



Modern pollen–vegetation relationships in subarctic southern Greenland and the interpretation of fossil pollen data from the Norse *landnám*

J. Edward Schofield^{1*}, Kevin J. Edwards¹ and J. Andy McMullen²

¹Department of Geography & Environment and Northern Studies Centre, University of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, UK and ²Coulmakyle Farm Cottage, Nethy Bridge, Inverness-shire PH25 3EA, UK

ABSTRACT

Aim The objective of this paper is to explore the relationships that exist between vegetation and modern pollen rain in the open, largely treeless landscape of subarctic Greenland. The implications of these results for the interpretation of fossil pollen assemblages from the time of the Norse *landnám* are then examined.

Location The study area is the sheep farming district of Qassiarsuk in the subarctic, subcontinental vegetational and climatic zone of southern Greenland (61° N, 45° W). Between c. AD 1000–1500 this region was contained within the Norse Eastern Settlement.

Methods Detrended Correspondence Analysis (DCA) of harmonized plant–pollen data sets is used to compare plant cover in 64 vegetation quadrats with pollen assemblages obtained from moss polsters at matching locations. Presence/absence data are also used to calculate indices of association, over- and under-representation for pollen types.

Results Good correspondence between paired vegetation–pollen samples occurs in many cases, particularly in locations where *Salix glauca*–*Betula glandulosa* dwarf shrub heath is dominant, and across herbaceous field boundaries and meadows. Pollen samples are found to be poor at reflecting actual ground cover where ericales or *Juniperus communis* are the locally dominant shrubs. Dominant or ubiquitous taxa within this landscape (*Betula*, *Salix* and Poaceae) are found to be over-represented in pollen assemblages, as are several of the ‘weeds’ generally accepted as introduced by the Norse settlers.

Main conclusions Due to their over-representation in the pollen rain, many of the Norse apophytes and introductions (e.g. *Rumex acetosa* and *R. acetosella*) traditionally used to infer human activity in Greenland should be particularly sensitive indicators for *landnám*, allowing early detection of Norse activity in fossil assemblages. Pteridophyte spores are found to be disassociated with the ground cover of ferns and clubmosses, but are over-represented in pollen assemblages, indicating extra-local or regional sources and long residence times in soil/sediment profiles for these microfossils. A pollen record for *Hordeum*-type registered in close proximity to a field containing barley suggests that summer temperatures under the current climatic regime are, at least on occasion, sufficient to allow flowering.

Keywords

Landnám, modern analogue, Norse, ordination, pollen representation, Southern Greenland, subarctic, vegetation.

*Correspondence: Edward Schofield, Department of Geography & Environment and Northern Studies Centre, University of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, UK.
E-mail: j.e.schofield@abdn.ac.uk

INTRODUCTION

An understanding of the relationships between the modern pollen rain and the floristic composition of plant communities under different environmental settings is vital if palynologists are to attempt objective and accurate reconstruction of vegetation histories from fossil pollen assemblages. Initially the study of modern pollen–vegetation relationships, and the implications this has for interpretation of fossil pollen data, concentrated upon forest hollows and small lake basins within temperate fully forested environments, and a substantial body of literature now exists covering this subject (e.g. Andersen, 1973; Bradshaw, 1981; Sugita, 1994; Calcote, 1995). More recently there has been growing recognition of the need to expand this research theme into high latitude, treeless, partially-wooded and heterogeneous landscapes, such as those characteristic of northern Fennoscandia and the North Atlantic islands (e.g. Gaillard *et al.*, 1994; Brayshay *et al.*, 2000; Bunting, 2003; Bennett & Hicks, 2005; Broström *et al.*, 2005).

The region around Qassiarsuk in southern Greenland (Fig. 1) provides an excellent opportunity to investigate modern pollen–vegetation relationships within an open, largely treeless landscape where modern land use (sheep farming) is potentially a close analogue for conditions that existed at the time of the Norse *landnám* (the first colonization by the Vikings) some 500–1000 years ago. This paper will investigate how closely pollen samples obtained from moss polsters in the Qassiarsuk district approximate the modern vegetation communities from which these samples are derived, and will address the key issue of whether pollen analysis in this region is sufficiently sensitive to differentiate between different vegetation communities. Relationships between plant species and their pollen representation in this landscape are explored through empirical studies, and the implications of these results for the interpretation of fossil pollen assemblages from the time of the Norse *landnám* are examined. The results provide a benchmark from which to begin interpretation of Greenlandic pollen diagrams obtained from peat profiles with small source areas as part of the ongoing study into the human and

ecological consequences of Norse settlement in the North Atlantic (Edwards *et al.*, 2004).

STUDY AREA

The region featured in this study is centred upon the sheep farming settlements of Qassiarsuk (61°09' N, 45°31' W) and Igaliku (60°59' N, 45°25' W) (Fig. 2). These villages stand respectively upon the Norse site reputedly occupied by Erik the Red's farm (*Brattahlíð*) and the site of the seat of the bishop of Greenland (*Garðar*) (Seaver, 1996). Both settlements are located within what was formerly the Eastern Settlement or Østerbygd, a Norse colony comprising over 300 farms founded by settlers from Iceland after AD 985. The settlement was occupied until the 15th century AD, after which time it appears that 'Little Ice Age' climatic deterioration, perhaps coupled with cultural intransigence, forced the settlement to be abandoned (Barlow *et al.*, 1997; Dugmore *et al.*, 2005).

The study area is situated in the subcontinental, subarctic climatic and vegetational zone of southern Greenland (Feilberg, 1984). Rounded mountain topography characterizes the region, with relief ranging from sea-level to in excess of 600 m. Mean monthly temperatures for Narsarsuaq range between 14°C (July maximum) and –11°C (December–February minimum) with mean annual precipitation of 617 mm (<http://uk.weather.com/weather/climatology/>). Foehn winds blowing off the ice-cap may occur all through the year causing the greatest damage to vegetation during the winter (Feilberg, 1984). Local basement geology comprises gneisses, granites and metamorphosed supracrustal rocks of the Ketilidian mobile belt (Allaart, 1976), with sandstones of the Gardar succession overlaying the granites around Igaliku (Emeleus & Upton, 1976). Soils are generally shallow rankers, though deeper brown earths or podzols are noted as present under areas of dense vegetation (Feilberg, 1984).

Despite being the richest botanical province in Greenland, the modern flora of this region is still somewhat restricted, comprising only slightly more than 300 native species of vascular plant (Böcher *et al.*, 1959; Böcher, 1963; Feilberg, 1984). The most widespread plant community is dwarf shrub heath or scrub, dominated by *Salix glauca* and/or *Betula glandulosa*. Patches of lichen-rich grassland heath/steppe-like communities, with *Agrostis canina* and *Deschampsia flexuosa* prominent, are found interspersed amongst the scrub in well-drained sites. Small mires supporting *Carex* spp., *Menyanthes trifoliata* and bryophytes are widespread around lake margins and beside streams. Cyperaceous communities also occupy the numerous isolated poorly-draining peaty hollows that are found scattered throughout the landscape.

The local economy of Qassiarsuk district is heavily dependent upon sheep farming. Consequently, large areas of land around the major farming settlements (Qassiarsuk, the Qorlortup valley, Tasiusaq and Igaliku) have been improved for hay-making (fenced-off, manured and mown) to produce winter fodder for livestock. Grazing by sheep outside fenced areas has undoubtedly been a factor in limiting tree growth.



Figure 1 Location of the study region within the North Atlantic area.

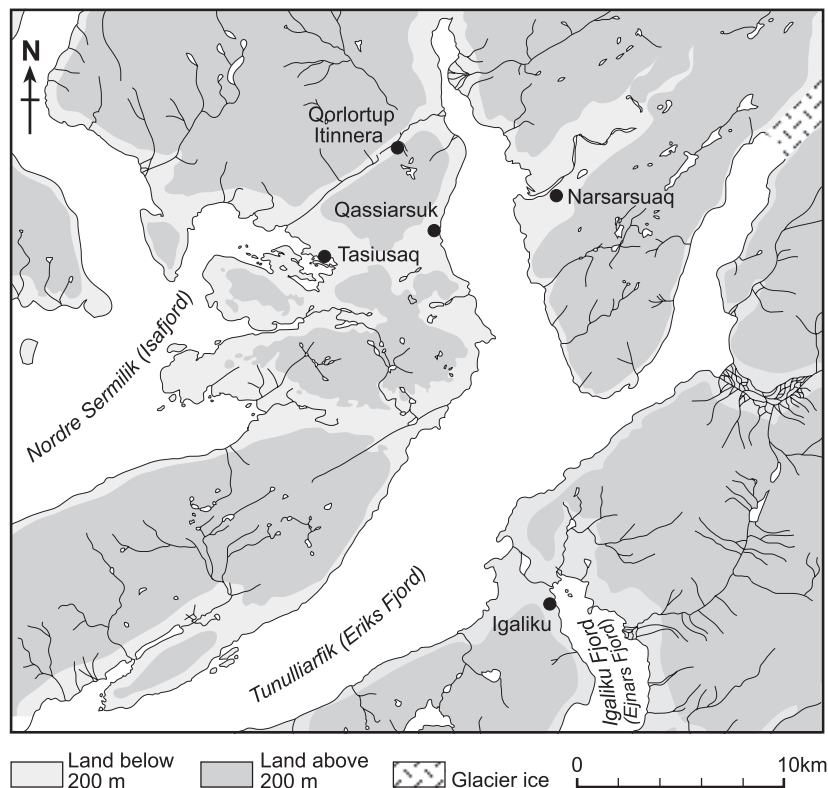


Figure 2 Sampling localities in southern Greenland featured in this study.

On the eastern side of the Tunulliarfik fjord around Narsarsuaq, where sheep farming is not practiced, birch and willow copses are present in protected valley locations. Here individual trees approach heights of up to 5 m. A number of conifers (*Picea*, *Pinus* and *Larix* species) have also been introduced on slopes overlooking Narsarsuaq. This practice was initiated in 1892 although the majority of the extant trees appear to date from afforestation experiments by the IUFRO (International Union of Forest Research Organisation) and the establishment of an arboretum in 1976 (Ødum, 1990).

Palaeobotanical studies by Fredskild (1973, 1978) have proved invaluable in establishing a chronology for Holocene vegetation development in the Eastern Settlement. Pollen and plant macrofossils are available for two lakes near Qassiarsuk, Comarum Sø (61°08' N, 45°32' W) and Galium Kær (61°10' N, 43°31' W), and from four open sections through peat-filled hollows located in close proximity to settlement ruins at *Brattahlíð*. These studies reveal that after the arrival of the Norse around AD 1000, and the introduction of a European-style agricultural system based upon the rearing of domesticated animals, there followed a reduction in pollen of *Salix* and *Betula* (mainly tree birch) and an increase in pollen from pioneering or native ruderal herbs (e.g. the Caryophyllaceae, *Plantago maritima* and *Thalictrum alpinum*) and agricultural 'weeds' introduced by the settlers (e.g. *Rumex acetosella* and *R. acetosa*). Fredskild (1973, 1978, 1988) interpreted this pattern as a response to shrub clearance, trampling, grazing and the cutting of turf for the construction of turf- and stone-built buildings.

Given the many similarities between present-day land use and that during the Norse era, it seems likely that modern plant communities in southern Greenland (and their pollen assemblages) may provide close analogues for vegetation during the period of Norse settlement. This study will explore the relationships that exist between the modern pollen rain and plant communities, and will attempt to quantify the correspondence between pollen types and their source communities. Particular emphasis is placed upon those taxa already identified as indicative of, or strongly responsive to, the Norse colonization.

METHODOLOGY

Field methods

The vegetation survey and collection of modern pollen samples was undertaken in late summer over the course of two field seasons (August 2004 and July–August 2005). Samples were collected from five different locations across Qassiarsuk district, with positional and altitudinal data recorded using a portable Garmin GPS device (Romsey, UK) (Fig. 3 and Appendix S1 in Supplementary Material).

Vegetation recording was undertaken using 1 m² quadrats with species cover within each quadrat estimated as a percentage by eye (Kent & Coker, 1992). Nomenclature for vascular plants encountered during the vegetation survey followed Böcher *et al.* (1968). At each site an attempt was made to ensure that the samples collected were representative

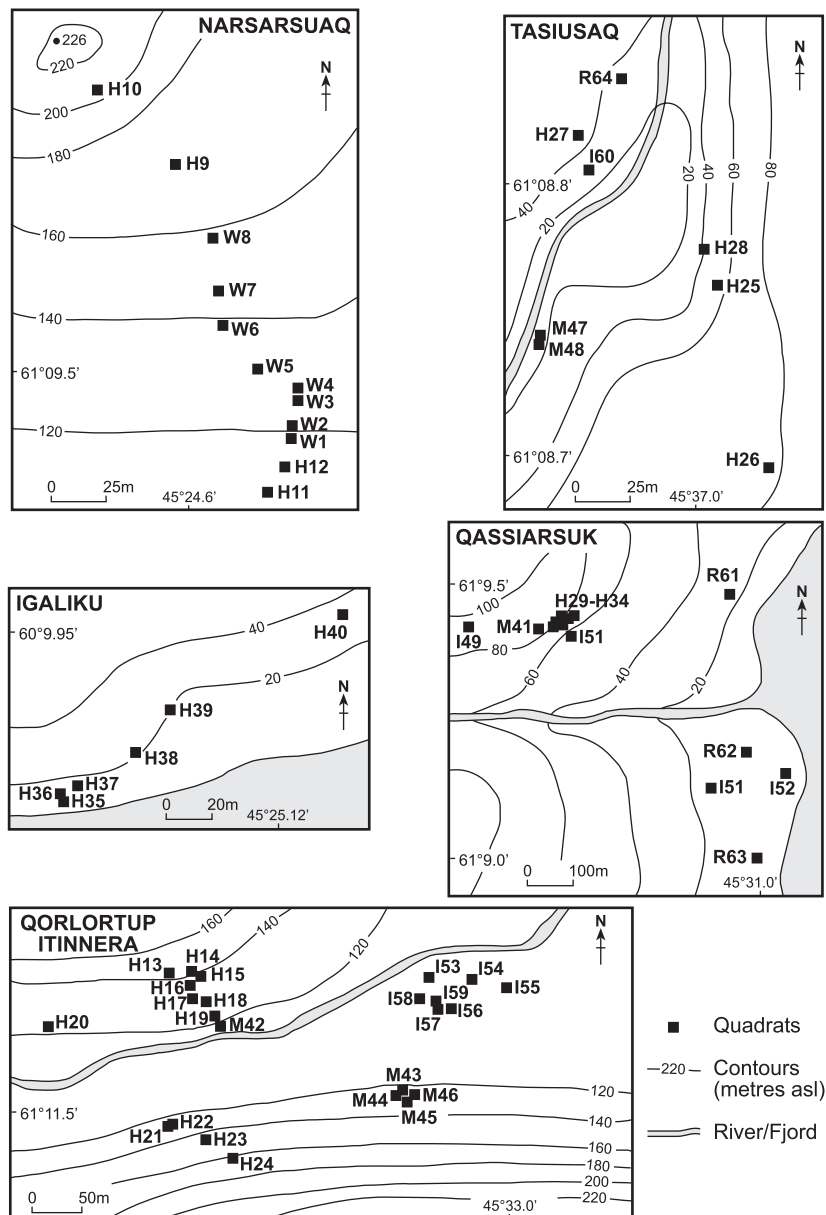


Figure 3 Locations of quadrats where vegetation surveys and pollen sampling was undertaken.

of the local vegetation mosaic. Quadrats were positioned to incorporate the full range of distinctive vegetational communities that characterized each area, and at the ecotonal boundaries between these. Vegetation communities were categorized as follows: (1) woodland, (2) dwarf shrub heath (including both scrub and steppe), (3) mires, (4) hay-fields, field boundaries and meadows (collectively the infields), and (5) ruderal and footpath communities.

At each site the close spacing of quadrats (Fig. 3) was often necessary in order to sample the full range of distinctive vegetation communities. This raises the issue of spatial autocorrelation between samples. Coefficients such as Moran's *I* and Geary's *c* can be used to measure the degree of autocorrelation between vegetation quadrats under different sampling strategies (e.g. Fortin *et al.*, 1989) although it is recommended that these are not performed with fewer than around 30 samples (the

maximum number of quadrats at any locality featured in this study is 24 at Qorlortup). The authors therefore recognize the potential problem, but regard it as largely unavoidable in the context of southern Greenland landscapes. Given the nature of palynological representation, the results provide us with considerable confidence in the approach used in this study.

Moss polsters were collected from within each quadrat to provide samples for pollen analysis (Moore *et al.*, 1991). For quadrats where moss polsters were unavailable a surface litter or organic matter/soil sample was taken as a comparable substitute (cf. Hall, 1989). The sample data set covers more than one growing season and this should reduce any effect from annual variations in pollen production (Hjelle, 1997). Empirical estimates for the relevant pollen source area of moss polsters in open landscapes range from under 2 m across Scottish heaths (Bunting, 2003) to *c.* 400 m in the open

agricultural landscape of southern Sweden (Broström *et al.*, 2005). It is anticipated that the polsters examined in this study should therefore provide reliable modern analogues for fossil pollen assemblages derived from small peat-filled hollows, which theoretically should have small pollen source areas. However, caution should be taken if the results from this approach are to be used to interpret fossil pollen assemblages derived from lake sites where increased basin size results in a greater proportion of the pollen rain being derived from the regional vegetation (e.g. Jacobson & Bradshaw, 1981).

Laboratory methods

Samples for pollen analysis were prepared using standard NaOH, HF and acetolysis procedures (Moore *et al.*, 1991). Sample residues were suspended in silicone oil, mounted on slides, and examined using a Nikon E600 light microscope ($\times 400$ and $\times 600$ magnification). Each pollen sample was counted until a sum in excess of 500 total land pollen grains (TLP) had been surpassed. Pollen and spores were identified with the aid of the key and descriptions given in Moore *et al.* (1991) and the reference collection held within the Department of Geography and Environment, University of Aberdeen. Nomenclature for pollen and spore types largely follows Moore *et al.* (1991). Separation of tree birch (*Betula pubescens*) and dwarf birch (*Betula glandulosa*) pollen was achieved on the basis of grain size, with *Betula* pollen grains $< 20 \mu\text{m}$ diameter classified as dwarf birch (cf. Fredskild, 1973). Cereal-type pollen grains were identified and categorized according to the recommendations of Andersen (1979). Pollen and spore data were converted into percentages using TILIA software

(Grimm, 1993) and the pollen diagram constructed using TGView (Grimm, 2004). Percentages were calculated variously on a group basis (TLP, TLP + aquatics, TLP + pteridophytes). Unless stated otherwise, cited pollen percentage data are based on the TLP sum.

Ordination and representation indices

Ordination of percentage vegetation (quadrat) and pollen (polster) data was carried out to examine the degree of similarity/difference in the floristic composition of samples (Jongman *et al.*, 1995). Detrended Correspondence Analysis (DCA) (Hill & Gauch, 1980) of data was performed using PC-ORD Version 4 computer software (MjM Software Design, Gleneden Beach, OR, USA) (McCune & Mefford, 1999). Initially, vegetation samples were ordinated separately (with all taxa included) to allow examination of the underlying structure within the modern vegetation communities. Pollen samples were then placed passively into the ordination of the vegetation data set, and a scatterplot was produced allowing visual comparison between quadrats and pollen samples in the same geometric space. Taxonomic harmonization of the data sets was necessary to allow appropriate comparison between vegetation and pollen samples, because many pollen types are only identifiable to family level, or are taxonomic groupings that comprise several plant species. This necessarily involved the aggregation of some plant species into larger groups, the removal of any plants not recorded in pollen assemblages, and the removal of pollen types or spores without representation amongst the flora. Table 1 shows which plant species were aggregated as members of the same pollen type, whilst Table 2

Table 1 Palynological equivalents of plants recorded in quadrats

Pollen type	Plant species included within this category
<i>Achillea</i> -type	<i>Achillea millefolium</i> ; <i>Matricaria matricarioides</i>
Apiaceae	<i>Angelica archangelica</i>
Brassicaceae	<i>Capsella bursa-pastoris</i> ; <i>Cardamine pratensis</i> ; <i>Draba incana</i> ; <i>Draba norvegica</i>
Caryophyllaceae	<i>Cerastium alpinum</i> ; <i>Lychnis viscaria</i> ; <i>Sagina nodosa</i> ; <i>Silene acaulis</i> ; <i>Stellaria alsine</i> ; <i>Stellaria longipes</i> ; <i>Stellaria media</i> ; <i>Viscaria alpina</i>
<i>Cerastium</i> -type	<i>Cerastium alpinum</i> ; <i>Stellaria alsine</i> ; <i>Stellaria longipes</i> ; <i>Stellaria media</i>
Cyperaceae	<i>Carex atrata</i> ; <i>Carex capitata</i> ; <i>Carex curta</i> ; <i>Carex nigra</i> ; <i>Carex panacea</i> ; <i>Carex praticola</i> ; <i>Carex rariflora</i> ; <i>Carex scirpoidea</i> ; <i>Eriophorum angustifolium</i> ; <i>Eriophorum scheuchzeri</i> ; <i>Kobresia myosuroides</i>
<i>Epilobium</i> -type	<i>Chamaenerion angustifolium</i> ; <i>Epilobium palustre</i>
<i>Equisetum</i>	<i>Equisetum arvense</i> ; <i>Equisetum variegatum</i>
Ericales undiff.	<i>Empetrum nigrum</i> ; <i>Vaccinium uliginosum</i>
Fabaceae	<i>Lathyrus japonicus</i>
Gentianaceae	<i>Gentiana nivalis</i> ; <i>Lomatogonium rotatum</i>
Lactuceae	<i>Hieracium</i> spp.; <i>Leontodon autumnalis</i> ; <i>Taraxacum</i> spp.
Poaceae	<i>Agrostis</i> spp.; <i>Alopecurus geniculatus</i> ; <i>Anthoxanthum odoratum</i> ; <i>Calamagrostis neglecta</i> ; <i>Deschampsia caespitosa</i> ; <i>Deschampsia flexuosa</i> ; <i>Festuca</i> spp.; <i>Phleum commutatum</i> ; <i>Poa</i> spp.; <i>Trisetum spicatum</i> ; <i>Trisetum triflorum</i>
<i>Potentilla</i> -type	<i>Potentilla anserina</i> ; <i>Potentilla palustris</i> ; <i>Potentilla tridentata</i> ; <i>Sibbaldia procumbens</i>
Pteropsida (monolete) indet.	<i>Woodsia ilvensis</i>
<i>Rhinanthus</i> -type	<i>Euphrasia frigida</i> ; <i>Rhinanthus minor</i>
<i>Salix</i>	<i>Salix arctophila</i> ; <i>Salix glauca</i>

Table 2 Plants and pollen types excluded from the combined DCA of vegetation and pollen samples, and the calculation of indices of association, over- and under-representation. The total number of quadrats/pollen samples where each plant/pollen type was recorded is given, together with the maximum percentage recorded in any one sample.

Taxon	Number of quadrats	Maximum cover (%)
Plant species		
<i>Armeria maritima</i>	1	4
<i>Galium brandegei</i>	2	15
<i>Geranium sylvaticum</i>	1	1
<i>Juncus trifidus</i>	8	7
<i>Luzula multiflorum</i>	7	4
<i>Luzula spicata</i>	14	3
<i>Pinguicula vulgaris</i>	1	1
<i>Platanthera hyperborea</i>	1	1
<i>Sedum annuum</i>	4	2
<i>Sedum rosea</i>	1	3
<i>Sedum villosum</i>	1	1
<i>Viola canina</i>	1	1
<i>Viola palustris</i>	2	1
Pollen/spore type		
<i>Alnus</i>	33	0.6
<i>Ambrosia</i>	2	0.2
<i>Artemisia</i>	1	0.2
<i>Botrychium</i>	31	8.6
<i>Huperzia selago</i>	3	0.3
<i>Lycopodium annotinum</i>	43	11.1
<i>Menyanthes trifoliata</i>	4	0.6
<i>Picea</i>	23	0.6
<i>Pinus</i>	9	0.4
<i>Potamogeton</i>	5	4.7
Pre-Quaternary spores	1	0.8
<i>Saxifraga oppositifolia</i> -type	3	0.2
<i>Saxifraga stellaris</i> -type	1	0.2
<i>Selaginella selaginoides</i>	7	0.6
<i>Sphagnum</i>	17	0.5
<i>Ulmus</i>	1	0.2

lists outlying plants and pollen types excluded from these analyses.

Indices of association (*A*), under-representation (*U*) and over-representation (*O*) were also calculated for all taxa present in both vegetation and pollen data sets, in accordance with the technique devised by Davis (1984) and reproduced by Hjelle (1997) and Bunting (2003). Again, any taxa occurring only as plants or only in pollen assemblages were excluded from these analyses. Indices were calculated using the following formulae:

$$A = B_0 / (P_0 + P_1 + B_0)$$

$$U = P_1 / (P_1 + B_0)$$

$$O = P_0 / (P_0 + B_0)$$

where *B*₀ is the number of samples where the pollen type and associated plant taxon are both present, *P*₀ is the number of

samples where the pollen type is present but the associated plant taxon absent from the quadrat, and *P*₁ the number of samples where the pollen type is absent but the associated plant taxon is present within the quadrat.

RESULTS

DCA vegetation

Results from the ordination of the vegetation data from Qassarsuk district are presented as scatterplots of axis 1 vs. axis 2 scores (Figs 4 & 5). The ordination axes record eigenvalues of 0.931 and 0.847, with axes lengths of 6.26 and 7.46 standard deviation (SD) units respectively. These values denote good separation of species along both axes, and high 'turnover' of species between samples (i.e. quadrats at opposite ends of the axes share few, if any, of the same taxa) (Jongman *et al.*, 1995).

Axis 1 appears to reflect the degree to which habitats have been modified, managed or disturbed by human activity. Along this axis there is clear separation of quadrats representative of the fields and ruderal habitats (to the centre and right of the diagram) from the other vegetation types. Quadrats representing fields, field boundaries and meadows, plot in a cluster focused on the centre of the ordination diagram. These communities are dominated by *Poa* spp. and *Phleum commutatum*, suggesting that these taxa are probably favoured for hay production in this region. *Alchemilla filicaulis*, *Deschampsia caespitosa*, *Equisetum arvense*, *Rhinanthus minor* and *Rumex acetosa* are also closely associated with the field quadrat cluster. Quadrats from the farmyards (R62, R64) record axis 1 values that are generally slightly greater than for the infields, and are more closely associated with annual herbs which typically invade bare ground where disturbance is common (e.g. *Capsella bursa-pastoris*, *Polygonum aviculare*, *Stellaria media* and *Matricaria matricarioides*). *Ranunculus acris* is typical of pastoral activity in north-west Europe and is a common component of many field communities seen here (e.g. I51 and I57), although its position on the diagram close to the heath cluster and the footpath communities (R61 and R63) indicates that this taxon is also present within other habitats. *Leontodon autumnalis*, *Plantago maritima* and *Taraxacum officinale* appear to be closely associated with footpath habitats.

Axis 2 appears to reflect a soil hydrological gradient, with wet habitats correlated with high scores. The highest axis 2 quadrat score (7.46 SD units) is recorded for M41 which represents *Carex curta*–*Eriophorum scheuchzeri* reedswamp growing in up to c. 20 cm depth of standing water. The remainder of the mire quadrats (M42–M48) form a tight cluster slightly below the position of M41 and centre upon *Salix arctophila* and the sedges *Carex rariflora*, *Carex nigra*, *Carex praticola* and *Eriophorum angustifolium*. These samples represent mires that occupy drier sites than M41, in locations where the summer water table is at, or below, the level of the ground surface.

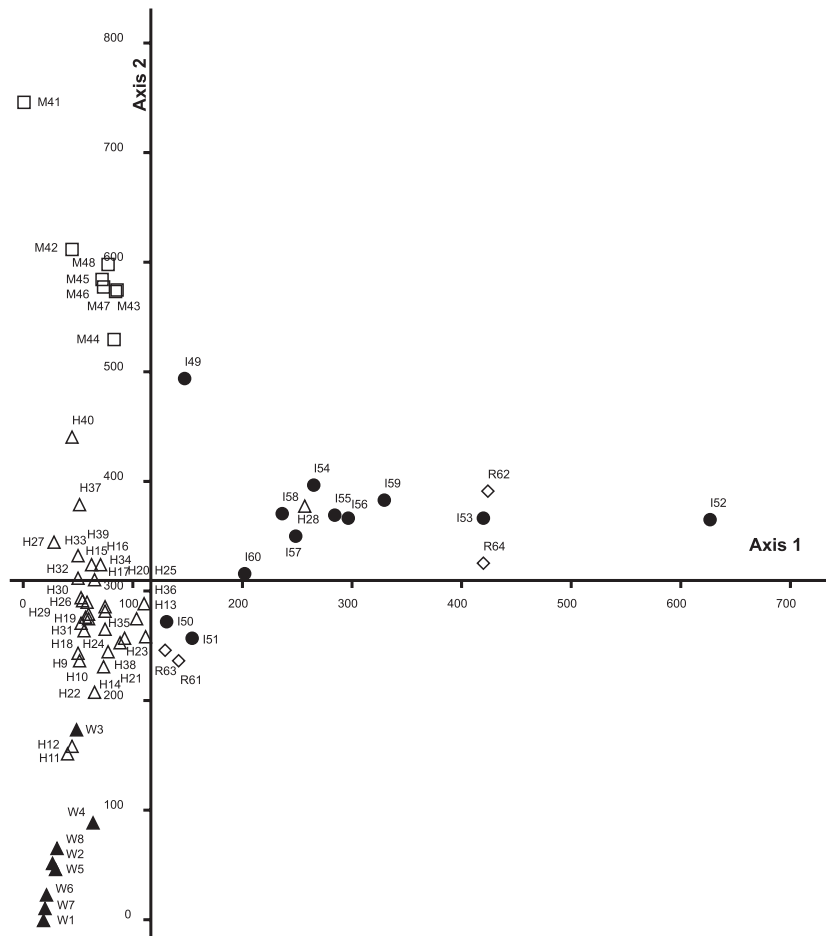


Figure 4 Scatterplot of DCA axis 1 vs. axis 2 scores for vegetation quadrats. Key: ▲ = woodland; △ = heath and steppe; □ = mire; ● = field; ◇ = ruderal. Coding and further details of individual samples are available in Appendix S1 (see *Supplementary Material*).

A number of taxa representative of damp herb slopes and/or snow-patches (e.g. *Euphrasia frigida*, *Luzula multiflora*, *Potentilla palustris* and *Viola palustris*) plot slightly below the mires cluster, and are closely associated with the sedge-dominated steppe samples H37 and H40. The heath samples form a very tight cluster near the origin of the diagram, between the mires and woodlands groupings. This cluster contains the dwarf shrubs *Betula glandulosa* and *Salix glauca*, plus the ericaceous shrubs, and a wide variety of herbs including *Campanula gieseckiana*, *Potentilla tridentata*, *Rumex acetosella*, and *Thalictrum alpinum*. Woodland quadrats, and scrub quadrats located in close proximity to the woodland edge (e.g. H11 and H12), record the lowest axis 2 scores. The woodland grouping contains *Betula pubescens* plus the dwarf shrub *Juniperus communis*. *Deschampsia flexuosa* also plots within this cluster suggesting this grass is common amongst taxa that make up the woodland field layer.

DCA paired quadrats and pollen samples

Results from the ordination of paired quadrat and pollen samples from Qassiarsuk district are presented as a scatterplot of DCA axis 1 vs. axis 2 scores (Fig. 6). The ordination axes for the harmonized vegetation data set record eigenvalues of 0.649 and 0.501, with axes lengths of 3.98 and 3.81 SD units,

respectively. Eigenvalues greater than 0.5 can generally be regarded as denoting good separation of species along axes (Jongman *et al.*, 1995). The ordination axes for the pollen data set, however, record smaller eigenvalues of 0.485 and 0.261, and shorter axes lengths of 2.84 and 2.04 SD units. These figures reflect somewhat poorer separation of pollen types between samples when compared with the separation of plant species between vegetation samples. This is partly to be expected given the inherent difficulties involved in separating many pollen types beyond the level of family or genus, and a pollen source area for the moss polsters which must certainly include neighbouring vegetation communities from the wider area beyond the boundaries of the quadrats.

Inspection of Fig. 6 suggests close correlation between the majority of sample pairs. This is particularly the case for many samples from heath and steppe habitats, and fields and meadows, which show limited dispersion and generally form quite tight point clusters. There are also a number of sample pairs which are a poor match. Six of the heathland quadrats (H10–H12 and H23–H25) plot in the lower left quarter of the diagram and away from the main heath cluster (which contains their respective pollen samples). Ground cover in three of these quadrats (H23, H24 and H25) is dominated by ericales, yet the associated pollen assemblages contain little or no pollen of this type. For example, in H23 ground cover for *Vaccinium*

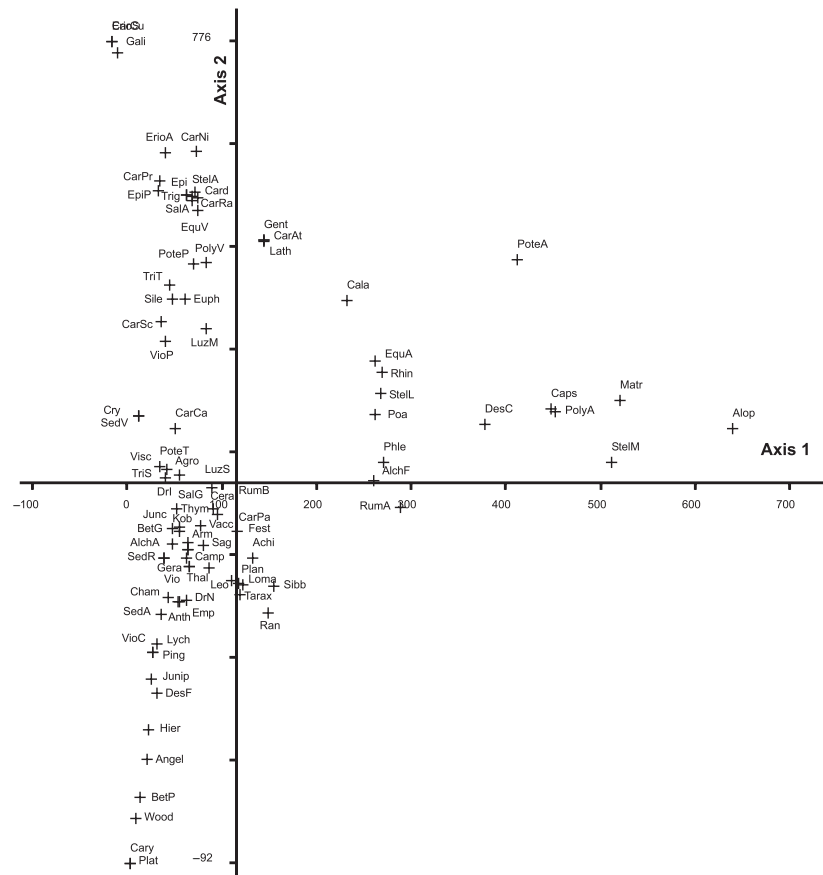


Figure 5 Scatterplot of DCA axis 1 vs. axis 2 scores for plant species recorded in quadrats. Key: Agro = *Agrostis* spp.; AlchA = *Alchemilla alpina*; AlchF = *Alchemilla filicaulis*; Achi = *Achillea millefolium*; Alop = *Alopecurus geniculatus*; Angel = *Angelica archangelica*; Anth = *Anthoxanthum odoratum*; Arm = *Armeria maritima*; BetG = *Betula glandulosa*; BetP = *Betula pubescens*; Cala = *Calamagrostis neglecta*; Camp = *Campanula gieseckiana*; Caps = *Capsella bursa-pastoris*; Card = *Cardamine pratensis*; CarAt = *Carex atrata*; CarCa = *Carex capillaris*; CarCu = *Carex curta*; CarNi = *Carex nigra*; CarPa = *Carex panicea*; CarPr = *Carex praticola*; CarRa = *Carex rariflora*; CarSc = *Carex scirpoidea*; Cary = *Caryophyllaceae* indet.; Cera = *Cerastium alpinum*; Cham = *Chamaenerion angustifolium*; Cry = *Cryptogramma* undiff.; DesC = *Deschampsia caespitosa*; DesF = *Deschampsia flexuosa*; DrI = *Draba incana*; DrN = *Draba norvegica*; Emp = *Empetrum nigrum*; Epi = *Epilobium* sp.; EpiP = *Epilobium palustre*; EquA = *Equisetum arvense*; EquV = *Equisetum variegatum*; ErioA = *Eriophorum angustifolium*; ErioS = *Eriophorum scheuchzeri*; Euph = *Euphrasia frigida*; Festu = *Festuca* spp.; Gali = *Galium brandegei*; Gent = *Gentiana nivalis*; Gera = *Geranium sylvaticum*; Hier = *Hieracium* sp.; Junc = *Juncus trifidus*; Junip = *Juniperus communis*; Kob = *Kobresia myosuroides*; Lath = *Lathyrus japonicus*; Leo = *Leontodon autumnalis*; Loma = *Lomatogonium rotatum*; LuzM = *Luzula multiflorum*; LuzS = *Luzula spicata*; Lych = *Lychnis viscaria*; Matr = *Matricaria matricarioides*; Phle = *Phleum commutatum*; Ping = *Pinguicula vulgaris*; Plan = *Plantago maritima*; Plat = *Platanthera hyperborea*; Poa = *Poa* spp.; PolyA = *Polygonum aviculare*; PolyV = *Polygonum viviparum*; PoteA = *Potentilla anserina*; PoteP = *Potentilla palustris*; PoteT = *Potentilla tridentata*; Ran = *Ranunculus acris*; RumA = *Rumex acetosa*; RumB = *Rumex acetosella*; Rhin = *Rhinanthus minor*; Sag = *Sagina nodosa*; SalA = *Salix arctophila*; SalG = *Salix glauca*; SedA = *Sedum annuum*; SedR = *Sedum rosea*; SedV = *Sedum villosum*; Sibb = *Sibbaldia procumbens*; Sile = *Silene acaulis*; StelA = *Stellaria alsine*; StelL = *Stellaria longipes*; StelM = *Stellaria media*; Tarax = *Taraxacum officinale*; Thal = *Thalictrum alpinum*; Thym = *Thymus drucei*; Trig = *Triglochin palustris*; TriS = *Trisetum spicatum*; TriT = *Trisetum triflorum*; Vacc = *Vaccinium uliginosum*; Vio = *Viola* sp.; VioC = *Viola canina*; VioP = *Viola palustris*; Visc = *Viscaria alpina*; Wood = *Woodsia ilvensis*.

uliginosum is 53% yet only 3.9% is recorded for this taxon in the pollen assemblage. Quadrats H11 and H12 also plot as outliers at the extreme left of the diagram, and a significant distance (approximately 2 SD units along axis 2) separates them from their respective pollen samples. In both cases, *Juniperus communis* is the locally dominant plant (55–65% ground cover) yet little or no pollen from this taxon is recorded for either pollen assemblage (a maximum of 2.4% of *Juniperus* pollen is

recorded in h11). Samples H10/h10 and H27/h27 also appear to be poor pairings. In both cases a single dominant taxon can be identified within the quadrat (*Betula glandulosa* 60% cover in H10; *Potentilla tridentata* 80% cover in H27) which is under-represented within the associated pollen assemblage (44% *B. glandulosa* in h10; 7.5% *Potentilla*-type in h27).

Woodland sample pairs, and scrub samples from the woodland–heathland ecotone, plot in the upper left quarter

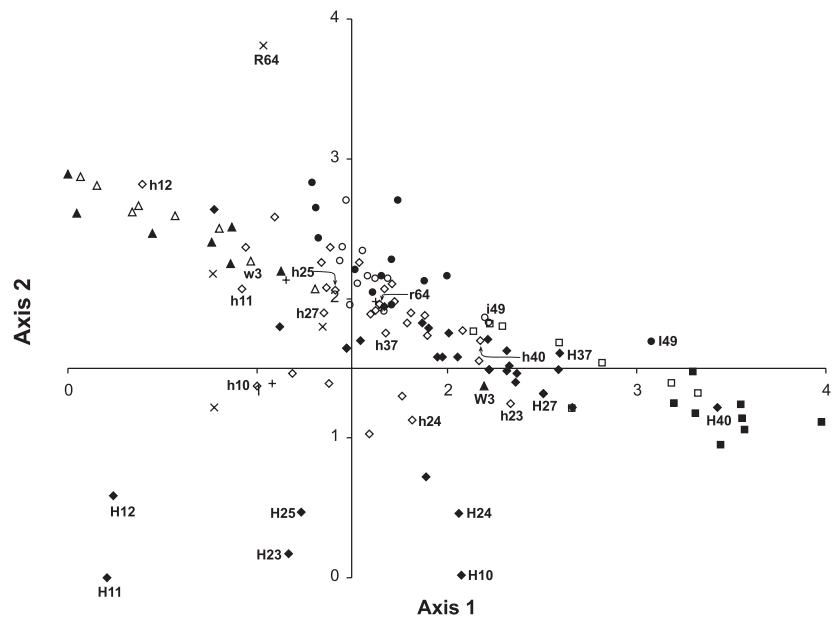


Figure 6 Scatterplot of DCA axis 1 vs. axis 2 scores for paired quadrats and pollen samples. Samples referred to in the text are labelled. Key: ▲▲ = woodland; ◆◆ = heath and steppe; ■□ = mire; ●○ = field; ×+ = ruderal; the first symbol of each pair indicates vegetation samples, the second symbol indicates pollen samples.

of the diagram. Many of the sample pairs from locations under the birch canopy at the centre of the woodland show close association. However, a sample taken from a *Salix glauca* stand within this predominantly birch woodland (W3) displays poor correlation with its pollen sample (w3) due to high *Betula pubescens* pollen deposition (38%).

Mire sample pairs plot far to the right along axis 1. Here there is clear separation between the quadrats, which plot on the edge of the ordination space, and their associated polsters, which plot closer to the diagram centre. Many sample pairs are separated by up to 1 SD unit along axis 1, indicating a near half-change or 50% species turnover (Kent & Coker, 1992) between plants occurring on the ground and those registered in the pollen assemblages. The position of mire quadrats as outliers on the diagram probably reflects the limited species diversity of these communities and their dominance by taxa (particularly *Carex* spp. or *Eriophorum* spp.) that reach their greatest abundance in this habitat. The position of the mire polsters closer to the centre of the diagram indicates pollen recruitment from non-local sources, most likely dryland vegetation communities at the mire edge. Although the sedge-dominated steppe communities (H37 and H40) plot amongst this cluster, their pollen assemblages (h37 and h40) plot closer to the diagram centre, indicating little difference between these pollen samples and those derived from the other heathland samples.

The majority of the field sample pairs plot in a tight cluster in the centre of the diagram. The only samples which match poorly are I49/i49. Quadrat I49 represents a field–heathland ecotone, and was the only quadrat sampled that contained a significant cover (55%) of *Lathyrus japonicus*. Pollen assemblages representative of ruderal habitats plot close to the fields cluster yet at some distance from their respective quadrats. These assemblages record very high Poaceae pollen frequencies (50–90%) despite significant ground cover from agricultural

‘weeds’ such as *Leontodon autumnalis*, *Matricaria matricarioides*, *Plantago maritima* and *Polygonum aviculare*. Ruderal pair R64/r64 (a soil heap populated almost exclusively by *Stellaria media*) shows a particularly poor correlation due to high Poaceae pollen input.

Modern pollen assemblages

Pollen assemblages for each of the 64 moss polsters analysed from Qassiarsuk district are displayed in Fig. 7.

The woodland pollen assemblages reflect pollen deposition below low-stature birch woodland on slopes above Narsarsuaq. Pollen frequencies for tree birch (*Betula pubescens*) are extremely high under a closed canopy (samples 1, 5–8) and lower where the canopy is more open (samples 2–4). The assemblages demonstrate that Poaceae pollen frequencies can approach 50% even directly below a woodland canopy. Pollen assemblages at the birch woodland–dwarf shrub heath ecotone (samples 9–12) continue to display high pollen values for *Betula pubescens* in combination with increased pollen input for *Betula glandulosa*.

Herbaceous pollen comprises 80–90% of most heath and steppe samples, with the largest single contribution coming from Poaceae. Other prominent herbaceous pollen types in this environment are *Thymus drucei*, *Thalictrum alpinum*, *Campanula gieseckiana*, *Potentilla*-type and *Rumex acetosella*. In samples from coastal heaths *Plantago maritima* is also important, approaching 30% in some assemblages around Igaliku. Patches of dense scrub amongst more open heath/steppe vegetation can be identified by elevated *Betula glandulosa* or *Salix* pollen frequencies (e.g. up to 40% in samples 13, 23, 24, 26, and 34). *Betula pubescens* recorded in open heath samples far from the woodland edge could represent procumbent individuals which were occasionally observed growing on the heaths amongst patches of *B. glandulosa*. Only traces of

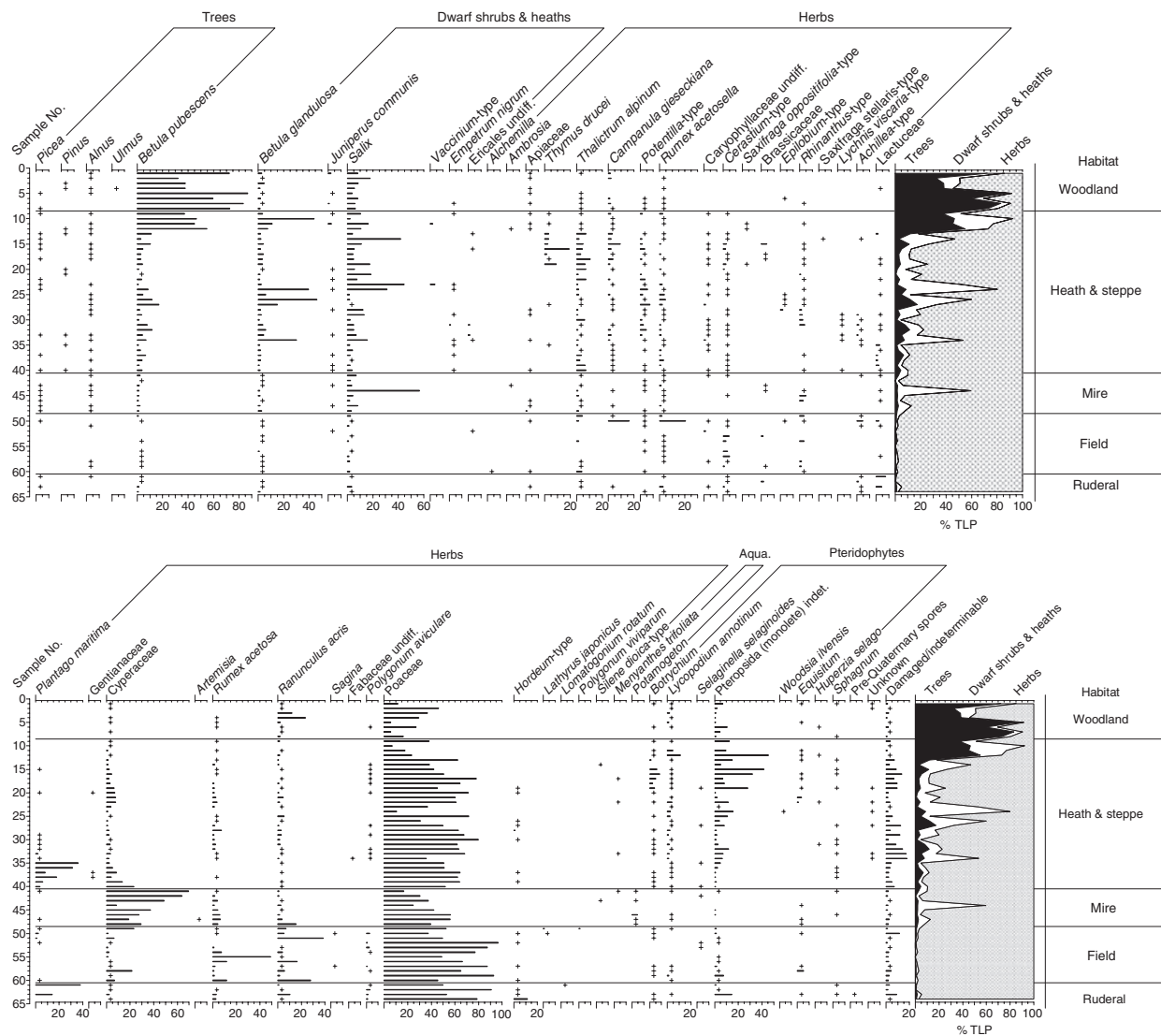


Figure 7 Pollen diagram displaying assemblages for the 64 samples analysed during this study. Percentages are based upon a TLP or TLP + group sum; + indicates representation at less than 1%.

pollen from the ericales and *Juniperus communis* are recorded, however, despite the prominence of these plants in many heathland communities.

The mires display high frequencies of Cyperaceae pollen. Poaceae pollen is also abundant despite grasses providing less than 5% ground cover in every mire quadrat except M42. *Salix* is generally poorly represented despite a ground cover of up to 35% for *Salix arctophila*. *Rumex acetosa* and *Ranunculus acris* pollen regularly approaches or exceeds 5% in these wetland assemblages. This pollen must be derived from non-local sources as both plants are absent from these wetland communities.

Poaceae pollen dominates pollen assemblages obtained from hay fields, field margins, meadows and ruderal habitats, approaching 90% in some cases. *Ranunculus acris* and *Rumex acetosa* pollen also record very high frequencies (40%) in some

of the field assemblages. *Cerastium*-type pollen reaches maximum abundance in the field samples, whilst pollen from Lactuceae (probably representative of *Leontodon autumnalis*) and *Plantago maritima* is more important in assemblages from footpaths (samples 61 and 63). An unusual feature of the ruderal pollen assemblages is the 11% *Hordeum*-type pollen registered in sample 64. This sample was taken from a soil heap colonized by *Stellaria media* and *Polygonum aviculare*, in close proximity (< 100 m) to a field containing an unripened barley crop at Tasiusaq.

Representation indices

Indices of association (A), under- (U) and over-representation (O) for taxa occurring as both plants and pollen types in samples from Qassarsuk district are presented in Table 3. Of

Table 3 Indices of association (*A*), under-representation (*U*), and over-representation (*O*) for taxa present as both plants and pollen in data sets

Pollen type	<i>B</i> ₀	<i>P</i> ₀	<i>P</i> ₁	<i>A</i>	<i>U</i>	<i>O</i>	Category of association
<i>Achillea</i> -type	8	8	1	0.47	0.11	0.50	Weakly associated
<i>Alchemilla</i>	1	0	2	0.33	0.67	0.00	Under-represented
Apiaceae	4	13	2	0.21	0.33	0.76	Weakly associated
<i>Betula glandulosa</i>	9	43	0	0.17	0.00	0.83	Over-represented
<i>Betula pubescens</i>	8	51	0	0.14	0.00	0.86	Over-represented
Brassicaceae	4	4	4	0.33	0.50	0.50	Weakly associated
<i>Campanula gieseckiana</i>	23	15	2	0.58	0.08	0.39	Associated
Caryophyllaceae	20	24	4	0.42	0.17	0.55	Weakly associated
<i>Cerastium</i> -type	16	21	2	0.41	0.11	0.57	Weakly associated
Cyperaceae	18	43	0	0.30	0.00	0.70	Over-represented
<i>Empetrum nigrum</i>	1	9	1	0.09	0.50	0.90	Weakly associated
<i>Epilobium</i> -type	3	3	12	0.17	0.80	0.50	Weakly associated
<i>Equisetum</i>	6	12	6	0.25	0.50	0.67	Weakly associated
Ericales undiff.	5	10	3	0.28	0.38	0.67	Weakly associated
Gentianaceae	2	2	4	0.25	0.67	0.50	Weakly associated
<i>Juniperus communis</i>	3	13	5	0.14	0.63	0.81	Weakly associated
Lactuceae	5	18	9	0.16	0.64	0.78	Weakly associated
<i>Lathyrus japonicus</i>	2	0	0	1.00	0.00	0.00	Strongly associated
<i>Plantago maritima</i>	7	16	0	0.30	0.00	0.70	Over-represented
Poaceae	63	1	0	0.98	0.00	0.02	Strongly associated
<i>Polygonum aviculare</i>	3	19	1	0.13	0.25	0.86	Over-represented
<i>Polygonum viviparum</i>	1	0	24	0.04	0.96	0.00	Under-represented
<i>Potentilla</i> -type	19	18	7	0.43	0.27	0.49	Weakly associated
Pteropsida (mono) indet.	3	52	0	0.05	0.00	0.95	Over-represented
<i>Ranunculus acris</i>	20	39	0	0.34	0.00	0.66	Over-represented
<i>Rhinanthus</i> -type	20	6	14	0.50	0.41	0.23	Weakly associated
<i>Rumex acetosa</i>	9	38	0	0.19	0.00	0.81	Over-represented
<i>Rumex acetosella</i>	9	43	0	0.17	0.00	0.83	Over-represented
<i>Salix</i>	33	24	0	0.58	0.00	0.42	Associated
<i>Thalictrum alpinum</i>	21	30	2	0.40	0.09	0.59	Weakly associated
<i>Thymus praecox</i>	9	2	3	0.64	0.25	0.18	Associated
<i>Vaccinium</i> -type	2	0	7	0.22	0.78	0.00	Under-represented

*B*₀ = number of samples with both pollen type and plant present. *P*₀ = number of samples where pollen type is present but plant is absent. *P*₁ = number of samples where pollen type is absent but plant is present.

the 32 taxa analysed, half can be considered to show only a weak association between the plant on the ground and its pollen equivalent, displaying relatively low *A* values (generally < 0.5) and moderate to high *U* and *O* values (generally > 0.5). However, five taxa record *A* values in excess of 0.5 and moderate to low *U* and *O* values, indicating there is good agreement between the presence of the plant and its pollen (cf. Davis, 1984; Hjelle, 1997; Bunting, 2003). This group includes taxa that are ubiquitous throughout the Greenlandic landscape (e.g. Poaceae), or are common to many but not all communities (e.g. *Salix*), or are insect-pollinated with limited pollen dispersal capability (e.g. *Campanula*, *Lathyrus* and *Thymus*). Eight over-represented taxa can be identified, displaying high *O* values (> 0.65), low *A* values, and zero *U* values. These taxa are generally wind-pollinated or frequent throughout a number of habitats and include *Betula* spp., *Rumex* spp., Cyperaceae, *Plantago maritima* and *Ranunculus acris*. Undifferentiated fern spores also fall within this category.

Only three taxa were found to be under-represented, displaying high *U* values (> 0.65), low *A* values and zero *O* values. Plants within this category are either self-fertilized (*Polygonum viviparum* and *Vaccinium*) or apomictic (*Alchemilla*).

DISCUSSION

To date, relatively little published research is available concerning the study of modern pollen assemblages in Greenland. Pennington's (1980) investigation of modern pollen rain from lake sediments and moss polsters around Søndre Strømfjord (67° N) and Disko Island (70° N) is the most recent publication on this theme, and it is now over 30 years since Fredskild (1973) made available his data on Tauber traps placed around Qassiarsuk. The new results presented in this study expand significantly upon this earlier work and quantify some of the relationships that exist between vegetation and pollen deposition in this landscape.

Comparison of modern pollen samples and vegetation communities

One of the limitations of pollen analysis as a technique for reconstructing vegetation communities is its inability in many cases to allow taxonomic identification of pollen grains and spores to species level. Within any landscape, the relationships that exist between the occurrence of some plant species and pollen representation may always be somewhat unclear even where interspecific differences in pollen production, dispersal and taphonomy can be resolved. This is clearly demonstrated in the ordination diagrams where the vegetation samples show much greater separation and species turnover relative to the pollen samples. Furthermore, although the number of seasons over which moss polsters collect pollen rain is generally considered to be low (e.g. Räsänen *et al.*, 2004), Davis (1984) has suggested that in some cases moss polsters may integrate pollen rain over several decades. Over such a timescale the local vegetation mosaic could change significantly, especially where herbaceous plants with short life spans are involved.

Despite these inherent problems, the majority of modern pollen samples analysed for this investigation are close approximations of the plant communities from which they are derived. In this sense the new data presented here support the conclusions reached by Hjelle (1999) that there is good agreement between modern pollen assemblages and vegetation in the open vegetation types (pastures, meadows and heaths) of western Norway. In particular, in southern Greenland there appears to be good correspondence between paired vegetation and pollen samples in *Salix glauca* and *Betula glandulosa* dwarf shrub heath communities, and amongst field boundary and meadow plant communities, which are presently the two most common and extensive habitats found within this region.

Dwarf shrub heaths comprise a mosaic of scrub (with shrubs dominant) and steppe (with grasses dominant). Pennington (1980) found it near impossible to distinguish between these components, other than on the basis of percentages of minor herb taxa, due to over-representation of two dominant taxa (*Betula nana* and Poaceae). Pollen of *Campanula gieseckiana*, *Potentilla*-type, *Thymus* and *Thalictrum alpinum* are consistently recorded and commonly well represented in the majority of heath and steppe assemblages analysed here, and the occurrence of these pollen types should therefore be interpreted as indicative of this type of vegetation. In addition the new data also suggest patches of dense *Salix glauca* and *Betula glandulosa* scrub within the heathland mosaic can, in some cases, be differentiated from more open steppe areas through their high shrub pollen frequencies (which approach 40%). Although *Salix* is generally regarded as an under-represented taxon (e.g. Bradshaw, 1981), plant and pollen in this landscape appear to be well-associated ($A = 0.58$) and even over-represented in some quadrats ($O = 0.42$, $U = 0.00$). This could be a function of the common status of this genus (and hence its pollen) in every natural habitat throughout southern Greenland, with the shrub being important not only in heath

and woodland communities (as *Salix glauca*) but also present in high numbers across mire surfaces (as *Salix arctophila*).

Pollen assemblages from moss polsters beneath *Vaccinium uliginosum*, *Empetrum nigrum* and *Juniperus communis* dwarf shrub heath, however, appear poor at replicating plant abundance. The dominant taxa in these quadrats were found to be either heavily under-represented (e.g. *Vaccinium*-type) or only weakly associated (e.g. *E. nigrum* and *J. communis*) in pollen assemblages. The poor association and under-representation of *Vaccinium* ($A = 0.22$, $U = 0.78$) is contrary to palynological data collected from other open heath or moorland landscapes in northwest Scotland and western Norway, where *Vaccinium*-type pollen and ground cover recorded in quadrats were found to be strongly associated ($A \geq 0.78$, $U \leq 0.07$) (Hjelle, 1997; Bunting, 2003). Different species of *Vaccinium* (*V. myrtillis* and *V. vitis-idaea*) were, however, involved in these studies. Rymer (1973) also noted a complete absence of Ericaceae undiff. pollen in modern Icelandic assemblages taken from communities containing *V. uliginosum*.

Implications for the interpretation of Norse-age fossil pollen data from Greenland

Even in pre-*landnám* pollen assemblages from this region (e.g. Fredskild, 1973, 1978), the balance between tree, dwarf shrub and herbaceous components is heavily biased in favour of the latter. Shifts in the balance between these groups are used to infer human disturbance (clearance of copses or scrub) following the arrival of the Norse. Woodland and scrub clearance in this predominantly open landscape results in less dramatic vegetation changes when compared with heavily wooded regions, and produces subtle rather than major changes in pollen diagrams. Interpretation of vegetational changes is not improved by the main arboreal and non-arboreal taxa in Greenlandic pollen diagrams (*Betula* spp. and Poaceae) being heavily over-represented and, in the case of Poaceae, largely ubiquitous throughout every plant community in the region. Modern pollen assemblages from Narsarsuaq demonstrate that even in the centre of birch woodland, Poaceae pollen frequencies can approach 50%. Over-representation of both these pollen types has long been known (e.g. Andersen, 1979; Pennington, 1980; Bradshaw, 1981).

As a consequence of the above, the use of indicator species (*sensu* Behre, 1981) to demonstrate the presence of human activity and agriculture takes on an important role. A number of European plant species are generally considered to have been introduced to the Greenlandic flora by Norse settlers, the majority of which are characteristic of human-disturbed agricultural and ruderal habitats. In the district around Qassiarsuk these plants include *Achillea millefolium*, *Capsella bursa-pastoris*, *Leontodon autumnalis*, *Rumex acetosella* and some strains of *R. acetosa* (Feilberg, 1984) together with *Polygonum aviculare*, *Stellaria media*, *Potentilla anserina*, *Poa annua* and some strains of *Ranunculus acris* (Fredskild, 1973). The sustained appearance and expansion of pollen from

Rumex spp. in pollen diagrams from southern Greenland is commonly used to date the arrival of Norse settlers (e.g. Fredskild, 1973). *Rumex acetosa* and *R. acetosella* are both proven to be heavily over-represented in modern pollen assemblages from the region ($O = 0.81$ and 0.83 , respectively, $U = 0$). Over-representation may be considered an advantage in this context because it allows the plants to be detected even when present in low numbers and not growing within the immediate vicinity of the sampling location. *Ranunculus acris* and *Polygonum aviculare* are other over-represented apophytes favoured by the Norse arrival ($O = 0.66$ and 0.86 , respectively), although a non-zero under-representation index for *Polygonum* ($U = 0.25$) does indicate that the dispersal of this pollen type can be somewhat unpredictable. Hjelle (1997) and Bunting (2003) record both *Rumex* and *Ranunculus* as over-represented taxa in studies from high latitude open landscapes, and the results presented here provide further evidence to support this.

Another interesting feature of the modern pollen samples from around Qassiarsuk is the presence of *Hordeum*-type pollen in around one quarter of the assemblages. It is possible that at least some of these pollen grains may represent *Elymus arenarius*, which is included within the *Hordeum*-type cereal category of Andersen (1979; and cf. Tweddle *et al.*, 2005). *Elymus* is today common on open sandy or stony ground in and amongst the settlement ruin groups at the head of Ejnars Fjord near Igaliiku. Yet the highest *Hordeum*-type frequencies (c. 11%) are recorded in a farmyard at Tasiusaq, in close proximity to a barley field. *Elymus* was not observed growing in this area during the 2004–2005 vegetation study, and does not appear at this location on species distribution maps produced by Feilberg (1984), suggesting that the pollen seen in samples from Tasiusaq is likely to represent *Hordeum vulgare* derived from arable fields. The barley crop in Tasiusaq was harvested in early August before ripening and was presumably grown to provide winter hay or silage for farm livestock. Pollen of cultivated crops is naturally the best indicator of agriculture (Behre, 1981) and Fredskild (1978) notes that according to the Norse sagas there were occasional but unsuccessful attempts by the Norse to grow cereals in Greenland, although at the time of writing only one fossil cereal-type pollen grain has been recorded for the Eastern Settlement (Fredskild, 1978). The climate at the start of the Norse *landnám* is considered to have been as warm, if not slightly warmer than the mid-20th century (Fredskild, 1988) and modern pollen samples, especially from the area around Tasiusaq, demonstrate that temperatures today must occasionally be sufficient to allow cereals to flower.

Fossil pollen assemblages from Qassiarsuk also record high numbers of pteridophyte spores. Fern spores from *Dryopteris* and *Gymnocarpium* record frequencies of 5–10% TP (total pollen) in profiles from Comarum Sø and Galium Kær (Fredskild, 1973), and approach 40% in pre-*landnám* clay and sand-rich deposits in profiles from Qassiarsuk (Fredskild, 1978). Dwarf shrub vegetation surrounding these sites was consequently considered to be rich in ferns.

Data produced by the current study, however, suggest that this was probably not the case, and that numbers of pteridophyte spores found in pollen assemblages heavily over-represent the real number of plants on the ground. Pteropsida (monoete) indet. record frequencies of up to 40% TLP + group in some samples, yet only 1 of 64 quadrats sampled record pteridophytes amongst the flora (an individual of *Woodsia ilvensis* was recorded in H9) and the over-representation factor for Pteropsida monoete indet. ($O = 0.95$) is the highest for any of the taxa featured in this study. Spores of *Botrychium* (present in 31 polsters with maximum abundance 8.6% + group) and *Lycopodium annotinum* (present in 43 polsters, maximum 11.1% + group) were also recorded in many of the same pollen assemblages, despite a complete absence of these taxa within the quadrats.

The source of these spores is uncertain. Given the low numbers of individuals observed in the modern vegetation, perhaps many are extra-local or regional in origin, or derived from plant communities growing in mountain top fell-fields or scree that were not visited during the vegetation survey, because most of the taxa within this group can tolerate long periods of snow-cover and wind exposure (Böcher *et al.*, 1968). What appears certain is that spores are readily incorporated into soil profiles, where they may reside for long periods. In this study the highest spore frequencies were recorded where the predominant sampling medium was soil, with consistently lower fern spore frequencies recorded in the moss polsters. Soil samples also register much higher percentages of damaged/indeterminable pollen grains relative to the moss polsters, and a statistically significant positive correlation ($\alpha \leq 0.05$) exists between fern spore frequencies and frequencies of indeterminable grains for both sampling media (Table 4).

The resistance of spores to biological and chemical degradation has been long known from experimental studies (cf. Havinga, 1964, 1984) and an abundance of pteridophyte spores and indeterminable grains in pollen assemblages can often be indicative of post-depositional biasing (Bunting & Tipping, 2000). In this context soil samples (and many leaf litter samples, which can incorporate a soil component) should be regarded as potentially less reliable sampling media for modern pollen than moss polsters. Knowledge that high numbers of fern spores are closely associated with soil samples

Table 4 Pearson's product–moment correlation coefficients (r) correlating percentage Pteropsida (monoete) indet. against percentage damaged/indeterminable pollen grains for different sampling media

Sampling medium	Samples	Pearson's r
Moss	19	0.388
Leaf litter	28	0.144
Soil	17	0.444
All samples	64	0.350

Significant relationships at the 0.05 level (one-tailed test) are indicated in bold.

should, however, prove advantageous for future palaeoenvironmental studies. It appears likely that elevated frequencies of pteridophyte spores in fossil pollen assemblages will indicate the presence of topsoil reworked into peat basins by fluvial or aeolian processes. Fluctuating fern spore frequencies in Greenlandic pollen diagrams thus potentially provide another proxy to complement standard methods used in detecting past levels of soil erosion in this landscape (e.g. loss-on-ignition and magnetic susceptibility measurements).

CONCLUSIONS

The representation of modern plant communities by means of their pollen assemblages is inevitably always going to involve some loss of ecological information given the difficulty in separating all pollen types to species level. In spite of this, modern pollen assemblages obtained from moss polsters in southern Greenland appear to offer good representations of the local vegetation recorded in quadrats within 1 m of the sampling point for many floristic communities. The pollen samples were poor, however, at representing dwarf shrub vegetation dominated by *Vaccinium uliginosum*, *Empetrum nigrum* and *Juniperus communis*; suggesting that these communities will be heavily under-represented in fossil pollen assemblages in this environment. Indices of association and representation calculated for taxa found in both the quadrats and pollen samples show that many of the apophytes used in this environment to detect Norse activity (e.g. *Rumex acetosa*, *R. acetosella* and *Ranunculus acris*) should be particularly sensitive indicators for the onset of *landnám* due to their over-representation in the pollen rain. The over-representation of *Betula* and Poaceae in pollen assemblages is again demonstrated in this study. High spore frequencies combined with low percentage ground cover of ferns and clubmosses also suggests that spores are highly over-represented. Flowering of *Hordeum vulgare* (during at least one season) was demonstrated by the presence of cereal-type pollen in close proximity to an arable field containing a barley crop.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online from <http://www.blackwell-synergy.com>:

Appendix S1 Community notes for quadrats together with GPS positional and altitudinal data.

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BIOSKETCHES

Ed Schofield is a post-doctoral research fellow with specific research interests in palynology, palaeoecology and the impact of early human societies on vegetation and landscape.

Kevin Edwards is Professor in Physical Geography with research interests in palynology and early human impacts on landscape development.

Andy McMullen is a freelance botanist with particular interests in bryophytes, palaeoecology, macrofossil and testate amoebae analysis.

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