

Peat initiation in the Faroe Islands: climate change, pedogenesis, or human impact?

Running title: Peat initiation in the Faroe Islands

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Abstract

As an isolated island group lying off the NW European mainland which was uninhabited until the mid-first millennium AD, the Faroes offer a unique opportunity to study natural processes of Holocene ecosystem development in a region where anthropogenic activity is usually a complicating factor. In this paper new radiocarbon dates and pollen-analytical data from the island of Sandoy, in the centre of the Faroes archipelago, are presented. Together with existing pollen and plant macrofossil records, these data allow a reconstruction of patterns of Holocene vegetational and edaphic change. Basal peat dates indicate that large areas of blanket mire were established long before the first human settlement, demonstrating conclusively that human impact is not necessary for the development of such ecosystems. The timing of the initiation of the blanket peats varies markedly, both across the Faroes as a whole and at a landscape scale, with dates distributed evenly over 9,000 years. This suggests that, in the Faroes at least, pedogenesis was more important than climatic change in determining the timing of the spread of blanket peat systems.

Keywords: Climate change, Holocene, Human Impact, Norse, Peat initiation, Pollen, Radiocarbon.

The Faroe Islands represent an unusual opportunity to study natural vegetation change over Holocene timescales. As an isolated archipelago in the North Atlantic, the vegetation communities of the Faroes are broadly analogous to other oceanic communities in NW Europe, albeit that the flora is a small sub-set of the European one. Wet grassland and mire communities prevail, and there are no remaining native tree populations (Fosaa 2001). The archaeological consensus is that the islands are unlikely to have been inhabited until the mid-first millennium AD (Arge 1991, 1993; Debes 1993; Arge *et al.* 2005). There have been no firm indications of human presence from earlier periods, either in the archaeological or palaeoecological records (cf. the situation in the Northern and Western Isles of Scotland: Bennett *et al.* 1992; Edwards 1996; Hannon *et al.* 2005). Although there is mention of a prior presence of small numbers of Christian hermits in *De mensura orbis terrae*, written in 825 AD by the Irish monk Dicuil, supported by a growing body of palaeoenvironmental evidence (e.g. Hannon & Bradshaw 2000; Edwards *et al.* 2005; but see Thorsteinsson 2005), the oldest unequivocal archaeological traces are those of the Norse who probably arrived in the first half of the ninth century (Vickers *et al.* 2005; Church *et al.* 2005). Jóhansen's (1986–87) claim that the pollen grains of the weed *Plantago lanceolata* (ribwort plantain) indicate a prehistoric human presence as long ago as 2300 BC are now considered to be untenable (Edwards 2005). Faroese ecosystems may therefore be presumed to have developed free from anthropogenic influence for most of the Holocene.

These circumstances make the Faroes a useful laboratory in which to improve our understanding of a long-standing palaeoecological problem, that of when and how blanket peat forms (Edwards & Hiron 1982; Moore 1973, 1993). Blanket peat landscapes consist of a complex of different mire types (Charman 2002), including terrestrialized basins (filled with “primary peat”, in the terminology of Moore & Bellamy [1973], and sometimes capped and surrounded by “secondary peat” affected by the raised groundwater associated with primary peat formation), as well as peat growing more widely on flat and sloping land surfaces above the influence of groundwater (“tertiary peat”). In oceanic or mountainous areas, high rainfall over centuries or millennia may lead to progressive leaching, acidification and waterlogging (paludification) of soils, inhibiting the decay of organic matter and encouraging the spread of blanket peat (Moore 1973; Charman 2002). It has been

suggested that discrete episodes of blanket peat expansion may relate to climatic events, or to step-like transitions, involving increased precipitation and/or lower temperatures (e.g. Conway 1954; Tallis 1991; Ellis and Tallis 2000). On the other hand, numerous palaeoecological studies, from the British Isles and Norway in particular, have found indications that blanket peat initiation is often related to human impact. For example, charcoal from burning is thought to block soil pores and impede drainage (e.g. Mallik *et al.* 1984; Smith & Cloutman 1988; Charman 1992). Deforestation can likewise alter the hydrological balance of soils (e.g. Moore 1973), although this is not relevant in the Faroes, where there has never been any extensive woodland (Jóhansen 1985). The three primary drivers of peat initiation, gradual pedogenesis, climate change, and human impact, are difficult to separate without independent evidence, hence the value of studying peatland development in a situation such as the Faroes where one of these factors can be ruled out for most of the Holocene.

1. Study area

The Faroe Islands (Fig. 1) consist of 18 sizeable islands (Streymoy, the largest, has maximum dimensions of 48 by 12 km) formed of near-horizontally bedded Tertiary flood basalts and intercalated tuffs, which gives a very characteristic, stepped, mountainous terrain. The climate is extremely oceanic, with mean July/August temperatures of 11°C and mean February temperatures of 4°C; precipitation, concentrated in the winter, is around 1400 mm y⁻¹ close to sea level at Tórshavn (Jóhansen 1985: 13). Glacial drift deposits left by extensive Weichselian (approximately, Marine Isotope Stages 2 to 5d) ice sheets occur throughout the islands (Humlum & Christiansen 1998a). Pollen data indicate that early Holocene soils supported, successively, fell-field then tall herb/grasslands, and probably had a high base-status (e.g. Jóhansen 1975, 1982, 1985; Hannon *et al.* 2003).

Today, soil characteristics vary considerably according to altitude and slope angle. Wet mires occur in valleys and basins, often capping the deposits of former lakes. Peats also occur on gentle slopes, grading into more inorganic 'peaty soils' (Jóhansen 1985) on steeper slopes. At higher altitudes and on very steep slopes, where erosional processes are active and growth rates lower, soils are more minerogenic (Jóhansen 1985; Humlum & Christiansen 1998b; Fosaa 2001). This gradation requires care in

the identification of soil materials as peat. Here, we define peats as having an organic content of 65% (dry weight) or more, following Charman (2002: 4). Implicit to this definition is the understanding that such organic soils are likely to be very wet, acidic and nutrient poor, and will tend to accumulate upwards in the absence of physical erosion. Most of the peat sequences studied here achieve much higher organic contents, but some appear to have had some input of inorganic material through slopewash and/or aeolian transport.

This study has two principal aims. The first is to test the (null) hypothesis that the spread of blanket peat across parts of Sandoy occurred as a result of human activity, e.g. by burning, deforestation or shrub clearance, or trampling by introduced animals. A key, testable prediction of this hypothesis is that at least some peat sequences should be younger than *c.* AD 800. Our alternative hypothesis is that blanket peat initiation occurred through natural processes alone. The second aim is to provide a more generalized account of the spatio-temporal pattern of peat development, and associated environmental change, in the Faroe Islands, particularly in relation to the relative contributions of gradual pedogenesis and climatic change to the spread of blanket peat.

To address these aims, a study area of approximately 2 km² was selected on the island of Sandoy (Figs 1 and 2) where a large area of blanket peat extends across a wide valley, glacial in origin, around Stóravatn and Lítlavatn (literally ‘large lake’ and ‘small lake’). The valley floor runs from about 25 m above sea level (asl) at its western end, where it terminates in cliffs at the coast, to about 75 m asl at the watershed with the next valley to the east. The valley is surrounded by steep, stepped slopes, with surrounding peaks between 400 and 480 m asl; soils on the steep slopes are thinner and more minerogenic than the thick peats on the floor of the valley, which range up to more than a metre in thickness. At one location at least (Millum Vatna, literally ‘between the lakes’) the peats are underlain by limnic sediments rather than the more usual regolith. Numerous streams and rivers carry water and sediment down from the surrounding hills; the primary drainage system runs through the two lakes and terminates in a waterfall at the coastal cliffs. The vegetation on the peats consists of a mosaic of communities, with *Carex*, *Sphagnum* and *Eriophorum angustifolium* dominating in the wettest areas, and *Calluna vulgaris*, *Potentilla erecta*, *Nardus stricta*, *Festuca vivipara* and other grasses on drier peats. Grass moorland

vegetation dominates on more minerogenic soils (Fosaa 2001). There is evidence of peat cutting in the past, but today the valley and surrounding hills are primarily used for rough grazing. Known archaeological remains are limited to a number of ruined walls or field banks and several structures that may have been shielings or for stock control (Lawson *et al.* 2005).

Investigation of the palaeoecology of the Faroes was pioneered by Jóhansen (1971, 1975, 1982, 1985), who produced pollen diagrams from a number of lake and mire sites, as well as radiocarbon dates of several basal (oldest) peat samples. Further work has since been published by other authors (Edwards & Craigie 1998; Edwards *et al.* 1998, 2005; Hannon & Bradshaw 2000; Hannon *et al.* 1998, 2001, 2003, 2005; Lawson *et al.* 2005; Vickers *et al.* 2005). The present study differs in being the first study focused on reconstructing the history of peat expansion at a landscape scale, and in presenting the first data pertaining to this issue from the island of Sandoy. This study also approximately doubles the number of available estimates of peat initiation dates in the Faroes.

2. Methods

Ten sections through the peat to the underlying mineral regolith were taken, either using monolith tins or a Russian-type corer (Jowsey 1966), with sections labelled (discontinuously) Lít-2 to Lít-16 (additional sections described in the field were not subjected to laboratory analysis and dating). Only the section in each sequence spanning the transition between regolith and peat was analysed in detail. Sites were chosen along two rough transects running along and across the study area, making use of natural sections wherever possible and avoiding topographic depressions where the basal organic deposits might not be blanket peats. Lít-2 is exceptional in representing a sequence of alluvial fan deposits with interbedded peats. Following laboratory description, contiguous 1 cm³ samples were analysed for loss-on-ignition (LOI) at 450°C to constant weight (Dean 1974; Heiri *et al.* 2001). Horizons for radiocarbon dating were selected using the LOI data as a guide, identifying the level at which values first reached sustained high values (always > 65% and usually *c.* 90%). A case could be made for taking the dates from slightly lower horizons in some cases – for example, at the point where Charman's (2002) threshold of 65% was first achieved – but, under our criteria, horizons for dating were selected conservatively in the sense

that any inaccuracy would tend to underestimate the age of peat initiation (reducing the likelihood of falsely rejecting the null hypothesis). Peat or sediment samples of 1 cm³ were taken for radiocarbon dating, from which the humic acid fraction was extracted and AMS-dated at SUERC in East Kilbride, UK. Calibrations were performed using OxCal version 3.10 (Bronk Ramsey 1995, 2001) with the IntCal98 calibration data set (Stuiver *et al.* 1998); calibrated age ranges are quoted using 2 σ confidence intervals.

Samples were analysed for pollen across the regolith-peat boundary in nine of the sequences in order to assess the relationship between peat initiation and vegetation change, and spatial variability in vegetation histories across the catchment. Samples were 1 cm³ in volume and contiguous across the regolith-peat boundary. In some cases the regolith material proved to be palynologically sterile.

Peats and soils generally have small effective pollen source areas, with much of their explanatory power restricted to within a few metres of the sampling site (Bunting 2003), whereas lakes recruit pollen from wider areas (Jacobson & Bradshaw 1981). Two lake sites were accordingly selected in order to determine the landscape-scale pattern of Holocene environmental change. Cores were taken from open water using Russian corers from Lítlavatn (core designated Lít-20) and from Gróthúsvatn, a lake situated 5 km WNW of Lítlavatn. Amongst other analyses (Lawson *et al.* 2005), LOI and pollen data were generated for both sequences, supported by radiocarbon dating.

Pollen preparations followed a standard technique as outlined by Bennett & Willis (2002, omitting steps 2, 4, 5, 6, and 9) using *Lycopodium* tablets as a source of exotic markers and silicone oil as a mounting medium. Samples were counted to a total exceeding 300 (Lítlavatn Lít-20 lake sequence and short peat sequences) or 500 (Gróthúsvatn) terrestrial pollen grains, excluding spores, aquatics, and alien taxa. 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 *Betula pubescens*, were excluded from the total land pollen (TLP) sum. A small number of occasional pollen and spore taxa which might reasonably be expected to have occurred in the past, but which are not listed in Fosaa (2000), were included in the calculations. Those taxa are: *Chrysosplenium*, *Drosera*

intermedia, *Erica tetralix*, *Limonium vulgare*, *Myrrhis odorata*, *Nymphaea alba*, and *Pteridium aquilinum*.

3. Results and initial interpretations

3.1 Short peat/regolith sections and basal peat dates

Figure 2 shows the spatial variation in the age of the basal blanket peats sampled at the ten sites around Lítlavatn, and details of the dates are given in Table 1. The dates range from 5585 ± 40 to 1270 ± 35 ^{14}C BP (6450-6290 and 1290-1080 cal BP, respectively). There is no clear spatial pattern in the ages. The youngest date falls just within the period of Norse occupation, and it is possible that older peat has been mined from this site, although care was taken to avoid sampling in areas that showed signs of disturbance. Even taking a very conservative view by rejecting the two youngest dates, and accepting the younger of the two dates from Lít-7 as the age of true peat initiation at this site, the period of peat initiation can be seen to have spanned almost 2,000 years. With a sample size as small as ten, it is entirely possible that older and younger basal peats have escaped sampling, and the true span of the period of peat initiation could be larger.

Figure 3 shows LOI data together with pollen percentage curves for *Calluna vulgaris* and *Empetrum nigrum*, two species which are abundant on blanket peats today (Fosaa 2001). The stratigraphic locations of the radiocarbon dates are also shown. The Lít-2 sequence, which includes several distinct bands of alluvial material, was not analysed for pollen owing to the strong possibility of reworking. LOI curves in general show a rapid transition over 2-3 cm from low (5-20%) to high (*c.* 90%) values. In some cases the transitions as defined in the loss-on-ignition data did not correspond exactly with visual descriptions of the sections; samples with around 50% LOI were difficult to distinguish visually from more organic peats, which underlines the importance of using LOI data to identify basal peats. In three cases (Lít-2, Lít-7 and Lít-11) there are reversals in the LOI curves, perhaps due to slopewash, and in three further cases (Lít-13, Lít-14 and Lít-15) the LOI values of the peats fluctuate markedly.

Vegetational responses to peat initiation vary substantially from site to site. This is less clear in some sequences than in others, partly due to a lack of data in some instances owing to the absence of pollen in the regolith. In most cases, however, an

increase in *Calluna* and/or *Empetrum* can be seen to accompany peat initiation. The relative importance of these two taxa varies considerably; for instance, in the uppermost samples in Lít-3, *Calluna* contributes about 30% TLP and *Empetrum* around 10%; in Lít-16 the proportions are 10-15% and 25%, respectively. In the better-developed datasets, the relative timing of LOI and pollen changes can be seen to vary: in Lít-3, the expansion of *Calluna* is preceded by the rise in LOI values; in Lít-6 and Lít-7, the two are more or less synchronous; the limited data from Lít-12 appear to show that *Calluna* values are high 2 cm below the rise in LOI values.

Pollen diagrams showing a wider range of taxa from three of the sites (Fig. 4) reinforce the impression that, on a small scale, the landscape consisted of a mosaic of vegetation types, both before and after peat initiation. For example, Lít-3 contains very high values of *Nymphaea alba* pollen in the regolith material towards the base of the studied section, indicating that the site was close to open water; *Salix*, Poaceae and Cyperaceae were also locally important. The peat overlying the regolith in Lít-3 remains rich in Poaceae and Cyperaceae pollen, but with large amounts of *Calluna* and lesser amounts of *Juniperus*, *Empetrum* and *Potentilla*. *Nymphaea* and *Potentilla* are both absent in the regolith material from Lít-6, but the pollen assemblages from the peat are similar to those of Lít-3. Lít-16, on the other hand, has much higher values of *Empetrum* and *Potentilla* pollen in the peat. Assuming that peat accumulation was steady and that there has been no vertical movement in the pollen (cf. Clymo & Mackay 1987; Moore *et al.* 1991), these highly localized pollen assemblages appear to have persisted at individual sites for several centuries, implying considerable inertia in the vegetation patches.

Apart from the selected pollen data shown here, there are a number of additional notable finds worthy of comment. One sample from Lít-14 contained large amounts of *Betula pubescens* pollen (14.7% at 106-107 cm in Lít-7; *B. pubescens* was differentiated from *B. nana* by size measurements [cf. Mäkelä 1996; Caseldine 2001]), presumably indicating local presence, as has been attested by macrofossil finds of tree birch elsewhere in the Faroes (cf. Malmros 1990, 1994), though not previously on Sandoy. The fact that only one of the 66 samples analysed here gave such high values (the next highest value was 3.8% at 41-42 cm in Lít-12, and the mean value across all samples 1.5%) suggests that tree birch was not abundant in the landscape. Other taxa which are occasionally, but not usually abundant include *Betula*

nana (maximum 6.2% at 47-48 cm in Lít-6, mean across all samples 1.1%), *Plantago major* (4.5% at 100-101 cm in Lít-7 / mean 0.5%), *Potentilla* (37.6% at 35-36 cm in Lít-11 / mean 3.1%), and *Sedum* (32.9% at 106-107 cm in Lít-7 / mean 1.3%), together reinforcing the notion that there was considerable spatial heterogeneity among the vegetation communities. Today *Sphagnum* is locally dominant in the wettest areas of the mire, but *Sphagnum* spores are rare in all of the pollen samples studied from the short cores (maximum 1.1% at 43-44 cm in Lít-13), which perhaps indicates that the ecosystems on the thin early peats were not truly ombrotrophic but received some nutrients from the regolith. Occasional finds of charcoal were made in only five samples, at low values (maximum 0.9% at 35-36 cm in Lít-12, mean 0.04%), which can probably be attributed to long-distance transport rather than local burning, although natural fires ignited by lightning strikes cannot be ruled out.

3.2 Lake sequences

Selected-taxa pollen diagrams are shown from Lítlavatn (lake sequence, Lít-20) and Gróthúsvatn (Fig. 5; cf. Lawson *et al.* 2005). Relatively poor pollen preservation suggests that much of the pollen entering these lakes does so via the streams that feed them, or via slopewash, and therefore their pollen assemblages should reflect, to some degree, the vegetation across their hydrological catchments. Although similar in area (both c. 500 ha), the catchments vary in character. That of Lítlavatn includes large areas above 200 m asl and one flank of the island's highest peak (479 m), so its pollen record should represent to a large degree changes on the high ground above the blanket peat-filled valley in which the lake itself is situated. Steep slopes and alluvial fans are common, and the main river feeding Lítlavatn is sizeable and fast-flowing, suggesting considerable capacity for sediment transport. The Gróthúsvatn catchment is generally lower (Gróthúsvatn itself is approximately at sea level) and less rugged, and the main inflow to the lake is much smaller and slower.

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 (cf. Edwards & Whittington 2001). In view of this, the remaining four dates should be treated as maximum age estimates. The curve showing the number of degraded TLP grains indicates the proportion of pollen grains showing signs of physical and chemical degradation. Changes in the proportion of

degraded pollen in a sequence are usually taken to indicate changes in the input of reworked catchment soils together with the pollen they contain (e.g. Cushing 1964, 1967; Havinga 1967; Wilmshurst & McGlone 2005). Comparison between the lake samples in zones Lít-20-2 and Lít-20-4, where pollen preservation is particularly poor, and the samples from the mineral soils at the base of the short peat sequences presented above, supports this interpretation: there is a strong similarity in the degraded appearance of the grains, and a dominance of Poaceae pollen in both sets of samples. Zones Lít-20-2 and Lít-20-4 are therefore probably strongly affected by reworking of soils and are unrepresentative of catchment vegetation. The remaining zones show better preservation, but some contribution from reworking cannot be ruled out anywhere in the sequence.

Underlying the reworking signal, however, are coherent changes in the pollen assemblages which we interpret as reflecting changes in catchment vegetation. In zone Lít-20-1 (approximately 9000-5000 cal BP, based on linear interpolation between the dates) there is very little *Calluna vulgaris* pollen, suggesting that it was not as abundant in the catchment at this time as later (during zone Lít-20-3, where it peaks at 24%). Similar patterns apply to Cyperaceae, *Potentilla* and *Sphagnum*, suggesting that the *Calluna* cover is a reasonable proxy for the extent of blanket mire communities. On this basis, there appears to have been little blanket peat in the Lítlavatn catchment before c. 5000 cal BP at the earliest. *Empetrum nigrum*, on the other hand, shows a different pattern, being moderately abundant throughout the record (apart from the reworking phase in Lít-20-2). Jóhansen (1982) found a similar pattern of abundant *E. nigrum* in the first half of the Holocene in his Hoydalar sequence and interpreted this as indicating that the species was growing, not on blanket peats, but on mineral soils. Grasses, together with a wide range of herbs, were also relatively more abundant during the earlier part of the Holocene. The expansion of blanket peat is probably obscured by the reworking in zone Lít-20-2, but we can constrain the date of that expansion to some time after c. 5000 cal BP, and to before c. 2200 cal BP.

There is no basal radiocarbon date available for the Gróthúsvatn sequence, but 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 (Jóhansen

1982, 1985). The lowermost radiocarbon date, 3990-3730 cal BP at 453 cm, suggests the presence of a substantial hiatus in deposition at the Grót-1/2 boundary. Two more radiocarbon dates in stratigraphic sequence occur at 373 and 325.5 cm. The two remaining 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.

The Gróthúsvatn data show low values of *Calluna vulgaris* in the earliest zone, Grót-1, contrasting with higher values in Grót-2. *Calluna* shows a sharp expansion at the boundary between Grót-2 and Grót-3, coinciding with step-changes in other taxa, notably Cyperaceae. The absence of any overlap between the confidence intervals for the *Calluna* curve (Fig. 5) at this boundary suggests that the pattern is not the result of stochastic noise in the data set. Cyperaceae, *Potentilla* and *Sphagnum* increase alongside *Calluna*, at the expense of Poaceae and a variety of herbs, as in Lít-20. At the very top of the sequence, above 210 cm, five samples show a sustained dip in *Calluna* values and an expansion of Poaceae and Cyperaceae.

4. Discussion

4.1 Timing of peat initiation on Sandoy

The basal peat dates from the short sequences around Lítlavatn clearly show that blanket peat began to accumulate as early as 5890-5600 cal BP, and leave open the possibility that peat initiation began earlier at sites in the valley that have escaped sampling. Peat initiation appears to have continued until at least 1290-1080 cal BP, i.e. potentially as late as AD 870, a few decades after the Norse colonization (again, there is the possibility that younger peats exist but have not been sampled). The other dates are quite evenly spread between these two limits. Potentially, the very late date could be explained as representing re-growth after peat cutting, but the spread of the dates as a whole suggests that the process of peat initiation was genuinely a long drawn-out, discontinuous process, which is perhaps still continuing.

The Lít-20 record demonstrates that blanket peats were relatively insignificant in its pollen catchment, which is probably biased towards the slopes and high ground above the lake itself, before c. 5000 cal BP. The Gróthúsvatn pollen record suggests that *Calluna* and accessory taxa representing mire communities were rare in the early Holocene, but was moderately abundant between c. 3800 cal BP (when sedimentation

resumed following the hiatus in deposition) and *c.* 2800 cal BP, at which point it expanded sharply. The long-term expansion of *Calluna* is echoed by other mire taxa such as *Potentilla* and *Sphagnum*, but their lower abundance makes it more difficult to identify step-changes in their abundance. The timing of *Calluna* expansion is poorly constrained here, but could have begun several thousand years earlier than at Lítlavatn, perhaps as early as 9000 cal BP.

Taken together, these lines of evidence allow us to reject the null hypothesis, that blanket peat spread on Sandoy was related to human activity; there is only one instance where a date could be interpreted as indicating post-settlement peat initiation. Any human role in aiding the spread of blanket peats across the Sandoy landscape is clearly minor.

4.2 Variation of peat histories across the Faroes

Figure 6 collates published data on peat initiation from across the Faroes and plots estimates of peat age against time, following the approach of Tallis (1991) who undertook a similar exercise for Wales and northern England. There are a number of problems with this strategy, reflecting the fundamental difficulty of defining ‘peat initiation’ and identifying and dating it in the geological record (cf. Edwards & Hiron 1982). Firstly, not all of the dates necessarily pertain to blanket peat; those marked with a T in Figure 6 are dates resulting from terrestrialization of lake basins, with peat accumulating on top of limnic sediments (‘secondary’ peat, *sensu* Moore & Bellamy 1973). In one such case (Hovsdalur) the lowermost peat is described in the original publication as ‘fen peat’. Today, ‘tertiary’, blanket peats have often encroached on these sites, but the mechanisms underlying the change from limnic sediments to peat are likely to be substantially different from those underlying the paludification of mineral soils and the onset of blanket peat accumulation across whole landscapes. Secondly, in some cases, it is not clear that what is referred to as ‘peat’ in published work meets Charman’s (2002) definition of peat as yielding loss-on-ignition values in excess of 65%. For example, Jóhansen (1985) described the sequence at the site “East of Uldalíð” as peat, but the published sediment log shows that the material included bands of gravel and clay; and at Tjørnuvík, Hannon & Bradshaw (2000) analysed a lithological unit referred to as peat by Jóhansen (1971) and found LOI values of only 20-30%. Thirdly, there are the usual uncertainties over the accuracy of radiocarbon

dates. Fourthly, in some cases (points grouped under ‘pollen evidence’ in Fig. 6) the evidence for blanket peat initiation comes principally from the beginning of a rise in *Calluna* pollen percentages, an indirect estimate of blanket peat extent at best, and the beginning of the expansion is sometimes difficult to define and rarely dated with precision. Finally, a number of the estimates for peat initiation are only minimum ages (indicated with dashed lines in Fig. 6), where sequences or dates did not extend to the very deepest peats, but where we can at least demonstrate that peat was present by a certain time. In short, the new basal peat dates presented here make a substantial contribution to a small and imperfect data set of peat initiation age estimates, and we remain far from having as complete a picture of the pattern of peat initiation in space and time across the Faroes as a whole as we now have from central Sandoy.

There are a number of points, however, which can be made from Figure 6. The estimates of peat age span more than 9,000 years, practically the entirety of the Holocene, and the oldest date (from Saksunardalur) is replicated and secure: Edwards & Craigie (1998) found peat at Saksunardalur underlying the so-called Saksunsarvatn tephra, dated at several sites in the Faroes and elsewhere to *c.* 10,000 cal BP (Wastegård 2002). There is no obvious spatial pattern in the data, although if there is any determinism underlying peat initiation, it is likely to operate through small-scale (1-1000 m) variations in hydrology or substrate chemistry, given the absence of strong climatic or geological gradients across the Faroes (the dates all come from relatively low-altitude sites, so the effect of altitude on peat initiation cannot be assessed).

Tallis (1991) undertook his survey of English and Welsh basal peat dates in order to look for evidence of clustering of basal peat dates in time. His argument was that if such clustering exists, it would suggest that blanket peat initiation is driven by one or more regional events affecting the whole of the study area more or less synchronously, the most likely candidate being a change in climate. (This should be distinguished from the positive feedback that might cause rapid peat initiation across all or part of a hydrological catchment; see below). Tallis’ (1991) dataset shows little clustering of dates, suggesting that local conditions and human activity were more important in determining the timing of peat initiation.

The distribution of dates on basal peats from the Faroes in Figure 6 shows a concentration of dates between *c.* 4000 and 6000 cal BP, which could be taken to

imply a climatic forcing (cf. Tallis 1991). As the sample size is small, the significance of this clustering was tested by numerical simulation using a bootstrapping procedure. With each iteration of the simulation, 17 ‘dates’ were randomly selected from within the age range of the 19 actual dates, using the two remaining dates (Lít-16, 1185 cal BP, and Saksunardalur, 9825 cal BP) to define the extremities of the sampling space. Minimum ages and estimates based on pollen evidence alone were not included in the analysis. The linear nearest neighbour statistic (Young 1982), which is a measure of clustering of objects or events along a one-dimensional axis (in this case, time), was calculated for the simulated set of dates. A total of 73.3% of 10^5 iterations of this simulation produced more clustered samples (a smaller nearest neighbour statistic) than the actual dates shown in Figure 6, suggesting that the observed distribution of basal peat dates could have been produced by random sampling of peats whose initiation had also been random, and at a uniform rate.

Hence there is, at present, no strong evidence to suggest that climatic changes have played a role in the timing of peat initiation in the Faroes. It seems more likely that peat initiation (by paludification) occurs at any given site once enough time has passed for water, weathering and vegetation to have created the right conditions for accumulation of organic material to outpace its removal. The fact that the time required for this to happen varies by 9,000 years may perhaps be a function of spatial variability in microclimate, hydrology and substrate chemistry. If climatic change does play a role in forcing peat initiation – for example, a hypothetical change to wetter and cooler conditions around 6000 cal BP encouraging a spurt of peat initiation – then it apparently only encourages blanket peat expansion at a small number of sites, presumably those where conditions are already almost suitable for peat accumulation to begin.

We conclude from this analysis that there is no evidence to support the contention that discrete climatic changes have caused a landscape-wide acceleration of peat initiation during the Holocene. Several workers have argued in the other direction, using data on peat accumulation at one, or a small number of Faroese sites to draw conclusions about climatic history (Jóhansen 1985: 53-54; Wastegård 2002; Hannon *et al.* 2005: 645). Our interpretation of the available data, including the new data presented here, is that such an approach is unsound, given the variability in peat histories on a range of spatial scales across the Faroes. If peat accumulation histories can tell anything

about Holocene climatic change, a much larger data set will be needed before reliable conclusions can be drawn.

4.3 Step change at the catchment scale

Theories of peat initiation (e.g. Moore 1993; Charman 2002) predict that it should involve an autogenic positive feedback: once organic matter starts to accumulate under waterlogged conditions, the moisture retention capacity of the soil increases and the local water table rises, so there is a mechanism for accelerating the process of peat initiation at adjacent locations. A rapid lateral expansion of peat consistent with this has been observed in a number of situations, particularly raised ombrotrophic mires (e.g. Mäkilä 1997; Foster & Wright 1990), but also with blanket peats (Solem 1986) and blanket peats spreading from terrestrialized lakes (Anderson *et al.* 2003).

Catchment-scale pollen records from lakes would be expected to reflect a rapid expansion of peat as an abrupt increase in pollen percentages of indicator taxa such as *Calluna vulgaris*.

The basal peat dates from the valley around Lítlavatn are distributed over approximately 5000 years, which would seem to suggest that feedback of this kind was not particularly strong here. On the other hand, the pollen record from Gróthúsvatn appears to show the spread of *Calluna* as a step-like process with an abrupt increase in abundance at the Grót-2/3 boundary, which could indicate autogenic feedback at work. Such step-like changes are not visible in the *Calluna* record from other sites in the Faroes (Fig. 7; an exception is Hoydalar [Jóhansen 1985] where one of the changes in the *Calluna* curve, estimated here as occurring at c. 8000 cal BP, coincides with sedimentological evidence for a local change from a limnic to a terrestrial depositional environment). Feedback is more likely to occur in an area of subdued topography, where factors such as drainage are similar across the area, and Gróthúsvatn certainly has a relatively homogenous catchment compared to many lakes in the Faroes.

4.4 Implications of blanket mire expansion for other aspects of the ecosystem

The spread of blanket peat may have had indirect effects on other parts of the Faroese landscape system. Limnological indicators from Gróthúsvatn, including the alga

Pediastrum (Lawson *et al.* 2005), indicate that relatively productive conditions in pollen zone Grót-1 gave way, after a hiatus, to less productive conditions, until the settlement period when the nutrient status of the lake apparently increased again. A likely explanation is that acidification of catchment soils caused a decline in the pH of runoff and hence a decline in the pH of the lake itself, and a reduction in the solubility of nutrients (cf. Pennington 1981; Wetzel 2001). Similarly, the sedimentation regime of the lake changed substantially following the resumption of sedimentation during zone Grót-2, with much more silt in the lower unit, and more organic sediments above, perhaps representing the stabilization of the catchment regolith beneath the peat cover. Conversely, geomorphological studies on Sandoy and elsewhere in the Faroes suggest that erosion rates have increased at many localities through the course of the second half of the Holocene, and the suggestion has been made that gullying within the peat could have focused the erosive power of runoff, leading to higher overall rates of sediment transport (cf. Solem 1986; Humlum & Christiansen 1998a, 1998b; Bragg & Tallis 2001; Edwards *et al.* 2005).

4.5 Human impact and peat initiation

The principal motivation for this study was to determine whether landscape-scale accumulation of blanket peat on Sandoy had been precipitated by human activity, as suggested for many other sites in Atlantic Europe. Our conclusion is emphatically that they were not: all but one of the basal peat dates presented here are older than the first settlement of the Faroes, and our survey of dates from other islands in the archipelago suggests that the same conclusion holds elsewhere too. In fact, there is evidence that the opposite situation pertains, namely that people were responsible for a net reduction in peat cover. For the Faroese, living in a treeless environment, peat has long been an important source of fuel; archaeobotanical evidence from the sites of Undir Junkarinsfløtti at Sandur on Sandoy and Toftanes on Eysturoy shows that this was the case as long ago as the Norse period (Church *et al.* 2005; Lawson *et al.* 2005; Vickers *et al.* 2005). Peat mining must therefore have had some impact on the area and/or volume of peat. Drainage and cultivation of fields for agriculture and to improve grazing, a process which is still occurring today, must also have had a more localized impact on any peat that existed closer to settlements (cf. Borthwick *et al.* 2005). Perhaps some combination of these two factors is responsible for the decline in

Calluna pollen percentages seen in the uppermost five samples from Gróthúsvatn, which is today surrounded by a narrow belt of cultivated fields.

These conclusions have implications for our understanding of peat initiation and development in areas outside the Faroes. Blanket peat initiation has clearly occurred in the Faroes without human intervention, a result which is significant given that many studies from outside the Faroes have implicated human activity (particularly burning and/or deforestation) in the spread of blanket peats (e.g. Solem 1986; Charman 1992; Tallis 1991; Bennett *et al.* 1992, 1997; Fossitt 1996; Huang 2002; Moe 2003) and other ombrotrophic mires (Smith & Cloutman 1988). Our conclusion supports those who would suggest that natural processes may account for mire initiation and development in at least some instances (e.g. Clymo 1984; Solem 1989; Foster & Wright 1990; Mäkilä 1997; Ellis & Tallis 2000; Anderson *et al.* 2003), particularly where the pre-peat environment was never substantially wooded; the question of whether natural peat formation can occur in wooded environments remains open. Analysis of the limited data set of peat initiation dates for the Faroes suggests that there is no reason to claim that peat initiation is strongly determined by climatic changes; the spread of peat has been fairly steady throughout the course of the Holocene, and local topographic, hydrological and pedological variations appear to have been more important controls on the timing of peat spread than climatic change. At a landscape scale in the Sandoy study area, the peat appears to have spread from multiple starting locations (cf. Edwards & Hirons 1982); furthermore, according to the pollen data from lake sites such as Gróthúsvatn and Saksunarvatn, peat expansion followed quite different temporal patterns over time from one catchment to the next. The same may be expected to hold true for areas outside the Faroes, with human activity just one of a number of factors which interact to give a complex spatio-temporal pattern of peat initiation (cf. Tallis 1991; Prøsch-Danielsen & Simonsen 2000; Charman 2002).

5. Conclusions

1. The major benefit of studying peat histories in the Faroe Islands is that human impact can be ruled out as a contributory factor before the first known settlement at *c.* AD 800. The isolation of this group of islands from the anthropogenic activity that increasingly dominated Holocene environments in

neighbouring locations allows the investigation of natural processes of environmental change in a simplified setting. The results have implications for our understanding of landscape change in other areas where anthropogenic activity complicates interpretations.

2. Basal peat dates from the Faroes are distributed evenly throughout the last 9,000 years. The timing of blanket peat initiation thus cannot be tied to climatic changes during the Holocene. There is, however, some indication that peat initiation was more active in the Faroes between 4000 and 6000 cal BP than at other times, although this result is not statistically significant.
3. Basal peat dates vary markedly both across the Faroes as a whole, and within our c. 2 km² study area. At a landscape scale on Sandoy, blanket peat appears to have initiated in small patches which gradually coalesced. Current models (e.g. Moore 1993) would predict earliest peat growth in waterlogged topographic hollows, which is partly supported by a tendency for early peat dates where shallow lakes have infilled (e.g. at Hovsdalur and Hoydalar), although there are situations (e.g. Saksunardalur) where this is not the case (Buckland *et al.* 1998; Edwards & Craigie 1998).

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Figure captions

Figure 1 Location map showing the Faroes, with the island of Sandoy and sites mentioned in the text.

Figure 2 Map showing the spatial distribution of basal peat dates from the area around Lítlavatn. Dates are in ^{14}C yr BP with 1σ confidence intervals; the area of each circle is proportional to its ^{14}C age, with the exact location of the date indicated by a dot in the centre of each circle. The location of the lake core Lít-20 is also shown. Inset shows the study area in the context of the island of Sandoy; Gróthúsvatn is also marked.

Figure 3 Data from the nine short peat cores from the Lítlavatn study area, showing loss-on-ignition data, pollen percentage data for *Calluna vulgaris* and *Empetrum nigrum*, and the stratigraphic location of the radiocarbon-dated samples. Loss-on-ignition data and radiocarbon dates are also shown for Lít-2.

Figure 4 Selected taxa pollen percentage diagrams for three of the short peat cores, showing trends in the dominant taxa. In the diagram for Lít-3, *Nymphaea alba* percentages are calculated relative to a main sum including TLP and aquatic taxa.

Figure 5 Selected taxa pollen percentage diagrams for the sequences from Lítlavatn (Lít-20) and Gróthúsvatn. Unshaded curves show the pollen data for rare taxa with $\times 10$ exaggeration. Depths are measured below the water surface. Confidence intervals at the 2σ level are shown for the Gróthúsvatn *Calluna vulgaris* curve, following Maher (1972).

Figure 6 Available estimates for the expansion of blanket peat in the Faroes. Estimates which represent minimum ages for peat expansion are shown with a dashed line of arbitrary length to indicate that the uncertainty exists. ‘T’ indicates a telmatic situation (see text). References for sources: Argisbrekka: Jóhansen (1989); East of Uldalið, Lambi, Havnardalur, Hovi-A, Hoydalar, Hvalba, Saksunardalur (J 1985), Sandur (J 1985): Jóhansen (1985); Heimavatn: Hannon *et al.* (2005); Korkadalur: Hannon *et al.* (2001); Saksunardalur (E&C 1998): Edwards & Craigie (1998); Sandur (L. *et al.* 2005): Lawson *et al.* (2005); Tjørnuvík: Jóhansen (1985) and Hannon & Bradshaw (2000); Toftanes: Edwards *et al.* (1998); Lítlavatn and Gróthúsvatn: this paper.

Figure 7 Pollen percentage curves for *Calluna vulgaris* from selected sites across the Faroes. Age models were calculated by linear interpolation between calibrated radiocarbon dates, tephra layers, and the landnám horizon, as detailed in the original publications for sites other than Lítlavatn and Gróthúsvatn; in the case of Tjørnuvik the assumption was made that 0 cm depth was equivalent to the present. Redrawn using data from Jóhansen (1971, 1975, 1982). The age models for Lítlavatn and Gróthúsvatn are based on linear interpolation between the four and three lowermost radiocarbon dates from each sequence respectively, assigning -50 BP as the age of the sediment-water interface. The lowermost three pollen samples from the Gróthúsvatn sequence are not included here due to the likely presence of a depositional hiatus at the Grót-1/2 boundary, as discussed in the text.

Table 1 AMS radiocarbon dates from Sandoy sequences. Dates from peats were carried out on the humic fraction; those from lake sediments were based on the bulk sample following an acid wash. All samples were based on 1 cm³ of material. Dates from the lake sequences are reported in Lawson *et al.* (2005). c.i. = confidence interval.

Code	Site and sample	$\delta^{13}\text{C}$	^{14}C yr BP	Cal yr BP
SUERC-757	Lít-2 16-17 cm	-30.7	360±40	510-310
SUERC-759	Lít-2 36-37 cm	-28.6	1380±40	1370-1180
SUERC-2363	Lít-2 86-87 cm	-28.0	3225±35	3560-3370
SUERC-2364	Lít-2 119-120 cm	-27.8	4955±50	5890-5590
SUERC-166	Lít-3 39-40 cm	-28.2	4330±40	5040-4830
SUERC-167	Lít-6 41-42 cm	-27.7	4425±35	5280-4870
SUERC-168	Lít-7 97-98 cm	-27.7	4555±35	5440-5050
SUERC-169	Lít-7 104-105 cm	-27.7	5585±40	6450-6290
SUERC-170	Lít-11 36-37 cm	-27.9	3580±40	3990-3720
SUERC-171	Lít-12 36-37 cm	-27.9	4990±40	5890-5600
SUERC-178	Lít-13 42-43 cm	-28.0	1805±35	1830-1610
SUERC-179	Lít-14 35-36 cm	-28.3	3135±40	3450-3260
SUERC-180	Lít-14 40-41 cm	-28.4	3265±40	3580-3390
SUERC-181	Lít-15 42-43 cm	-28.4	4045±40	4800-4410
SUERC-182	Lít-16 20-21 cm	-27.7	1270±35	1290-1080
SUERC-1821	Lít-20 126-127 cm	-27.5	2980±35	3330-3030
SUERC-1826	Lít-20 157-158 cm	-26.8	2125±40	2310-1990
SUERC-1827	Lít-20 200-201 cm	-25.0	4200±35	4850-4610
SUERC-9013	Lít-20 233-234 cm	-25.0	4755±35	5590-5330
SUERC-1828	Lít-20 300-301 cm	-22.1	7430±45	8360-8170
SUERC-1829	Grót 248-249 cm	-27.2	2955±40	3260-2970
SUERC-1830	Grót 271-272 cm	-27.3	3050±40	3370-3150
SUERC-11079	Grót 325-326 cm	-27.7	2525±35	2750-2470
SUERC-11080	Grót 372.5-373.5 cm	-27.6	2750±35	2950-2770
SUERC-11514	Grót 452.5-453.5 cm	-27.2	3595±35	3990-3730

Fig. 1

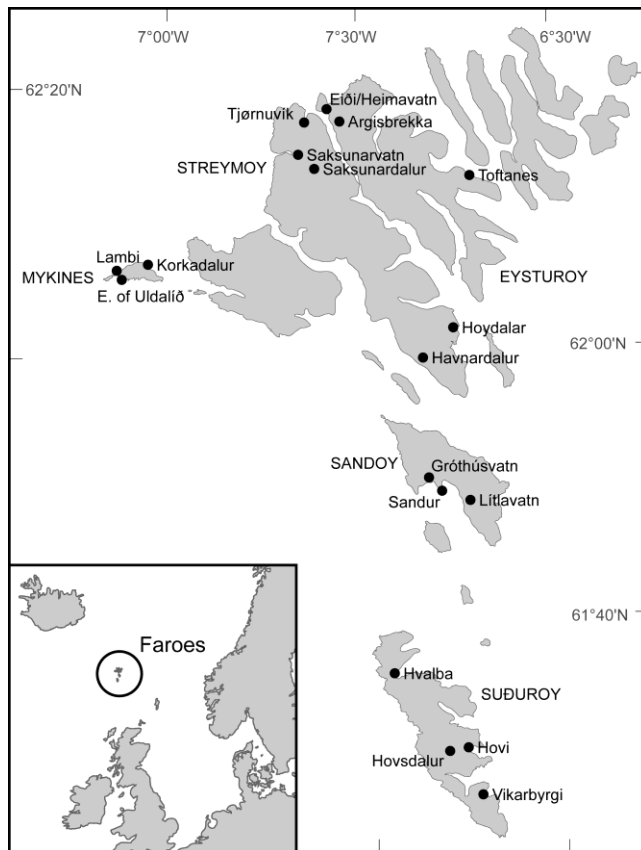


Fig. 2

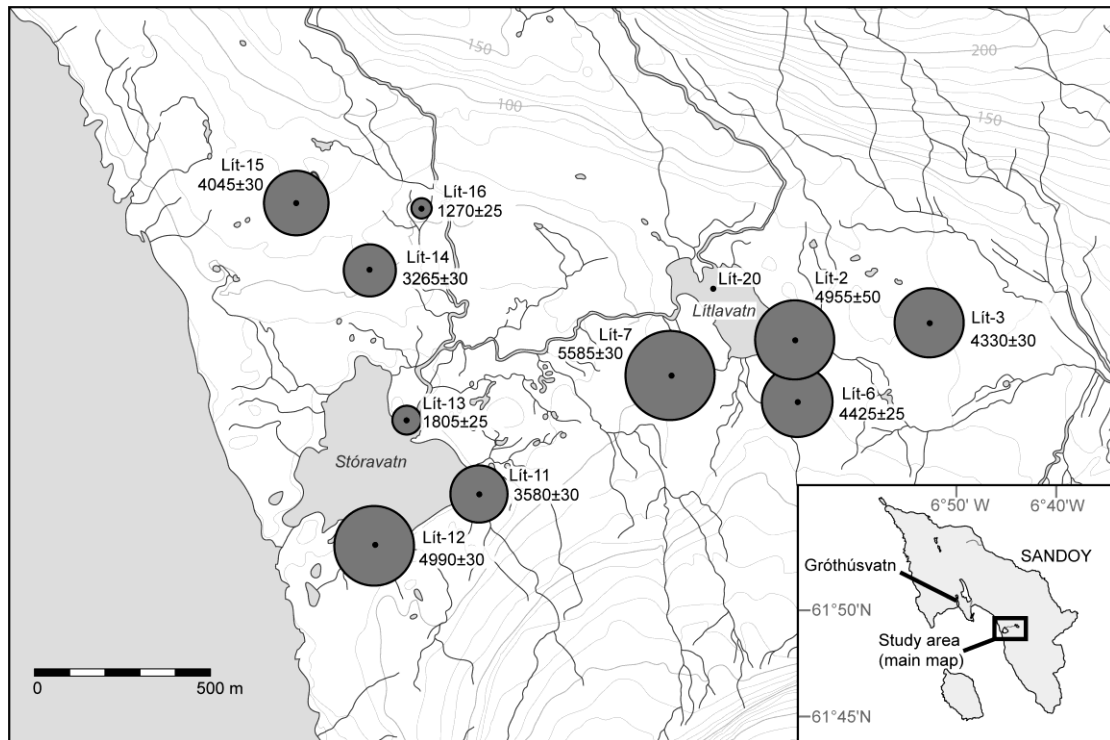


Fig. 3

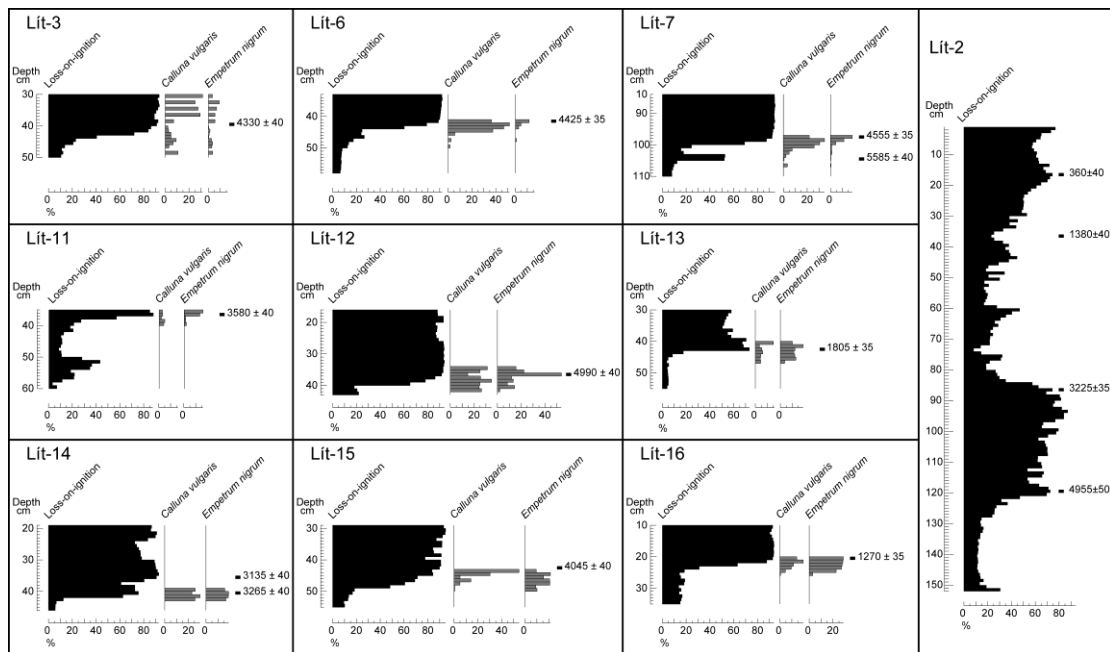


Fig. 4

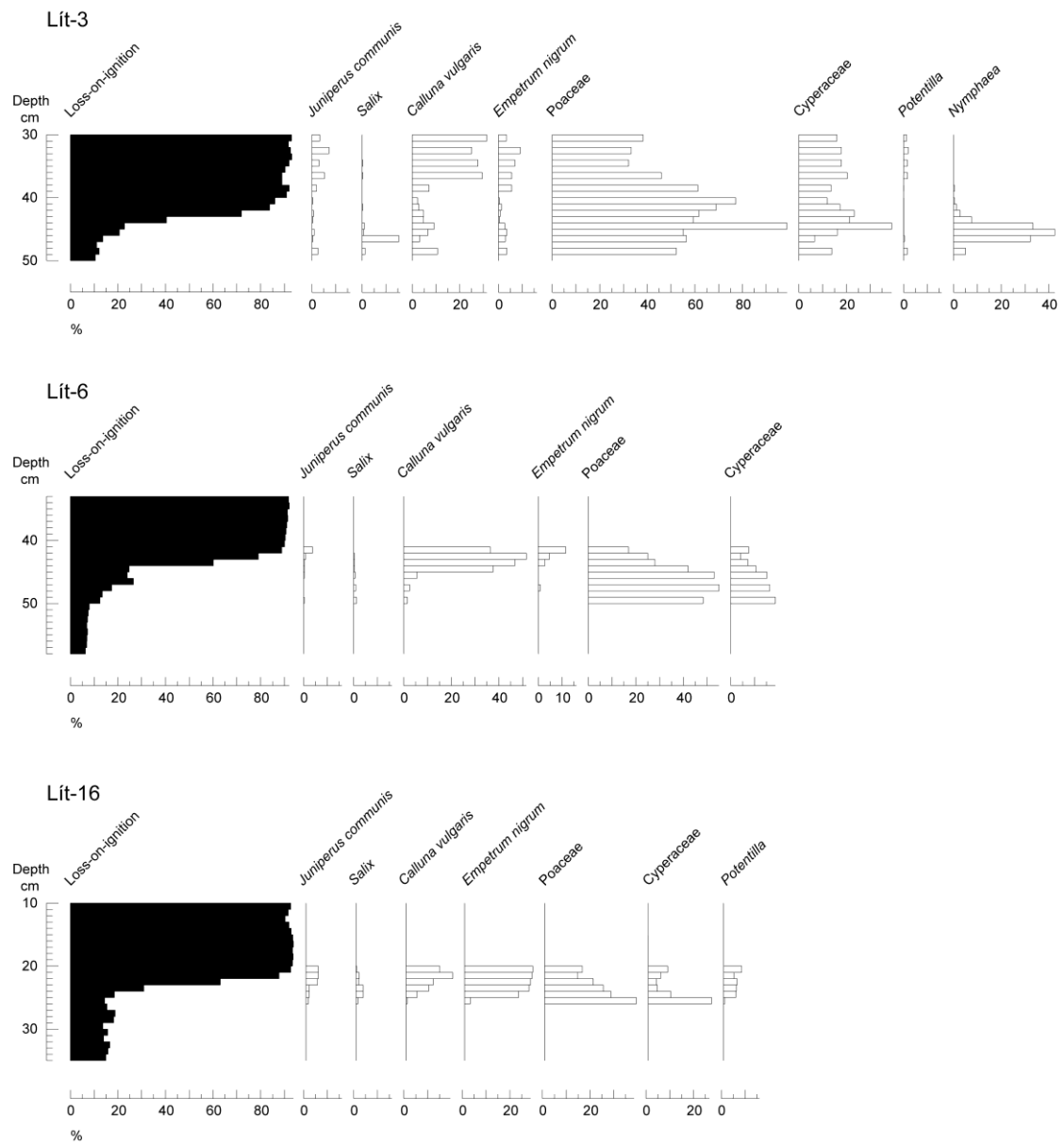
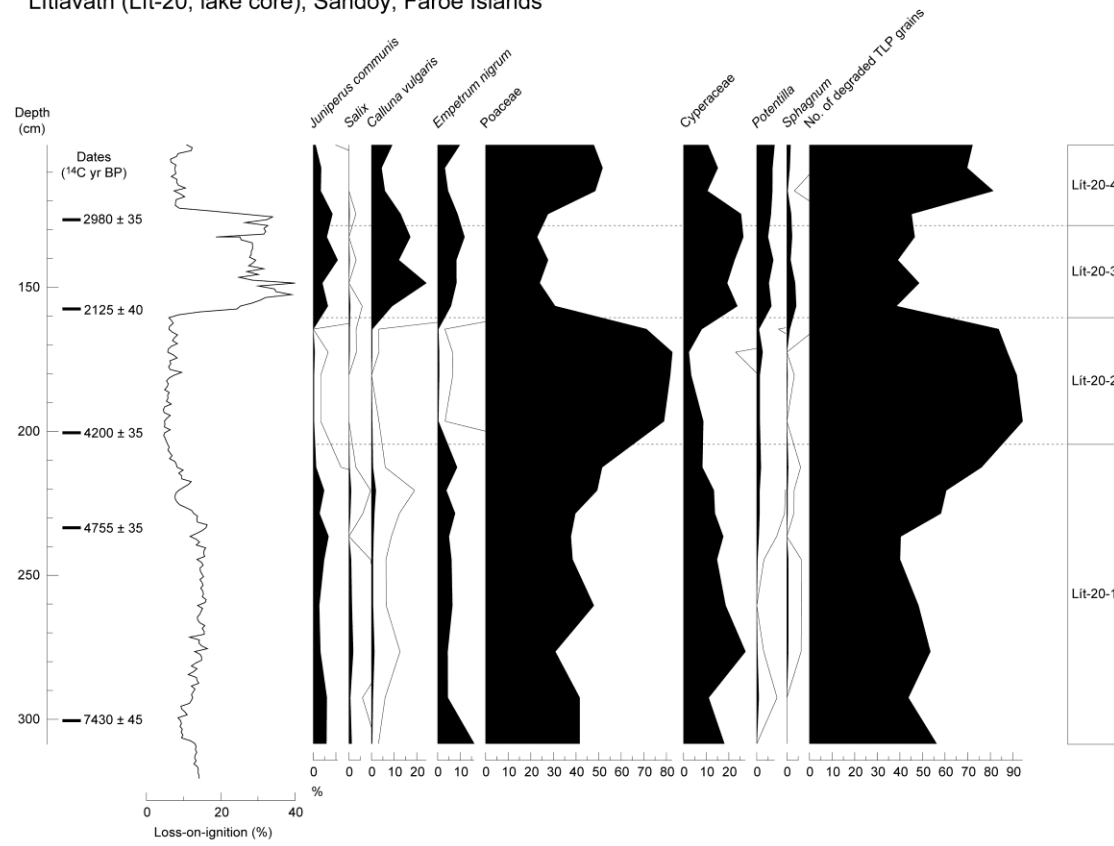


Fig. 5

Lítlavvatn (Lít-20, lake core), Sandoy, Faroe Islands



Gróthúsvatn, Sandoy, Faroe Islands

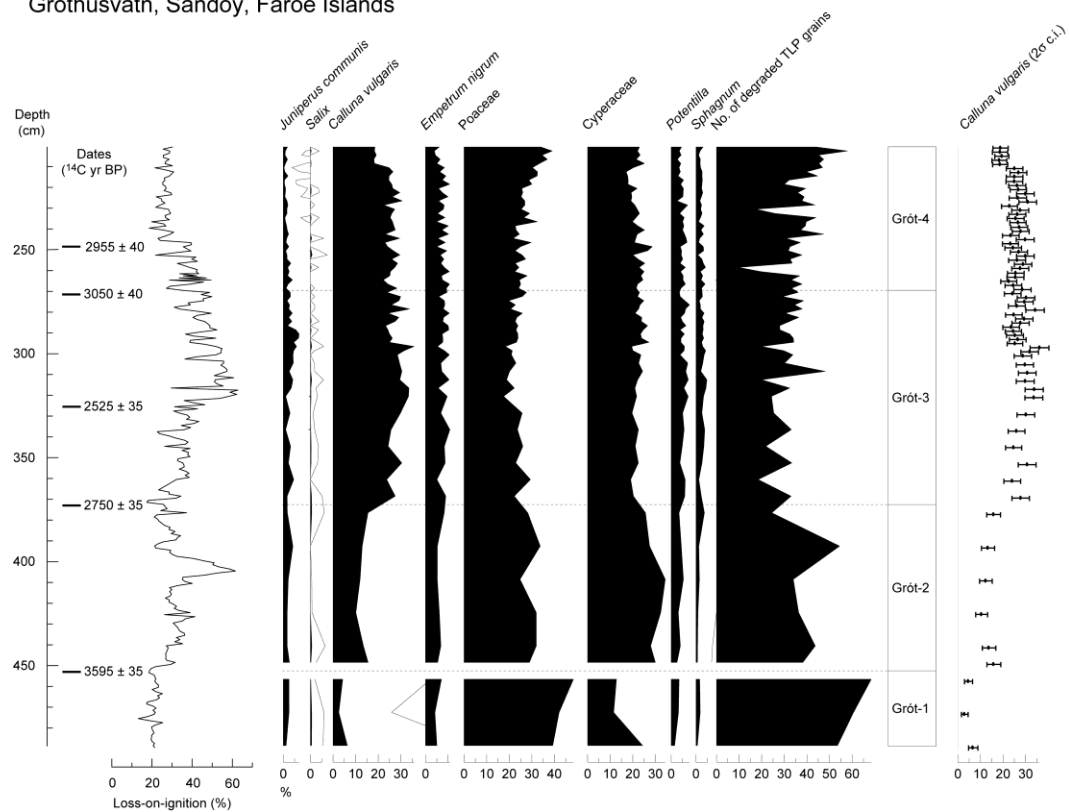


Fig. 6



Fig. 7

