Original Article

Human impact on an island ecosystem: pollen data from Sandoy, Faroe Islands

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Running title: Pollen data from Sandoy, Faroe Islands

ABSTRACT

Aim To investigate the form and dynamics of ecosystems on an isolated island in the North Atlantic before human settlement in the first millennium AD, and the effects of human activities thereafter.

Location The island of Sandoy, Faroes (61º 50’N, 6º 45’W).

Methods Two sequences of lake sediments and one of peat were studied using pollen analysis and sedimentological techniques. Age models were constructed on the basis of radiocarbon dating and, in one case, tephrochronology. The data were analysed statistically and compared with existing data from the region.

Results The pollen data indicate that early Holocene vegetation consisted of fell-field communities probably growing on raw, skeletal soils. These communities gave way to grass- and sedge-dominated communities, which in turn were largely replaced by dwarf shrub-dominated blanket mire communities well before the first arrival of humans. There is evidence for episodic soil erosion, particularly in the uplands. Changes in the records attributable to human impact are minor in comparison with many other situations in the North Atlantic margins, and with certain published sequences from elsewhere in the Faroes. They include: 1) the appearance of cereal pollen, and charcoal; 2) an expansion of ruderal taxa; 3) a decline in certain taxa, notably *Juniperus communis* and *Filipendula ulmaria*; and 4) a renewed increase in upland soil erosion rates. The reliability of palaeoecological inferences drawn from these sites, and more generally from sites in similar unforested situations, is discussed.

Main conclusions The subdued amplitude of palynological and sedimentological responses to settlement at these sites can be explained partly in terms of their location, and partly in terms of the sensitivity of different parts of the ecosystem to human activities. This study is important in establishing that the imposition of people on the pristine environment of Sandoy, while far from negligible especially in the immediate vicinity of early farms and at high altitudes, had relatively little ecological impact in many parts of the landscape.

Keywords

Faroe Islands, human impact, *Landnám*, Norse, palaeoecology, pollen, soil erosion, vegetation

INTRODUCTION

Sandoy is a small island within the Faroese archipelago, 23 km long and 11 km wide at its maximum extent (Fig. 1). Typically for the Faroes, Sandoy has a hilly terrain, reaching 479 m above sea level (asl), composed of gently sloping beds of Tertiary flood basalts intercalated with softer tuffs which give a characteristic stepped profile to hillslopes. Glaciation during Quaternary cold stages has further conditioned the physical geography of the island, leaving relict glacial landforms and widespread deposits of Weichselian age (Humlum & Christiansen, 1998).

Current archaeological and palaeoecological data suggest that the Faroes were not settled until the first millennium AD, presumably as a consequence of their isolation. The first settlement may have been by small numbers of ecclesiastical hermits from the British Isles in the 6th to early 9th century, according to contemporary literature (*De mensura orbis terrae* written in 825 AD by the Irish monk Dicuil; Tierney, 1967) and equivocal palaeoenvironmental evidence (cf. Jóhansen, 1985; Hannon *et al.*, 2001, 2005; Edwards *et al.*, 2005a). The earliest firmly-attested period of substantial settlement occurred during the 9th century AD with the arrival of Norse settlers (Arge, 1991, 1993; Debes, 1993; Church *et al.*, 2005). This settlement – the so-called *landnám* (Old Norse: 'land-take') – occurred during the peak of the Viking/Norse expansion across northwest Europe and the Atlantic (Dugmore *et al.*, 2005). Despite such isolation, and a cool and extremely oceanic climate unfavourable to arable farming, an apparently sustainable economy based on pastoralism (primarily sheep with small numbers of cattle and pigs), limited barley cultivation and exploitation of wild resources (birds, fish and whales) was established early and continued into the twentieth century (Church *et al*., 2005; Edwards, 2005; Lawson *et al.*, 2005; Vickers *et al.*, 2005).

The present study was undertaken as part of a wider international project investigating the human impact on the environment during the Norse colonization of the Faroes, Iceland and Greenland (Edwards *et al.*, 2004; Lawson *et al.*, 2005). Their late settlement makes these islands ideal laboratories for studying the effect of people on landscapes which, in this case, had developed undisturbed for over 10,000 years under interglacial conditions since the beginning of the Holocene. In addition, although foreign imports and trade have apparently been important components of the North Atlantic island economies from the outset (e.g. Arge, 2001; Forster & Bond, 2004; Church *et al.*, 2005), these communities were to a large extent dependent on a more strongly delimited, finite resource base than continental communities. This clarifies the relationship between landscape management strategies, environmental conditions, and the long-term sustainability of these societies.

The principal aims of this study were:

(1) To determine the pre-*landnám* structure and dynamics of the Sandoy ecosystem (including geomorphological and landscape factors), thereby identifying whether the environment was stable or changing when the first people arrived, and characterising the natural resource base available to the settlers;

(2) To identify the ways in which settlement changed the structure and dynamics of the ecosystem, particularly with respect to changes that would affect the resource base in the long term.

These aims were addressed by palynological and sedimentological analysis of three sediment sequences from contrasting palaeoecological sites on Sandoy. The data from these sites are presented and interpreted here in full for the first time with supporting statistical analyses and contextualisation through comparison with relevant sites elsewhere. Age models have been improved and revised since preliminary results were discussed as part of the multidisciplinary synthesis of Lawson *et al*. (2005).

METHODS

The sites

Gróthúsvatn (61º 50.5' N, 6º 49.9' W; meaning 'stone house lake') is a shallow lake, not more than 2 m deep, about 1 km long and 200 m wide, situated close to sea level and separated from the sea by a storm beach (Fig. 2). Small streams enter the lake via a fen at its northern end, and there is no surface outflow. Today a narrow strip of cultivated hayfields rings the lake, but most of its hydrological catchment (~500 ha) consists of low-angled slopes covered by grass heath. Gróthúsvatn is situated about 1.5 km northwest of the Norse period archaeological site of Undir Junkarinsfløtti in the modern village of Sandur (61º 50.0' N, 6º 48.5' W; Arge, 2001, 2006; Church *et al.*, 2005). This lake is the closest available site to the village capable of yielding a continuous palaeoecological record of the settlement period, and was expected to reflect changes in one of the more intensively worked parts of the Sandoy landscape.

Lítlavatn (6º 49.3 N, 6º 43.9 W; 'small lake') is also a shallow lake, in this case less than 1 m deep and measuring *c.* 400 by 200 m (Fig. 3). Lítlavatn lies at 62 m asl in an area of blanket mire in the floor of a glacial valley 5 km east-southeast of Sandur. It is fed by two streams, the larger of which drains a steeply-sloping upland area to the north. The catchment today is primarily used for rough grazing, and the extensive remains of structures interpreted as being related to shielings (summer grazing areas for cattle) and sheep folds suggest that this was also the case during the Medieval and

Norse periods (Lawson *et al.*, 2005). Although not within the hydrological catchment of the lake, the hayfields of the village of Húsavík lie less than 1 km to the east. A stream drains Lítlavatn seawards via the larger lake of Stóravatn to the west.

Between Lítlavatn and Stóravatn lies a flat depression in the peatland known as Millum Vatna (6º 49.3 N, 6º 44.7 W; 'between the lakes'; Fig. 3), which trial borings showed to be underlain by gyttja, and thus to represent an infilled lake. Only the thick peats that have developed on top of the gyttja were sampled and analysed. Oral tradition records that the Millum Vatna area was formerly used as the site of the open-air *thing*-meeting (council assembly) of the island (Lawson *et al.*, 2005).

These three sites were selected to give information about different parts of the physical and economic landscape. The nature of the sites will also condition the palaeoenvironmental signals they preserve. The two lake sites probably recruit pollen and other sediment from a relatively large hydrological catchment, with some input from wind transportation (Peck, 1973; Jacobsen & Bradshaw, 1981), while the peat sequence would be anticipated to have a much smaller effective pollen source area (Bunting, 2003). Lítlavatn's hydrological catchment is almost exactly the same size as that of Gróthúsvatn, *c.* 460 ha, but being situated for the most part at higher elevations, the records provide information about different parts of the landscape: GIS-based calculations suggest that about 47% of the Lítlavatn catchment lies above 300 m, compared to just 6% of the Gróthúsvatn catchment (Lawson *et al.*, 2005). Parts of the Gróthúsvatn catchment are cultivated at the present day, but the Lítlavatn catchment and Millum Vatna area appear only ever to have been used for rough grazing and peat extraction on a domestic scale.

Core retrieval, storage and description

Cores were retrieved using a Russian-type corer (Jowsey, 1966). The lake cores were taken close to the centre of each lake, and depths were measured relative to the water surface. The Lítlavatn core has the numerical designation of 20 as it was one of a series of cores taken for the purposes of related palaeoenvironmental analyses focusing on peat initiation (Lawson *et al.*, in press). In the case of Millum Vatna, the sequence came from the edge of the infilled lake basin, in order to increase the probability of detecting evidence of human impact on the surrounding slopes (Edwards, 1982, 1983). All material was stored at 4 ºC prior to analysis.

Sedimentological analyses

All three sequences were described using the Troels-Smith (1955) system, as modified by Aaby & Berglund (1986), and X-rayed using a Muller 150 kV CP Be unit. The resulting X-ray photographs were scanned and corrected for distortion, then used to identify accurately the overlap positions between each 0.5 m core section by matching prominent stratigraphical features. Samples of 1 cm^3 were taken contiguously at 1 cm intervals and analysed by loss-on-ignition (LOI) at 550ºC to constant weight (Dean, 1974; Heiri *et al.*, 2001). Low-frequency magnetic susceptibility (Dearing, 1994) was measured at 1 cm contiguous intervals using a Bartington Instruments (Witney, Oxfordshire, UK) MS-2 meter and MS-2f sensor.

Pollen analysis

Pollen preparations of 1 cm thick, 1 cm^3 samples followed a standard technique employing HF and acetolysis (Bennett & Willis, 2002; omitting steps 2, 4, 5, 6, and 9), with *Lycopodium* tablets as a source of exotic markers and silicone oil of 12,500 cSt viscocity as a mounting medium. Samples were counted to a main sum of total land pollen (TLP) exceeding 300 (Lítlavatn Lít-20) or 500 (Gróthúsvatn and Millum Vatna) grains. Identification followed Moore *et al.* (1991), Andersen (1979) for the cereals, and Punt (1984) for the Apiaceae, making use of pollen reference collections at the Universities of Aberdeen and Leeds. *Betula* was tentatively divided into *B. pubescens*-type and *B. nana* based on size measurements, taking 20 μm as the cut-off following Mäkelä (1996); *Isoetes* was similarly identified to inferred species level on the basis of size measurements following Birks (1973). Pollen nomenclature follows Bennett *et al.* (1994), except where the limited flora of the Faroes allows an increase in taxonomic precision (Fosaa, 2000). Most non-native taxa, including all trees except cf. *Betula pubescens*, were excluded from the TLP sum, along with spores and aquatics. A small number of rare pollen taxa which might reasonably be expected to have occurred in the past, but which are not listed as native in the Faroes today by Fosaa (2000, 2001), were included in the sum. These taxa are: *Chrysosplenium*, *Drosera intermedia*, *Erica tetralix*, *Limonium vulgare*, *Myrrhis odorata*, plus *Nymphaea alba* (which is actually present today in a small lake near Gróthúsvatn) and *Pteridium aquilinum*, which, while not part of the TLP, are expressed relative to that sum. Finds of pollen taxa that are too rare to be shown in the diagrams (Figs 4-6) are listed in Tables S1-S3 (see Supplementary Material). Charcoal concentrations were too low for the point-count method (Clark, 1982) to be applied, so the charcoal curves in the diagrams represent the number of charcoal fragments larger than 2 μm, expressed as a percentage of TLP.

Local pollen assemblage zones were defined with the aid of quantitative analysis (CONISS and binary splitting as implemented in the program PSIMPOLL 4.10; Bennett, 2002), with some subjective adjustments to take into account changes in those taxa that are significant in terms of identifying human impact. Detrended correspondence analysis (DCA) was carried out using PC-ORD (McCune & Mefford, 1999). In order to reduce the statistical artefacts that can be caused by rare taxa, selected taxa were amalgamated into higher taxonomic groups where this was unlikely to affect adversely the ecological interpretation of the DCA results. Any remaining taxa which never exceeded 0.5% were excluded from the analysis, and the option in PC-ORD to down-weight rare taxa was used. The significance of variations in the minor taxa that could be used as anthropogenic indicators (*sensu* Behre, 1981) between the two zones in the Millum Vatna sequence was tested using a Monte Carlo procedure to simulate the random partitioning of grains between the two zones, with a fixed probability of success (equal to the proportion of the taxon in the data set as a whole), without replacement, over 10^5 iterations.

Radiocarbon dating

Samples for radiocarbon dating were chosen on the basis of changes in the sedimentological and palynological data. Samples of 1 cm^3 bulk sediment from the lake sequences were pretreated by an acid wash; in the case of the Millum Vatna samples, which were also of 1 cm^3, the humic acid fraction of the peat was extracted for dating. Pretreatments and AMS dating were carried out at SUERC, East Kilbride, UK. Calibrations were performed using CALIB 5.0.1 (Stuiver & Reimer, 1993), with the INTCAL04 data set (Reimer *et al.*, 2004).

Tephra

One discrete tephra layer was identified in the Millum Vatna sequence from quantitative analyses of LOI residues. Pretreatment for microprobe analysis of the tephra layer followed Dugmore *et al.* (1995). Tephra samples were mounted in resin and then ground, polished and carbon coated. Analysis was undertaken on a five-spectrometer Cameca (Gennevilliers, France) SX100 electron using an accelerating voltage of 20 kV. A beam with a 4 nA current and a 10 µm raster was used to reduce the possibility of bias due to sodium migration. Peak count times were 10 seconds per suite of elements (total count time 45 seconds). The instrument was calibrated using a mixture of pure metals and simple silica compounds, and counter deadtime, fluorescence and atomic number effects were corrected using Cameca's PAP correction program. Reference material and comparative data sets included Tephrabase (http://www.tephrabase.org) and published reference profiles from the Faroes (Dugmore & Newton, 1998; Hannon & Bradshaw, 2000; Hannon *et al.*, 1998, 2001, 2005; Wastegård, 2002). Tephra data are shown in Table S4 in the Supplementary Materials. The age models have been refined on the basis of new data since preliminary results were discussed in Lawson *et al.* (2005).

RESULTS

Gróthúsvatn

The Gróthúsvatn core (Fig. 4) was retrieved at a water depth of 181 cm. The sediments consist mainly of detrital gyttja, with a more silty unit at the base of the sequence (490-450 cm). Although uncalibrated, the magnetic susceptibility values are typically a factor of five lower than those in the Lítlavatn sequence, and show small, unsustained peaks with no clear long-term structure. X-ray photographs suggest that the sequence is punctuated by numerous fine bands of sandy material, which account for the rapid changes in magnetic susceptibility. LOI values are similarly variable, ranging between 13 and 62%, although there is a sustained period of relatively high LOI between 320 and 245 cm. The pollen diagram is divided into four local pollen assemblage zones.

Zone Grót-1 (489-452.5 cm): characterized by high values of Poaceae (mean 43%) and *Sedum* (12%), and lower representation for Cyperaceae (16%), *Calluna vulgaris* (4%), and *Empetrum nigrum* (5%). Apiaceae (4%), *Filipendula ulmaria* (6%), *Huperzia selago* (4%), and *Isoetes* (10%, mostly *I. lacustris* – see Fig. 7) are also all more abundant than in later zones.

Zone Grót-2 (452.5-372.5 cm): *Calluna* values rise sharply to a mean frequency of 13%, and Cyperaceae climbs to a mean of 30% at the expense of Poaceae and *Sedum*. According to the size distribution data (Fig. 7), the *Isoetes* counts include a marked contribution from *I. echinospora* in this and the succeeding zones. Apiaceae (2.3%) and *Filipendula* (5%) remain relatively abundant.

Zone Grót-3 (372.5-269.5 cm): *Calluna* values increase markedly a second time to a mean of 28% at the expense mainly of Cyperaceae; *Empetrum* (8%) and *Sphagnum* (3%) exhibit a more gradual increase, while tall herbs, notably Apiaceae (1.2%) and *Filipendula* (2.0%), decline.

Zone Grót-4 (269.5-200 cm): The base of this zone is marked by the first appearance of cereal (*Hordeum*-type) pollen, and by the first persistent presence of charcoal, which increases from a mean of 0.1% across the three previous zones to a mean of 1.5% in this zone. *Plantago lanceolata* and other *Plantago* species also increase at or close to the base of the zone (in total from 1.0% to 3.2%). Other taxa show little change apart from a decline in *Juniperus communis* (from 4% to 1.6%) and an increase in Poaceae in the uppermost five samples.

DCA results: The biplot of the first two axes (Fig. 8A) indicates that the bulk of the variation in the dataset is associated with the transition from assemblages dominated by *Sedum*, *Huperzia*, or the various forbs (large positive values on axis 1) to those dominated by *Calluna*, *Sphagnum* and *Potentilla* (large negative values on axis 1). The stratigraphic plot of the axis 1 scores for each sample (Fig. 4) shows clearly the steady decline in values from Grót-1 to Grót-3 associated with this transition. The second axis has at one extreme *Plantago* and the Cardueae tribe of the Asteraceae, and at the other *Juniperus*. The stratigraphic plot shows that sample scores are relatively uniform through zones Grót-1 to Grót-3, with a steady rise throughout Grót-4. The assemblage zones are generally well separated in the biplot, with the exception of some overlap between the uppermost two zones.

Age model: The lowermost three pollen samples have a characteristic composition dominated by *Sedum* and *Huperzia selago*. Similar assemblages frequently occur in other sequences from the Faroes and have not been dated to younger than 9000 cal BP. The lowermost radiocarbon date, 4060-3780 cal BP at 453 cm, therefore suggests the presence of a substantial hiatus in deposition at the Grót-1/2 boundary, marked by a change in the sedimentology as well as the pollen content of the sequence (see Discussion). Two more radiocarbon dates in stratigraphic sequence occur at 373 and 325.5 cm. The two uppermost dates, at 271.5 and 248.5 cm, are out of sequence, suggesting that they contain old, reworked carbon from the catchment peats and soils (cf. Edwards & Whittington, 2001; Amsinck *et al.*, 2006). The age estimates shown in Figs 4 and 9 are based on linear interpolation using the median of the calibrated age range of the three lowermost dates, assuming a date of -50 BP for the top of the sequence.

Lítlavatn

The water depth at the core site in Lítlavatn (Fig. 5) was 90 cm. The sequence consists of discrete units of, alternately, fine-grained gyttja and organic silt. This is reflected in the highly-structured LOI and magnetic susceptibility data, which show large changes, often but not always in both proxies at once. There is, however, much less sub-centimetre variability visible in the X-ray photographs compared with Gróthúsvatn. Pollen preservation at Lítlavatn varies markedly depending on the nature of the sediment. The diagram was divided into four local pollen assemblage zones.

Zone Lít-20-1 (321-204.5 cm): Poaceae (mean 42%) and Cyperaceae (16%) dominate, with moderately high values for *Juniperus* (4.2%), *Empetrum* (7.0%), *Angelica sylvestris* (2.8%), *Sedum* (4.0%), and *Filipendula ulmaria* (8.1%). Towards the top of the zone, *Isoetes* shows a large spike (note the compressed scale for *Isoetes*, which is outside the TLP sum, in Fig. 5).

Zone Lít-20-2 (204.5-160.5 cm): Pollen preservation is poor, magnetic susceptibility values are relatively high, and Poaceae (79%) dominates the spectra along with lesser amounts of Cyperaceae (5.6%) and *Filipendula* (3.6%). *Isoetes* has decreased representation. Other taxa including

Juniperus (0.3%), *Empetrum* (0.5%), and *Angelica* (0.6%) decline dramatically at the Lít-20-1/2 boundary and remain scarce throughout the remainder of the zone.

Zone Lít-20-3 (160.5-128.5 cm): Pollen preservation improves and Poaceae (26%) ceases to be as dominant, but this zone differs from Lít-20-2 in having higher proportions of *Calluna* (8.1%), *Potentilla* (6.0%), and *Sphagnum* (2.9%), while *Angelica* (0.8%), *Sedum* (1.6%), and *Filipendula* (1.3%) are all reduced.

Zone Lít-20-4 (128.5-100 cm): Pollen preservation is poor and magnetic susceptibility values increase substantially, especially towards the top of the zone where Poaceae (44%) becomes dominant once more, with corresponding declines in *Juniperus* (4.0%), *Calluna* (8.1%), and Cyperaceae (16%); *Potentilla* (7.0%) shows a clear increase to the top of the sequence.

DCA results: As was the case with Gróthúsvatn, the first axis of the DCA (Fig. 8B) separates forbs such as *Filipendula* and the Apiaceae from wet heath taxa including *Calluna*, *Sphagnum* and *Potentilla*. The distinctive *Huperzia–Sedum* association seen in zone Grót-1 is not represented in the Lítlavatn sequence and so these taxa are not so clearly separated in the biplot. However, whereas Poaceae plotted close to the centre of the Gróthúsvatn biplot, in the case of Lítlavatn they plot well to the left, reflecting the considerable variation in Poaceae percentages in this sequence. Zones Lit-3 and Lit-4, with high *Calluna* values, are clearly differentiated from the preceding zones in the stratigraphic plot of sample scores (Fig. 5). The second DCA axis effectively differentiates zone Lit-1 from the later zones, placing forbs such as *Filipendula* in opposition to wet heath taxa, especially *Potentilla* (the very high positive values for *Polypodium* and *Ranunculus flammula* are likely to be a statistical artefact as these taxa are rare).

Age model: The Lítlavatn sequence is supported by five radiocarbon dates, the uppermost of which is out of chronostratigraphic sequence, presumably reflecting the inclusion of reworked carbon from the catchment as in Gróthúsvatn. In view of this, the remaining dates should be treated as maximum age estimates. The age model shown in Figs 5 and 9 is constructed as for Gróthúsvatn.

Millum Vatna

The Millum Vatna sequence (Fig. 6) consists of peat with LOI values always above 80%. Magnetic susceptibility values, albeit uncalibrated but measured in the same way as the other two sequences, are extremely low throughout the sequence, and the resulting curve covaries inversely almost exactly with the LOI data. In general the sequence has relatively good pollen preservation and shows a marked lack of taxonomic diversity, with *Calluna vulgaris*, *Empetrum nigrum*, Poaceae, Cyperaceae, *Potentilla* and, occasionally, *Sphagnum* dominating the spectra. The Millum Vatna pollen diagram is divided into two local assemblage zones, the boundary reflecting a gradual change in several taxa.

Zone Mill-1 (169-54.5 cm): This zone begins with high *Sphagnum* values in the lowest two samples (43% at the base and 65% just above), accompanied by relatively high Poaceae and Cyperaceae and low *Calluna vulgaris,* but *Sphagnum* percentages rapidly decline almost to zero. The relative proportions of the dominant taxa vary throughout the rest of the zone; *Calluna vulgaris*, which shows the greatest variation in terms of absolute percentages, ranges from 27 to 58%, but there is little clear stratigraphic trend in the data.

Zone Mill-2 (54.5-16 cm): This zone is distinguished from zone Mill-1 by a decline in *Angelica sylvestris* (from 0.5 to 0.2%) and *Filipendula ulmaria* (2.6 to 1.5%), and by an increase in *Plantago* (from 0.1 to 1.8%; charcoal also expands). These changes are very small numerically. Towards the top of the zone *Potentilla* and *Sphagnum* increase considerably, and the other dominant taxa remain irregularly variable, as in zone Mill-1.

DCA results: In this case the pollen assemblage zones are not clearly separated in the biplot (Fig. 8C) for the reasons discussed above. The stratigraphic plot of sample scores for the first axis (Fig. 6) follow very closely the *Potentilla* and *Sphagnum* curves, with *Juniperus* and *Rumex*/*Oxyria* in opposition to this, mainly representing the difference between the lowermost two samples and the rest of the dataset. On the second axis *Calluna* and *Empetrum* plot opposite *Plantago*, reflecting the gradual decline in the Ericaceae and expansion of *Plantago* through the sequence.

Age model: Two radiocarbon dates are available for Millum Vatna (Table 1). The calibrated age ranges at the 95% confidence level almost overlap. The tephra layer at 169-170 cm has been identified as Hekla-Selsund (see Table S4 in the Supplementary Material), radiocarbon dated in Iceland to 3515±55 ^{14}C BP (Larsen *et al.*, 2001), calibrating at 95% confidence levels to 3960-3640 cal BP. Linear interpolation between the tephra layer, the midpoints of the calibrated ranges of the two radiocarbon dates, and the top of the sequence (assumed equivalent to -50 BP) yields an age model implying very slow accumulation between *c.* 3800 and 1480 BP, increasing by a factor of ten between 1480 and 1270 BP, then returning to close to the original rate between 1270 BP and the present. A more straightforward scenario is to assume that the uppermost date is affected by reworked organic material, as in Gróthúsvatn and Lítlavatn. The resulting age model, shown in Figs 6 and 9, should be interpreted with caution.

INTERPRETATIONS

Gróthúsvatn

In zone Grót-1 the high values for Poaceae, *Sedum* and *Huperzia selago* are broadly similar to assemblages found by Jóhansen (1975, 1982) in early Holocene sediments from Hoydalar (zones H1 and H2), Saksunarvatn (zones S1 and S2), and Hovi-A (his zones Hovi-A-1 and Hovi-A-2), dating to before *c.* 10 000 BP. Jóhansen interpreted these assemblages as indicative of pioneer, 'fell-field' vegetation communities growing on raw, skeletal soils. Field observation of relict soils underlying mid to late Holocene peats within the catchment of the lake confirms the minerogenic nature of these early Holocene soils (Lawson *et al.*, 2005). A low presence of *Calluna vulgaris* in the lake catchment is suggested by the pollen data, and *Calluna* was perhaps growing in patches of mire alongside *Empetrum*, *Potentilla*, and *Sphagnum*, all of which are also represented in the pollen assemblages. Relatively high levels of silt in the sediment, relatively low pollen concentrations, and pollen degradation, suggest that soils were unstable and prone to erosion, bringing reworked pollen into the lake. The inferred hiatus at the Grót-1/2 boundary perhaps reflects infilling of an original basin, followed by a cessation of deposition until the outflow level was raised by emplacement of the storm beach around 4000 BP. Further work would be required to test this suggestion.

By the time deposition had recommenced, the environment had changed markedly. The pollen spectra from Grót-2 show that *Calluna* had become an important constituent of the vegetation, accompanied by other taxa typical of wet heath, including *Empetrum*, *Potentilla* and *Sphagnum*. At this stage, Poaceae- and Cyperaceae-dominated communities seem to have been prevalent, and tall herbs were relatively abundant, suggesting that soils remained relatively nutrient-rich.

The transition from Grót-2 to Grót-3 is marked by a rapid doubling in *Calluna* frequencies at the expense of almost all other taxa. *Filipendula* declines the most, with only *Potentilla* and *Sphagnum* showing slight increases. A macrofossil study of a core from the margins of Gróthúsvatn by Hannon *et al.* (2001) is relevant to the interpretation of the pollen data at these levels. A tephra layer attributed to the Hekla-4 eruption (3826±12 ^{14}C BP, calibrating to 4150-4280 cal BP; Dugmore *et al.*, 1995) was found at 180 cm depth in their sequence (Hannon *et al.*, 2001), above which plant macrofossil finds were rare. The data from the sequence below the tephra showed one major change, from macrofossil assemblages dominated by *Viola riviniana*, *Filipendula ulmaria*, *Caltha palustris* and *Carex* spp. between the lowermost part of the sequence at *c.* 440 cm and *c.* 390 cm, and assemblages containing *Juniperus communis*, *Salix phylicifolia*, *Erica cinerea*, *Calluna vulgaris*, *Empetrum nigrum* and occasional remains of *Betula pubescens* above. This was interpreted by Hannon *et al.* (2001) as indicating the encroachment of shrub woodland and heathland communities on herb-rich fen communities at their core site. The Gróthúsvatn pollen record presented here suggests that a similar change may have taken place on a larger scale across much of the catchment. The macrofossil and pollen records complement each other in terms of taxonomic precision and completeness of the fossil flora. *Salix*, which the macrofossil record from Gróthúsvatn and elsewhere tells us included *S. phylicifolia*, a taxon now all but absent from the Faroes (Hansen, 1966; cf. Jóhansen, 1982: 128), and *Erica cinerea* in particular are both apparently under-represented in the pollen record, although *Erica tetralix* and *Arctostaphylos uva-ursi* also appear in the pollen data. The macrofossil record also confirms the local presence on Sandoy of tree birch.

The main aim in constructing the pollen data set from Gróthúsvatn was to identify vegetational changes brought about by human impact, and accordingly the depth/time resolution of the pollen data is highest towards the top of the sequence. Many taxa occur only sporadically, making it difficult to determine exactly the level at which the first changes attributable to human activity become apparent. The best estimate of this horizon defines the Grót-3/4 boundary, and marks the point where the charcoal curve becomes consistent, if not continuous to the very top of the sequence. The scores for the second DCA axis, which has at opposite extremes *Plantago* and *Juniperus* and which can be interpreted as encapsulating the distinction between pristine and anthropogenic environments, begin to increase just below this zone boundary. The increase in *Plantago* spp., including *P. lanceolata*, could indicate disturbance consistent with trampling and grazing. The decline in *Juniperus* may be due to collection for domestic use (Small, 1992; Stummann Hansen, 2003; Church *et al.*, 2005), while *Salix*, *Angelica* and *Filipendula* may have succumbed to grazing. Other changes that occur around this boundary and which may be attributed to human impact include the first appearance of cereal-type pollen, attributed to *Hordeum*-type, and an increase in aquatic productivity, as measured by *Pediastrum* and chironomid abundance, and chironomid-based total phosphorus reconstructions (Lawson *et al.*, 2005; Gathorne-Hardy *et al.*, in press).

The most significant indication of vegetation change in the post-settlement period occurs in the uppermost five samples: Poaceae and Cyperaceae expand, chiefly at the expense of *Calluna*. Without better age control the timing of this change cannot accurately be estimated, but it could relate to the expansion of hayfields since the 19th century (Arge *et al.*, 2005).

Lítlavatn

The preservation of pollen in the Lítlavatn sequence is generally slightly poorer than in Gróthúsvatn, and damaged pollen was probably largely introduced to the lake via the fluvial system (cf. Bonny, 1976; Wilmshurst & McGlone, 2005). The more complex taphonomy of this lake compared with Gróthúsvatn means that the Lítlavatn DCA is less readily interpretable in terms of ecological changes, although the dominant trend is from forbs to wet heath taxa in both cases.

The pollen spectra in zone Lít-20-1 suggest the presence of vegetation communities dominated by Poaceae, accompanied by *Juniperus, Empetrum,* Cyperaceae, *Sedum*, tall herbs including members of the Apiaceae and *Filipendula*, and ferns. *Betula pubescens* percentages are perhaps sufficient to indicate its local presence; stronger evidence suggests it was present on Sandoy at some point during the Holocene (Hannon *et al.*, 2001; Lawson *et al.*, 2005). This pollen zone resembles zones from three other sites in the Faroes: Hoydalar (zone H4, dating very approximately to 9000-6000 ^{14}C BP; Jóhansen, 1975) and Saksunarvatn and Hovi-A (zones S3 and S4, again dated to approximately 9000-6000 ^{14}C BP, and zone Hovi-A-3; Jóhansen, 1982). The strong similarity suggests that these zones may be approximately synchronous (Jóhansen, 1996), although Hoydalar has rather less *Filipendula*, Saksunarvatn has less *Filipendula* and *Empetrum*, and Hovi-A has rather more *Salix*, suggesting some variation in the nature of the vegetation across the Faroes. Jóhansen considered that this period was dominated by ‘grassy heaths’ (Jóhansen, 1982: 121-128), but with the most extensive shrub development seen at any point in the Holocene, and abundant tall herb communities, and the data presented here do not challenge this interpretation. The spike in *Isoetes* at the top of zone Lít-20-1 has correlates in the Hoydalar and Hovi-A sequences, attributed by Jóhansen (1975: 385) to the gradual acidification of the lake, in turn reflecting the acidification of catchment soils, which could likewise be the explanation here.

Zone Lít-20-2 sees a sharp drop in the diversity of taxa recorded, with only Poaceae, Cyperaceae and *Filipendula* making significant contributions to the pollen sum. The proportion of TLP grains showing signs of degradation also increases substantially, peaking at over 90%. The preservation state of pollen in this zone appears very similar to that of samples from mineral soils underlying peats around Lítlavatn (Lawson *et al.*, 2005, in press), which also tend to have a high proportion of Poaceae pollen. Furthermore, during this zone, magnetic susceptibility values increase. All of these observations together indicate that the pollen and other sediments in this zone are largely reworked from soils in the Lítlavatn catchment, suggesting that the catchment experienced a period of geomorphological instability. Taking the radiocarbon dates at face value, this period lasted from approximately 2750 to 200 BC. Although we cannot place total confidence in these dates, which may contain reworked carbon, data from marine sequences from Skálafjord, Eysturoy (Roncaglia, 2004; Witak *et al.*, 2005) and from lake sequences from Starvatn on Eysturoy and Lykkjuvøtn on Sandoy (Andresen *et al.*, 2006) suggest that a climatic cooling affected the Faroes after *c.* 5000 cal

BP, which broadly accords with our data; Roncaglia (2004) also reported an apparent warming from AD 260-1090, followed by renewed cooling. Suppression of the vegetation cover and enhanced freeze-thaw activity are two possible mechanisms which could link a cooler climate with higher rates of erosion.

Zone Lít-20-3 sees diversity restored to the pollen record and pollen preservation improves, but the pollen spectra here show that *Calluna* was now abundant in the landscape, along with *Potentilla* and *Sphagnum*, supporting the interpretation of Lít-20-2 as a prolonged period of erosion. Together, these taxa indicate that wet mire communities were now abundant in the catchment. *Juniperus* and *Empetrum*, both strongly represented in this zone, may have grown in the same wet mire communities. The tall herb vegetation represented by Apiaceae and *Filipendula* had all but disappeared by this time. Despite the inferred acidophilic vegetation and acidified soils, *Isoetes* was no longer abundant in the lake, perhaps due to a change to a more organic substrate (Birks, 1973: 332).

In the final zone, Lít-20-4, the pollen preservation data suggest renewed reworking. The increase in Poaceae pollen towards the top of this zone may thus represent a taphonomic change rather than an ecological one; if the latter, it could reflect an increase in grazing pressure. High magnetic susceptibility values imply another period of unstable soils, which again could be a response to grazing and trampling by introduced animals, and/or peat cutting, and/or a natural cause such as climatic change. A growing but still limited body of evidence (e.g. Roncaglia, 2004; Witon *et al*., 2006) points to changes in climate affecting the Faroes during the second millennium AD, probably associated with the ‘Little Ice Age’ *sensu lato* (Grove, 1988; Meeker & Mayewski, 2002). The evidence from Lítlavatn and elsewhere of prehistoric episodes of climatic change and soil erosion demonstrates that it is impossible to discount climatic change as a causal factor in historical soil erosion, and identification of the relative importance of anthropogenic and natural factors is likely to prove very difficult.

Millum Vatna

The Millum Vatna sequence appears to span the period when human impact became significant in the landscape. The charcoal record is perhaps the most incontrovertible indication of human presence in the diagram, given that natural burning is likely to have been exceedingly rare in such a wet environment. The co-occurrence of increasing *Plantago*, especially *P. lanceolata*, and declines in *Juniperus, Angelica sylvestris,* and *Filipendula*, marking the boundary between zones Mill-1 and Mill-2, has the hallmark of human impact as inferred from other records in the Faroes where age models are more robust (e.g. Hov, e.g. Edwards *et al.*, 2005a; Tjørnuvík, e.g. Hannon *et al.*, 1998, 2001). If the uppermost of the two radiocarbon dates at Millum Vatna is accurate, then the first effects of human impact occurred prior to the conventional date for Norse settlement (*c*. AD 800). The age model preferred here, which rejects this date, would suggest that significant human impact did not begin until *c.* AD 1300.

Assuming that the lower part of zone Mill-1 (below *c.* 115 cm) pre-dates the settlement period, the pollen record appears to indicate that the vegetation at and around the site was naturally dynamic, with substantial shifts in the abundance of taxa, particularly *Sphagnum*, *Calluna*, *Empetrum*, Poaceae and Cyperaceae. The effective pollen source area for mire taxa in peat sequences is considered to be very small (Bunting, 2003), of the order of a few metres at most, so the most straightforward explanation of this variability is that it represents small-scale changes in the vegetation mosaic, rather than large-scale changes in the dominance of taxa across the whole landscape. Other pollen data from Sandoy support the idea that the pre-settlement mire vegetation was spatially patchy (Lawson *et al.*, 2005, in press). The diversity of the natural vegetation at Millum Vatna appears to have been very poor compared with the richer pollen flora from Gróthúsvatn. The explanation may be that Gróthúsvatn recruits pollen from a much larger area, which will include a greater diversity of habitats. At least three taxa which are no longer present around Millum Vatna were present in the past, namely *Juniperus communis*, *Angelica sylvestris*, and *Filipendula ulmaria*; values for *Caltha palustris* are very low in zone Mill-1 but its total absence from Mill-2 suggests that it may also have disappeared from the locality following settlement.

The evidence in the record for human impact is very limited, in part due to the low diversity of the pollen assemblages. Significance testing found highly significant declines from Mill-1 to Mill-2 in the grazing-sensitive taxa *Juniperus* and *Filipendula*, together with (surprisingly) *Rumex acetosa*, while the Tubuliflorae, *Plantago lanceolata*, *P. maritima* and charcoal, all possible indicators of disturbance, showed highly significant increases. Liguliflorae and *Sedum* showed marginally significant increases at the 5% level (H_0: no increase in probability of occurrence in samples from Mill-2, compared to Mill-1; one-tailed test; P estimated as 0.0307 and 0.0402, respectively). The small amounts of charcoal found in zone Mill-2 are probably not sufficient to indicate burning of the mire vegetation, at least at the site itself. Instead, the charcoal could reflect fallout from domestic fires, emanating from farmsteads or shielings. The expansions of *Potentilla* and *Sphagnum* in Mill-2 may be entirely unrelated to human impact, given their variability lower in the sequence, although a short-lived expansion of *Potentilla* did accompany settlement at Hovi-B/Hov (Jóhansen, 1982; Edwards *et al.*, 2005a).

The extent to which the Millum Vatna sequence can ultimately tell us anything about changes in landscape stability is uncertain. There is little mineral material in any part of the sequence. Finds of small numbers of tephra grains throughout the sequence suggest that at least some of the mineral input is from primary aeolian fallout from Icelandic volcanic eruptions, but the remainder presumably results from local aeolian and/or colluvial reworking. Concordant variations in the LOI and magnetic data do suggest that there were periods of increased mineral input, perhaps indicating landscape instability. The earliest such event that is clearly expressed in the record occurs around 115-100 cm, below the first definite palynological indications of human settlement, although the dating control is not strong enough to rule out the possibility that this represents a response to anthropogenic activity. If the age model is correct, then a considerable change in peat accumulation rate occurred at about this point in the record, the cause of which is unclear.

DISCUSSION

Pre-settlement ecosystem dynamics

There was clearly significant similarity in vegetation development across the Faroes during the pre-settlement Holocene. All three records presented here indicate that, on the eve of settlement, the vegetation was dominated by a mixture of grasses, sedges, and ericaceous taxa; differences between the sites are small and could be interpreted in terms of taphonomic differences. Comparing these results with published data from elsewhere in the Faroes, there is some variation: for example, *Calluna* percentages are only about half as great at Saksunarvatn (Jóhansen, 1982) as at Gróthúsvatn around 3000 cal BP, while ferns are more abundant; at Hoví-A (*ibid.*) *Calluna* is even less abundant. Pollen analysis lacks taxonomic precision for some families, and many parts of the Faroese landscape, for instance the mid to high altitudes, remain almost unstudied, so we are almost certainly not detecting the full diversity of vegetation in the pre-settlement period.

Vegetation development is just one aspect of the development of the landscape as a whole, and there is evidence here for at least two other major changes during the Holocene, the first being to the soil system. The lowermost pollen analyses from Gróthúsvatn accord with previous pollen evidence from elsewhere in the Faroes in suggesting that early Holocene vegetation was dominated by fell-field communities represented by *Sedum* and *Huperzia* in the pollen record, interpreted by Jóhansen (e.g. 1985) as indicating raw, base-rich soils. The expansion of grasses and herbs such as *Filipendula* subsequent to this early Holocene phase in the pollen records (represented here by zone Lít-20-1) suggests that soils remained base-rich for several millennia. Gradually, indicators of more acidic and perhaps waterlogged soils, including Cyperaceae, *Calluna* and *Empetrum nigrum*, become more important in the pollen records. Dating of blanket peat in the valley around Lítlavatn and Millum Vatna suggests that peatlands slowly expanded from about 6000 BP onwards (Lawson *et al.*, in press), and it is likely that soils on the slopes also became gradually more leached, organic and acidic over time.

Secondly, and associated with the changing nutrient status of the soil, is the geomorphological stability of the landscape. The Lítlavatn lake sequence appears to indicate, on the grounds of sedimentology and pollen preservation, that significant erosion began in its catchment abruptly at some time after ca. 5000 BP (the beginning of zone Lít-20-2). A later period of apparent re-stabilisation occurs during zone Lít-20-3 before renewed erosion in Lít-20-4. This pattern of sudden changes in erosion rates in the second half of the Holocene accords with geomorphological evidence for episodic destabilisation of the landscape, possibly driven by climatic change (Edwards *et al.*, 2005b; Hannon *et al.*, 2005; Lawson *et al.*, 2005). The lack of evidence for a similar event at Gróthúsvatn suggests that destabilisation may have been limited to the uplands.

Effects of settlement in cultivated areas

Data on ecological changes in the cultivated areas which went on to become the present-day ‘infields’ (the enclosed land close to farms used for growing crops including hay, as opposed to the ‘outfields’ used for rough grazing; Baldwin, 1983; Mahler, 1993) on Sandoy is limited. Only Gróthúsvatn today includes cultivated fields in its catchment, although these do not necessarily date back to the settlement period. The five finds of cereal-type pollen in Gróthúsvatn, four of which could be attributed to *Hordeum*-type, indicate that local cereal production probably took place in the past. The finds of cereal grain and chaff of six-row hulled barley (*Hordeum vulgare* var. *vulgare* L.) from the Norse-period deposits at Undir Junkarinsfløtti are likely to derive from locally-grown rather than imported crops; radiocarbon dates of some of these grains date them directly to the late 10th to early 13th centuries (Church *et al.*, 2005). A few oat grains (*Avena* sp.) were recovered from Undir Junkarinsfløtti that have no counterpart in the pollen record from Gróthúsvatn, though Jóhansen (1979, 1985) found pollen ascribed to *Avena* in deposits from the island of Mykines. However, oat only accounted for less than 1% of the identifiable cereal grains from Undir Junkarinsfløtti and was interpreted as a weed contaminant of the barley crop (Church *et al.*, 2005). The increase in Poaceae pollen at the top of zone Grót-4 suggests that hayfields were not as extensive in the settlement period as they are today (Arge *et al.*, 2005).

Less equivocal pollen data from other sites in the Faroes, such as Hov/Hoví-B on Suðuroy

(Jóhansen, 1982; Edwards *et al.*, 2005a) and Tjørnuvík on Streymoy (Jóhansen, 1971, 1985; Hannon *et al.*, 1998, 2001; Hannon & Bradshaw, 2000), come from those sites where peat deposits occur close to ancient farms. Typical responses to settlement include the appearance of cereal-type pollen, an expansion of ruderals such as *Plantago lanceolata*, and a decline in such as *Filipendula ulmaria* and *Juniperus communis* that are prone to grazing or gathering. Detailed comparisons, however, show that there is considerable variation in this response. For example, in Jóhansen's (1982) Hoví-B sequence, settlement appears to encourage a large expansion of *Potentilla*, a pattern replicated in the Hov sequence of Edwards *et al.* (2005a). *Potentilla* shows barely any change in the three available diagrams from Tjørnuvík, nor at Gróthúsvatn. On the other hand, one of the three Tjørnuvík diagrams shows a large spike in *Sedum* just above the *landnám* horizon, which, if not reflecting a hiatus in sediment accumulation, is a feature which has no equivalent in any other diagram at Tjørnuvík or elsewhere. Clearly, there are some variations in the nature of changes in heavily-impacted parts of the Faroese landscape, and these variations appear to operate both on an inter-island scale (the differences between Hovi, Tjørnuvík, and Gróthúsvatn), and on a scale of a few metres (the differences between the three Tjørnuvík sequences).

Effects of settlement in uncultivated areas

Palaeoecological sites in areas that appear only to have been used for rough grazing (present-day 'outfields'), such as Lítlavatn and Millum Vatna, are rare in the Faroes. The best-developed, and the only one spanning the settlement period, is Hovsdalur on Suðuroy (Edwards *et al.*, 2005a, b; Borthwick *et al.*, 2006; Borthwick, 2007). This sequence shows even more muted evidence for human impact than at Millum Vatna, the most significant palynological changes occurring above a date of *c.* AD 1460 and related mainly to an expansion of Cyperaceae at the expense of all other taxa, which could be attributable purely to natural ecological changes. Edwards *et al.* (2005a) identified one other period of change, dated to *c.* AD 610 and characterized by the beginning of a gradual expansion of Cyperaceae and declines in *Ranunculus flammula* and *Sphagnum*, all of which are in the opposite sense to the changes in these taxa at Millum Vatna (although a decline in *Caltha* at Hovsdalur may be matched by a barely detectable decrease at Millum Vatna). Charcoal was found in very small quantities throughout the sequence, and there is a tendency for more frequent occurrences of *Plantago lanceolata* towards the middle and top of the sequence, though again it is present even in the lowermost (pre-settlement?) zone (cf. Jóhansen, 1987). Millum Vatna and Hovsdalur together give the strong impression that human impacts in lowland outfield situations were extremely limited in degree, and so subtle as to be barely detectable through palynology, with natural vegetation dynamics probably accounting for most of the observed variation in the pollen stratigraphies.

The record of upland erosion from Lítlavatn suggests that, although erosion has certainly been active in recent times, the pre-settlement landscape was also unstable, with episodic erosion. Thus, although the presence of humans may have encouraged erosion, this took the form of an amplification of an ongoing process, rather than the imposition of an entirely new geomorphological regime as has been observed in many other areas, such as parts of Iceland (Dugmore *et al.*, 2000; Simpson *et al.*, 2001) and the British Isles (Edwards & Whittington, 2001).

A number of uncertainties remain. The long-term (millennial-scale) trajectories of change across the settlement horizon are reasonably well represented on Sandoy, but dating uncertainties, and the difficulty of precisely identifying the settlement horizon, mean that it is difficult to assess shorter-term (centennial-scale) trajectories. For example, did the decline in *Juniperus* towards the top of zone Grót-3 pre-date settlement, as Jóhansen (1982) thought was the case at Hoví-B, or was it a consequence of settlement? A comparable decline in *Betula pubescens* in the centuries before *landnám* in Iceland has been attributed to climatic change (Einarsson, 1963). Similarly, it is clear from the archaeological and historical records (Lawson *et al.*, 2005; Church *et al.*, 2005) that considerable changes took place in the centuries following *landnám* on Sandoy, as elsewhere in the Faroes (Arge *et al.*, 2005), including changes to the administration of the grazing land, expansion of the hayfields, and the decline of certain elements of the economy such as pig-keeping. The chronological uncertainties in our records make it impossible to investigate the ecological impact of these changes with as much certainty as we would wish. In addition, the possibility of changes to the vegetation that do not necessarily result in palynological changes, such as the height and age structure of *Calluna*-dominated communities, or the species composition of the Poaceae and Cyperaceae, may in part be amenable to future plant macrofossil studies. Further research in upland areas would also fill a substantial blank on the map.

CONCLUSIONS AND WIDER SIGNIFICANCE

On the eve of Norse settlement, the landscape of the study area of Sandoy was remarkably similar to that of the present day. There was a range of blanket mire, tall herb, shrub and grassland communities in different parts of the landscape. At a landscape scale, these communities were remarkably stable over long periods of time, but the data from Millum Vatna shows that blanket mire communities at least displayed small-scale dynamism. Erosion was active, albeit apparently episodic and restricted to certain parts of the landscape.

Following settlement, the palaeoenvironmental records detect an expansion of ruderals such as

Plantago lanceolata, the introduction of cereal cultivation, a late (possibly early modern) increase in Poaceae at Gróthúsvatn which could represent either hayfield expansion or changes to the composition of the rough grazing land, the suppression of some species such as *Juniperus communis*, *Salix* spp., tall herbs such as *Filipendula ulmaria*, and possibly (at Lítlavatn at least) an increase in the rate of erosion. Conclusions about the detailed timing of changes cannot be drawn due to the uncertainty in the age models.

The data presented here make a significant addition to the body of palaeoecological knowledge relating to the effects of settlement on the Faroes, partly because there are few such datasets, but also because they shift the emphasis of investigation away from sequences located with the maximum probability of detecting human impact (peat sequences in infield areas) towards a more balanced assessment of the whole landscape using a group of sites which includes lakes with large hydrological/sedimentological/palynological catchments as well as a peat sequence in an outfield area. Unsurprisingly perhaps, the evidence for substantial change after settlement is much less than in most previous studies (the exception being the site of Hovsdalur discussed above). Some of the more marked changes seen in the records from sites such as Tjørnuvík and Hov/Hoví, such as the sudden appearance of ruderals such as *Plantago lanceolata* and *Rumex acetosa*, an expansion of Poaceae, and the decline (or, sometimes, expansion) of *Caltha palustris* and *Potentilla* across horizons ascribed to the settlement period, should thus be seen as local changes restricted at most to the relatively small infield areas. In fact the substantial variation between the records of many taxa from almost adjacent peat sequences (the clearest example being the three Tjørnuvík sequences) shows just how spatially restricted some of these changes may have been. On the other hand, the Lítlavatn record suggests that upland areas (above *c.* 300 m) may have been more sensitive to the effect of humans or their introduced herbivores; this requires further investigation.

In comparison to other late-colonized lands which were initially wooded, such as Iceland and Greenland, the introduction of farming to the Faroes had a very subtle ecological impact across much of the landscape. Similarly subdued responses are more common in parts of the Western and Northern Isles of Scotland (e.g. Edwards *et al.*, 2000; Ritchie *et al.*, 2001), although in these cases some involvement of human impact in deforestation and peatland expansion cannot be ruled out. Deforestation is a typical hallmark of agricultural colonization in many parts of the world, and it causes substantial changes to the structure of the ecosystem: a large reduction in biomass, loss of keystone species, a step-shift in hydrological conditions, and the loss of deep rooting systems, to name just a few of its components. Where deforestation cannot proceed because there are few trees to begin with, and where the ecosystem continues to be ‘sub-natural’ (*sensu* Simmons, 1993), ecosystem responses at the landscape scale are likely to be much more subtle. Apart from this, a number of other factors probably contributed to the stability of Faroese terrestrial ecosystems in the face of settlement, among them a low human population density until the 19th century (Arge *et al*., 2005); thin, coarse-grained soils that were much less prone to catastrophic erosion than the thick, friable Icelandic andisols; and the mountainous topography, which meant that only relatively small parts of the landscape were suitable for intensive exploitation, making low-impact pastoralism the only significant economical use over most of the landscape.

ACKNOWLEDGEMENTS

This work was funded by the Leverhulme Trust under the programme 'Landscapes circum-*Landnám*'. We thank Maureen Lamb, Iona Grant, Julie Mitchell and Kate Smith for technical support, Jill Barber for logistical assistance, Doug Borthwick, Kerry-Anne Mairs, Andy McMullen, and Jim Woollett for help in the field, Símun Arge and Katy Roucoux for useful discussions and comments on the text, and the people of Sandur and Sandoy and their mayor, Páll á Reynatúgvu, for permission to work at the sites. The comments of Jeff Blackford and an anonymous reviewer are gratefully acknowledged.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article:

Table S1 Rare taxa found at Gróthusvatn.

Table S2 Rare taxa found at Lítlavatn

Table S3 Rare taxa found at Millum Vatna

Table S4 Geochemical data for individual tephra grains from 170-169 cm at Millum Vatna.

This material is available as part of the online article from: http://www.blackwell-synergy.com/doi (This link will take you to the article abstract).

BIOSKETCHES

Ian Lawson is a Lecturer in Physical Geography specialising in the reconstruction of environmental change using pollen analysis and other palaeoecological and geological techniques. He has worked on Holocene and Late-glacial records from Greece, and on the effects of the Norse settlement in Iceland, as well as in the Faroes.

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Editor: Jon Sadler

FIGURE CAPTIONS

Figure 1 Location map: (A) Inset showing the location of the Faroe islands; (B) the Faroe islands, including Sandoy and other sites mentioned in the text; (C) Sandoy, including villages and sites mentioned in the text. Contours at 50 m intervals.

Figure 2 Gróthusvatn viewed from the northwest. A storm beach separates the lake (centre) from the sea (top).

Figure 3 Lítlavatn (L) and Millum Vatna (M) viewed from the north.

Figure 4 Gróthusvatn sedimentological and palynological data. In this figure, and Figs 5 and 6, lithological symbols follow Troels-Smith (1955). Pollen percentage curves are filled with horizontal lines which mark the location of samples, while unfilled curves show the data exaggerated by a factor of 10 for rare taxa.

Figure 5 Lítlavatn core 20 sedimentological and palynological data.

Figure 6 Millum Vatna sedimentological and palynological data.

Figure 7 Palynomorph size frequency data: A) *Betula*, totals for each sequence; B) *Isoetes*, totals for each sequence; C) *Isoetes*, totals per zone.

Figure 8 DCA biplots for the three pollen datasets. Species scores are indicated with crosses. For clarity, individual sample scores are not shown; the numbered polygons indicate the boundaries of the regions within which the sample scores plot, for each pollen zone.

Figure 9 Age-depth curves for the three sequences.

Site	*Level (cm)*	*Lab. code*	*$\delta^{13}C$ (‰)*	*Age (^{14}C yr BP)*	*Calibrated age range (2σ, yr BP)*	*Median probability (yr BP)*
Gróthúsvatn	249-248	SUERC-1829	-27.2	2955±40	3260-2980	3130
Gróthúsvatn	272-271	SUERC-1830	-27.3	3050±40	3370-3080	3270
Gróthúsvatn	326-325	SUERC-11079	-27.7	2525±35	2740-2490	2600
Gróthúsvatn	373.5-372.5	SUERC-11080	-27.6	2750±35	2930-2770	2840
Gróthúsvatn	453.5-452.5	SUERC-11514	-27.2	3595±35	4060-3780	3900
Lít-20	127-126	SUERC-1821	-27.5	2980±35	3320-3010	3170
Lít-20	158-157	SUERC-1826	-26.8	2125±40	2300-1990	2100
Lít-20	201-200	SUERC-1827	-25.0	4200±35	4850-4620	4730
Lít-20	234-233	SUERC-9013	-25.0	4755±35	5590-5330	5520
Lít-20	301-300	SUERC-1828	-22.1	7430±45	8360-8180	8260
Millum Vatna	46-45	SUERC-1831	-28.2	1375±35	1350-1190	1300
Millum Vatna	114-113	SUERC-1832	-27.8	1595±35	1550-1400	1470

Table 1. Radiocarbon dates from the three sequences. Calibration results are rounded to the nearest decade.

Taxon	**Level(s)**
Abies	328.5
Achillea-type	202.5, 216.5, 226.5, 280.5
Aegopodium podagraria	218.5
Armeria maritima type B	360.5
Artemisia	216.5, 234.5, 300.5, 352.5
Botrychium lunaria	212.5, 236.5, 294.5, 392.5
Carpinus betulus	242.5, 244.5
Carum carvi	264.5, 360.5
Caryophyllaceae undiff.	220.5 (2), 240.5, 280.5, 284.5, 392.5
Cerastium-type	202.5, 336.5
Chenopodiaceae	222.5, 298.5, 312.5, 316.5
Chrysosoplenium	238.5, 258.5, 344.5 (2), 360.5
Cirsium	230.5, 250.5 (2), 258.5, 262.5
Drosera intermedia	236.5
Epilobium-type	360.5 (2)
Fagus sylvatica	244.5, 328.5, 336.5, 352.5
Fraxinus excelsior	232.5, 270.5, 286.5, 328.5
Geranium sylvaticum	274.5, 276.5
Hypericum perforatum-type	286.5
Ilex aquifolium	226.5
Koenigia islandica	248.5
Ligusticum scoticum	264.5, 344.5
Limonium vulgare type A	252.5
Littorella uniflora	220.5
Menyanthes trifoliata	290.5, 292.5, 316.5, 328.5, 448.5
Myrrhis odorata	488.5
Oxyria digyna	230.5, 298.5, 336.5, 448.5
Pediastrum cf. *integrum*	264.5, 344.5, 376.5
Picea	204.5 (0.5)
Plantago coronopus	200.5 (2), 216.5, 232.5, 248.5, 264.5
Polygala	268.5
Primula vulgaris	268.5
Pteropsida trilete undiff.	210.5, 274.5, 344.5
Rubiaceae	202.5, 210.5, 214.5, 220.5 (2), 328.5
Saxifraga granulata-type	238.5, 264.5, 296.5, 312.5, 488.5
Scrophulariaceae	208.5, 268.5, 272.5, 376.5
Solidago virgaurea-type	208.5
Tilia cordata	298.5, 300.5
Vaccinium	248.5, 252.5, 280.5
Veronica-type	304.5, 316.5
Vicia cracca	274.5

Table S1. Rare taxa found at Gróthusvatn. Finds of other than one grain per level are indicated with the total shown in brackets (the value of 0.5 for *Picea* refers to a broken grain). Many of the taxa in this table are not currently found in the Faroes; these finds may be ascribed to long-distance transport.

Taxon	**Level(s)**
Achillea-type	100.5, 140.5
Arctostaphylos uva-ursi	148.5
Armeria maritima type A	156.5
Artemisia	140.5
Botrychium lunaria	220.5
Cardueae undiff.	108.5, 116.5
Carpinus betulus	132.5
Caryophyllaceae undiff.	100.5, 140.5, 156.5, 260.5, 276.5
Cerastium-type	148.5, 156.5, 260.5
Charcoal	100.5, 236.5
Chenopodiaceae	100.5, 124.5
Cirsium-type	236.5, 276.5
Fagus sylvatica	244.5
Galeopsis-type	228.5
Ligusticum scoticum	228.5
Lychnis flos-cuculi	132.5, 212.5, 260.5, 292.5, 308.5
Mentha-type	260.5
Picea	244.5
Pinus/*Picea* undiff.	292.5
Plantago lanceolata	100.5, 124.5
Pteridium aquilinum	124.5
Pteropsida trilete undiff.	100.5, 116.5, 164.5, 260.5
Ranunculus undiff.	100.5, 260.5, 276.5
Rosaceae undiff.	244.5
Rubiaceae	100.5, 244.5
Saxifraga granulata-type	228.5
Urtica dioica/*urens* undiff.	116.5
Urtica pilulifera	100.5

Table S2. Rare taxa found in the Lítlavatn Lít-20 sequence. All finds were of individual grains.

Taxon	**Level(s)**
Anthemis-type	28.5, 40.5, 44.5
Anthriscus sylvestris	44.5, 112.5
Arctostaphylos uva-ursi	36.5
Aster-type	24.5, 28.5
Brassicaceae	36.5
Cardueae undiff.	24.5
Carpinus betulus	32.5
Carum carvi	40.5
Caryophyllaceae undiff.	24.5
Cerastium	76.5
Chenopodiaceae	64.5
Chrysosoplenium	80.5 (2)
Cirsium-type.	32.5
Isoetes	168.5
Lactuceae undiff	16.5 (2), 20.5 (2), 48.5
Lotus	96.5
Lycopodium annotinum	28.5, 128.5
Menyanthes trifoliata	168.5
Nymphaea alba	52.5, 72.5
Polygala	16.5
Pteridium aquilinum	20.5 (2), 168.5
Pteropsida trilete undiff.	16.5
Rubiaceae	32.5, 128.5, 160.5
Saxifraga granulata-type.	160.5
Saxifraga stellaris-type	32.5, 36.5, 68.5, 76.5, 128.5
Succisa pratensis	44.5, 52.5, 76.5 (2), 80.5, 112.5
Thalictrum	24.5, 32.5, 60.5, 64.5
Tilia cordata	36.5, 72.5
Urtica urens	80.5
Urtica urens/*dioica* undiff.	68.5

Table S3. Rare taxa found at Millum Vatna. Finds of more than one grain per level are indicated with the total shown in brackets.

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
	72.66	0.18	14.01	2.92	0.12	0.13	1.88	4.84	2.40	0.00	99.13
	71.95	0.27	14.45	4.02	0.13	0.23	2.46	3.94	2.26	0.06	99.76
	71.75	0.25	14.68	3.81	0.14	0.25	2.27	1.38	2.08	0.03	96.63
	69.69	0.44	15.40	5.37	0.18	0.48	3.13	1.86	2.03	0.13	98.72
	69.41	0.39	15.39	5.21	0.24	0.42	3.02	1.56	1.89	0.08	97.61
	68.91	0.38	14.88	5.30	0.17	0.45	3.19	3.91	2.05	0.08	99.31
	68.00	0.34	14.34	5.18	0.16	0.42	3.07	4.77	2.08	0.08	98.44
	67.99	0.41	14.89	5.45	0.23	0.52	3.19	4.34	2.03	0.08	99.12
	67.97	0.39	15.00	5.49	0.19	0.48	3.24	4.62	2.03	0.07	99.47
	67.39	0.45	14.69	5.78	0.17	0.55	3.41	4.66	1.94	0.08	99.11
	67.05	0.41	14.75	5.70	0.23	0.45	3.21	4.56	2.10	0.09	98.55
Mean (%)	69.34	0.36	14.77	4.93	0.18	0.40	2.91	3.68	2.08	0.07	98.71
Standard deviation	1.87	0.08	0.40	0.88	0.04	0.13	0.47	1.31	0.13	0.03	0.86

Table S4. Geochemical data for individual tephra grains from 170-169 cm at Millum Vatna. Values expressed as percentages; total iron is expressed as FeO equivalent.

Fig. 1

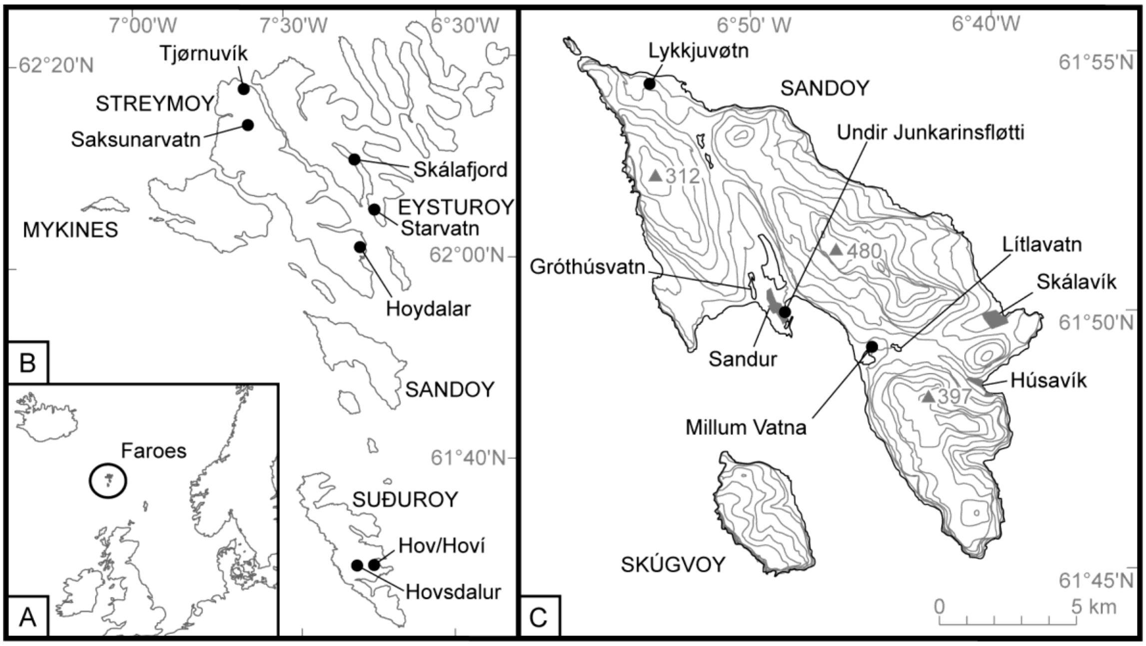

7°00'W
7°30'W
6°30'W
62°20'N
Tjørnuvík
STREYMOY
Saksunarvatn
Skálafjord
EYSTUROY
Starvatn
MYKINES
62°00'N
Hoydalar
B
SANDOY
Faroes
61°40'N
SUÐUROY
Hov/Hoví
Hovsdalur
A
6°50' W
6°40'W
Lykkjuvøtn
61°55'N
SANDOY
Undir Junkarinsfløtti
312
480
Lítlavatn
Gróthúsvatn
Skálavík
61°50'N
Sandur
Húsavík
397
Millum Vatna
SKÚGVOY
61°45'N
0
5 km
C

Fig. 2

Fig.3

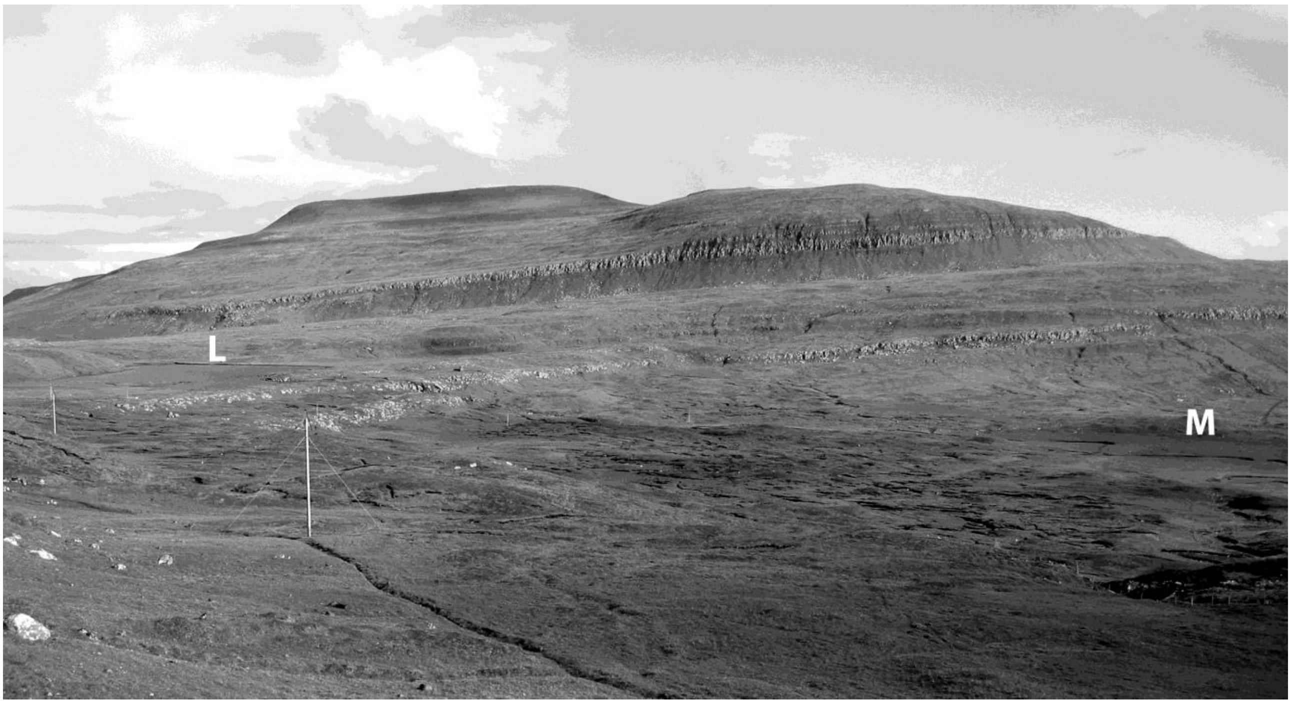


Fig. 4a

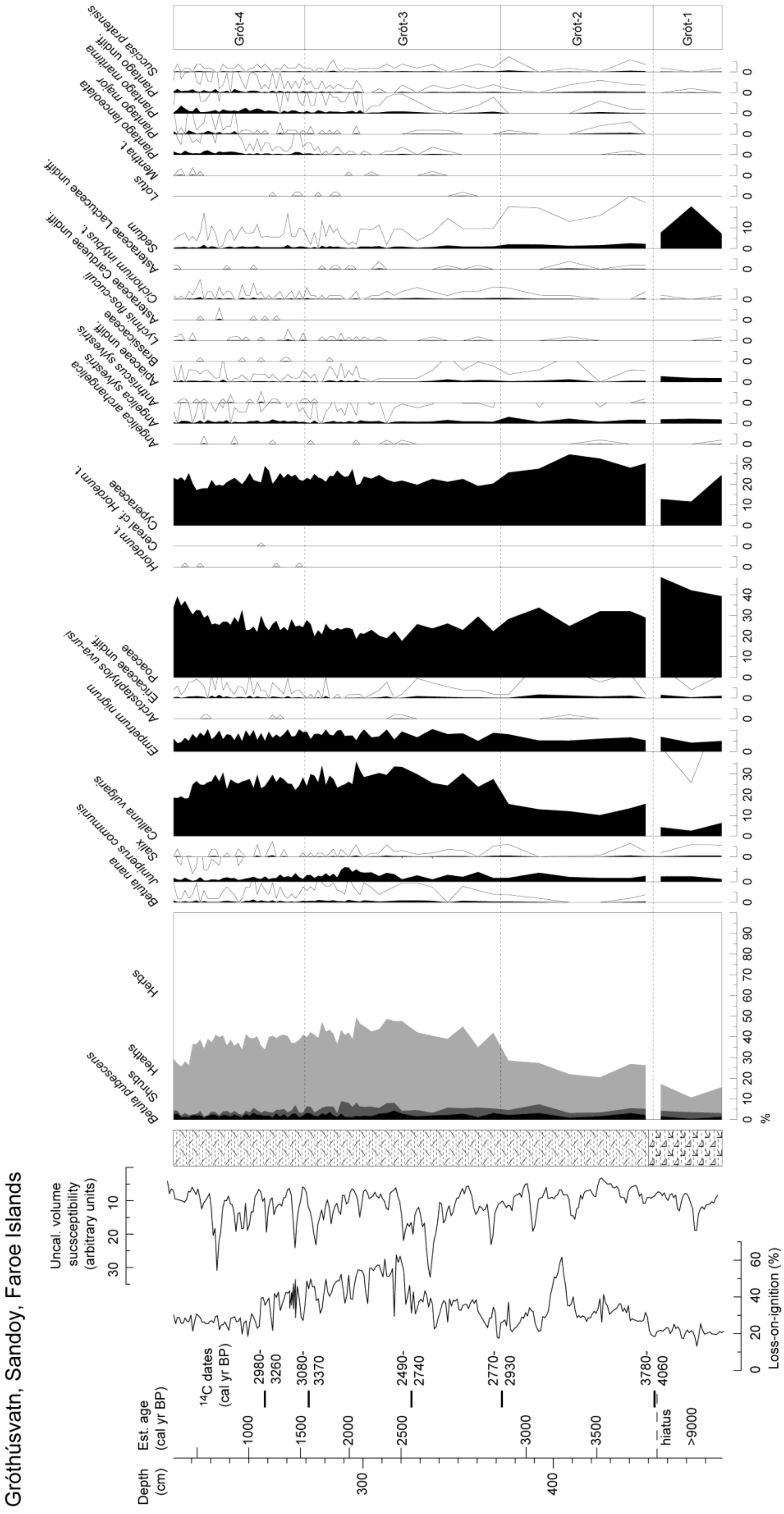

Gróthúsvatn, Sandoy, Faroe Islands
Depth (cm)
300
400
Est. age (cal yr BP)
1000
1500
2000
2500
3000
3500
hiatus
>9000
^{14}C dates (cal yr BP)
2980-3260
3080-3370
2490-2740
2770-2930
3780-4060
Loss-on-ignition (%)
0
20
40
60
Uncal. volume sucsceptibility (arbitrary units)
10
20
30
Betula pubescens
Shrubs
Heaths
Herbs
%
Betula nana
Juniperus communis
Salix
Calluna vulgaris
Empetrum nigrum
Arctostaphylos uva-ursi
Ericaceae undiff.
Poaceae
Hordeum t.
Cereal cf. Hordeum t.
Cyperaceae
Angelica archangelica
Angelica sylvestris
Anthriscus sylvestris
Apiaceae undiff.
Brassicaceae
Lychnis flos-cuculi
Asteraceae Carduee undiff.
Cichorium intybus t.
Asteraceae Lactuceae undiff.
Sedum
Lotus
Mentha t.
Plantago lanceolata
Plantago major
Plantago maritima
Plantago undiff.
Succisa pratensis
Grót-1
Grót-2
Grót-3
Grót-4

Fig. 4b

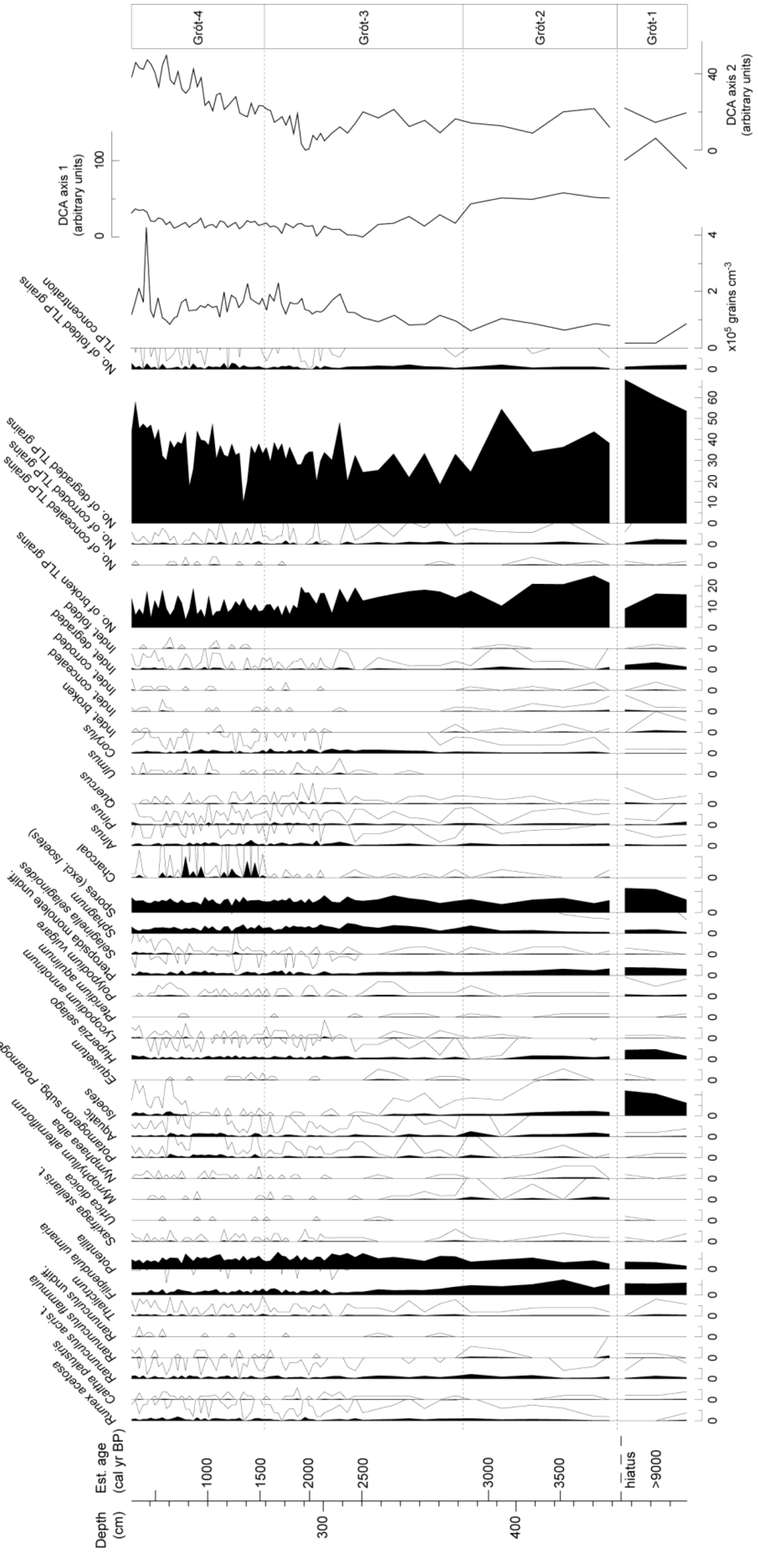

Gröt-4
Gröt-3
Gröt-2
Gröt-1
DCA axis 2 (arbitrary units)
0
40
DCA axis 1 (arbitrary units)
0
100
TLP concentration
x10^5 grains cm^-3
0
2
4
No. of folded TLP grains
No. of degraded TLP grains
No. of corroded TLP grains
No. of concealed TLP grains
No. of broken TLP grains
Indet. folded
Indet. degraded
Indet. corroded
Indet. concealed
Indet. broken
Corylus
Ulmus
Quercus
Pinus
Alnus
Charcoal
Spores (excl. Isoetes)
Sphagnum
Selaginella selaginoides
Pteropsida monolete undiff.
Polypodium vulgare
Pteridium aquilinum
Lycopodium annotinum
Huperzia selago
Equisetum
Isoetes
Aquatic
Potamogeton subg. Potamogeton
Nymphaea alba
Myriophyllum alterniflorum
Urtica dioica
Saxifraga stellaris t.
Potentilla
Filipendula ulmaria
Filipendula undiff.
Thalictrum
Ranunculus flammula
Ranunculus acris t.
Caltha palustris
Rumex acetosa
0
10
20
30
40
50
60
Est. age (cal yr BP)
1000
1500
2000
2500
3000
3500
hiatus
>9000
Depth (cm)
300
400

Fig. 5a

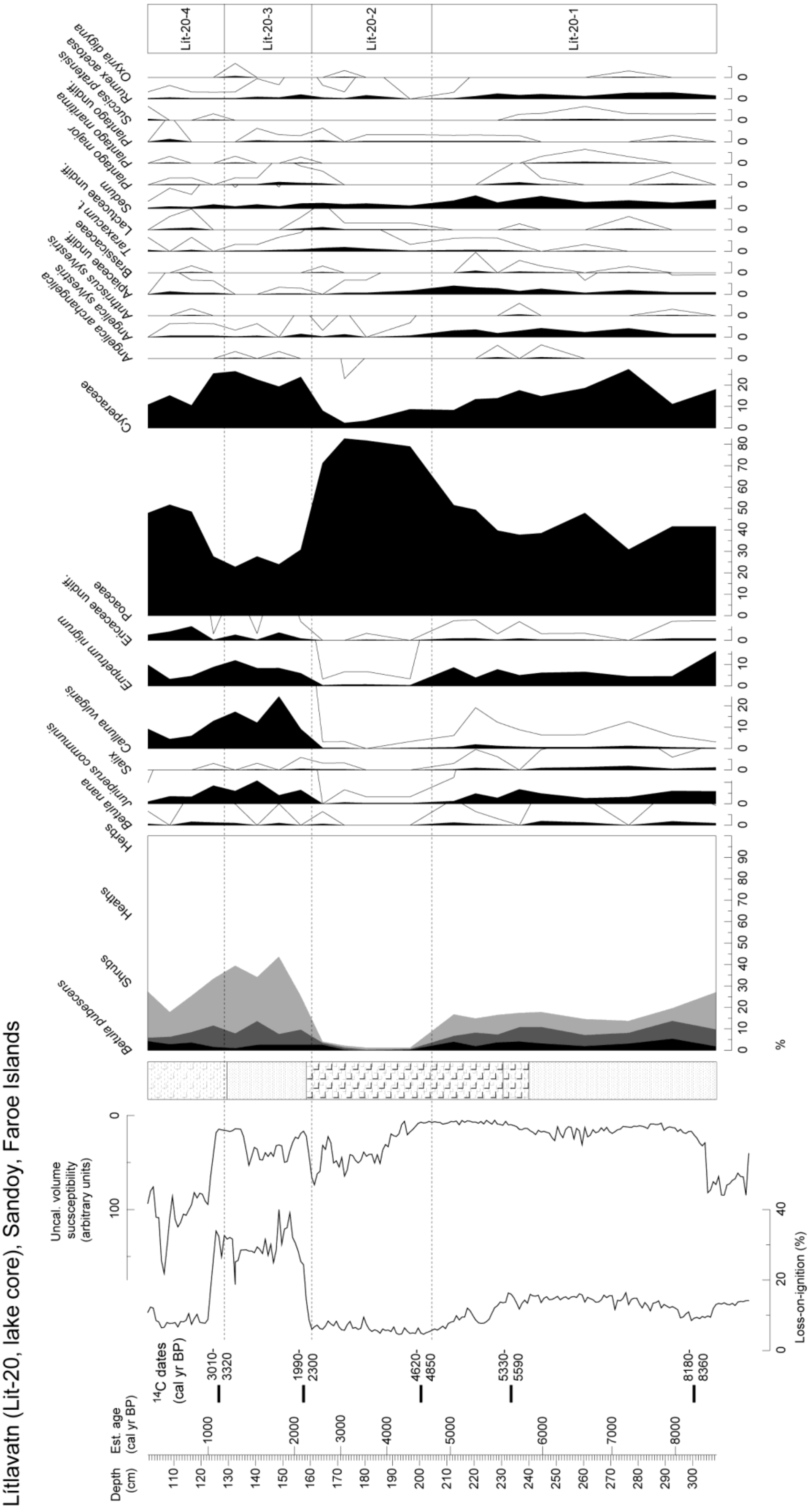

Lítlavatn (Lit-20, lake core), Sandoy, Faroe Islands
Depth (cm)
Est. age (cal yr BP)
14C dates (cal yr BP)
3010-3320
1990-2300
4620-4850
5330-5590
8180-8360
Uncal. volume susceptibility (arbitrary units)
Loss-on-ignition (%)
Betula pubescens
Shrubs
Heaths
Herbs
Betula nana
Juniperus communis
Salix
Calluna vulgaris
Empetrum nigrum
Ericaceae undiff.
Poaceae
Cyperaceae
Angelica archangelica
Angelica sylvestris
Anthriscus sylvestris
Apiaceae undiff.
Brassicaceae
Taraxacum t.
Lactuceae undiff.
Sedum
Plantago major
Plantago maritima
Succisa pratensis
Rumex acetosa
Oxyria digyna
Lit-20-1
Lit-20-2
Lit-20-3
Lit-20-4
%

Fig.5b

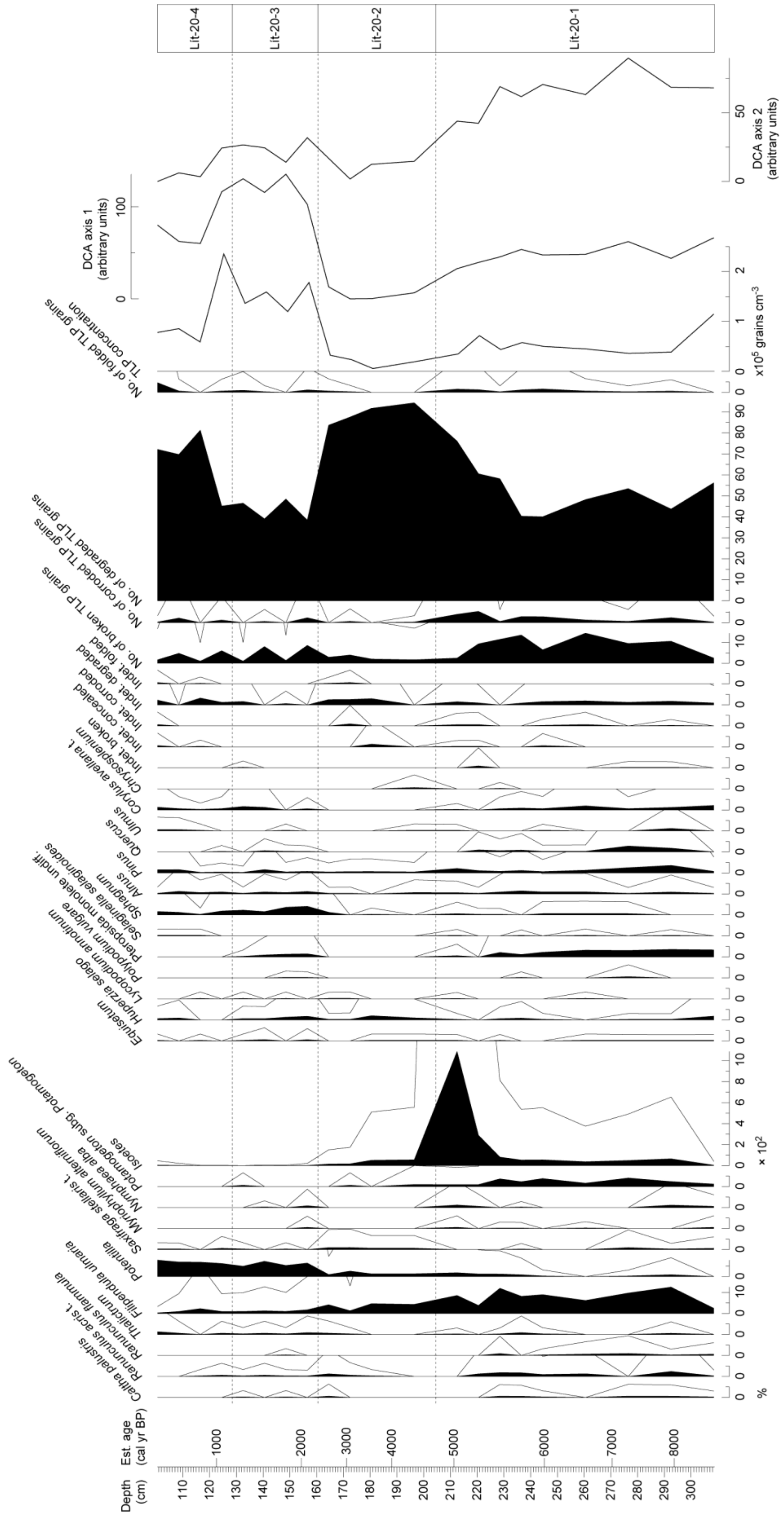

Lit-20-4
Lit-20-3
Lit-20-2
Lit-20-1
DCA axis 2 (arbitrary units)
0
50
DCA axis 1 (arbitrary units)
0
100
TLP concentration
$\times 10^5$ grains cm^{-3}
0
1
2
No. of folded TLP grains
No. of degraded TLP grains
No. of corroded TLP grains
No. of broken TLP grains
0
10
20
30
40
50
60
70
80
90
Indet. folded
Indet. degraded
Indet. corroded
Indet. concealed
Indet. broken
Chrysosplenium
Corylus avellana t.
Ulmus
Quercus
Pinus
Alnus
Sphagnum
Selaginella selaginoides
Pteropsida monolete undiff.
Polypodium vulgare
Lycopodium annotinum
Huperzia selago
Equisetum
Isoetes
Potamogeton subg. Potamogeton
Nymphaea alba
Myriophyllum alterniflorum
Saxifraga stellaris t.
Potentilla
Filipendula ulmaria
Thalictrum
Ranunculus flammula
Ranunculus acris t.
Caltha palustris
$\times 10^2$
0
2
4
6
8
10
%
Est. age (cal yr BP)
1000
2000
3000
4000
5000
6000
7000
8000
Depth (cm)
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300

Fig. 6a

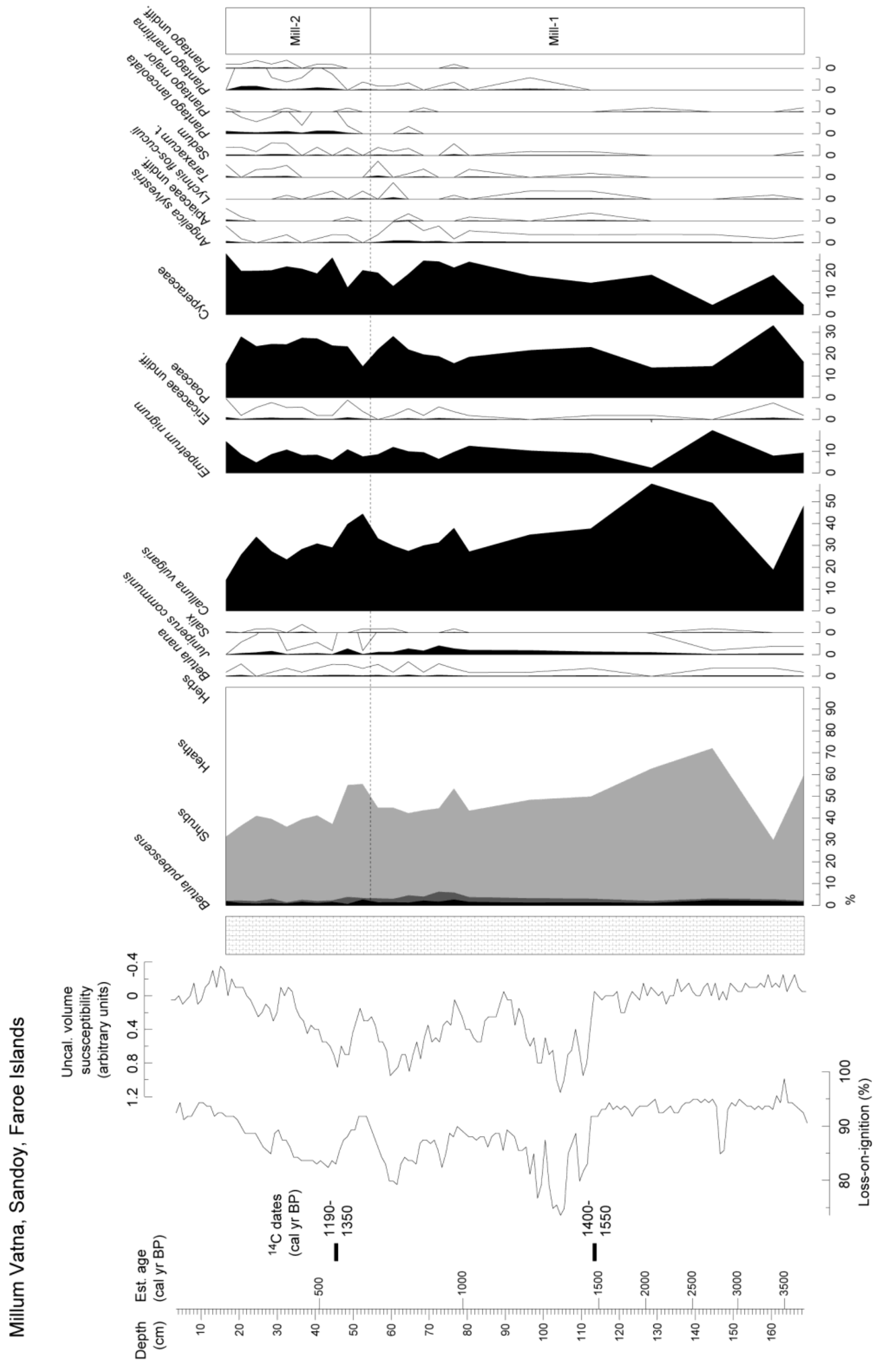

Millum Vatna, Sandoy, Faroe Islands
Depth (cm)
Est. age (cal yr BP)
^{14}C dates (cal yr BP)
1190-1350
1400-1550
Loss-on-ignition (%)
Uncal. volume sucsceptibility (arbitrary units)
Betula pubescens
Shrubs
Heaths
Herbs
Betula nana
Juniperus communis
Salix
Calluna vulgaris
Empetrum nigrum
Ericaceae undiff.
Poaceae
Cyperaceae
Angelica sylvestris
Apiaceae undiff.
Lychnis flos-cuculi
Taraxacum t.
Sedum
Plantago lanceolata
Plantago major
Plantago maritima
Plantago undiff.
Mill-2
Mill-1
%

Fig. 6b

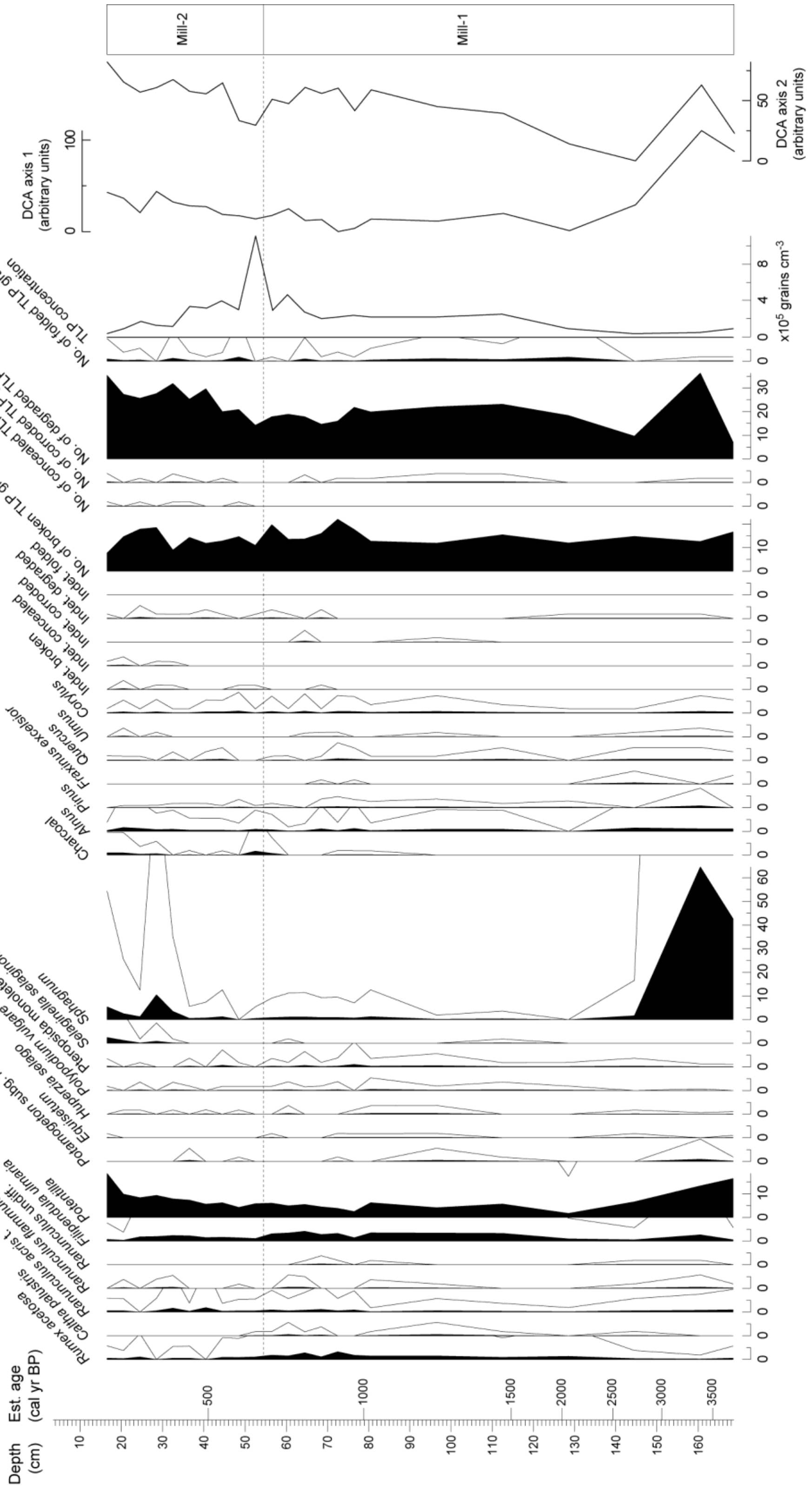

Mill-2
Mill-1
DCA axis 2 (arbitrary units)
0
50
DCA axis 1 (arbitrary units)
0
100
No. of folded TLP grains
TLP concentration
0
4
8
$\times 10^5$ grains cm^{-3}
No. of degraded TLP grains
No. of corroded TLP grains
No. of concealed TLP grains
No. of broken TLP grains
Indet. folded
Indet. degraded
Indet. corroded
Indet. concealed
Indet. broken
Corylus
Ulmus
Quercus
Fraxinus excelsior
Pinus
Alnus
Charcoal
Sphagnum
Selaginella selaginoides
Pteropsida monolete undiff.
Polypodium vulgare
Huperzia selago
Equisetum
Potamogeton subg. Potamogeton
Potentilla
Filipendula ulmaria
Ranunculus undiff.
Ranunculus flammula
Ranunculus acris t.
Caltha palustris
Rumex acetosa
0
10
20
30
40
50
60
Est. age (cal yr BP)
500
1000
1500
2000
2500
3000
3500
Depth (cm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Fig. 7

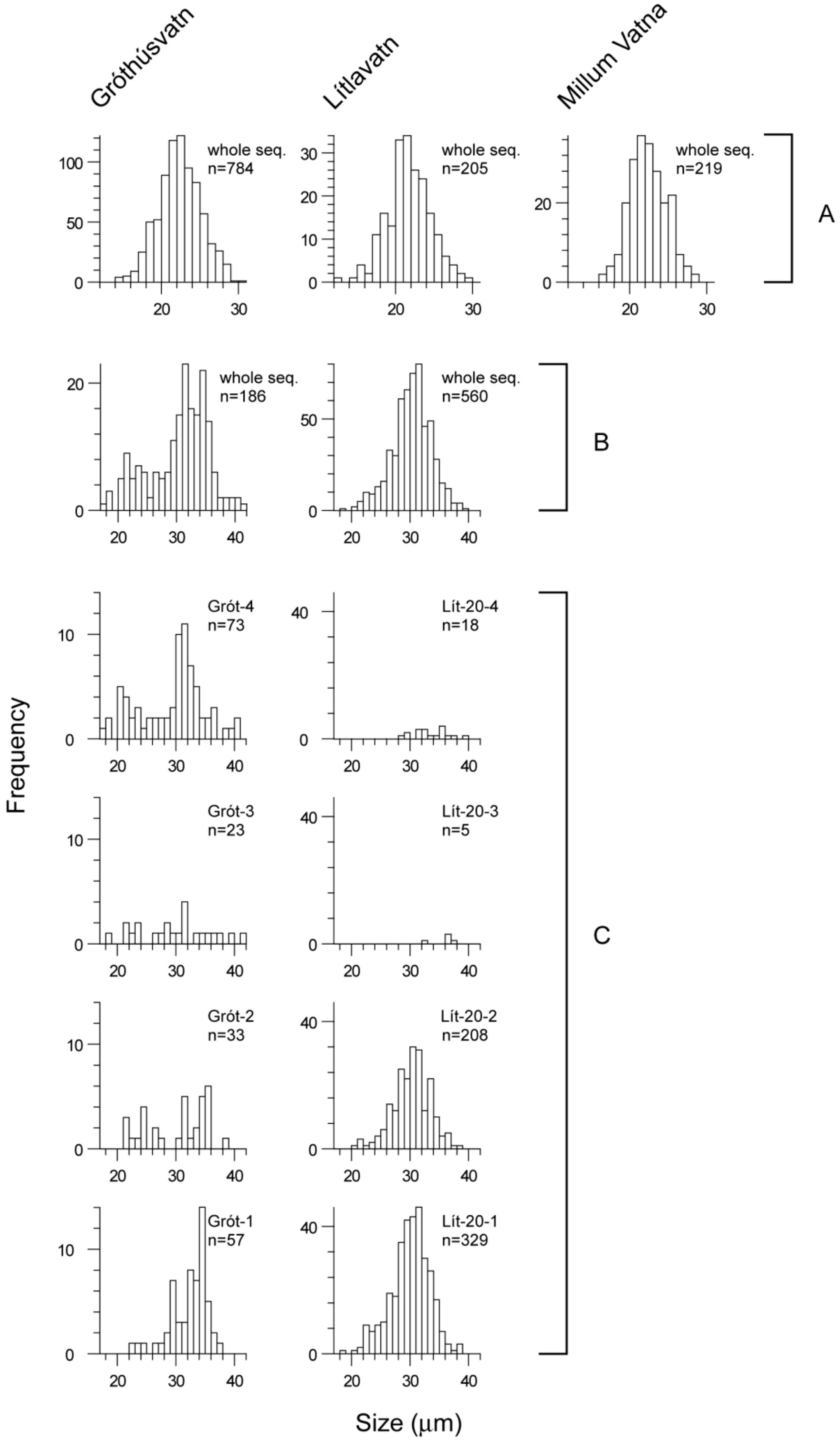

Gróthúsvatn
Lítlavatn
Millum Vatna
whole seq.
n=784
whole seq.
n=205
whole seq.
n=219
A
whole seq.
n=186
whole seq.
n=560
B
Grót-4
n=73
Lít-20-4
n=18
Grót-3
n=23
Lít-20-3
n=5
Grót-2
n=33
Lít-20-2
n=208
Grót-1
n=57
Lít-20-1
n=329
C
Frequency
Size (μm)
0
50
100
10
20
30
40

Fig. 8

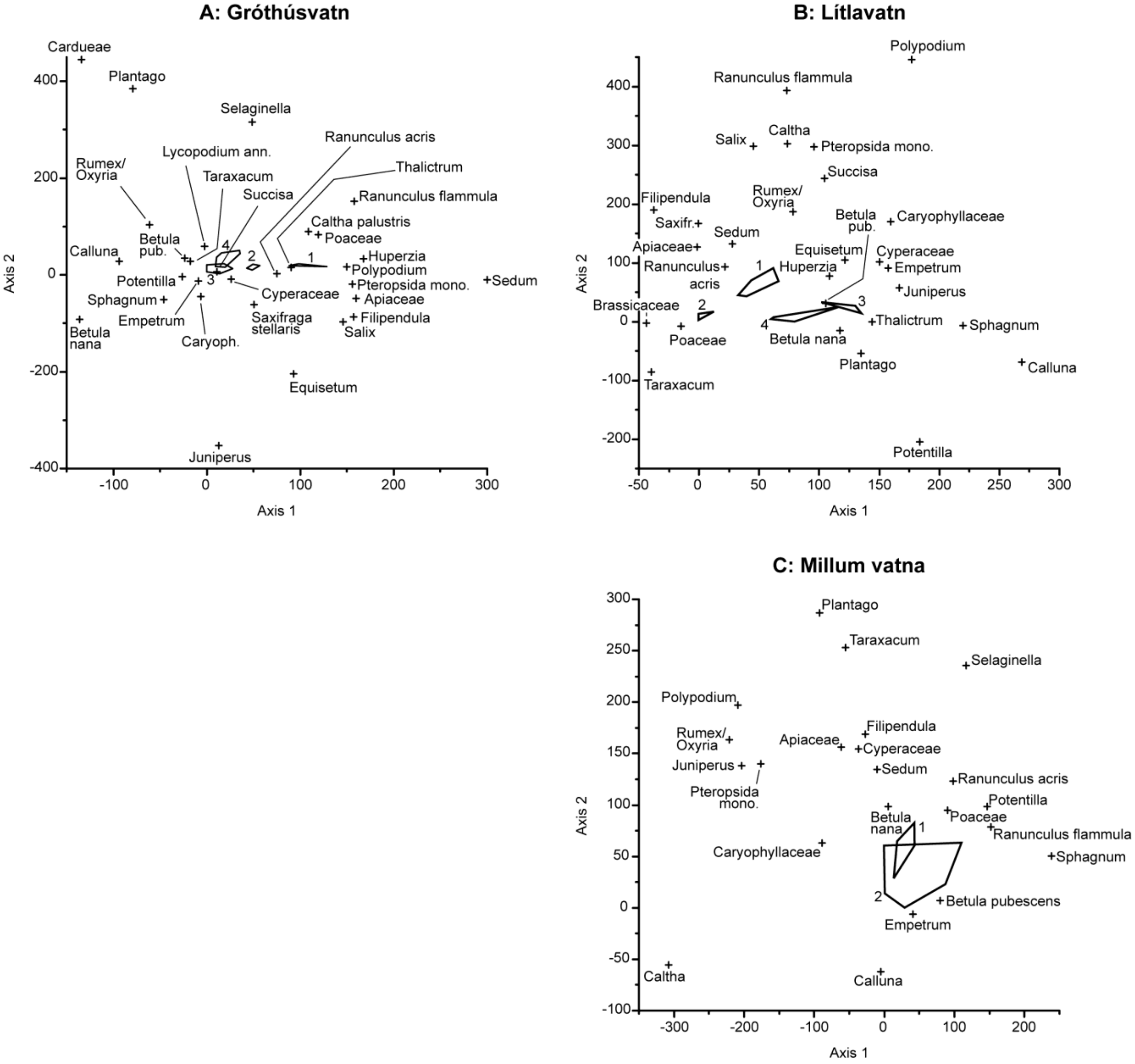
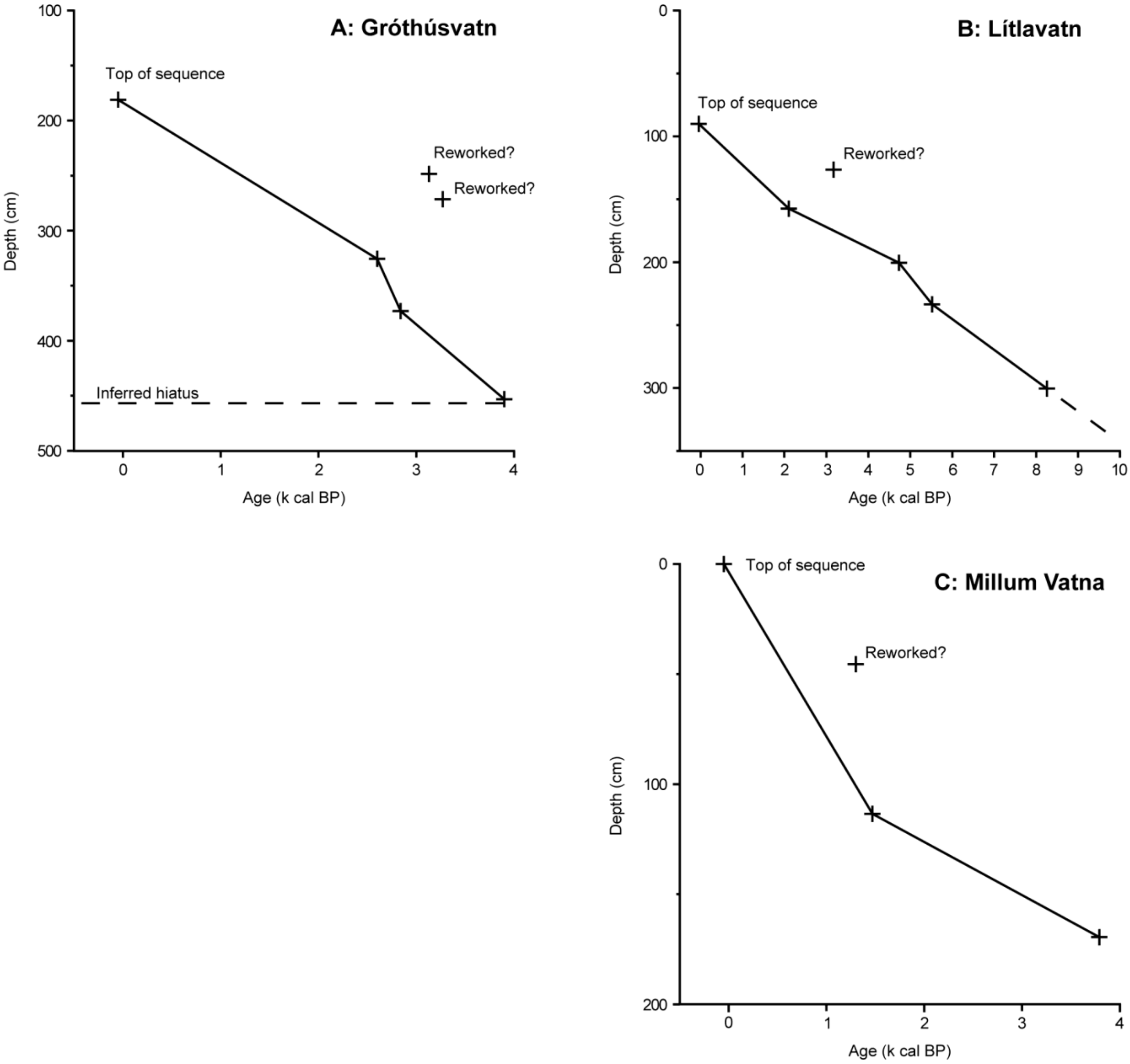

A: Gróthúsvatn
Cardueae
Plantago
Selaginella
Ranunculus acris
Lycopodium ann.
Thalictrum
Rumex/
Oxyria
Taraxacum
Succisa
Ranunculus flammula
Caltha palustris
Poaceae
Betula
pub.
Calluna
Huperzia
Polypodium
Potentilla
Pteropsida mono.
Sedum
Sphagnum
Cyperaceae
Apiaceae
Empetrum
Saxifraga
stellaris
Filipendula
Betula
nana
Caryoph.
Salix
Equisetum
Juniperus
1
2
3
4
Axis 1
Axis 2
400
200
0
-200
-400
-100
0
100
200
300
B: Lítlavatn
Polypodium
Ranunculus flammula
Salix
Caltha
Pteropsida mono.
Succisa
Filipendula
Rumex/
Oxyria
Saxifr.
Betula
pub.
Caryophyllaceae
Sedum
Apiaceae
Equisetum
Cyperaceae
Ranunculus
acris
Huperzia
Empetrum
Juniperus
Brassicaceae
Thalictrum
Sphagnum
Poaceae
Betula nana
Plantago
Calluna
Taraxacum
Potentilla
1
2
3
4
Axis 1
Axis 2
400
300
200
100
0
-100
-200
-50
0
50
100
150
200
250
300
C: Millum vatna
Plantago
Taraxacum
Selaginella
Polypodium
Rumex/
Oxyria
Apiaceae
Filipendula
Cyperaceae
Juniperus
Sedum
Pteropsida
mono.
Ranunculus acris
Potentilla
Betula
nana
Poaceae
Ranunculus flammula
Caryophyllaceae
Sphagnum
Betula pubescens
Empetrum
Caltha
Calluna
1
2
Axis 1
Axis 2
300
250
200
150
100
50
0
-50
-100
-300
-200
-100
0
100
200

Fig. 9


A: Gróthúsvatn
Top of sequence
Reworked?
Reworked?
Inferred hiatus
Depth (cm)
100
200
300
400
500
Age (k cal BP)
0
1
2
3
4
B: Lítlavatn
Top of sequence
Reworked?
Depth (cm)
0
100
200
300
Age (k cal BP)
0
1
2
3
4
5
6
7
8
9
10
C: Millum Vatna
Top of sequence
Reworked?
Depth (cm)
0
100
200
Age (k cal BP)
0
1
2
3
4