Nutrient ecology, vegetation and biomass of two South-Greenlandic birch forest sites

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Two semi-dry birch forest sites were studied in Narssarssuaq (hemiarctic, subcontinental) and in Qingua-dalen (hemiarctic, suboceanic). The height of the scrub is only 1.3–2.8 m. A heavy podsolic soil prevails with thick moss-litter-humus and iron-rich horizons. The biomass of litter and dead material is high (1595 g/m^2). *Deschampsia flexuosa* prevails in the field layer. Twenty site types were distinguished in the vegetation transect across the Qingua-dalen. Mesic and moist types are dominant on the north exposed slope without any vertical differences which are more clear on the opposite side of the valley. The Ca content in the soil is high, particularly at Narssarssuaq (5–10 times higher than for K and Mg). The somewhat increased Na content in the humus layer at Narssarssuaq may be caused by minerals in the sea spray at this site which is relatively close to the fjord. Loss on ignition and total N in the humus layer are approx. low at both sites, probably because of considerable mixing with the mineral soil. Both the Ca and the N content in the plants are higher at Narssarssuaq than in those from Qingua-dalen, and are, generally, also higher than on oligotrophic subalpine/subarctic (northern oroboreal) birch forest sites of Fennoscandia. The high Na content in the sea spray at Narssarssuaq is reflected in a high content of Na in the birch bark and in *Cladina* lichens. "Total" sums of sugars (glucose+fructose+sucrose) in all parts of birch determined were higher in Qingua-dalen than at Narssarssuaq except in older twigs and roots. Starch contents, generally, show the same tendency, due to higher temperature (south exposed slope) and higher net assimilation. There were no differences in the contents of "total" carbohydrate (total sugar + starch) in other species between the two study sites.

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Our study group of the internordic Subarctic Birch Project (SBP) studied July 23 – August 6, 1984 nutrient ecology and vegetation of birch scrubs at Narssarssuaq (appr. 61°10′N, 45°28′W) and in Qingua-dalen east of Tasermiut Fjord (60°17′N, 44°33′W). In both areas birch scrubs are growing up to 150 m a.s.l., and willow copses 250 m a.s.l. in the hemiarctic zone. The humidity climate at Narssarssuaq is subcontinental (annual precipitation 698 mm, temperature of June-august 9.8°C), in Qingua-dalen suboceanic (Feilberg 1984, Fig. 5).

Two semi-dry birch scrub sites were selected for sampling (Fig. 1). At Narssarssuaq the site is situated on a hill side close to the fjord on a low (15–20 m) ridge appr. 30 m a.s.l., in Qingua-dalen near to the valley bottom on a slope (exposition 160° at the angle of 10 degrees) appr. 50 m a.s.l. Three birches were taken for study via a systematic probability sampling with distances of 10 m between the trees. The vegetation analyses, biomass collections, and soil profile analyses were made at the distance of 2 m from the sample trees from which were collected buds, catkins, leaves, one-year shoots, <0.5 cm older twigs, thicker twigs, roots, outer and inner bark, and stem wood for mineral nutrients (total N, total P, Ca, Mg, Na and K) and carbohydrate (glucose, fructose, sucrose and starch) analyses. Mineral elements were extracted from ashed material by a concentrated $HCl-HNO_3$ mixture and analysed by emission (K, Na) and absorption (Ca, Mg) in an atomic absorption spectrophotometer and by spectrophotometer (P). Total N was analysed by a semi-micro Kjeldahl technique. Carbohydrate contents (starch and the soluble sugars: glucose, fructose and sucrose) were analyzed by an enzymatic method, described in detail by Beutler et al. (1978). The same carbohydrates and mineral nutrients were determined in *Deschampsia flexuosa, Pleurozium schreberi,* and *Cladina* coll., and also *Empetrum* at two sites in Qingua-dalen. The mineral elements are also determined in the soil. A vegetation transect across the Qingua-dalen was analysed. Comparisons are made with the results from Hardangervidda, South Norway (60°N, 7°30′E, 780 m a.s.l.), Kilpisjärvi (69°N, 20°50′E, 500–600 m a.s.l.), and Kevo (70°N, 27°E, 130 m a.s.l.), North Finland (Sonesson et al. 1975).

The nomenclature of the vascular plants is in accordance with Feilberg (1984), the bryophytes with Koponen et al. (1977), and the lichens with Santesson (1984).

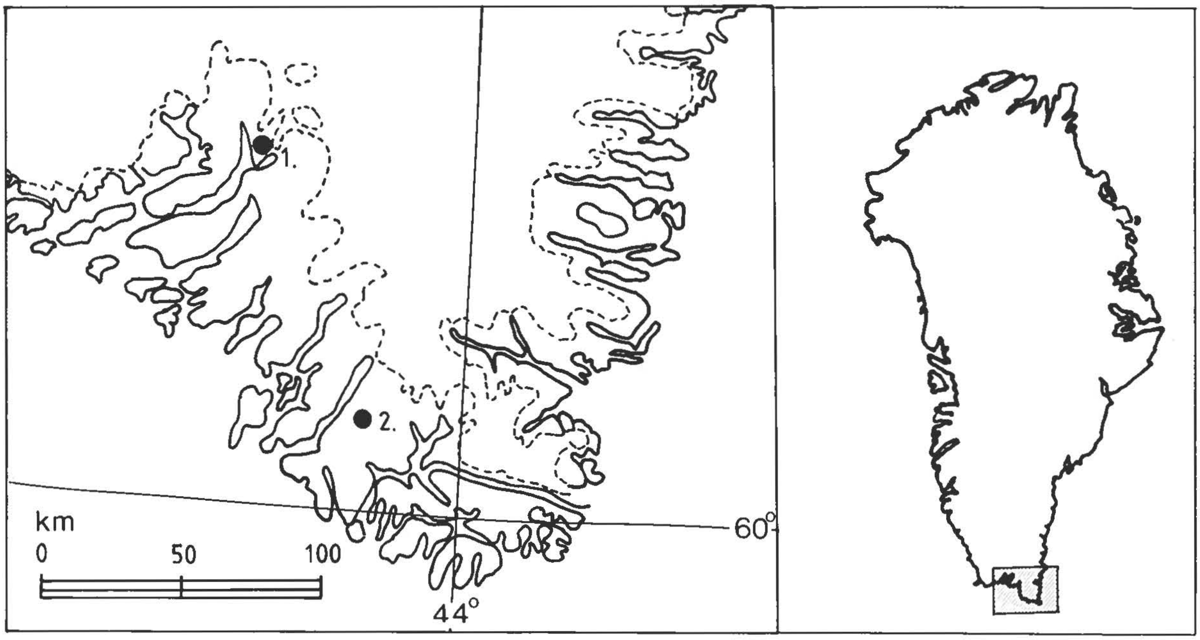


Fig. 1. The study area in Greenland. 1 = Narssarssuaq, 2 = Quingua-dalen.

Results and discussion

Soil

The sample plots at both Qingua-dalen and Narssarssuaq sites are relatively dry in spite of a thick litter-humus layer (Table 1), on an average for both sites 12 cm, higher than at Hardangervidda, subalpine southern Norway (4 cm), and in northern Finland, at Kevo (9 cm; Hinneri et al. 1975) and at Kilpisjärvi (3–8 cm; Seppo Eurola, pers. comm.).

In Qingua-dalen the strongest eluviated A_2 horizon is observed in the upper part of the valley (plot 4), which also has the thickest litter-humus layer as seen in Table 1. This may indicate a higher precipitation just in front of the mighty mountains than further down in the valley. In spite of the thick humus layer and the strong podzolization at this site, the accumulation of precipitated humus is rather weak in the B-horizon. This is due to the good drainage in the coarse, sandy mineral soil with most of the grains (about 80%) in the 2–0.2 mm fraction. However, the loss on ignition in the B-horizon at plot 4 is higher (9.5%) than the average in that horizon of all plots in Qingua-dalen (8%), and especially at Narssarssuaq (3.8%) (Table 6). This may be the cause of the B-horizon of the plot 4, which may be called an iron-humus podzol, being more brownish than at the other plots. Here the B-horizons are light yellow and are true iron-rich podzols, as also observed in subalpine and subarctic birch forests of Fennoscandia (Hinneri et al. 1975). Although the thickness of the eluviated A_2-horizon varies much between the Greenlandic plots, it seems, generally, thicker than in the birch forest studied in the relatively continental Kevo, northern Finland (4 cm), but thinner than in the oceanic, subalpine southern Norwegian birch forest (13 cm) (Hinneri et al. 1975).

Table 1. Soil profiles from Qingua-dalen (4 sample plots) and Narssarssuaq (3 sample plots). Depth of each layer in cm, normal subsoil may be found deeper in the profile. Question mark means iron-rich horizon deeper than about 30 cm. Eluviated A_2 horizon are not always observed.

		Qingua-dalen				Narssarssuaq		
Study plot	(no.)	1	2	3	4	1	2	3
Litter	A_{00}	5	1	2	6	5	3	4
Humus	A_{0-1}	10	9	7	12	5	8	8
Leached	A_2	9	2	3	17	–	10	–
Iron-rich	B	?	25	35	20	23	24	27

Sample plots

In average the height of birches in Greenland ranges between 2 and 5 metres (Feilberg 1984). The average height of the birches studied were only 1.5 (Narssarssuaq) and 2.4 metres (Qingua-dalen). Some trees in the herb-rich scrub measured in Qingua-dalen were 8 m high and 16 cm thick. Most of the trees are polycormic (Table 2). Especially in Qingua-dalen the main stems are often lying wave-like with many erect, stem-like

Table 2. Vegetation of the sample (1 m^2) in Qingua-dalen and at Narssarssuaq. Nrs. 1–3 are percentage cover analyses, P. A. is a percentage of point (stick) analysis with distances of 20 cm (The point area <1 cm^2). x = growing in the neighbourhood of the sample plot.

	Qingua-dalen				Narssarssuaq			
Study plot (No.)	1	2	3	P.A.	1	2	3	P.A.
Betula pubescens:								
The thickest branch (cm) at the base	10	15	12	7	6	11		
The thickest branch 1.3 m	8	13	12	3	4	8		
Number of branches at the base (ø >2 cm)	9	5	2	18	7	11		
The highest branch (m)	3	3.2	3.5	2.6	2	2.3		
Average height (m)	2.7	1.6	2.8	1.3	1.3	2		
Age in years	75	95	87					
Betula pubescens				67				98
B. glandulosa × *pubescens*					*60*		*40*	
B. glandulosa								2
Juniperus communis	10	5	15	17				2
Salix glauca		×				2		10
Angelica archangelica		1						
Anthoxanthum odoratum							30	1
Campanula gieseckiana	+	5	×	8				
Chamaenerion angustifolium		2	+					
Deschampsia flexuosa	70	80	30	81	20	50	20	62
Festuca rubra		×						
Hieracium sp.	×	×	×	2			1	
Lycopodium annotinum		×	×					
Poa pratensis		×		3	+			
Potentilla tridentata	×							
Dicranum majus	+		+					
D. scoparium	×			2				2
Hylocomium splendens	+	1						
Pleurozium schreberi	×	1	+	13	60	10	70	40
Polytrichum juniperinum								2
Ptilidium ciliare		+		1				
Tortula ruralis	+							
Cetraria islandica	+	×	×	2	1	1	5	2
Cladonia cornuta	×					+		
C. deformis + *sulphurina*	×	×	×	1				
C. fimbriata	×			1		+		
C. gracilis coll.	×		×	1	1			4
C. mitis	×		×		0,5	2	3	14
C. rangiferina	×	×	×					12
C. squamosa			×	1				
Peltigera aphthosa		×					2	14
Litter	15	30	80	85	20	80	10	46

branches. *Deschampsia flexuosa* dominates in the field layer (Table 2) with an average percentage cover of 60 in Qingua-dalen, 30 at Narssarssuaq (81 and 62% respectively in the point analyses). At Narssarssuaq the moss (average 33%) and lichen cover are greater than in Qingua-dalen (see especially the point analysis values in Table 2). In spite of this both sample plots belong to the *Agrostis borealis – Anthoxanthum odoratum* subsp. *alpinum* type with scrub and low forest vegetation after Böcher (1954). It is vicarious to the suboceanic *Empetrum* and to the subcontinental *Empetrum-Myrtillus* types (Hämet-Ahti 1963) of Northern Fennoscandia. Richness of dwarf shrubs is typical to the Fennoscandian types.

Biomass

The biomass analyses from the Qingua-dalen (Table 3 and Fig. 2) show the abundance of litter + dead material as a result of a low decomposition rate. Compared to the amount of biomass in Fennoscandian subalpine birch forests the biomass of the field layer in Qingua-dalen is much lower, whereas the weight of litter + dead material is 3–10 times higher. The biomass of the bottom layer is also higher in Qingua-dalen. *Deschampsia flexuosa* makes 98% of the field layer biomass; the corresponding value of this grass is in Hardangervidda approx. 8%, in Kilpisjärvi 6%, and in Kevo only 0.3%. According to these biomass data conditions seems to be

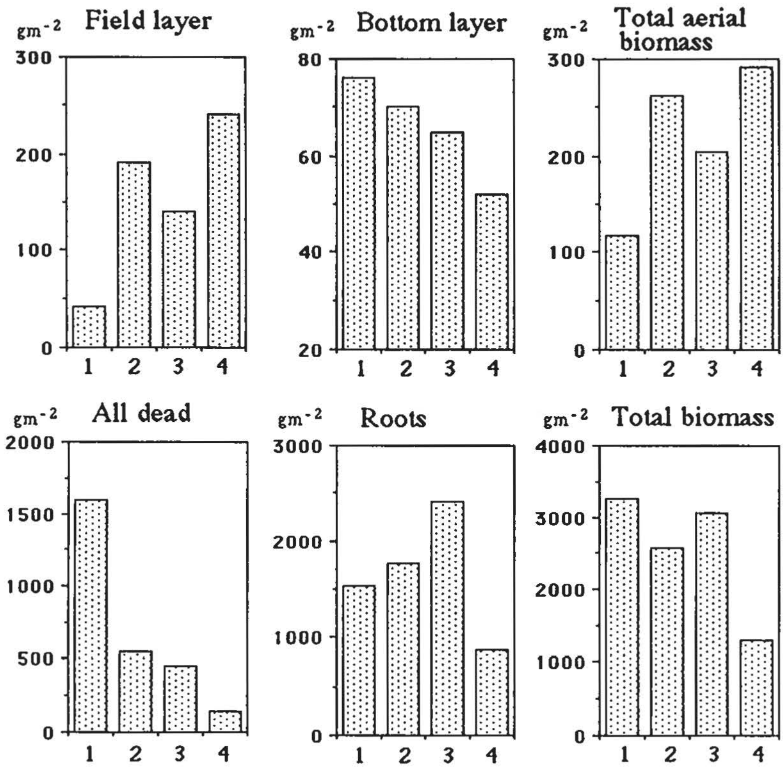


Fig. 2. Biomass (dry weight, g/m²) of the birch forests excl. above-ground trees and shrubs in Qingua-dalen, Greenland (nr. 1; suboceanic), Hardangervidda, Norway (nr. 2, relatively oceanic), Kilpisjärvi, Finland (nr. 3; suboceanic; mean of 7 forest types), and Kevo, Finland (nr. 4; subcontinental) after Östbye et al. 1975 and Kjellvik & Kärenlampi 1975 (nrs. 2 and 4), Kallio 1975 (nr. 4), and Kyllönen 1988 and Eurola et al. 1982 (nr. 3).

more oceanic in the Greenlandic sites than in the Fennoscandian ones.

Vegetation transect

The vegetation transect gives an overview of the vegetation incl. the birch scrubs in Qingua-dalen. There was no time for exact vegetation analyses, only for notes about the most important species. Thus the vegetation was grouped into 19 types (Table 4, see also table 5) and the species of these types, in turn, into six clusters, namely 1) fjeld, 2) dry to mesic scrub/copse, 3) herb-rich vegetation, 4) ubiquitous on mineral soil, 5) mire/seepage, and 6) ubiquitous on all sites.

Comparisons of the types in Table 4 with the vegetation classifications of Böcher (1954), Knapp (1964) and Daniels (1982) are approximately as follows:

0. Rocky area (see Table 5).
1. Block field. – Böcher: 47, Table 5: 4–6, *Veronica fruticans – Sedum annuum* type; Knapp: 119, Tab. 7, *Rhacomitrium lanuginosum* – Gesellschaft.
2. Wind exposed heath. – Böcher: 149–154, Table 15 *Dryas* and *Rhododendron* sociations of the *Rhododendron – Pedicularis lanata* type; Knapp: 99– 104, Tab. 1: H. Zwergstrauch-Heiden; Daniels: 50–60, Ass. Carici – Dryadetum integrifoliae.
3. Lichen-rich heath. – As nr. 2.
4. Talus slope. – Böcher: 46–53 *Thymus drucei* sociation of the *Veronica fruticans – Sedum annuum* type.
5. South exposed heath. – Böcher: 46–53, scrub-like vegetation associated with the *Veronica fruticans – Sedum annuum* type; Daniels: 57, Carici – Dryadetum integrifoliae subass. thymetosum drucei.
6. South exposed birch scrub. – As nr. 5, intermediates between nrs 5 and 7.
7. Dry birch scrub. – Böcher: 64, scrub or low forest vegetation associated with the *Agrostis borealis – Anthoxanthum alpinum* type, its *Deschampsia flexuosa* sociation.
8. Semi-dry birch scrub. – As nr. 7.
9. Semi-dry willow copse. – As nr. 7, perhaps near to the *Angelica – Stellaria longipes* type of Böcher: 89–94.
10. Moss-rich, mesic willow copse. – Böcher: 103, scrubs associated with the *Phyllodoce coerulea – Lycopodium alpinum* type; Knapp: 112, Tab. 4, Weiden-Gebüsche mit Zwergstrauchern; Daniels: 37–43, Ass. Phyllodoco – Salicetum callicarpaeae.
11. Mesic birch scrub. – As nr. 10.
12. Herb-rich birch scrub. – Böcher: 70–76, *Betula pubescens* scrub of scrub or low wood vegetation connected with the *Streptopus – Lastrea* type.
13. Herb-rich willow copse. – Böcher, the same vegetation type as in nr. 12, but its *Salix glauca callicarpaea* scrub; Knapp: 113, Table 5, Kraut-reiche Weiden-Gebüsche; Daniels: 31, Lactucion alpinae generally taken.

Table 3. Biomass of the birch scrub in Qingua-dalen. The mean values (d.w.g.) are calculated on a square meter basis, while the other figures are on a sample plot basis (50 × 50 cm for vascular plants, 25 × 25 cm for mosses, lichens, litter + dead plants, and 10 × 10 cm for humus and roots).

Sample plot	1	2	3	Mean
Juniperus	–	34.50	–	46.00
Deschampsia	4.86	11.40	13.48	39.64
Hieracium	–	0.51	–	0.68
Campanula	–	0.10	0.07	0.24
Mosses	7.15	0.11	2.19	50.40
Lichens	4.65	–	0.07	25.12
Litter + dead plants	48.20	113.38	137.56	1595.36
Humus	6.14	11.71	–	595.00
Roots	4.39	26.29	15.52	1540.00

14. Willow copse on alluvial gravel.

15. Open alluvial gravel.

16. Birch- and willow-rich mire. – Böcher: 102 *Vaccinium uliginosum – Betula glandulosa rotundifolia* sociation rich in *Sphagnum*; Daniels: 25, Ass. Sphagno – Salicetum callicarpaeae.

17. Open bog. – Böcher, as nr. 16; Daniels: 23 *Vaccinium microphyllum – Carex rariflora – Sphagnum fuscum* community.

18. Open fen. – Böcher: 103–108, *Scirpus austriacus* type; Knapp: 123, acidiphile Seggen-Moorgesellschaften; Daniels: 70–71, Table 23, *Paludella squarrosa Carex rariflora* sociation.

19. Seepage site. – Daniels. 70–71, Table 23, *Calliergon sarmentosum* communities.

Based on transect data (Fig. 3 a and b) it can be concluded that:

1) At the SSE facing side the driest types are situated in the upper part, the mesic and herb-rich ones in the lower part of the slope. This succession is generally lacking on the NW slope.

2) Generally taken, on mineral soil the height of *Betula pubescens*, *B. glandulosa*, *Salix glauca* and *Sorbus groenlandica* increases downslope.

3) The birch scrub limit (forest limit) is situated lower at the northern exposition (appr. 100 m a.s.l. N, 150 m S); willow copses begin to disappear over 200 m a.s.l. on both slopes.

4) Together dry and semi-dry birch scrubs are common (15% of all types in the transect, 70% of the scrub types).

5) *Sorbus groenlandica* grows only on the north exposed slope.

Chemical soil and plant analyses

The soil "total" sum of bases, in which the measured amounts of K, Ca, Mg and Na are added, is higher at Narssarssuaq than in Qingua-dalen in the humus and

Table 5. Percentage cover of the vegetation types in the transect across Qingua-dalen.

	%		%
Rocky area	6	Moss-rich willow copse	14
Block field	6	Mesic birch scrub	4
Wind exposed heath	2	Herb-rich birch scrub	4
Lichen-rich heath	10	Herb-rich willow copse	6
Talus	7	Willow copse on gravel	3
South exposed heath	1	Open gravel	3
South exposed scrub	2	Birch-willow mire	1
Dry birch scrub	11	Open bog	2
Semi-dry birch scrub	4	Open fen	3
Semi-dry willow copse	10	Seepage	1

iron rich layers (A_{0-1} and B horizons, Table 6), mostly due to higher content of Ca, at least in two of the Narssarssuaq plots. The content of this element is 5–10 times higher than for K and Mg at Narssarssuaq, while only twice as high in Qingua-dalen. In a relatively rich alpine meadow at Hardangervidda, southern Norway, Ca dominated even more. In oligotrophic birch forests both in that area and in northern Finland, however, the content in the humus layers was again only twice as high as for Mg and only slightly higher than for K, while the amount of these elements often exceeded that of Ca in the B-horizon (Hinneri et al. 1975). The comparison between the two Greenlandic birch forest sites suggests that the rocks generally are rather calcium-rich at Narssarssuaq, while relatively calcium-poor in Qingua-dalen. The low sum of bases in the alluviated A_2 layer at Narssarssuaq is due to strong leaching of all elements. However, analyses from one sample plot only is carried out for this layer at Narssarssuaq as it was missing in the other sample plots at that site. Generally, the contents of Na and Mg are highest in the humus layer at Narssarssuaq, while differences between the sites are small in the other layers, maybe somewhat higher in Qingua-dalen than at Narssarssuaq, both for Na, Mg and K. The increased amounts in the humus layer at Narssarssuaq are probably caused by spray from the fjord, which the sample plots at this site are relatively well exposed to because of the nearness to the fjord.

The loss on ignition is surprisingly low in the humus layer at all sample plots (Table 6). The highest value (23.3%) is observed at plot 4 in the upper part of Qingua-dalen, causing a somewhat higher average compared to Narssarssuaq. This means that most of the humus layer is mixed up with mineral soil (A_1), and is not a really true raw humus (A_0), which may have a loss on ignition at about 80% (Hinneri et al., op.cit.). This indicates relatively good nutrient conditions at least at Narssarssuaq, in spite of a strong cryptogam cover, to some degree also reflected in the vegetation. The mixing of inorganic matter in the humus layer may be explained by the many dust storms caused by the heavy foehns down the valleys. The loss on ignition is low for all plots in the eluviated A_2-horizon, but somewhat higher in the B-horizon in analyses from Qingua-dalen

Table 4. Some floristic data of the vegetation types in Qingua-dalen (see text).

1.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Racomitrium lanuginosum	×																		
Cetraria islandica	×	×																	
Cladonia cornuta	×	×																	
Rhytidium rugosum	×	×																	
Umbilicaria sp.	×	×																	
Alectoria nigricans		×																	
Cladonia bellidiflora		×																	
Ochrolechia frigida		×																	
Polytrichum piliferum		×																	
Thamnolia vermicularis		×																	
Alectoria ochroleuca		×	×																
Cetraria cucullata		×	×																
Sphaerophorus globosus		×	×																
Betula glandulosa × *pubescens*		×	×																
Rhododendron lapponicum		×	×					×											
Juncus trifidus		×	×										×						
Solorina crocea		×	×										×						
Cetraria ericetorum	×	×	×					×											
Diapensia lapponica			×																
Hierochloë alpina			×																
Loiseleuria procumbens			×																
Bryum sp.			×																
Trisetum triflorum			×												×				
Cladonia mitis	×	×	×		×	×				×									
Cladonia rangiferina	×	×	×			×				×									
Cetraria nivalis	×	×	×	×															
Luzula spicata	×	×	×	×									×						
Woodsia ilvensis	×			×															
Saxifraga cespitosa	×			×						×									
Draba incana			×	×															
Potentilla tridentata			×	×									×						
Cladonia fimbriata				×															
Cladonia pyxidata				×															
Phyllodoce coerulea				×									×						
Thymus praecox				×		×													
Viscaria alpina				×	×		×												
Silene acaulis				×									×						

2.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Agrostis tenuis					×														
Cladonia deformis						×													
Nardus stricta						×													
Cladonia gracilis						×				×									
Dicranum scoparium							×												
Draba aurea							×												
Pleurozium schreberi							×	×	×	×	×								
Eriophorum angustifolium									×										
Cardamine pratensis									×										
Carex canescens									×										
Cerastium fontanum									×										
Rhinanthus minor ssp. *groenlandicus*			×						×	×	×	×							
Poa pratensis				×					×	×	×	×							
Rhytidiadelphus squarrosus									×	×	×	×							
Angelica archangelica									×	×	×	×				×			
Thalictrum alpinum									×	×		×							×
Sanionia uncinata									×	×		×	×	×					
Equisetum arvense									×	×		×	×			×	×		
Peltigera aphtosa						×				×	×								
Ledum palustre ssp. *decumbens*								×		×	×	×	×			×	×	×	
Dicranum majus										×	×	×							
Climacium dendroides										×		×							
Peltigera canina										×		×							
Gymnocarpium dryopteris										×	×	×	×						
Lycopodium dubium										×	×	×	×			×			
Hieracium groenlandicum											×	×							
Stellaria calycantha									×		×	×				×			
Bartsia alpina									×		×		×						×
Barbilophozia sp.											×								
Coptis trifoliata											×	×	×						

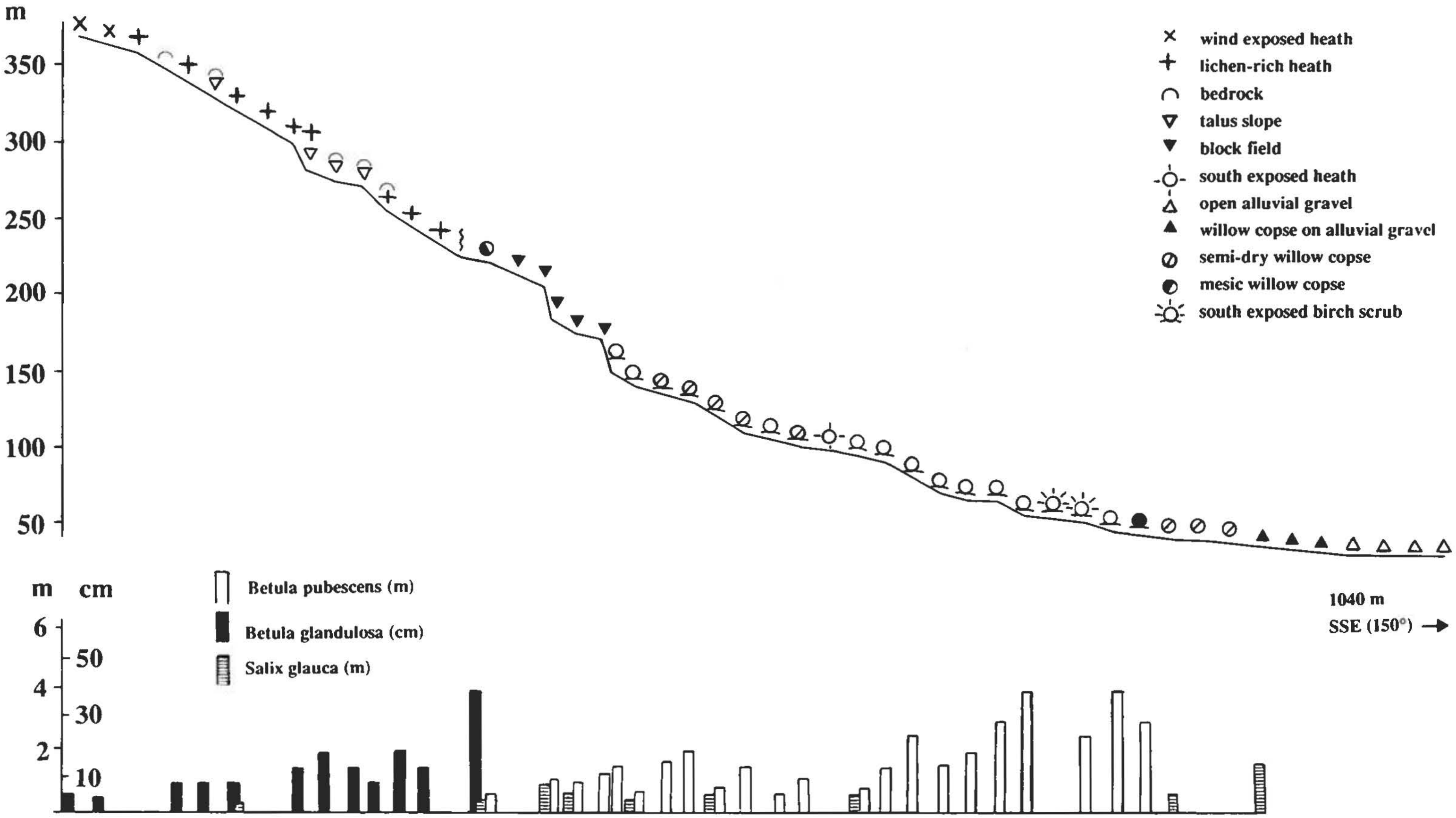
Listera cordata											×	×				×			
Sorbus groenlandica											×		×			×			
Taraxacum spp.						×						×	×						
Platanthera hyperborea										×		×	×						
Lycopodium clavatum												×							
Marchantia polymorpha												×							
Streptopus amplexifolius												×	×						
Alchemilla alpina												×	×			×			
Pseudobryum cinclidioides												×				×			

3.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Festuca rubra			×										×		×				
Agrostis mertensii			×						×				×	×	×				
Luzula multiflora				×									×	×					
Carex macloviana													×						
Gnaphalium norvegicum													×						
Huperzia selago													×						
Poa alpina													×						
Phegopteris connectilis													×						
Calamagrostis langsdorffii												×		×		×			
Juncus filiformis														×					
Juncus arcticus														×					
Racomitrium canescens				×									×		×				
Chamaenerion latifolium													×		×				
Carex atrata															×				
Deschampsia alpina															×				

4.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Cerastium alpinum	×		×				×			×					×				
Deschampsia flexuosa	×		×	×	×	×	×	×		×	×	×			×				
Chamaenerion angustifolium			×		×	×	×			×	×	×							
Hieracium sp.	×		×			×	×			×			×						
Poa glauca	×		×	×	×		×		×	×		×	×		×				
Alchemilla alpina	×		×							×	×	×	×		×				×
Campanula gieseckiana	×		×	×	×	×	×	×		×		×	×	×					×
Juniperus communis	×		×	×		×	×	×		×			×						×
Polygonum viviparum				×					×			×	×						×

5.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Sphagnum fimbriatum																×			
Sphagnum teres																×			
Sphagnum warnstorfii																×			
Equisetum sylvaticum																×	×		
Sphagnum angustifolium																	×		
Sphagnum fuscum																	×		
Sphagnum russowii																	×		
Vaccinium oxycoccos ssp. *microphyllum*																	×		
Aulacomnium palustre																	×	×	
Carex rariflora																		×	
Cinclidium arcticum																		×	
Paludella squarrosa																		×	
Polytrichum swartzii																		×	
Salix arctophila																		×	
Aulacomnium turgidum																		×	×
Scirpus cespitosus																		×	×
Carex capillaris																			×
Carex scirpoidea																			×
Dicranum undulatum																			×
Kiaeria sp.																			×
Oncophorus virens																			×
Orthothecium chryseum																			×
Pinguicula vulgaris																			×
Calliergon sarmentosum																			×
Calliergon trifarium																			×

6.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Betula glandulosa		×	×	×					×	×							×	×	×
Betula pubescens	×					×	×	×		×	×	×				×	×	×	
Empetrum hermaphroditum			×	×				×		×	×		×				×	×	×
Hylocomium splendens	×						×	×	×	×	×					×			×
Vaccinium uliginosum		×	×	×				×	×	×			×					×	



m
350
300
250
200
150
100
50
wind exposed heath
lichen-rich heath
bedrock
talus slope
block field
south exposed heath
open alluvial gravel
willow copse on alluvial gravel
semi-dry willow copse
mesic willow copse
south exposed birch scrub
m cm
6
4
2
50
30
10
Betula pubescens (m)
Betula glandulosa (cm)
Salix glauca (m)
1040 m
SSE (150°)

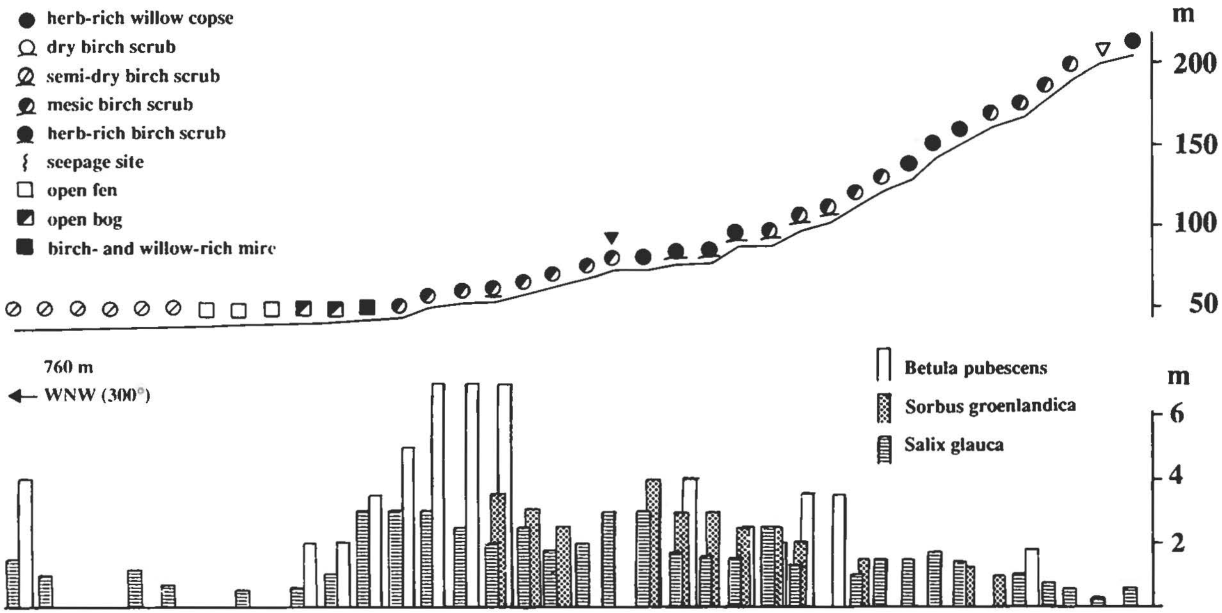


Fig. 3. Vegetation transect across Qingua-dalen. The distance between the study site is 20 m. 3a. The SSE facing valley side (length 1040 m). 3b. The WNW facing side (760 m).

than from Narssarssuaq due to more humus washed down to the deeper layers.

"Total" N normally reflects directly the amount of organic material in the soil. This is the main reason for the generally low N contents observed at all plots in Greenland. However, compared to loss on ignition the N content may even be lower in the mineral layers at some of the Greenland plots than found in other birch forest studies, reflected for instance by 0.12% "total" N in the B-layer in plots from Qingua-dalen compared to a loss on ignition at 8% (Table 6), while in the B-layer at a subalpine birch forest at Hardangervidda, southern Norway, a "total" N of 0.44% is found compared to a loss on ignition at 6.5% (Hinneri et al., op. cit.). By using the regression equation in that paper (tot. C = $-0.17 + 0.53 \times$ loss on ignition) on the Greenland material a C/N ratio of 25.9 is calculated as an average for the humus layers in the Qingua-dalen and 22.5 for the same layer at Narssarssuaq. These ratios are fairly high, yet somewhat lower than corresponding ratios in the birch forest humus layers at Hardangervidda (Norway, 28.6) and Kevo (Finland, 36.1). A high C/N ratio means that the availability of N to plants is poor, but based on the calculations it might be a little better in the humus layer of the Greenland sites than of the Fennoscandian sites.

A thicker humus layer and consequently a higher loss on ignition in Qingua-dalen may be the reason for the higher total weight down to 35 cm (Table 7). In the discussion on the sum of bases it is mentioned that two plots at Narssarssuaq show relatively high Ca percentages both in the humus and the B-horizons. This is reflected also in a higher Ca content on a weight basis at Narssarssuaq. Although the Na weight is approximately the same at both sites as total sum down to 35 cm, a detailed study on the various layers again shows higher Na weight in the humus layer at Narssarssuaq (26.7 gm^{-2}) than in Qingua-dalen (12.5 gm^{-2}) in spite of thinner humus layers at the first site reflecting the supposed sea spray Na accumulation in the upper soil layers.

The Narssarssuaq soils down to 35 cm (Table 7) contain nearly 1.5 times as much Ca on a weight basis as a Norwegian subalpine birch forest soil down to the same depth, while the weight of total minerals of N, P, K and Mg are 3–5 times higher in the Norwegian soil than in the Greenland ones (Wielgolaski et al. 1975). This indicates the importance of Ca for the release of most nutrients in the soil to make them available to the plants, as the vegetation data presented do not suggest particularly poor ecosystems for plant growth at the Greenland sites. Also the Norwegian chemical soil analyses showed that the only element that increased in so-called nutrient rich soil was Ca (Wielgolaski et al. op. cit., Table 4).

The ash content in most of the various parts of birch from Greenland (Table 8) is generally of the same order as for the same parts of similar phenological stages in subalpine and subarctic birch from Fennoscandia, harvested in early August (Wielgolaski et al., op. cit.). However, the contents particularly in leaf buds, annual shoots and roots seem to be significantly higher in Greenland, especially of Ca, but significantly of N as well. Generally, the Ca and N contens are highest in nearly all birch parts from Narssarssuaq (Table 8). The high Ca content in the Narssarssuaq plant reflects the often high Ca percentage both in the humus and the iron-rich layers at this site. The high N content in the birches at Narssarssuaq, however, does not reflect the amount of total N in the soil, but rather the lower C/N ratio in the humus at Narssarssuaq. In most parts of birch K and Mg percentages are highest at Narssarssuaq. However, this is not the case for K in leaf buds and annual shoots and for Mg in leaf buds. One reason for those discrepancies may be that the phenological development had gone further in the probably warmer Qingua-dalen. K is one of the elements which is most

Table 6. Total sum of bases (sum K, Ca, Mg and Na), loss on ignition, and total N (all in % of dry weight). Average for the same plots in Qingua-dalen (Qin, 4 plots) and at Narssarssuaq (Nar, 3 plots) in the various soil layers. In all plots average of 3 replicates. – = not determinated.

	"Total" sum bases		Loss on ignition		"Total" nitrogen	
	Qin	Nar	Qin	Nar	Qin	Nar
Humus A_{0-1}	0.62	0.99	17.9	15.6	0.36	0.36
Leached A_2	0.58	0.22	3.1	3.7	0.06	0.04
Iron-rich B	0.69	1.36	8.0	3.8	0.12	0.06
"Sub"-soil B–C	0.74	–	4.3	–	0.08	–

Table 7. Amount of minerals (total) in kg m^{-2} in the upper 35 cm, average for the sample plots Qingua-dalen (4 plots) and Narssarssuaq (3 plots), respectively, calculated for each horizon, but summed. Average of 3 replicates of each plot.

	Soil weight	N	P	K	Ca	Mg	Na
Qingua-dalen	220.6	0.37	0.20	0.23	0.95	0.29	0.05
Narssarssuaq	228.0	0.24	0.22	0.23	1.84	0.27	0.06

Table 8. Total "macronutrients" and ash (% of dry weight) in various plant parts of *Betula pubescens* in late July at two sites in southwestern Greenland, Qingua-dalen (Qin, average of 4 sample plots) and Narssarssuaq (Nar, average of 3 plots), in most plots 3 replicates.

	Ash		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sodium	
	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Catkins	2.6	2.5	1.49	1.85	0.26	0.21	0.55	0.60	0.38	0.20	0.13	0.13	0.46	0.47
Leaf buds	4.3	4.0	2.12	2.40	0.34	0.26	0.65	0.48	0.70	0.98	0.24	0.19	0.10	0.11
Leaves	4.7	3.5	2.13	2.25	0.31	0.24	0.18	0.62	0.55	0.92	0.17	0.28	0.10	0.11
Annual shoots	2.9	3.0	1.60	1.65	0.24	0.22	0.95	0.46	0.40	0.68	0.14	0.21	0.30	0.15
Older twigs	1.5	1.2	0.39	0.54	0.08	0.06	0.21	0.33	0.18	0.27	0.06	0.07	0.10	0.08
Roots	2.9	3.2	0.39	0.47	0.10	0.06	0.17	0.43	0.35	0.44	0.08	0.09	0.12	0.11
Inner bark	2.7	2.0	0.58	0.58	0.06	0.05	0.22	0.46	0.60	0.68	0.05	0.21	0.12	0.17
Outer bark	0.6	0.8	0.35	0.36	0.03	0.02	0.13	0.13	0.10	0.19	0.02	0.03	0.06	0.18
Wood	0.4	0.4	0.15	0.14	0.02	0.01	0.04	0.18	0.10	0.10	0.03	0.03	0.07	0.11

easily transported in plants. It is reduced in leaves throughout the season (and is low in birch leaves analysed from Qingua-dalen compared to those from Narssarssuaq), but may be accumulated in newly formed young material as leaf buds and new shoots. The high content of Na in annual birch shoots in Qingua-dalen may be explained the same way. However, the Na content in outer birch bark exposed to the sea spray is higher at Narssarssuaq.

The ash content of the other plant species analysed from Greenland (Table 9) show the same tendencies as birch when compared with figures from Fennoscandia (Wielgolaski et al., op. cit.). The extremely high ash content of non-green *Pleurozium,* however, must be caused by inclusion of some soil particles. The specific minerals analysed show less clear tendencies than the birch parts. The amount of K in green *Deschampsia* and *Pleurozium* is lower at both sites in Greenland than in the same parts of these species from Fennoscandian birch forests. Similar tendencies are observed for Ca and Mg, as well as for total N in *Cladina*. Only for Na the highest figures are measured in the Greenlandic understorey plants. As mentioned this may be caused by the closer vicinity to the fjord at the Narssarssuaq sites. If so, the Na content should be higher at Narssarssuaq for these species as for most parts of birch. This is the case for *Cladina,* but not for *Deschampsia* and *Pleurozium* (Table 9), which is difficult to explain. Again, probably this is caused by the difference in phenological development between plants from the two Greenlandic sites. The phosphorus content is generally higher in plants from Qingua-dalen, both for the understorey plants and for the birch parts. This is true although there are no clear tendencies between the total phosphorus content in soil from the two Greenlandic sites. As for the parts of birch the Ca content of the understorey plants is generally highest at Narssarssuaq. On the other hand, there are no clear differencies in those plants between the sites for the elements K, Mg and total N in contrast to the birches.

Evergreen plants normally show low contents of most mineral nutrients. This general rule is particularly true for lichens, but also for mosses and evergreen shrubs compared to deciduous woody plants and to herbaceous phanerogams (Wielgolaski et al., op. cit.). Most evergreen plants may survive with a low metabolism and a low uptake of nutrients from the soil, which mean that they often grow on a poor soil. In Greenland the low mineral content in evergreens is clear when comparing on one hand the contents of different elements in *Cladina*, in green *Pleurozium* and in shoots of *Empetrum* (which show low, but still somewhat higher figures than

Table 9. Total macronutrients and ash (% of dry weight) in some understorey plants in Qingua-dalen (Qin, average of 4 plots) and Narssarssuaq (Nar, average of 3 plots). – = not determined.

	Ash		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sodium	
	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Cladina	1.7	3.7	0.32	0.30	0.07	0.06	0.09	0.28	0.08	0.15	0.04	0.04	0.08	0.17
Pleurozium														
Green	3.9	7.8	0.78	0.70	0.17	0.12	0.12	0.11	0.33	0.27	0.12	0.07	0.13	0.07
Non-green	7.4	22.0	0.58	0.54	0.10	0.08	0.72	0.41	0.57	0.60	0.12	0.12	0.23	0.13
Deschampsia														
Green	5.6	4.7	1.53	1.19	0.24	0.20	0.85	0.99	0.20	0.30	0.09	0.10	0.17	0.11
Non-green	3.5	5.4	0.69	0.80	0.17	0.11	0.46	0.33	0.12	0.16	0.04	0.05	0.24	0.16
Empetrum														
Fruits	2.3	–	0.25	–	0.11	–	0.50	–	0.14	–	0.07	–	0.38	–
Annual shoots	2.9	–	0.65	–	0.15	–	0.72	–	0.58	–	0.15	–	0.29	–
Earlier green	2.5	–	0.32	–	0.08	–	0.52	–	0.53	–	0.13	–	0.13	–
Non-green	1.3	–	0.34	–	0.06	–	0.27	–	0.25	–	0.10	–	0.11	–

Table 10. Glucose, fructose, sucrose and starch content (% of dry weight, average ± S.E.) in various plant parts of *Betula pubescens* in Qingua-dalen (Qin) and Narssarssuaq (Nar). n = number of replicates, . . = value about zero.

		Glucose		Fructose		Sucrose		Starch	
	n	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Catkins	4	4.94±0.96	3.59±0.34	1.81±0.37	2.04±0.15	0.06±0.06	0.45±0.11	0.15±0.05	0.76±0.30
Leaf buds	1	1.46	1.14	1.26	0.78	2.87	0.03	0.20	0.87
Leaves	4	3.87±0.22	3.45±0.20	2.78±0.09	1.68±0.88	0.18±0.08	0.18±0.02	2.36±0.41	0.42±0.01
Annual shoots	5	1.91±0.32	2.20±0.16	1.53±0.25	1.35±0.27	0.16±0.14	. .	1.14±0.58	0.21±0.15
Older twigs	4	1.33±0.24	1.45±0.09	0.75±0.12	0.80±0.03	0.10±0.10	0.44±0.02	1.08±0.35	0.29±0.04
Roots	4	1.11±0.09	1.09±0.05	0.72±0.21	0.67±0.02	0.01±0.01	0.40±0.05	3.97±0.57	2.93±0.47
Inner bark	4	2.04±0.43	1.38±0.04	1.14±0.25	1.07±0.14	. .	0.01±0.01	1.62±0.26	1.63±0.59
Outer bark	3	0.20±0.02	0.12±0.02	0.01±0.01	. .	. .	. .	0.22±0.09	0.11±0.06
Wood	3	0.06±0.05	0.04±0.02	0.10±0.02	0.08±0.02	0.57±0.05	0.48±0.07	0.97±0.21	0.79±0.10

the cryptogams) with on the other hand the higher content in green *Deschampsia* and in leaves and shoots of birch. This is particularly clear for total N. However, none of the plants analysed chemically from Greenland are eutrophic species. Such would probably have even higher percentages of most of the nutrients studied.

Glucose, fructose, sucrose and starch content (% of dry weight) in various part of birch are presented in Table 10. In most parts glucose is present in greater amounts than fructose and sucrose. Highest values of glucose and fructose were found in catkins and leaves, of starch in leaves and roots, and of sucrose in leaf buds. Contents of these compounds are highest in annual than in older shoots and high in inner than in outer bark. Wood of birch contains more sucrose and starch than other organic compounds studied here.

"Total" sums of sugars (glucose+fructose+sucrose) in all parts of birch determined here were highest in Qingua-dalen except in older twigs and roots. Starch contents, generally, showed the same tendency. Glucose content in catkins and inner bark of birch seems to be markedly high in Qingua-dalen. "Total" sum of carbohydrates (glucose + fructose + sucrose + starch) in various parts of birch are highest in Qingua-dalen, probably due to high temperature (more favourable exposure) and net assimilation, which is indicated also by better growth rate (biomass) of birches (see table 2). This is in accordance to results found by Mooney and Billings (1965) and Skre et al. (1975). However, the soil moisture and the soil nutrient levels may affect the total sugar content, causing a higher content in plants from nutrient rich sites than from poorer ones (Skre et al. 1975).

Among the species studied here *Cladina* showed the lowest values of glucose, fructose and sucrose (Table 11). Starch content in *Cladina* was two to three times higher than in *Pleurozium* and *Deschampsia*. Generally, green parts of plants had highest contents of glucose, fructose, sucrose and starch. However, two exceptions were found. Non-green leaves of *Deschampsia* contained more starch than green leaves and those of *Empetrum* more sucrose. Berries of *Empetrum* had high values of glucose and fructose, but standard errors were high because of only two replicates. High variations might depend on different stages of ripening of berries. Sucrose contents in green parts of *Pleurozium* were high at both study sites. "Total" sum of sugars in *Cladina* from Narssarssuaq is about 30% higher than in samples from Qingua-dalen. However, the contents of starch showed a converse pattern, and therefore the total amount of carbohydrates did not differ between the sites. Nor did the content of some other organic compounds differ.

The present study, however incomplete it is, shows some of the relationships between the birch wood ecosystems of Greenland and similar ones in Fennoscandia. In most cases the similarities are clear, although some discrepancies are also found.

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Table 11. Glucose, fructose, sucrose and starch content (% of dry weight, average ± S.E.) in some understorey plants in Quingua-dalen (Qin) and Narssarssuaq (Nar). n = number of replicates, – = not determined.

		Glucose		Fructose		Sucrose		Starch	
	n	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Cladina	3	0.12±0.04	0.21±0.03	0.04±0.03	0.09±0.04	0.10±0.01	0.08±0.03	0.05±0.06	0.41±0.09
Pleurozium									
Green	3	0.64±0.08	0.58±0.04	0.58±0.09	0.47±0.06	4.96±0.70	5.15±0.36	0.21±0.21	0.21±0.11
Non-green	3	0.55±0.06	0.60±0.07	0.46±0.07	0.46±0.08	1.21±0.34	2.41±0.70	0.19±0.10	0.29±0.03
Deschampsia									
Green	2	0.73±0.29	0.63[1]	0.66±0.19	0.80[1]	1.43±0.02	4.30[1]	0.06±0.04	0.17[1]
Non-green	2	0.56±0.03	0.69[1]	0.65±0.07	0.52[1]	0.72±0.02	0.49[1]	0.13±0.06	0.26[1]
Empetrum									
Fruits	2	5.38±4.61	–	3.63±3.76	–	0.63±0.62	–	0.18±0.12	–
Green	2	1.12±0.40	–	0.71±0.54	–	0.20±0.01	–	1.66±0.20	–
Non-green	2	0.31±0.04	–	0.13±0.08	–	0.63±0.03	–	1.03±0.19	–

1. Only one replicate.

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