponicum* (Schimp.) C. Hartm., *Pohlia vexans* (Limpr.) H. Lindb. and *Tortella alpicola* Dixon. Additionally four taxa are reported as new to east Greenland; *Grimmia plagiopodia* Hedw., *Riccardia latifrons* (Lindb.) Lindb. *Sphagnum olafii* Flatberg and *Tritomaria exsectiformis* (Breidl.) Schiffner ex Loeske. The bryophyte flora of the Zackenberg valley is characterised by pioneer species adapted to disturbance by frost and wind, but also more stable communities exist especially at the lower part of the valley with wet to moist tundra. The Zackenberg valley bryophyte flora shows higher similarity with the flora on Svalbard (81%) compared with Ellesmere Island (67% and 60% for liverworts and mosses, respectively). This is consistent with east Greenland and Svalbard belonging to the North Atlantic Arctic flora province while Ellesmere Island belongs to the Canadian Arctic flora province.

Bryophytes (i.e. liverworts and mosses) are an important plant group of arctic and tundra ecosystems both in relation to biomass and species diversity (Longton 1988, Hassel et al. 2012). To understand the dynamics and ecology of these ecosystems knowledge about the species and their ecology is fundamental. The exploration of Arctic bryophytes is still incomplete although pioneer work has been committed in areas like Chukotka, Ellesmere Island, Svalbard, Peary Land and Arctic Alaska (Schuster et al. 1959, Holmen 1960, Brassard 1971, Steere 1978, Steere and Inoue 1978, Frisvoll and Elvebakk 1996, Afonina 2004), but there are still large unexplored areas. Zackenberg Research Station, northeast Greenland, was established in 1995 with the purpose to describe an entire high-arctic ecosystem and monitor responses to climate change(Meltofte et al. 2008). However, the bryophyte flora of the research area is still to a large degree unexplored, and our current knowledge is fragmentary.

The large bulk of bryophytes collected from Greenland are deposited in herbarium C (Copenhagen), a list of the moss names in the herbarium was published by Goldberg (2003), consisting of 535 taxa, subspecies and varieties included, this is in agreement with Mogensen (1999) who estimated the number of moss species of Greenland to 478. The number of liverwort species was estimated to 135 by Mogensen (1999), while Damsholt (2013) in his flora of Greenland report 178 species. From northeast Greenland, defined as Kangerdlugssuaq (68°11'N lat.) to Lamberts land, Kap Drygalski (79°10'N lat.), and Norske øer, Damsholt (unpubl.) report 98 liverwort taxa (subspecies included). For mosses 286 taxa (including varieties and subspecies) are kept in herb. C from northeast Greenland (defined as region E5, E6 and E7 according to Long 1985). This area includes the south side of the fjord Kangertittivaq (Scoresbysund) north to Danmark fjord and Prinsesse Thyra Ø. In comparison Frisvoll and Elvebakk (1996) report 85 liverwort and 288 moss species from the arctic archipelago Svalbard.

The flora of northeast Greenland is very interesting in a historical perspective with Plio-Pleistocene moss and other plant fossils from the Kap København Formation, Iˆle de France Formation and Store Koldewey Forma-

tion (Bennike et al. 2010). Early hypothesis of survival of plants since the Tertiary seems less likely in the light of glacial deposits (Funder 1979). There has, however, been mountain peaks (nunataks) that have escaped glaciation, and poikilohydric organisms like bryophytes and lichens may well have survived here (Gjærevoll and Ryvarden 1977). During the last glacial maximum rather large, though isolated, unglaciated areas were present in northeast Greenland (Funder 1979, Funder and Hansen 1996), and areas at Wollaston Forland and Clavering Ø seem to have been ice-free for at least 40 000 years. Bennike et al. (1999) points to the low summer temperatures during the last glacial maximum as the most critical factor for vascular plant survival, but they also points out that "a larger portion of other plant groups, such as bryophytes, lichens, fungi, and algae, whose members are often less dependent on climatic conditions than vascular plants, may have survived". In situ survival has also been pointed out as a possible explanation for some occurrences of liverwort species in south Greenland (Schuster 1988). For many bryophytes moisture rather than temperature may have been the critical factor (Segreto et al. 2010). Thus survival of bryophytes in ice-free areas of northeast Greenland during the last glacial maximum seems possible.

The bryophyte flora of northeast Greenland may therefore be a mixture of survivors from the climatically warmer last interglacial which also consisted of species currently unknown in northeast Greenland (Hedenäs 1994), and long distance dispersal events after the last glaciations. The vegetation history, as reflected in pollen diagrams extending back to ca 10 000 years B.P., has shown that many species have dispersed from northern Europe and North America (Funder 1979). For spore producing organisms like bryophytes wind dispersal are probably the most important factor. For species lacking spore production bird dispersal or ice-rafted debris and driftwood are possible dispersal vectors (Johansen and Hytteborn 2001).

This study is part of the on-going research studying effects of climate change in the arctic Zackenberg valley, where long term monitoring of the flora in permanent plots is one component. The main aim of the current study is to describe the general moss and liverwort diversity of the area by compiling a species list of the bryophytes collected in the area together with reports from the literature.

Methods and study area

Study area

The Zackenberg study area (74°30'N, 20°30'W) is situated in The Northeast Greenland National Park (Fig. 1), the largest National Park in the world. It is situated in the high arctic, about 40 km west of the outer coast (Daneborg station) and about 70 km east of the permanent Greenland ice cap. Zackenberg area is close to the northernmost areas with extensive vegetation cover in lowland (Meltofte et al. 2008). The direct influence of human activity is minimal; Zackenberg research station was founded in 1995 and has since then hosted permanent staff and visiting scientists (June to August). Beside Daneborg weather station and Zackenberg research station the area is unpopulated by humans. However, there are old trapper's huts and remains of fox trapping.

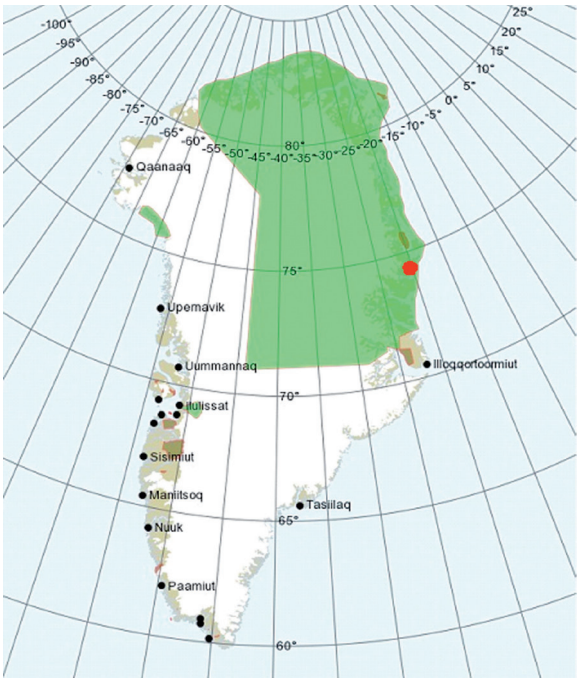

Figure 1. Map of Greenland with The Northeast Greenland National Park and the position of Zackenberg indicated (red dot).

Zackenberg area is rather mountainous, with peaks up to more than 1300 m a.s.l. The U-shaped valley is directed northeast from the fjord and is drained by Zackenbergelven. The Zackenberg study area is geologically divided by a fault zone separating areas with Cretaceous and Tertiary sandstones topped by basalts above about 600 m a.s.l. to the east of Zackenbergelven from Caledonian gneissic and granite bedrock to the west of the river (Meltofte et al. 2008).

Precipitation is rather low, about 250 mm year^{-1}, precipitation as rain is only 27 mm from June to September. The mean annual temperature is –9.5°C, monthly air temperature is around 3°–7°C in July and August, and goes down to –20°C during the period of polar night. The mean humidity, which is another important factors for bryophyte growth is between 60% and 80% throughout the year, being highest during the summer months (Hansen et al. 2008).

Beside the surrounding barren mountains the area is dominated by extensive wetlands at the valley bottom and

other vegetation up to about 300 m a.s.l. Most of Greenland high-arctic landforms and biodiversity is represented in the area (Elberling et al. 2008, Meltofte and Rasch 2008). The vegetation cover, including those of bryophytes is mostly influenced by melting water availability, controlled by topography and snow distribution patterns. About 83% of the vegetation cover is situated at altitudes below 300 m a.s.l. Elberling et al. (2008) distinguish at least five plant communities. Fens in the lowland are wettest and have the highest biomass, bryophyte cover is up to 100%. Grasslands occur in lower sloping areas with adequate water supply during early growing period. Snow bed communities with the character species *Salix arctica* often occur in sloping areas, but can also be found close to the sea. Bryophyte cover in snow beds is about 60%. Heathlands dominated by *Cassiope tetragona* or *Vaccinium uliginosum* (the latter especially on the west side of the valley) are situated mostly on the slopes just below *Dryas octopetala*-dominated heaths. The latter shows decreasing vegetation cover with increasing altitude. In all types of heaths bryophytes are less dominant compared to lichens or phanerogams. These general patterns of increasing frequency and dominance of bryophytes from the dry heath vegetation to the moist fen vegetation were also confirmed by Hassel et al. (2012). Extraordinary dense bryophyte dominated vegetation are found in up to 100 m wide stripes of grasslands and fens bordering small runoffs of water at altitude between 150 and 300 m. Above 300 m the vegetation is more scattered and open soil is dominating over plant cover, but bryophytes are the dominant plant group (Hassel et al. 2012).

Methods

The area was visited by KH and TP from 19 August to 31 August 2009, HZ visited the area from 4 August to 11 August 2009. The general survey of the bryophyte vegetation was a secondary aim of our project and most collections were done on the way from the research station to the plots for the vegetation analysis. In addition we used one day west of the research station along the coast of Zackenberg bugt, and one day on the west side of the river north of the station up to the small lake area. The rest of the time was spent on the east side of the river and mainly in proximity to Zero line (Fredskild and Mogensen 1997). The GPS positions of our collections (Fig. 2), gives an indication of the area that we have covered. All species reported by us have been collected at least once and are deposited in herbarium TRH or at Vienna University. Information on all specimens deposited at herbarium TRH, including their geographic coordinates, are available through the Global Biodiversity Information Facility portal (<http://data.gbif.org>). Taxonomy follows with few exceptions Hill et al. (2006) for mosses, Damsholt (2013) for liverworts and Böcher et al. (1978) for vascular plants.

Results and discussion

In total 513 specimens collected by Hassel and Prestø are deposited in herbarium TRH and 123 specimens collected by Zechmeister are stored at Vienna University. Table 1 includes 212 taxa collected in the Zackenberg valley, of these 43 are liverworts (Marchantiophyta) and 169 mosses (Bryophyta). In addition Damsholt (2013) reports five species of liverworts (*Gymnomitrion mucrophorum, Lophozia pellucida, Marsupella arctica, Cephaloziella grimsulana* and *Cephaloziella varians*), and Fredskild and Mogensen (1997) eight mosses (*Amphidium lapponicum, Bryum teres, Drepanocladus vernicosus, Heterocladium* sp., *Hymenostylium recurvirostre, Lyellia aspera, Pseudoleskeella* sp. and *Schistidium apocarpum*). Herbarium TRH also has a specimen of *Sphagnum balticum* from Zackenberg collected by Westergaard and Dahl in 2007. Making the total number of taxa known from the valley 226 (48 liverworts and 178 mosses), this number is probably a good estimate for the bryophyte species diversity in the Zackenberg valley.

The ratio between liverworts and mosses in the Zackenberg valley is 0.26, this is slightly lower compared to the bryophyte flora of Svalbard (0.30; Frisvoll and Elvebakk 1996) and Norway mainland (0.34; Hassel et al. 2010), probably reflecting a gradient in humidity from the moist Norway to the more continental Arctic climate at Zackenberg.

It is difficult to compare the bryophyte floras of different areas due to differences in area, bryological activity, and taxonomic concepts that change through time, however, with this in mind we compare the bryophyte flora of Zackenberg valley with northern Ellesmere Island and Svalbard. The mosses of northern Ellesmere Island was investigated by Brassard (Brassard 1971, 1976) and 166 species were reported. For liverworts Damsholt (2013) report the occurrences on Ellesmere Island for the species included in his flora. For Svalbard Frisvoll and Elvebakk (1996) report 85 liverworts and 288 mosses. Taxa recorded in Zackenberg and also occurring at Svalbard or Ellesmere Island are indicated in Table 1. The bryophyte flora of Zackenberg clearly shows higher affinity with the Svalbard flora with 81% similarity for both liverworts and mosses compared with 67% and 60% similarity with the liverwort and moss flora of Ellesmere, respectively. The high similarity with Svalbard may be due to more efficient dispersal between the east coast of Greenland and Svalbard compared with Ellesmere Island. The Greenlandic ice cap is a major dispersal barrier for vascular plants (Eidesen et al. 2013) and most likely for bryophytes as well. These patterns are also supported by the concept of Arctic floristic provinces and sub-provinces for vascular plant diversity put forward by Yurtsev (1994), Walker et al. (2005) and Eidesen et al. (2013). According to this system the eastern Greenland and Svalbard – Franz-Josef sub-provinces belong to the North Atlantic floristic province, while the

Ellesmere – N. Greenland sub-province belong to the Canada floristic province.

Comments on new records, distribution and ecology

New records to Greenland

***Lophochaete fryei* (Perss.) R.M. Schust.** was found in a wetland with *Eriophorum scheuchzeri* and *Dupontia psilosantha* on eroded peat in fen hummock, growing with *Aulacomnium turgidum*, *Cephalozia bicuspidata*, *Blepharostoma trichophyllum* ssp. *brevirete* and *Tritomaria quinquedentata* among *Sphagnum girgensohnii* (Fig. 3, TRH 691784). This arctic liverwort was described as late as 1946 from St. Lawrence Island, Alaska (Pearsson 1946). The distribution includes the Asiatic part of arctic Russia (Konstantinova et al. 1992), and arctic North America from Alaska to the west coast of Hudson Bay (Schuster 1966). The current report from northeast Greenland thus fills a significant gap of the known distribution and may

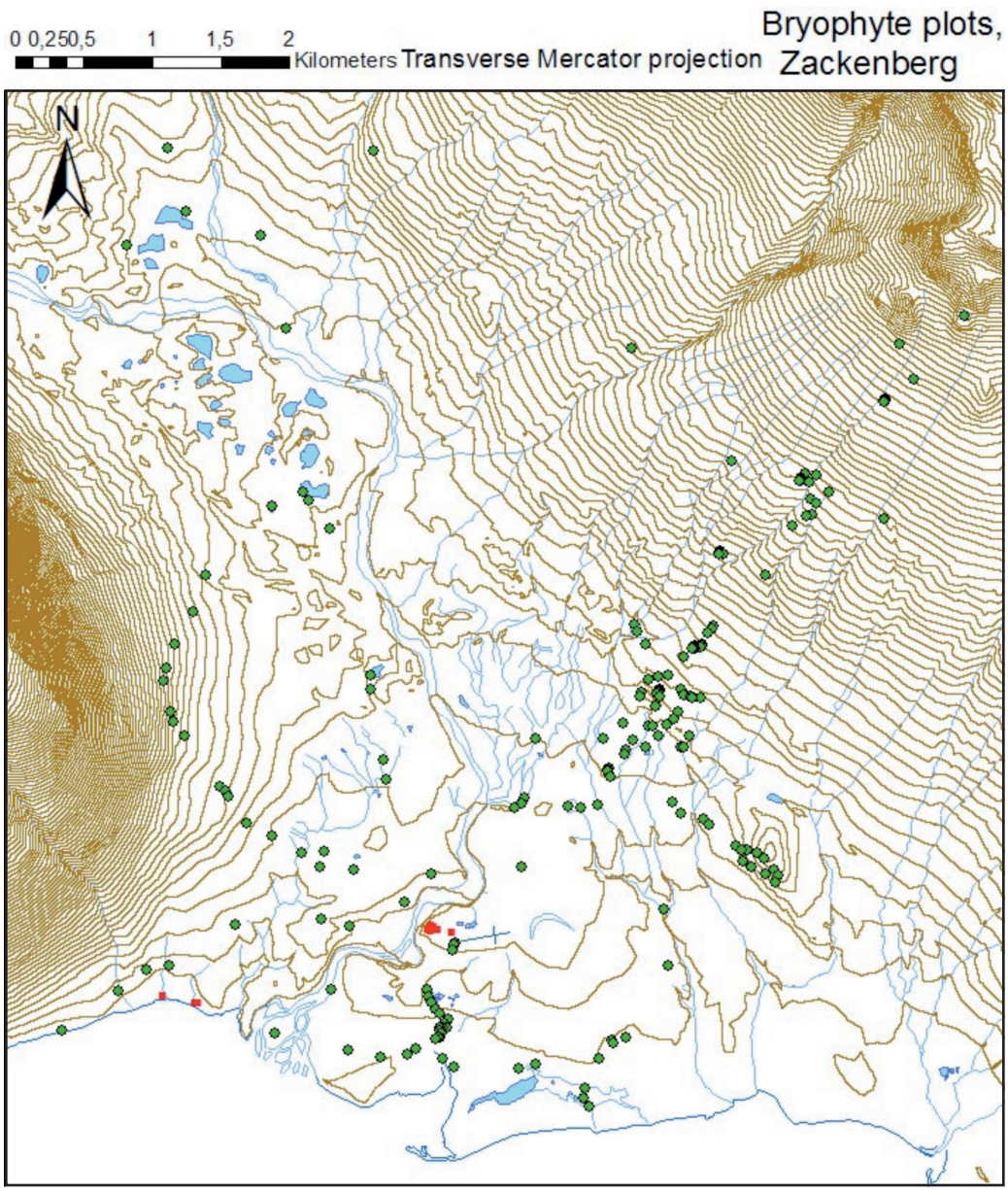

Figure 2. Collection points (green circles) for bryophytes during the investigations in the Zackenberg area by the authors during 2009. Red squares mark houses, the research station is in the centre of the map, while we see two trapper's huts by the fjord.

Table 1. List of bryophyte species collected during August 2009. The frequency of the species is given as 1 rare, 2 sporadic and 3 common. For most species habitats are given. Species presence in northern Ellesmere Island (E) and Svalbard (S) are given according to Brassard (1971), Frisvoll and Elvebakk (1996) and Damsholt (2013).

Species	Frequency	Habitat	Geogr. affinity
Marchantiophyta			
Anastrophyllum minutum	3	fen hummocks, all heathlands, snow beds, lake margin, river margin	ES
Aneura pinguis	2	fen, lake margin, river margin	ES
Anthelia juratzkana	3	snow beds, moist peat in heathlands and fens	ES
Apomarsupella revoluta	2	Only found west of river Zackenberg, by periodic small ponds	
Arnellia fennica	1	snow bed, river margin	ES
Athalamia hyalina	1	snow bed, base-rich	ES
Blepharostoma trichophyllum ssp. *brevirete*	3	indifferent in all moist – wet habitats, but not in abrasion plateaus	ES
Cephalozia bicuspidata	2	moist habitats	ES
Cephalozia pleniceps	2	moist habitats	ES
Cephalozia sp.		shore of periodic pond	
Cephaloziella divaricata	2	snow bed, rich fen and moss tundra	E
Cephaloziella rubella ssp. *arctogena*	1	snow bed	
Cephaloziella spp.		all heathland, fen, wetland, lake shores	
Gymnocolea borealis	2	rich fens	
Gymnocolea inflata	1	moist peat	S
Gymnomitrion concinnatum	2	*Cassiope* heath, river margin	ES
Gymnomitrion corallioides	3	snow beds, all heathlands	ES
Jungermannia pumila ssp. *polaris*		*Salix arctica* snow bed	ES
Jungermannia sp.		*Cassiope* heath, cliff wall, soil by brook	
Jungermannia sphaerocarpa	2	*Cassiope* heath, brook margin	ES
Lophochaete fryei	1	eroded peat in fen hummock	
Lophozia binsteadii	2	fen hummocks	E
Lophozia hatcheri	2	*Cassiope tetragona* heath, *Vaccinium* heath, boulder screes	ES
Lophozia heterocolpos	1	*Cassiope* heath	ES
Lophozia incisa ssp. *opacifolia*	2	peat, fen hummocks	ES
Lophozia kunzeana	2	sloping intermediate and rich fens	ES
Lophozia polaris	1	snow bed	S
Lophozia quadriloba	2	sloping rich fens	ES
Lophozia rutheana	1	rich fen	S
Lophozia sp.		soil by brook	
Lophozia spp.		fen, *Cassiope* heath	
Lophozia spp.		all heatlands, fens, lake shores, snow beds	
Lophozia wenzelii	1	snow bed/river margin	S
Nardia geoscyphus	1	snow bed	S
Odontoschisma macounii	2	snow beds, fens, river margins, lake margins	ES
Peltolepis quadrata	1	*Cassiope* heaths	ES
Prasanthus suecicus	1	Cassiope heath	S
Preissia quadrata ssp. *hyperborea*	1	snow bed, Cassiope heath	ES

Species	Frequency	Habitat	Geogr. affinity
Ptilidium ciliare	3	fens, *Cassiope* heaths	ES
Riccardia latifrons	1	lake margin	
Riccardia spp.		rich fens	
Riccia sorocarpa var. *arctica*	1	*Dryas* heaths	
Sauteria alpina	1	snow bed	ES
Scapania cuspiduligera	2	fens	ES
Scapania gymnostomophila	1	rocks in *Cassiope* heath	ES
Scapania paludicola fo. *kaalaasii*	1	rich fen	S
Scapania scandica	1	river margin	
Scapania spp.		*Cassiope* heath, *Vaccinium* heath, peaty soil, periodic pond	
Tritomaria exsectiformis	1	on rocks in *Vaccinium* heath	S
Tritomaria quinquedentata ssp. *quinquedentata*	3	fens, *Cassiope* heath, snow beds, wetlands, cliffs	ES
Tritomaria quinquedentata ssp. *turgida*	2	*Eriophorum* and *Dupontia* wetland, *Cassiope* heath, rich fen	ES
Tritomaria sp.		*Cassiope* heath	
Bryophyta			
Andreaea rupestris	2	granite rocks, boulder scree, common on west side of river	ES
Anoectangium aestivum	1	base rich rocks in moist heathland	
Anomobryum julaceum	1	big sloping fen at Aucella	
Aplodon wormskjoldii	2	muskox dung in moist habitats	ES
Arctoa anderssonii	1	only found west of river Zackenberg, boulder scree, gently sloping, base-poor	ES
Aulacomnium palustre	3	indifferent, heathlands, fens, lake margins, boulder screes, river margins, flood plains, but not in abrasion plateau	ES
Aulacomnium turgidum	3	indifferent, but not in abrasion plateau	ES
Bartramia ithyphylla var. *ithyphylla*	2	boulder screes, *Cassiope* heaths	ES
Bartramia ithyphylla var. *strigosa*	2	snow bed, brook margin	
Blindia acuta	2	rocks in running water	ES
Brachythecium coruscum	2	sloping rich fens	ES
Brachythecium turgidum	1	fen SW Domberget. Also collected by Holmen, TRH-82304; "wet, sandy soil at rivulet"	ES
Brachythecium spp.		heath communities, snow beds	
Bryoerythrophyllum ferruginascens	2	abrasion plateau, *Dryas* heath, *Vaccinium-Cassiope* heath	
Bryoerythrophyllum recurvirostrum	1	*Dryas* heath and peat on fen hummock	ES
Bryoxiphium norvegicum	2	abrasion plateau, *Dryas* heath	
Bryum algovicum	1	river bank (TRH-692755 as "cf. *algovicum*)	ES
Bryum archangelicum	2	snow beds, wetland, salt marsh	
Bryum arcticum	1	flood plain	ES
Bryum argenteum	2	rocks manured by birds and musk oxen, abrasion plateau, carcasses, *Dryas* heath	ES

Species	Frequency	Habitat	Geogr. affinity
Bryum axel-blyttii	1	flood plain, river margin. Treated as a synonym to *B. calophyllum* by Hill et al. (2006)	
Bryum calophyllum	2	river banks, fens	ES
Bryum creberrimum	1	wet heath S Domberget	S
Bryum cryophilum	2	flood plain, river margin	ES
Bryum pallens	2	flood plains, fens, river margins	S
Bryum pseudotriquetrum	3	rich fens	E (as *B. bimum*) S
Bryum warneum	1	river bank (TRH-692753 as "cf. *warneum*")	
Bryum weigelii	1	rich fen	S
Bryum spp.		indifferent	
Calliergon richardsonii	3	rich fens	S
Calliergon spp.		wetlands	
Campylium laxifolium	1	rich fen	
Campylium stellatum	3	fens in general	S
Campylium sp.		fens	
Campylophyllum sommerfeltii	1	rock at big fen at Aucella	
Catoscopium nigritum	1	fen at Domberget	ES
Ceratodon purpureus var. *purpureus*	2	rocks manured by birds and musk oxen, abrasion plateau, carcasses, *Dryas* heath	ES
Ceratodon purpureus var. *obtusifolius*	1	snow bed, wet depression. Treated as a synonym to *C. purpureus* by Hill et al. (2006)	S
Cinclidium arcticum	2	rich fens	ES
Cinclidium subrotundum	2	rich fens	ES
Cirriphyllum cirrosum	2	rich fens	ES
Conostomum tetragonum	3	all heathlands, hummocks in fens, boulder screes	ES
Cratoneuron filicinum	1	rich fen ("Bach im Hangmoor unterhalb Little Aucella", 450 m)	ES
Cynodontium tenellum	2	common on west side of Zackenberg river, granite rocks, boulder screes, rock crevices in rock fan SE Domberget, (350 m)	S
Cyrtomnium hymenophylloides	1	lake margin	ES
Dichodontium pellucidum	1	sloping rich fen	ES
Dicranella crispa	2	river margin, disturbed soil	ES
Dicranoweisia crispula	2	boulder screes, big granite blocks	ES
Dicranum laevidens	3	heathlands, fens, wetlands	ES
Dicranum scoparium	1	*Cassiope* heath (TRH-692491 as "cf. *scoparium*")	ES
Dicranum spadiceum	2	*Cassiope* heath SW Aucella (150 m)	S
Dicranum spp.		heathlands, palsas, hummocks	
Didymodon asperifolius	1	*Salix* snow bed	ES
Didymodon brachyphyllus	1	*Dryas* heath	
Didymodon icmadophilus	1	solid rock	E
Didymodon sp.	1	*Dryas* heath	
Distichium capillaceum var. *capillaceum*	1	boulder scree	ES
Distichium capillaceum var. *compactum*	3	fens, heathlands, river margins, lake margins	

Species	Frequency	Habitat	Geogr. affinity
Distichium hagenii	1	lake shore	ES
Distichium inclinatum	3	rare west of river and there only in fens, otherwise very common	ES
Ditrichum flexicaule	3	fens, heathlands, river margins, lake margins	ES
Ditrichum sp.		snow bed	
Drepanocladus arcticus	1	rich fen	ES
Drepanocladus polygamus	1	river margins	S
Drepanocladus spp.		rich fens	
Encalypta alpina	3	*Dryas* heaths, abrasion plateau	ES
Encalypta mutica		sandy soil by rock	S
Encalypta procera	2	moist soil by brook	ES
Encalypta rhaptocarpa var. *rhaptocarpa*	2	abrasion plateau, heaths, river margin, cliff	ES
Encalypta rhaptocarpa var. *leptodon*	1	on boulder	S
Encalypta sp.		heathland	
Fissidens adianthoides	1	rich fen	S
Fissidens arcticus	1	rich fen	ES
Fissidens bryoides	1	mineral soil on rock in *Cassiope* heath (TRH-692497 as "cf. *bryoides*")	
Fissidens osmundoides	2	fens, river margins, lake margins	S
Funaria arctica	1	*Dryas* heath	ES
Grimmia donniana	2	most common west side of Zackenberg river	S
Grimmia incurva	1	*Vaccinium* heath (TRH-692601 as "cf. *incurva*")	S
Grimmia plagiopodia	2	*Dryas* heath, *Cassiope* heath	E
Grimmia torquata	2	only west of Zackenberg river (TRH-692660 and 692671 as "cf. *torquata*")	ES
Grimmia spp.		rocks, boulders, scree	
Hennediella heimii	1	river bank	ES
Hygrohypnum alpestre	2	rocks in running water	S
Hygrohypnum polare	2	rocks in running water	ES
Hylocomium splendens	2	*Cassiope* heath, by big boulders, boulder screes	E (all var. *alaskanum*)S
Hypnum bambergeri	1	*Vaccinium* heath	ES
Hypnum revolutum	2	manured rocks, hummocks in fens	ES
Hypnum spp.		*Cassiope* heath, brook margin	
Isopterygiopsis pulchella	1	*Cassiope* heath, rock at big fen at Aucella	ES
Leptobryum pyriforme	2	*Eriophorum* wetland, sandy soil	ES
Loeskypnum badium	1	sloping rich fens	ES
Meesia hexasticha	1	rich fens	
Meesia triquetra	2	rich fens	ES
Meesia uliginosa	3	rich fens	ES
Mnium thomsonii	1	*Cassiope* heath (TRH-692581 as "cf. *thomsonii*")	ES
Myurella julacea	2	fen hummocks, lake margin, river margin, snow bed	ES
Myurella tenerrima	2	fen hummocks, lake margin, river margin, snow bed	ES

Species	Frequency	Habitat	Geogr. affinity
Oncophorus virens	2	rich fens (TRH-692613 as "cf. *virens*")	ES
Oncophorus wahlenbergii	3	fens, heathlands, river margins, lake margins	ES
Orthothecium chryseon	2	rich fens, river margins	ES
Orthothecium lapponicum	1	snow bed	S
Orthothecium strictum	1	rock wall	ES
Orthothecium spp.		fens, snow beds, brook edges	
Orthotrichum pylaisii	2	base-rich boulders, granite blockswith bird manure	S
Orthotrichum sordidium	1	cliff wall	S
Orthotrichum sp.		bird-manured granite blocks	
Paraleucobryum enerve	1	*Vaccinium* heath	
Philonotis caespitosa	2	fens	
Philonotis fontana	3	fens, river margins, lake margins, brook margins	
Philonotis tomentella	2	*Eriophorum* wetland, water spring S Aucella	ES
Philonotis spp.		fens, snow beds, river banks	
Plagiobryum demissum	2	brook margins at higher altitudes	S
Plagiomnium ellipticum	1	rich fen	S
Pogonatum dentatum	2	*Cassiope* heath, abrasion plateau	ES
Pogonatum urnigerum	2	boulder scree	S
Pohlia andalusica	1	*Dryas–Vaccinium* heath	
Pohlia cruda	2	*Cassiope* heath, boulder screes, by granite blocks, summit of Aucella	ES
Pohlia drummondii	3	snow beds, river margins, lake margin	ES
Pohlia filum	2	river margins	S
Pohlia nutans	2	*Cassiope* heath, *Vaccinium* heath, fen hummocks, eroded peat	ES
Pohlia proligera	2	eroded peat	ES
Pohlia vexans	1	*Eriophorum–Dupontia* wetland	
Pohlia wahlenbergii	2	brook margins	ES
Pohlia spp.		*Vaccinium* heath, snow bed	
Polytrichastrum alpinum var. *alpinum*	3	in all moist – wet habitats, but not in dry *Dryas* heats or abrasion plateaus	ES
Polytrichastrum alpinum var. *fragile*	2	snow bed, boulder scree	S
Polytrichastrum sexangulare	3	snow beds, river margins, lake margins	S
Polytrichum hyperboreum	3	in all moist – wet habitats, but not in dry *Dryas* heats or abrasion plateaus	ES
Polytrichum cf. *jensenii*	1	rich fen	S
Polytrichum juniperinum	2	wet habitats, heathlands, eroded peat	ES
Polytrichum piliferum	3	abrasion plateau, all heathlands, rare in wet habitats	ES
Polytrichum strictum	2	fens, from lawns to hummocks	S
Polytrichum swartzii	1	*Eriophorum* wetland, brook margin	S
Polytrichum sp.		*Dryas* heath	
Pseudocalliergon brevifolium	2	rich fens	ES
Pseudocalliergon trifarium	1	rich fens	ES
Pseudocalliergon turgescens	2	rich fens	ES

Species	Frequency	Habitat	Geogr. affinity
Psilopilum cavifolium	1	eroded peat	ES
Psilopilum laevigatum	2	brook and river margins, eroded peat	S
Racomitrium canescens ssp. *canescens*	2	boulder scree, heathlands, not as dry as abrasion plateau	E
Racomitrium canescens ssp. *latifolium*	2	heathlands, boulder screes, *Dryas* heaths	S
Racomitrium elongatum	1	*Cassiope* heath	
Racomitrium lanuginosum	2	common in boulder screes and *Cassiope* heaths on west side, rare in *Cassiope* heaths on east side of valley	ES
Racomitrium panschii	3	heathlands, not as dry as *Dryas* heaths	S
Rhizomnium andrewsianum	1	*Cassiope* heath close to lake margin, rich fen lawn	S
Rhizomnium pseudopunctatum	1	lake margin	
Saelania glaucescens	2	boulder scree, *Cassiope* heath	ES
Sanionia uncinata	3	indifferent, but not in the driest abrasion plateaus	ES
Sarmentypnum sarmentosum	3	rich fens, river margins with slow running water. Treated as *Warnstorfia sarmentosa* by Hill et al. (2006)	ES
Schistidium frigidum	2	heathlands, boulders and cliffs	S
Schistidium grandirete	3	all heathlands, fen margins	S
Schistidium holmenianum	1	*Vaccinium* heath	ES
Schistidium platyphyllum ssp. *platyphyllum*	2	rocks in *Cassiope*-heath and by Zackenberg river	
Schistidium tenerum	1	*Dryas* heath	ES
Schistidium spp.		boulders, cliffs	
Sciuro-hypnum glaciale	1	rock in *Cassiope* heath	S
Scorpidium cossonii	1	sloping rich fens	ES
Scorpidium revolvens	3	fens	ES
Scorpidium scorpioides	2	fens, ponds, lake margins	ES
Sphagnum girgensohnii	1	fens, fen hummocks	S
Sphagnum olafii	1	fens, fen hummocks	S
Sphagnum orientale	2	fens, fen hummocks	
Sphagnum squarrosum	1	*Vaccinium–Cassiope* heath	S
Sphagnum teres	1	*Vaccinium–Cassiope* heath	S
Sphagnum spp.		*Vaccinium–Cassiope* heath, brook margin	
Splachnum sphaericum	1	*Cassiope* heath SE Domberget, musk ox dung at Aucella	
Splachnum vasculosum	2	musk ox dung	ES
Stegonia latifolia var. *latifolia*	1	base-rich, dry soil in *Dryas* heath	ES
Stegonia latifolia var. *pilifera*	1	base-rich soil in *Dryas* heath	ES
Straminergon stramineum	1	rich fens	ES
Syntrichia ruralis	2	boulders, fens, heathlands, abrasion plateau, but not in wet habitats like snow beds or lake margins	ES
Tayloria lingulata	1	wetland – rich fen	S
Tetraplodon mnioides	2	musk ox dung	ES
Tetraplodon pallidus	2	musk ox dung	ES

Species	Frequency	Habitat	Geogr. affinity
Timmia austriaca	2	*Cassiope* heath, by boulders	ES
Timmia bavarica	2	cliffs, large boulder	ES
Timmia norvegica	1	river margin	ES
Tomentypnum nitens	3	fens, lake margins, river margins, not in snow beds or abrasion plateaus	ES
Tortella alpicola	1	cliffs	
Tortella fragilis	2	sloping rich fens, fell fields	ES
Tortella tortuosa var. *fragilifolia*	1	snow bed	
Tortula cernua	1	sloping, rich fen	ES
Tortula hoppeana	1	*Dryas* heath, *Cassiope* heath	ES
Tortula leucostoma	1	*Dryas* heath/abrasion plateau	ES
Tortula mucronifolia	2	*Dryas* heaths, rocky shore	ES
Trematodon brevicollis	2	sloping rich fens, fell fields	E
Warnstorfia fluitans	2	lake margins	ES
Warnstorfia spp.		ponds, lakes	

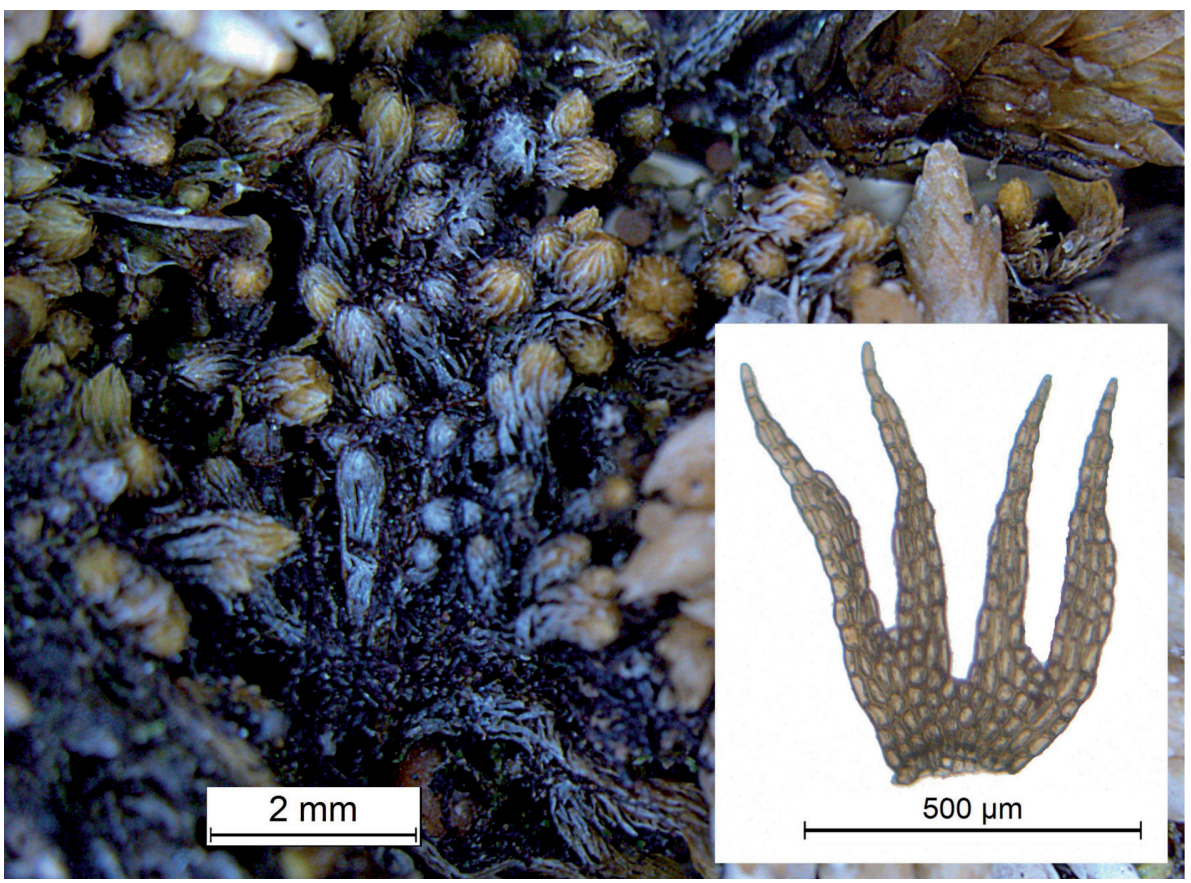

Figure 3. *Lophochaete fryei* growing with *Sphagnum girgensohnii* and *Aulacomnium turgidum*. A single leaf is inserted. (photo K. Hassel).

indicate a circumarctic distribution. *Lophochaete fryei* belongs to an arctic floristic element suggested to have survived in ice free areas of low precipitation north of the continental ice sheaths during the large continental glaciations (Steere 1953). Zackenberg valley is shown to have been totally glaciated during the last glaciation (Bennike et al. 2008), but ice free areas existed in neighbouring areas on the east coast of Greenland (Funder and Hansen 1996). Genetic analyses would be necessary to reveal if the east Greenlandic population is a result of long distance dispersal from arctic Russia or North America or if it could be result of short distance dispersal from east Greenlandic glacial refugia after the deglaciation of Zackenberg valley. The specimen collected in Zackenberg valley was without gametangia or sporophytes, but sporophytes are known from arctic Alaska (Steere 1953).

***Orthothecium lapponicum* (Schimp.) C. Hartm.** was growing in a snow bed with *Blepharostoma trichophyllum* ssp. *brevirete* and *Ranunculus pygmaeus* (TRH 692720). This species is previously only known from northern Fennoscandia and Svalbard (Hedenäs 1988, Frisvoll and Elvebakk 1996), this record thus represents the first record outside Europe.

***Pohlia vexans* (Limpr.) H. Lindb.** was found on in wetland with *Eriophorum* and *Dupontia* (TRH 692740). The species had sporophytes and was growing on moist, disturbed soil. In Europe *Pohlia vexans* is previously known from Russia, Sweden, Norway and the Alps, but not from Svalbard (Frisvoll and Elvebakk 1996). In Asia it is known from south Siberia and Arctic Far East (Ignatov et al. 2006). In North America it is known mainly from Canada and Alaska on disturbed substrates, mainly clay along streams (Shaw 2009).

***Sphagnum orientale* L.I. Savicz** is reported new to Greenland (Fig. 4). The oldest record of *S. orientale* in the Zackenberg area seems to be from 1947 (K. Holmen) but the specimens were named *S. subsecundum*. The main habitat of *S. orientale* in Zackenberg area was fens, but it was also found in moist *Vaccinium uliginosum* heathland and *Salix arctica* snow beds. The altitude ranges from 5–78 m a.s.l. In 2011 K. I. Flatberg (herbarium TRH) revised *S. subsecundum* in herbarium C. He identified 20 specimens of *S. orientale* from 16 localities, all in northeast Greenland (Table 2). These range from 70°N by Hurry Inlet to 76° N on Store Koldewey. *Sphagnum orientale* is previously re-

Figure 4. *Sphagnum orientale* growing in fens south of Zackenberg research station. (photo K. Hassel).

Table 2. *Sphagnum orientale* from northeast Greenland in herb. C and TRH. All specimens revised by Kjell Ivar Flatberg.

1. Hurry Inlet, [70,65°N, 22,53°W] leg. P. Dusén, 7.8.1899
2. Jameson Land, Draba sibirica Elv, 71°06′N, 23°22′W. leg. Sune Holt, 15.7.1982
3. Scoresbysund. 1 km N of Draba sibirica Elv, [71°06′N, 23°22′W], leg. Arve Elvebakk, Stein Rune Karlsen [no date] (TRH 724963)
4. Scoresbysund. 3 km N of Draba sibirica Elv, [71°06′N, 23°22′W], leg. Arve Elvebakk, Stein Rune Karlsen [no date] (TRH 724964)
5. Geographical Society Island: 72°44′N, 22°30′W, leg. Kjeld Holmen, 25. & 26.8.1958
6. Hold With Hope: south coast, 73°27′N, 21°03′W, leg. Th. Sørensen, 15.8.1934
7. Holland Island, 73°36′N, 20°20′W, leg. Thorv. Sørensen, 10.8.1934
8. Clavering Ø, Djævlekløften, 74°20′N, 20°30′W, leg. Kjeld Holmen, 23.8.1947
9. Zackenberg, 74°24′N, leg. Kjeld Holmen 28.7.1947
10. Nedenfor Aucella Bjerget, Wollaston Foreland, 74°24′N, leg. Kjeld Holmen, 25.8.1949
11. Zackenberg Bugt, 74°28′N, 20°35′W, leg. G. Halliday, 14.8.1980
12. Wollaston Foreland: Mt. Zackenberg, 74°28′N, 20°35′W, leg. Bodil Lange, 26.7.1950
13. Wollaston Foreland, Zackenberg, [74°28′N, 20°35′W], leg. Kristine Westergaard, Tina Dahl, 3.-6.8.2007 (TRH 673477, 673480, 741307, 741314)
14. Zackenberg, Moor am Fusse (N) des Zackenberg, [74°28′N, 20°35′W], leg. Christian Lettner, 8.8.2009 (TRH 674729)
15. Wollaston Forland Zackenberg, 74°27′32,6″N, 20°42′50,5″W, leg. Kristian Hassel, Tommy Prestø, 31.8.2009 (TRH 691300)
16. Wollaston Forland Zackenberg, 74°28′40,0″N, 20°32′27,3″W, leg. Kristian Hassel, Tommy Prestø, 23.8.2009 (TRH 691315)
17. Wollaston Forland Zackenberg, 74°28′53,9″N, 20°31′18,5″W, leg. Kristian Hassel, Tommy Prestø, 20.8.2009 (TRH 691316)
18. Wollaston Forland Zackenberg, 74°29′52,7″N, 20°36′14,3″W, leg. Kristian Hassel, Tommy Prestø, 26.8.2009 (TRH 691317)
19. Wollaston Forland Zackenberg, 74°27′55,4″N, 20°34′31,4″W, leg. Kristian Hassel, Tommy Prestø, 19.8.2009 (TRH 691318)
20. Between Peters Bugt and Lauge Kochs Vig, Hochstetter Forland, 75°20′N, 20°08′W, leg. G. Halliday, 1.8.1980
21. Northwest end of Peters Bugt, Hochstetter Forland, 75°21′N, 20°15′W, leg. G. Halliday, 1.8.1980
22. 7 km inland from northwest corner of Peters Bugt, Hochstetter Forland, 75°23′N, 20°17′W, leg. G. Halliday, 29.7.1980
23. Above the north side of the river, Hochstetter Forland, 75°29′N, 20°16′W, leg. G. Halliday 27.7.1980
24. Ved [Elven], [likely to be north on Store Koldewey and collected during the Danmark Expedition 1906–08] 76°40′N, leg. Andr. Lundager, 18.7.1908

ported from Alaska and arctic Canada (McQueen and Andrus 2007) but not from Europe (Hill et al. 2006). *Sphagnum orientale* also occur in Russia from Arctic Far East and southwards to south Far East, through Yakutia, east Siberia and northwards to Arctic west Siberia (Ignatov et al. 2006).

Tortella alpicola **Dixon** is reported new to Greenland (Fig. 5, TRH 692885). It was found growing on cliffs close by the fjord (11 m a.s.l.) west of the Zackenberg research station and the trapper's cabin. In North America the species is previously mainly known from a western corridor from Arizona to Alaska and a single locality from Quebec (Eckel 1998), our record is thus the second from eastern North America. The distribution seem to be scattered throughout northern Eurasia (Otnyukova et al. 2004), with recent reports from western Europe (Hassel and Høitomt 2013). *Tortella alpicola* is most likely confused with *Tortella fragilis* (Hooker & Wilson) Limpricht, but is separated, even in the field by its small size, whitish leaf bases and fragile leaf tips (Fig. 5, 6).

New records to east Greenland

Riccardia latifrons **(Lindb.) Lindb.** (TRH 692759, shore of periodic pond, growing with *Blepharostoma trichophyllum* and *Cephalozia* sp. *Riccardia latifrons* is known from south Greenland (Schuster 1988), but not from east Greenland (Damsholt 2013). The plants were small and the first thought was that this is *R. incurvata*. Oil-bodies of the specimen should have been checked on fresh material, but this was not done. However, the transverse section of the thallus is not lunate, but biconvex. It produces abundantly with gemmae (ca 25 × 35 µm) on short side branches along the main axes. The size of the gemmae resembles that described for *R. latifrons* and is smaller than *R. chamedryfolia*, the latter is also very rare with gemmae according to Schuster (1992).

Tritomaria exsectiformis **(Breidl.) Schiffner ex Loeske** was growing on rocks in *Vaccinium uliginosum* heath together with *Saelania glaucescens, Bartramia ithyphylla* and *Scapania* sp. (TRH 693401). It is known both from Svalbard and arctic Russia (Konstantinova et al. 1992, Frisvoll and Elvebakk 1996).

Grimmia plagiopodia **Hedw.** (TRH 692436 and 692905), was found growing in dry calcareous situations, once on rock in *Cassiope tetragona* heath with *Tortula hoppeana, Syntrichia ruralis* and *Sciuro-hypnum glaciale* and once in *Dryas octopetala* heath with *Carex nardina*. It was found with sporophytes. There is one report from Svalbard, but Frisvoll and Elvebakk (1996) does not include it as they find it likely that it is confused with the more common *G. anodon*. In light of the rather wide North American distribution of *G. plagiopodia* our records from Zackenberg is not surprising, the closest known localities eastwards are from northwestern Greenland and Ellesmere Island and westwards from Iceland (Hastings and Ochyra 2007).

Sphagnum olafii **Flatberg** is reported new to northeast Greenland (TRH 691296, 691297, 691298, 691301,

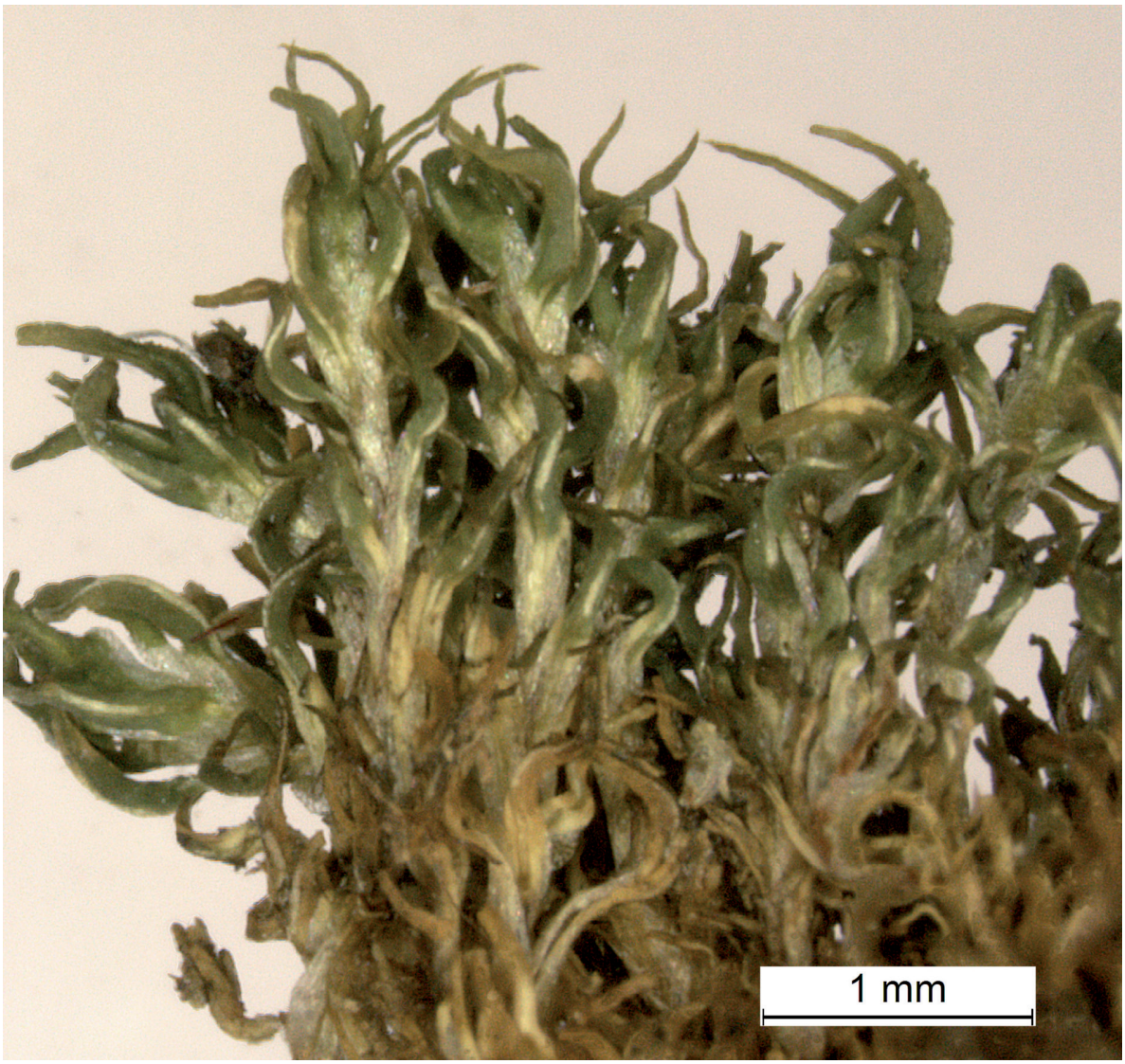

Figure 5. *Tortella alpicola*, habitus of specimens TRH 692885, showing the characteristic whitish leaf bases. (photo K. Hassel).

691303, 691304, 691306, 691307, 691308, 691315, 674726 and 674727). The species was found in intermediate fens in the lowlands around Zackenberg Research Station. It grows both in fen lawns and forms hummocks. The new findings in northeast Greenland shorten the distribution gap between western Greenland and Svalbard. Flatberg (2007) reported *S. olafii* new to Greenland based on specimens from Qeqertarsuaq and Illulissat in western Greenland. This was the first report of the species outside Svalbard. The species was described by Flatberg (1993) based on plants from central part of Spitsbergen, the largest of the Svalbard islands. In 2007 Flatberg found *S. olafii* in Canada, Quebec in arctic mire and fen lawn in Nunavik (Ivujivik and Salluit, herbarium TRH, DUKE). According to Flatberg (2007) records of *S. olafii* outside Svalbard makes it more likely that *S. olafii* and its relative *S. arcticum* do not have a common in situ ancestor in Svalbard but have different polyploid origins. *S. olafii* may have reached Svalbard during the Holocene, via spores or vegetative diaspores (Flatberg 2007). Surprisingly, *S. olafii* was found with numerous sporophytes in the Zackenberg Area in 2009 (Fig. 7). Sporophytes in *Sphagnum* are rare in northern parts of the Arctic. Neither *S. olafii* or other *Sphagnum* spp. in Svalbard are found with sporophytes (Flatberg 2007). The amount of sporophytes in 2009 may be related to special climatic conditions. The 2009 season in Zackenberg Area was characterized by unusual small amounts of snow, and a very early snowmelt, with snow disappearing several weeks earlier than registered before (Sigsgaard et al. 2010).

Figure 6. Leaf apices of *Tortella alpicola*, note the constrictions along the fragile tip of the leafs. (photo K. Hassel).

Comments on other taxa

***Riccia sorocarpa* ssp. *arctica* R.M. Schust.** was found on four localities in the area (TRH 692573, 692602, 692880, 693405). This taxon was described from west Greenland and is known with only one old locality from east Greenland (Schuster 1992). The taxon does not seem to be reported outside Greenland, but could be overlooked. It was found growing on disturbed soil in in a wide range of habitats like *Carex rupestris–Dryas octopetala* heath, soil by brook and boulders, soil-covered cliffs, and *Anthelia juratzkana*-snow bed. Spore characters separate ssp. *arctica* from the nominate form, by locally developed or lacking wing margin, smaller spore diameter, and smaller diameter of alveoles (Schuster 1992). One of our specimens (TRH 692602) had mature spores and the spores showed little variation in size and were about 70 µm in diameter. The spores had a narrow irregular wing margin, and the diameters of alveoles were 6.4–8.9 µm. One specimen (TRH 692880) had purplish pigmentation on the ventral side of the thallus.

***Riccardia* sp.** At an earlier point one specimen (TRH 692837) were det. *Riccardia* cf. *incurvata*, however a critical revision (by KH 13.05.2013) of the material place some uncertainty about this determination and we have chosen to refer to the specimen as *Riccardia* sp. *Riccardia* sp. grows in rich fen lawn with *Rhizomnium andrewsianum*. This specimen was the basis for the first report of *Riccardia incurvata* from Greenland and the reason for its inclusion in Damsholt (2013). *Riccardia incurvata* thus still needs to be confirmed for Greenland. (Another *Riccardia* sp. is specimen TRH 693382).

***Bryoxiphium norvegicum* (Brid.) Mitt.**, this fascinating species was growing on exposed ridges often together with *Dryas octopetala*. It made dense cushions packed with sand. The plants were small of growth, but this can be due to the tough environment on the ridges. This habitat is in strong contrast to the sheltered rock walls the species usually grows on in Iceland, here also the plants get larger and are commonly fruiting. Based on the habitat where *B. norvegicum* is found in at Zackenberg it is surprising that the species do not have a wider arctic distribution. In the Arctic region *B. norvegicum* is only known from Alaska, Yakutia and Chukotka (Ignatov et al. 2006, Pursell 2007), but not reported from Ellesmere Island or Svalbard (Bras-

Figure 7. *Sphangnum olafii*, for the first time recorded with sporophytes in Zackenberg valley. (photo K. Hassel).

sard 1971, Frisvoll and Elvebakk 1996). In Europe it is only known from Iceland.

***Bryum axel-blyttii* H. Philib.** is not reported from Greenland, but due to different taxonomic traditions collections representing this taxon may exist under *B. calophyllum* R. Br. We recorded *B. axel-blyttii* twice growing at riverbanks (TRH 692750, 692747). Holyoak (2004) treat this taxon and *Bryum acutiforme* Limpr. as synonyms of *Bryum calophyllum* R. Br. However Zolotov (2006) argues to keep *B. axel-blyttii* and *B. calophyllum* as separate taxa based on leaf and peristome morphology.

***Ceratodon purpureus* var. *obtusifolius* Limpr. (Syn. *Ceratodon heterophyllus* Kindb.)** This taxon is often not recognised and is included in *C. purpureus* (Hill et al. 2006). The main reason for this seems to be the variable leaf morphology of *C. purpureus*. However, when sporophytes are available the var. *obtusifolius* is separated from the nominate variety by the larger spores 19–21 µm versus 11–14 µm (McIntosh 2007). The specimen from Zackenberg was growing in a snow bed or wet depression, it was abundantly fruiting. Spores were generally large, but size and varied from 17 to 28 µm. Associated species were *Scapania scandica* and *Lophozia* sp. (TRH 692455). *Ceratodon purpureus* var. *obtusifolius* is not earlier reported from Greenland to our knowledge, but it is very likely that herbarium specimens exist.

***Polytrichum* cf. *jensenii* I. Hagen**, this taxon has earlier been included in the *P. commune* complex (Nyholm 1969), but is currently recognised at the species level (Hill et al. 2006). The material from Zackenberg is problematic to identify, but is quite similar to the description of the type of *P. jensenii* as referred by Frisvoll and Elvebakk (1996). Our specimen (TRH 692472) has fragile leaves, incurved and edentate leaf margin, and a short hyaline to brownish leaf point. However, the top cells of the lamellae are not deeply furrowed, but rather irregular in shape (Fig. 8). The plants were growing in a rich fen community with e.g. *Bryum pseudotriquetrum, Cinclidium arcticum* and *Meesia triquetra*.

***Tortella tortuosa* var. *fragilifolia* (Jur.) Limpr.**, was found only once in a snow bed with *Ranunculus pygmaeus* and *Salix arctica*. It was suspected to be *Tortella tortuosa* var. *arctica* (Arnell) Broth., as it is described to grow in moist to wet habitats from e.g. Ellesmere Island (Brassard 1971). Frisvoll and Elvebakk (1996) in their treatment of the Svalbard flora only refer to the nominate variety of *T. tortuosa.* It is thus a little bit surprising that it is the variety *fragilifolia* that is recorded in this study.

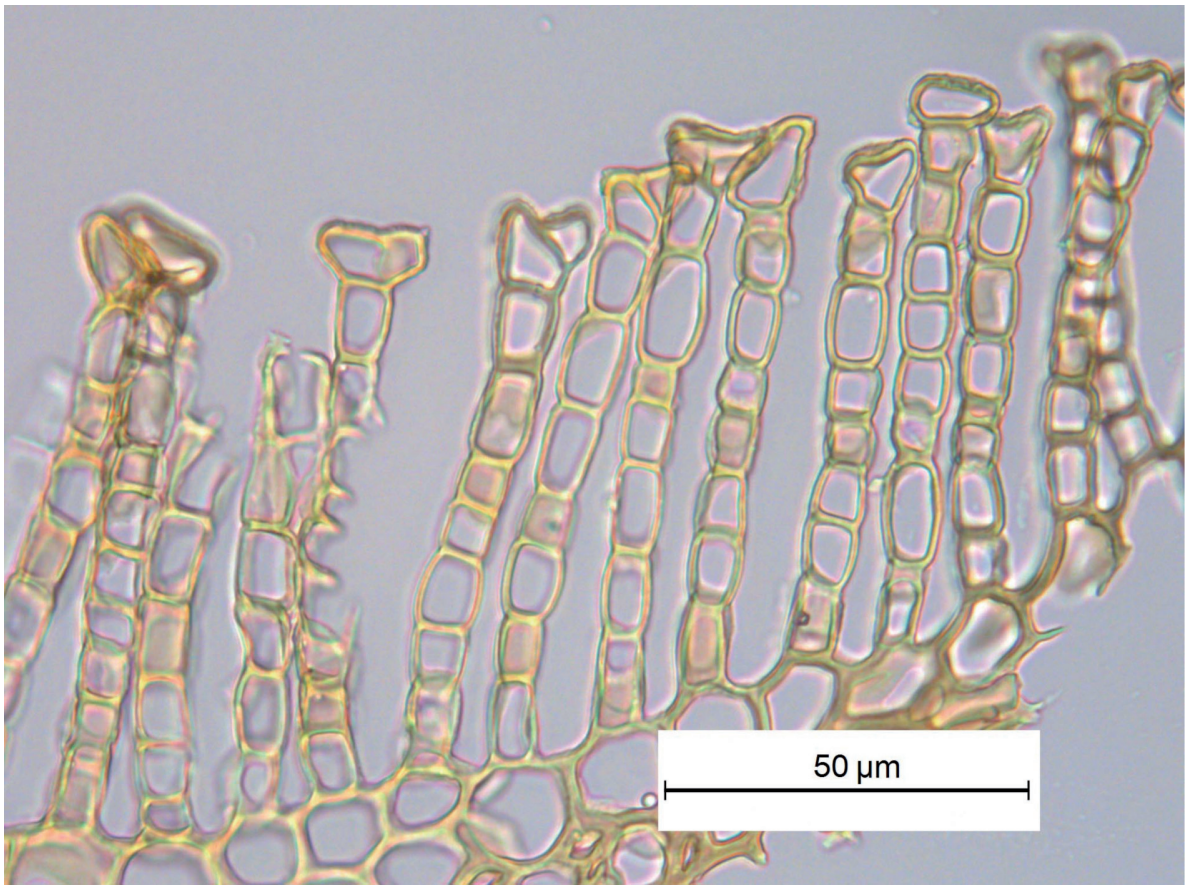

Figure 8. *Polytrichum* cf. *jensenii* with irregular shape of the top cells of the lamellae. (photo K. Hassel).

Species searched for but not found

During the field investigation we were looking for several species that we could not find. Based on our experience from other areas there were suitable habitats, but we were not able to demonstrate the occurrence of e.g. *Rhytidium rugosum, Paludella squarrosa, Schistidium holmenianum, Bryum wrigthii* or *Cinclidium latifolium* in the Zackenberg area. Brassard (1971) also reported several interesting species from northern Ellesmere Island that we have not been able to record from the Zackenberg area e.g. *Aulacomnium acuminatum*, *Orthothecium acuminatum*, *Pterygoneurum arcticum*, *Desmatodon ellesmerensis* (syn. *Pseudocrossidium obtusulum*).

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