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Vegetational response to human colonisation of the coastal and volcanic environments of Ketilsstaðir, southern Iceland

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ABSTRACT

Tephra-dated, high-resolution pollen profiles from Ketilsstaðir, southern Iceland, indicate a largely unwooded pre-settlement environment, a probable consequence of the exposed coastal location. The degree of change associated with the Norse *landnám* is more limited than in many Icelandic pollen diagrams. There are three main periods of change in the post-settlement vegetational development of the area. Firstly, Norse settlement affected the hydrology of the bog, resulting in the near-disappearance of *Sphagnum* and agricultural activity led to a reduction of some species (e.g. *Angelica* spp. and, *Salix*). Secondly, the establishment of probable permanent settlement in the mid-11th century AD initiated expansion of such apophytic taxa as *Plantago* spp. Lactuceae, *Ranunculus* spp. and Pteridophytes. Thirdly, the ≥10 cm thick Katla tephra, deposited in AD 1357, enhanced drainage of the bog surface, favouring dryland taxa (e.g. Poaceae, *Galium* and Lactuceae). The tephra deposit and the associated drainage probably caused or contributed to the local extinction of the wetland beetle *Hydraena britteni*. The study has enabled a series of natural and humanly-related issues to be addressed including tephra-vegetation relationships, the anthropogenic reduction in plant diversity, and comparisons between historical and environmental settlement records.

Introduction

The nature of environmental impacts following *landnám*, the first arrival of Norse settlers in Iceland in the late 9th century AD, is still debated (e.g. Ólafsdóttir, 2001; Dugmore et al., 2005). Sharp declines in the pollen of *Betula* cf. *pubescens* (downy birch), the only forest-forming tree taxon during *landnám* (e.g. Einarsson, 1963; Hallsdóttir, 1987; Erlendsson, 2007), have led to the conclusion that considerable woodland reduction, by direct removal or grazing, took place as land was opened up for agriculture between the tephra-constrained dates of ca. AD ~871 and ~920 (Hafliðason et al., 1992; Grönvold et al., 1995). Not all pollen diagrams conform, however, as some high-altitude changes, coastal and island locations indicate a more open character (Hallsdóttir, 1982; Buckland et al., 1995; Andrews et al., 2001). To date, little attention has been given to the human-environmental impacts in areas less likely to have sustained birch woodlands and where volcanic eruptions, jökulhlaups and sustained exposure have perhaps exerted strong controls on physical and cultural landscapes.

Employing high-resolution pollen analysis, constrained by a robust tephrochronological framework, this paper seeks to explore anthropogenic and natural impacts such as tephra deposition upon the vegetation (cf. Edwards et al., 2004) and the wider ecology of the coastal environment of Ketilsstaðir in Mýrdalur (Fig. 1), from the onset of Norse settlement (~AD 870) to 1597 when a Hekla tephra was deposited. The data offer a comparison with existing palynological studies from the less environmentally extreme southwestern and western Iceland, where woodlands formed an important part of pre-settlement plant communities (Hallsdóttir, 1987). Ketilsstaðir is of considerable interest in that its geographical characteristics contrast with previously investigated areas, yet it was subject to colonisation by Norse settlers as elsewhere in Iceland (Smith, 1995). In addition, the site stratigraphy offers an intriguing perspective on the utilisation of peatland resources and responses to volcanic impacts.

Sites and surroundings

Mýrdalur occupies a fairly well-vegetated and largely cultivated oasis bounded by the sandur spreads of Skóga- and Sólheimasandur to the west, Mýrdalssandur to the east, the glacier Mýrdalsjökull to the north and the Atlantic Ocean to the south (Fig. 1). The southerly location provides one of the warmest and wettest climates in Iceland. Over the period 1930–61 the closest weather station, at Vík, recorded a mean annual precipitation of 2256 mm, second only to Kvísker in Öræfi (3300 mm) and the highest mean temperature in Iceland, 5.7°C

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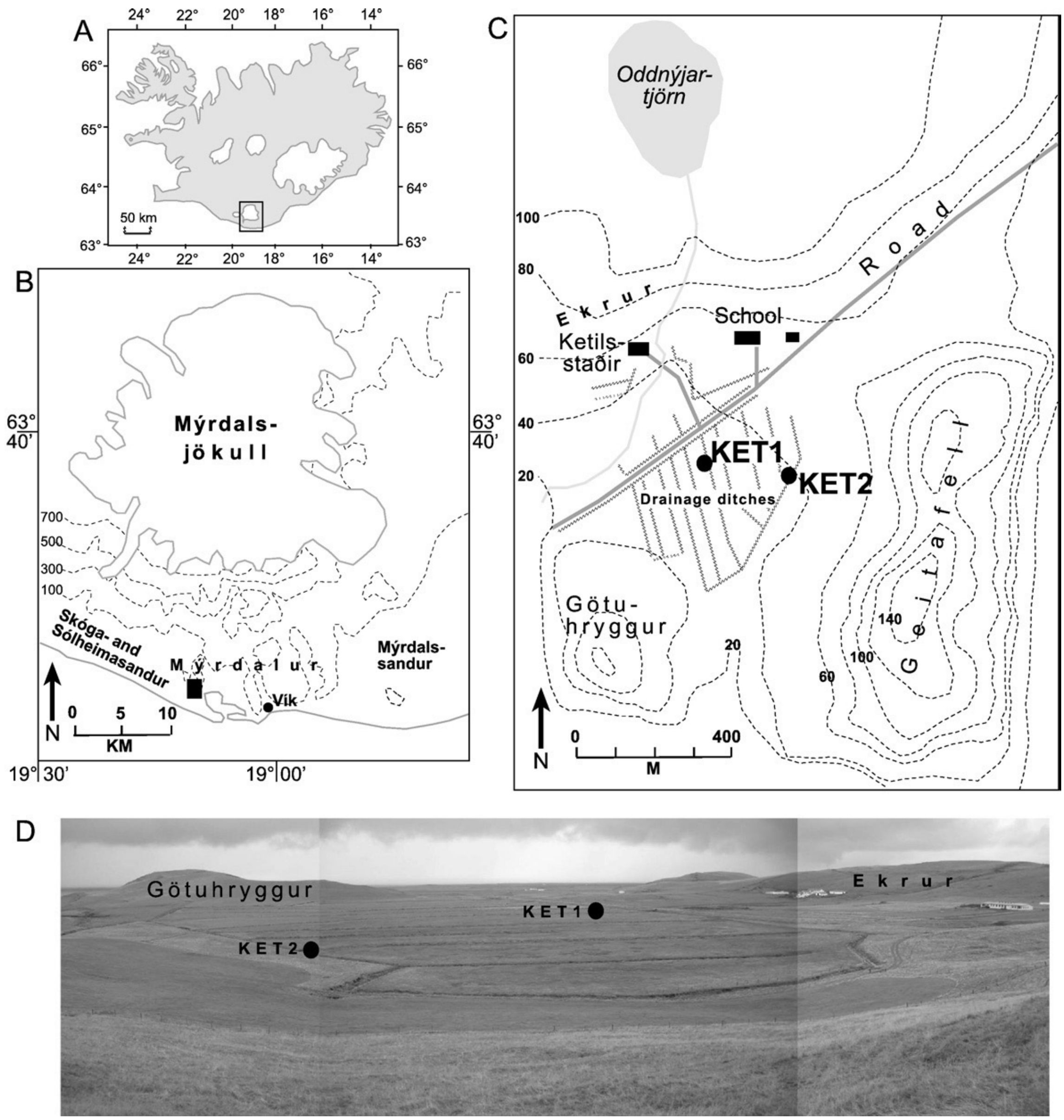

Figure 1. Maps showing the locations of Mýrdalur within Iceland (A), the Mýrdalur area (B) and Ketilsstaðir (C and square at base of B). The panorama (D) is taken from the slopes of Geitafell east of the mire (photographs: E. Erlendsson).

(Einarsson, 1976). The result is that the vegetated lowlands of Mýrdalur are typically wetlands – drained or otherwise – despite the porous palagonite bedrock and the extensive areas of sand (Einarsson, 1975). The area would seem to represent a last refuge for thermophilous elements of the microfauna before climatically driven extinction (Buckland and Wagner, 2001). Mýrdalur also houses the more thermophilous components of the flora, for example *Plantago lanceolata* (ribwort plantain, a herbaceous weedy taxon often associated with human activities and disturbed areas) and *Lychnis flos-cuculi* (ragged robin; Kristinsson, 1986), while more arctic species (e.g. *Betula nana*, dwarf birch) do not thrive in the area. Tree growth could be expected to have benefited from the relative warmth, but it appears from modern records that the sustained exposure, humidity, and climate instability are discouraging for *B. pubescens* (Einarsson, 1975). Such conditions seem to have remained during the late Holocene, as inferred from subfossil Coleoptera and plant remains (Buckland et al., 1986). A comparison might be made with the damp and exposed Faroe Islands where woodlands failed to develop over the same period (Borthwick, 2007; Lawson et al., 2008).

The Ketilsstaðir area benefits from a previous palaeobotanical and palaeoentomological study (Buckland et al., 1986) and the potential to construct an impressive dating framework following decades of tephrochronological research in Mýrdalur (e.g. Þórarinsson, 1975; Dugmore et al., 2000; Edwards et al., 2005a; Óladóttir et al., 2005).

The sampling sites are located within a drained valley mire south of the farm of Ketilsstaðir in a near-enclosed basin which is only narrowly open to the south (Figs. 1C and D). The mire has been transformed to an area for modern hay collection. Use of the mire in earlier times is indicated by pits in the bog filled with tephra from ~AD 1357 (Fig. 2; Buckland et al., 1986; Erlendsson, 2007). The deposition of this thick tephra layer (≥10 cm in the Ketilsstaðir area, forming a clear stratigraphic marker) is believed to have devastated several farms south of Mýrdalsjökull (Einarsson et al., 1980).

The historical record

Ketilsstaðir first appears in the historical record in a terrier (inventory) for a monastery at Þykkvibær from the year AD 1340 and

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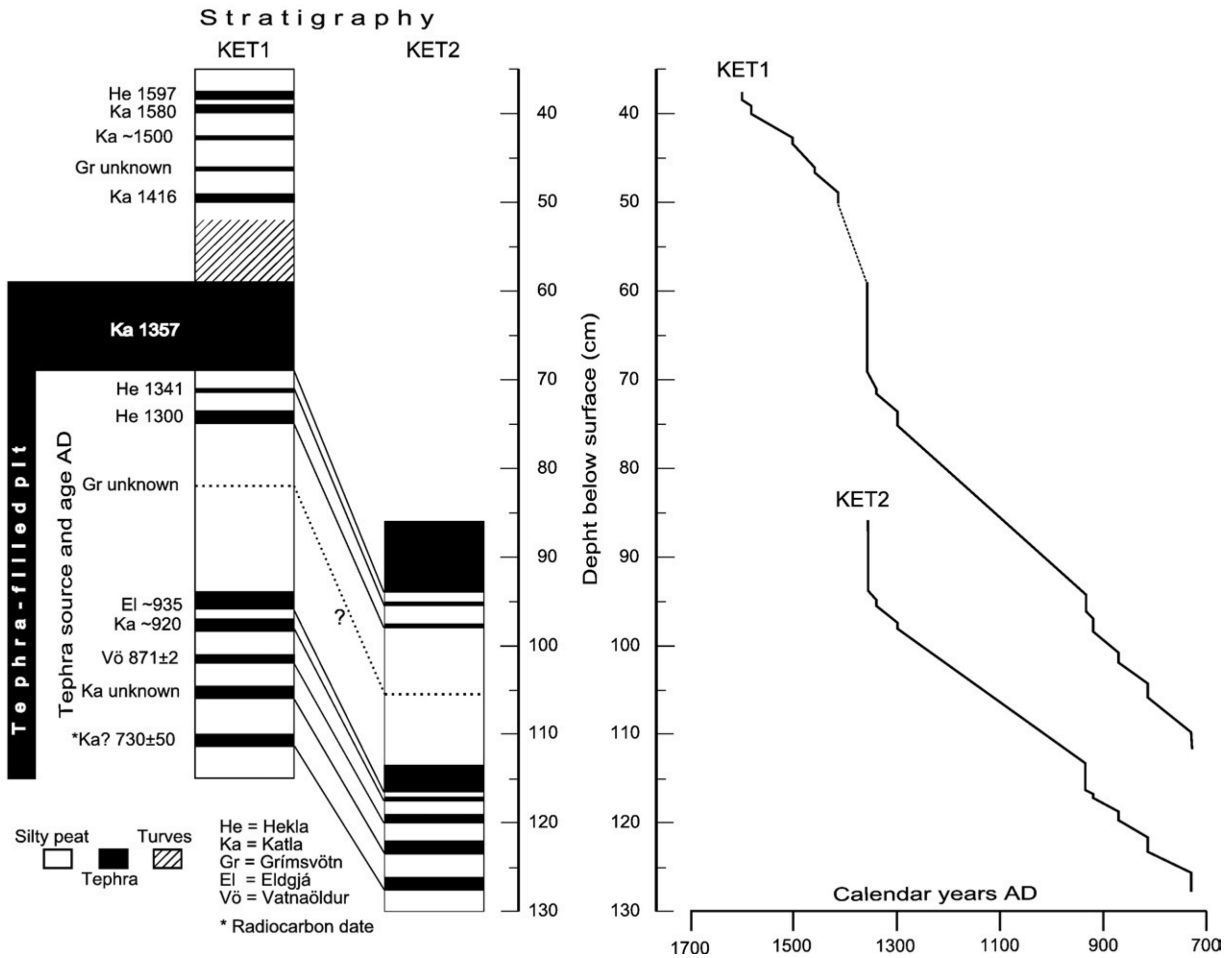

Figure 2. Tephra stratigraphy and age-depth models for KET1 and KET2.

in a similar document for a church at Dyrhólar (Buckland et al., 1986). Although probably established earlier, Ketilsstaðir is not necessarily of earliest settlement age (around or soon after AD 870), as the suffix *staðir* following a man's name (i.e. Ketil's-*staðir*) may indicate a later foundation (Vilmundarson, 1971). It appears that in 1340, the farm paid a tithe to the monastery at Þykkvibær and to the church of Dyrhólar, both of which include Ketilsstaðir among their taxpayers (D.I., 2, 1867–1972, 738, 742). The terrier from Þykkvibær implies that a substantial tax was paid by the farmers of Ketilsstaðir, or conceivably that of a farm valued at a quantity of 60 grand hundred (120) ells (forearm's length) of *vaðmál* (twill, woven woollen cloth), as supported by later similar valuations in 1639 and 1686 (Buckland et al., 1986).

In contrast to its late appearance in the historical record, the possession of a half-church and its high valuation would imply a farm of considerable status, perhaps settled early when almost unlimited access to land was available (Vésteinsson, 1998) — the conservative nature of Icelandic society would dictate that the farm's value would not change much over time.

At Ketilsstaðir, as in Mýrdalur and Iceland in general, pastoral agriculture is likely to have predominated (Buckland et al., 1986). Dairy production appears to have been practised at Ketilsstaðir, as the payment of tax in the form of butter implies renting of cows from the monastery in Þykkvibær (D.I., 2, 1867–1972, 738–739); sheep were kept at all farms. A greater mix of livestock may have existed at some point. The name Geitafell (Fig. 1) may indicate goats (*geit* = goat) and the presence of pigs is implied by the element *svín* (pig) in several local place-names (Einarsson, 1975).

At Ketilsstaðir the place-name *ekrur* (corn field) assigned to terraced, south-facing slopes north of the farm (Figs. 1C and D), suggests that the cultivation of cereals was at least attempted there and the field's stratigraphy implies ploughing before and after the Katla eruption in AD 1357 (Guðmundsson et al., 2004). Although the onset of this use cannot be determined, the stratigraphy of a similar

Table 1
Details of the basal ^{14}C date from Ketilsstaðir.

Lab no.	Depth (cm)	^{14}C yr BP	ca. yr AD 1 Sigma	ca. yr AD 2 Sigma	$\delta^{13}C$
SUERC-4323	112.0–111.5	1255 ± 35	685–778	672–869	−28.9

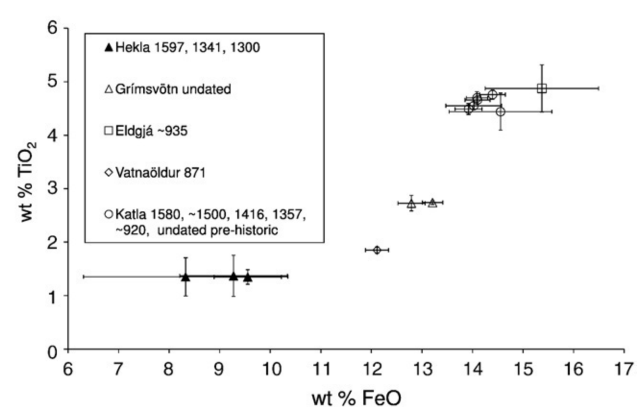

Figure 3. The geochemistry plot for tephras from KET1 showing mean scores and standard deviations of shard measurements for each layer.

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field at Fagridalur in Mýrdalur, a farm noted in *Landnámabók* (a list of settlements compiled in the 12th and 13th centuries AD and regarded as denoting the major pioneer farms in Iceland [Benediktsson, 1968]), suggests that that field was first cultivated between the deposition of tephra layers from Katla and Eldgjá in AD 920 and 935 respectively (Guðmundsson et al., 2004).

Materials and methods

Samples were collected from two sites (Figs. 1C and D). A peat monolith (KET1) was extracted from an exposed section in a ditch near the centre of the mire in 2002. The section displayed numerous layers of visible tephra layers, a subfossil turf stratum and a pit filled with Katla tephra from ~AD 1357 (Fig. 2). After the pollen analysis of this profile, a second peat monolith (KET2) was collected in 2004 from an open section near the eastern edge of the mire in a search for a comparative and potentially stronger anthropogenic signal.

1 cm^3 samples of sediment were analysed for organic content after drying at 105°C for 24 h followed by assessment of loss-on-ignition (LOI) at 550°C for 4 h (cf. Heiri et al., 2001).

Microprobe analysis for the geochemical signature of tephra layers to determine their origin used methods detailed in Dugmore et al. (1995). Calib 5.0.2html (Calib, 2009; cf. Stuiver and Reimer, 1993) was used for the calibration of a ^{14}C date. Data contained in TEPHRABASE (Newton et al., 2007) were used to determine the volcanic sources of the tephra. All dates presented are in calibrated ("calendar") years AD.

Depending on the inferred sample age, sub-sampling for pollen analysis from most of profile KET1 varied from 0.5 to 2.0 cm intervals, providing higher resolution across the early settlement period. Above most tephras, sampling resolution was narrowed to 0.25 cm for a more detailed analysis of potential impacts of tephra deposition upon vegetation. Sub-samples for pollen analysis from KET2 were taken contiguously at every 1.0 cm for the upper half of the profile.

The volume of sediment used for pollen analysis was 1 cm^3 for samples collected at ≥0.5 cm intervals but 0.5 cm^3 for samples collected at 0.25 cm intervals. The pollen preparation followed standard NaOH, HF and acetolysis methods (Moore et al., 1991) with the addition of *Lycopodium clavatum* spores to obtain concentration data (Stockmarr, 1971). Silicone oil of 12,500 cSt viscosity was the mounting medium. A modern type slide collection together with the keys of Moore et al. (1991) and Andersen (1979) were used for pollen and spore identification. The separation of *B. pubescens* from *B. nana* was based on the assignation of all *Betula* pollen ≤20 μm to *B. nana* and the remainder to *B. pubescens* (Caseldine, 2001; Karlsdóttir et al., 2007). In an attempt to enhance the anthropogenic pollen signal, rapid scanning for cereal pollen was applied (Edwards and McIntosh, 1988; Edwards et al., 2005b). Scanning at 100× magnification until an estimated total of ca. 1500 terrestrial pollen grains was found, was undertaken for all levels from KET2 given that site's proximity to possible arable fields on the adjacent hillslopes of Geitafell.

Terrestrial indigenous pollen was counted to ~500 and ~300 for KET1 and KET2 respectively, and the percentage values for all palynomorphs were calculated from the total land pollen (TLP) sums. Pollen and spore taxonomy follows Bennett (2009a) with some modifications for better presentation of the Icelandic flora (Erlendsson, 2007). Plant nomenclature follows Kristinsson (1986).

Diagram construction used TILIA and TGView (Grimm, 1991, 2004). TILIA's statistical routines of Detrended Correspondence Analysis (DCA) and CONISS were used for numerical analysis and to aid zonation of the pollen sequences. These analyses excluded taxa which did not reach 1% of the TLP in at least one level in the profile. Rarefaction analysis for the examination of palynological diversity (Birks and Line, 1992) was calculated within PSIMPOLL (Bennett, 2009b) using all terrestrial indigenous pollen.

Results

Chronology and stratigraphy

Although several pre-*landnám* tephras of known age occur in the Mýrdalur region (e.g. Óladóttir et al., 2005), there is no direct dating evidence from Ketilsstaðir. To constrain the analysed sequence, a basal ^{14}C-date (Table 1) was obtained from the humic acid of a bulk peat sample taken from underneath a black, coarsely-grained tephra layer (probably from the Katla volcanic system) from KET1. The lowest tephra layer in the KET2 sequence corresponds stratigraphically to this tephra (Fig. 2). The calibration curve for this ^{14}C date is negatively skewed at 2σ (Erlendsson, 2007) and therefore the 1σ dating estimate is used. The chronological framework for this site was otherwise constructed by tephrochronology. Of 14 visible tephra layers in the pollen-analysed part of the KET1 profile (Fig. 2), the origin of 13 has been confirmed by geochemistry (Fig. 3) (full tables in Erlendsson, 2007). In spite of the wide standard deviations on microprobe measurements in some places, the combination of stratigraphy and historical records provides a high degree of confidence enabling eleven tephras to be dated.

The stratigraphy of both sites generally consists of a mixture of well-humified silty peat interrupted by tephra layers (Fig. 2). The silt was probably transported to the sites by both sheet flow from the encircling slopes and by wind. A stratum of turves (slices of cut peat or peaty sods) deposited between the Katla 1357 and 1416 eruptions can be seen at KET1. There is little rise in sediment accumulation rate post-*landnám* at either sampling site compared to what has been found elsewhere (e.g. Þórarinsson, 1961; Dugmore and Buckland, 1991). The sole anomaly is a high sediment accumulation rate between the Hekla 1341 and Katla 1357 tephras at KET1, but this may stem from land use around the sampling site (discussed below). The LOI values (Figs. 4 and 6) are similarly homogenous except after AD 1416 at KET1, where organic content decreases, presumably because of increased local and regional erosion triggered or accelerated by the ~1357 eruption and the subsequent reworking of tephra.

Palynology

With the aid of CONISS and the DCA axis 1 sample scores (Figs. 4 and 6), the palynological data from KET1 were divided into six local pollen assemblage zones (LPAZ) (Table 2), while the palynological data from KET2 (Fig. 6) were divided into three LPAZs (Table 3).

Cereal scanning

The scanning for Cerealia-type pollen in KET2 (Fig. 6) resulted in two *Hordeum*-type (cf. barley) grains pre-dating the Landnám tephra. A near continuous record of *Hordeum*-type pollen from 113.5–107.5 cm (ca. AD 935–1075) established by routine counting and from scanning might imply the cultivation of *Hordeum vulgare* near the sampling site; no *Hordeum*-type pollen was found higher in the sequence. Grains of *Avena*-type (oat) were found at a depth of 102.5 (ca. AD 1195), one from routine counting and three during cereal scanning.

The *Hordeum*-type pollen is an important palynological indicator of human presence, although difficulties remain in separating its pollen from that of *Leymus arenarius* (lyme grass; cf. Tweddle et al., 2005) and the taxon is limited in its pollen productivity and dispersal (Edwards, 1989). The cultivation of cereals (mainly barley) in medieval Iceland is attested by palynological (Hallsdóttir, 1987; Erlendsson et al., in press), historical (cf. Hermannsson, 1993) and archaeological evidence (e.g. Friðriksson, 1959, 1960; Guðmundsson et al., 2004). The cultivation of barley is close to its northern climatic limits in Iceland and it is likely to have been most successful in the south and southwest. Even so, for those who first sowed its seed, the

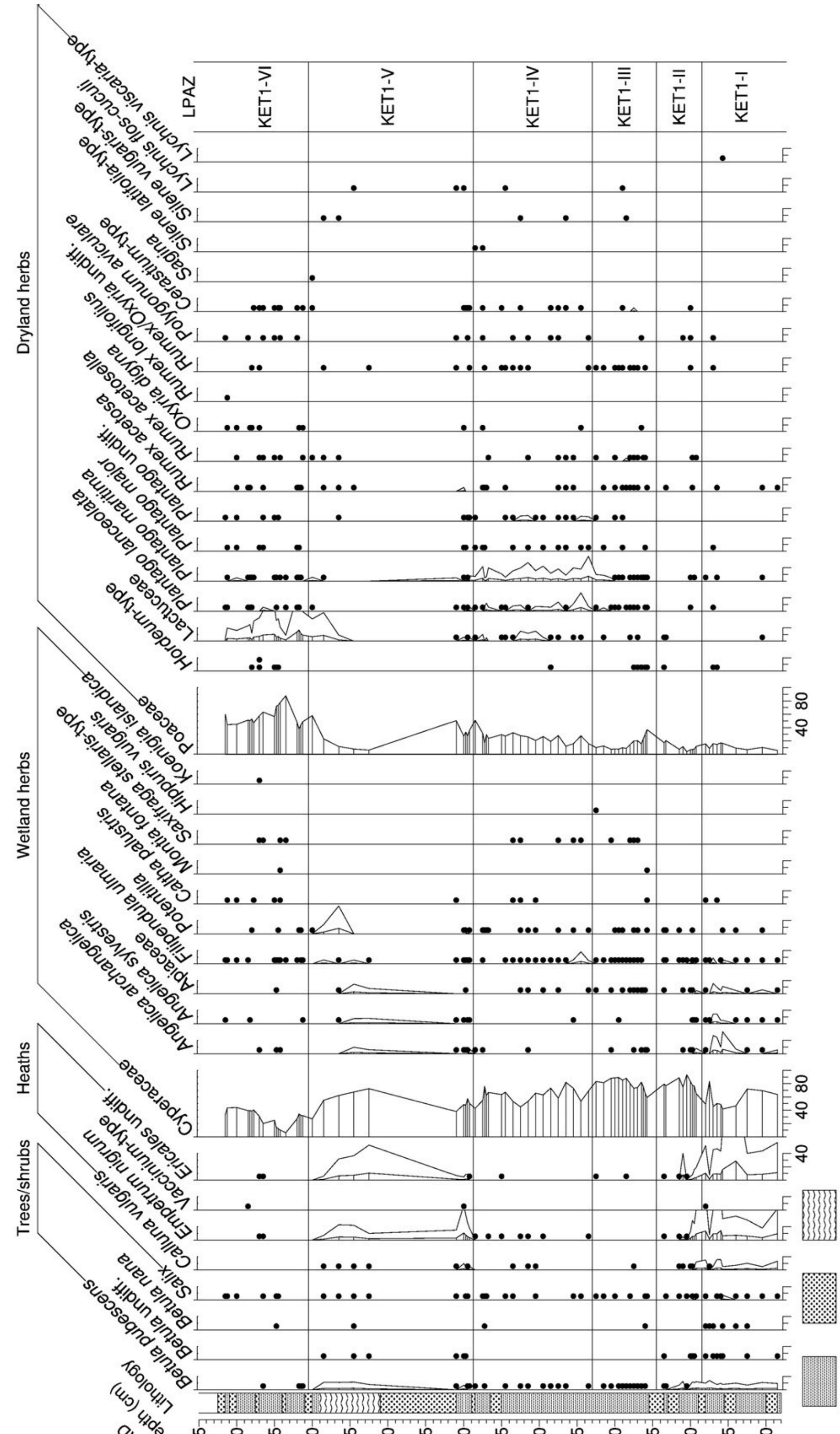

Figure 4. Pollen percentage diagram for KET1. Exaggeration curves are ×5. Dots signify values below 1% TLP, but for cereal-type pollen they indicate level-specific numbers of pollen encountered.

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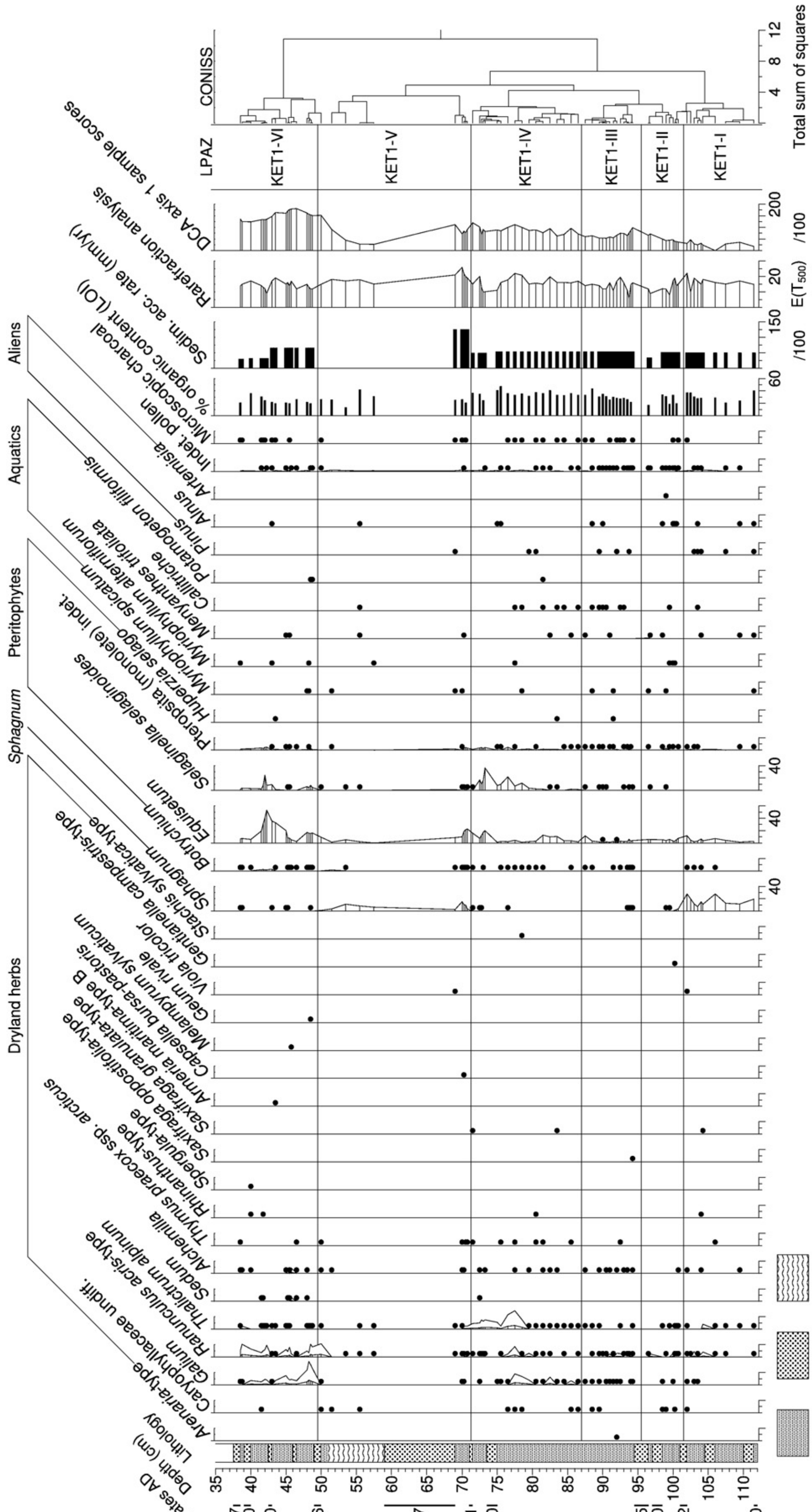

Figure 4 (*continued*).

Table 2
Major characteristics of the local pollen assemblage zones for profile KET1.

LPAZ	Depth (cm)	Age (AD)	Characteristic and main advancing taxa from previous zone	Main retreating taxa from previous zone
KET1-VI	49.5–38.5	1416–1597	Poaceae, Lactuceae, *Galium*, *Ranunculus acris*-type, *Equisetum*, *S. selaginoides*	Cyperaceae, *Plantago lanceolata*, *P. maritima*
KET1-V	71.5–49.5	1341–1416	N/A	N/A
KET1-IV	87–71.5	1075[a]–1341	Poaceae, *Galium*, *P. lanceolata*, *P. maritima*, *Rumex acetosella*, *R. acetosa*, Lactuceae, *Ranunculus acris*-type, *Thalictrum alpinum*, *Equisetum*, *Selaginella selaginoides*	Cyperaceae
KET1-III	95.5–87	935–1075[a]	Cyperaceae, *Galium*, *Plantago lanceolata*, *P. maritima*, *Rumex acetosella*, *R. acetosa*	Poaceae
KET1-II	101.5–95.5	871–935	Cyperaceae, Poaceae	Ericales, *E. nigrum*, *Betula pubescens*, Apiaceae spp. *Sphagnum*
KET1-I	112–101.5	730 ± 50–871 ± 2	Cyperaceae, Poaceae, Ericales, *Empetrum nigrum*, *Sphagnum*	N/A

[a] Extrapolated age.

harvest may have disappointed, as the average summer temperature (mid-May to mid-September) in southern Iceland probably was, as it is now, some 2–4°C lower than in western Norway or in the Scottish Isles, where the crop can be successfully grown. In particular, the autumn collection of seed corn for sowing the following spring could not be guaranteed (Hermannsson, 1993). Modern barley needs around 1200 day-degrees to reach full maturity (counted from 0°C) between mid-May and mid-September (an average of ~10°C) and for southwest Iceland this was reached on only ten occasions over a 30-year period between 1961 and 1990 (Ólafsson et al., 2007). Nevertheless, arable activity persisted in Iceland into the late medieval period, when both climatic deterioration (e.g. Sicre et al., 2008; Geirsdóttir et al., 2009) and considerable reductions in the price of imported barley (Gunnarsson, 1980) may have enforced its demise.

Discussion

Statistical, chrono- and biostratigraphical analyses of the data

Vegetational changes around the time of the Norse settlement in Iceland have been discussed by Þórhallsdóttir (1996). Unfortunately, numerous plants on which the Norse settlement is likely to have had an impact are palynologically invisible. In addition, the exposed landscapes around Ketilsstaðir could be expected to show a more limited response to human impact than wooded areas, and the pollen spectra could be assumed to reflect this. Nevertheless, the DCA variable score plots (Figs. 7A and C) reveal a fairly clear distinction between the pre- and post-*landnám* vegetational communities and the gradual conversion of a wholly natural flora to an increasingly anthropogenic one. Taxa listed by Þórhallsdóttir (1996) as having been impacted by grazing (e.g. *B. pubescens*, *Angelica* spp. [angelicas], *Salix* [willow] in LPAZ's KET1-I, II and KET2-I) are clearly separated from the supposed apophytes (e.g. Poaceae [grass family], *Plantago* spp., *Galium* [bedstraw], Lactuceae [e.g. dandelions and hawkweeds] in KET1-III, IV, VI and KET2-II, III). Of some interest is the fact that the palatable and grazing-intolerant tall herb *Filipendula ulmaria* (meadowsweet) appears with the post-*landnám* taxa. This might indicate that it is less palatable to herbivores or better equipped to withstand continuous grazing than, for example, *Angelica* spp. The pre-*landnám* positioning for the heaths *Empetrum nigrum* (crowberry) and Ericales (undifferentiated heaths) is also of note as these taxa commonly expand in Icelandic pollen diagrams post-settlement (e.g. Hallsdóttir, 1987; Erlendsson, 2007; Lawson et al., 2007). The heath taxa are far more prominent at KET1, closer to the mire centre. Of these, *E. nigrum* and *Vaccinium uliginosum* (bog bilberry) thrive amongst moss-rich hummocks in wet bogs (e.g. Kristinsson, 1986). The apparent retreat of *Sphagnum* (bog mosses), a clear pre-*landnám* taxon at both KET1 and KET2 (Figs. 4–6), and perhaps other moisture-demanding mosses, was probably associated with the decline of the heath taxa.

Apart from the KET1-III and -IV, and KET2-II and -III divides, the zone divisions are revealed quite strongly in the DCA sample scores (Figs. 7B and D). The lack of clear statistical separation between KET1-III and -IV, and KET2-II and -III can be explained by them being based as much on the ecological importance of the relevant taxa as on statistical grounds. As a result, the DCA sample score plots for KET1 and KET2 (Figs. 7B and D) contain one less assemblage each than is displayed on the pollen diagrams (Figs. 4 and 6).

Even though not part of the contemporary vegetational record as it consists almost exclusively of disturbed sediment, zone KET1-V groups fairly well with the pre- and early-*landnám* samples scores (Fig. 7B). This emphasises the alien stratigraphic placement of this stratum and underscores the pre-settlement age of the displaced deposits, while further demonstrating a statistically clear vegetation change between AD 870 and 1341.

The samples in zone KET1-VI form the best defined cluster in terms of sample scores (Fig. 7B). Accordingly, Poaceae, *Galium*, *Selaginella selaginoides* (lesser clubmoss) and Lactuceae, for instance, reach their highest values in both relative and absolute terms in this zone (Figs. 4 and 5) and separate well from other taxa (Fig. 7A). The statistical

Table 3
Major characteristics of the local pollen assemblage zones for profile KET2.

LPAZ	Depth (cm)	Age (AD)	Characteristic and main advancing taxa from previous zone	Main retreating taxa from previous zone
KET2-III	111–98	1030[a]–1300	Cyperaceae, *Galium*, *Plantago* spp., *Thalictrum alpinum*, *Equisetum*	Poaceae, Apiaceae, *Filipendula ulmaria*, *Rumex acetosa*
KET2–II	115–111	935–1030[a]	Poaceae, Apiaceae, *Filipendula ulmaria*, *Rumex acetosa*	*Betula pubescens*, *Salix*, Cyperaceae, *Equisetum*
KET2-I	126–115	730 ± 50–935	Cyperaceae, Poaceae, Apiaceae, *Salix, Betula pubescens, Rumex acetosa, Ranunclulus acris*-type, *Equisetum*	N/A

[a] Extrapolated age.

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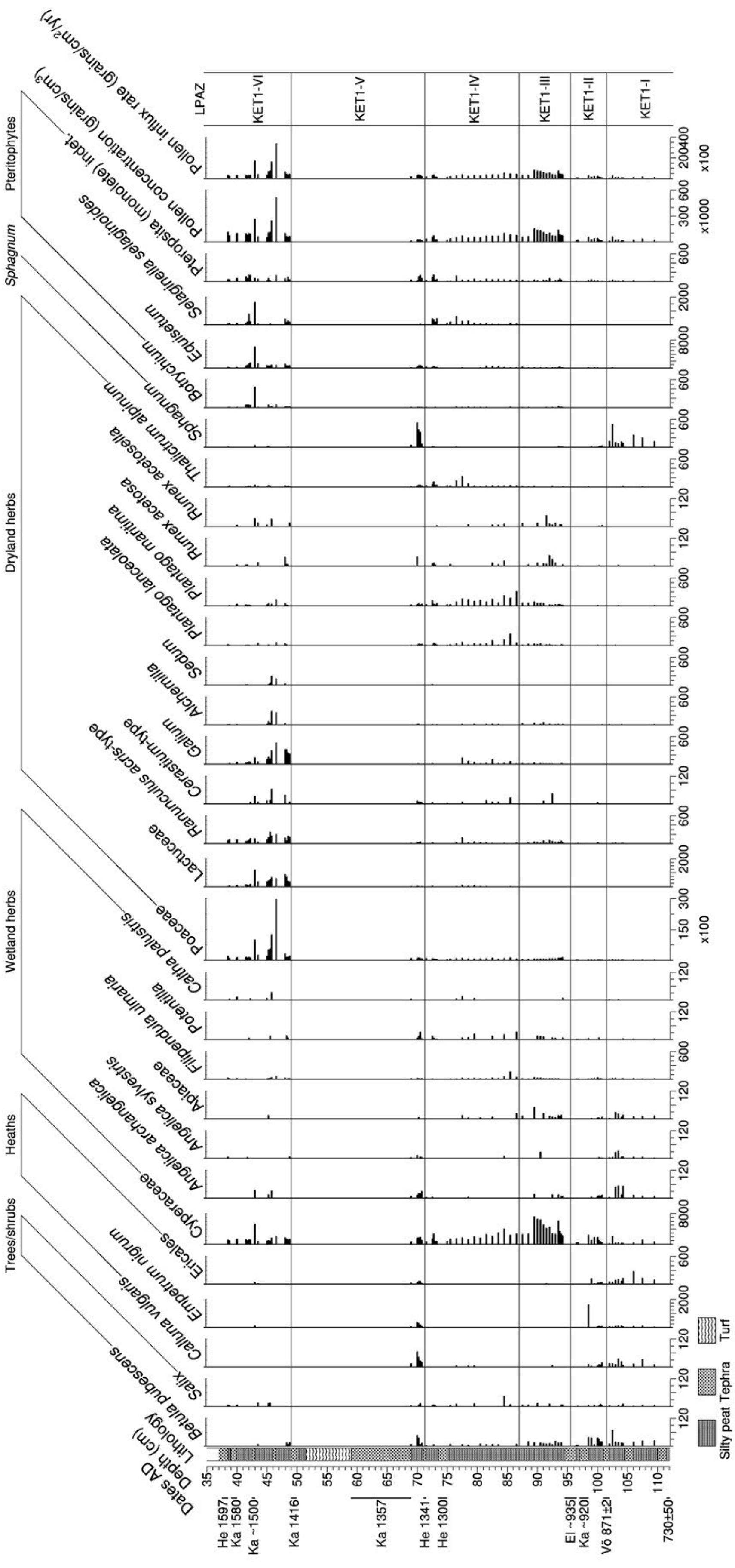

Figure 5. Pollen influx diagram for KET1. Taxa reaching ≥1% TLP are presented. The period AD 1357–1416 is omitted as pollen and sediment accumulation rates cannot be determined for this interval.

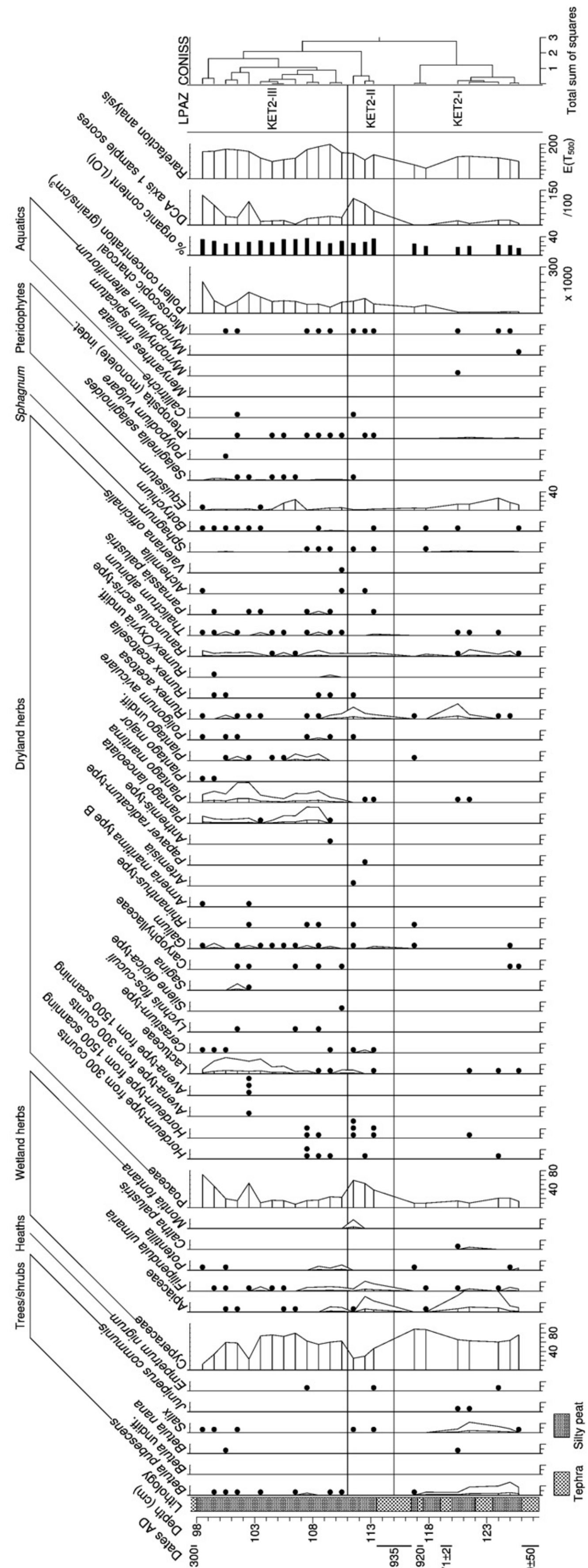

Figure 6. Pollen percentage diagram for KET2. The diagram excludes alien pollen. Exaggeration curves are ×5. Dots signify values below 1% but for cereal-type pollen they indicate level-specific numbers of pollen encountered.

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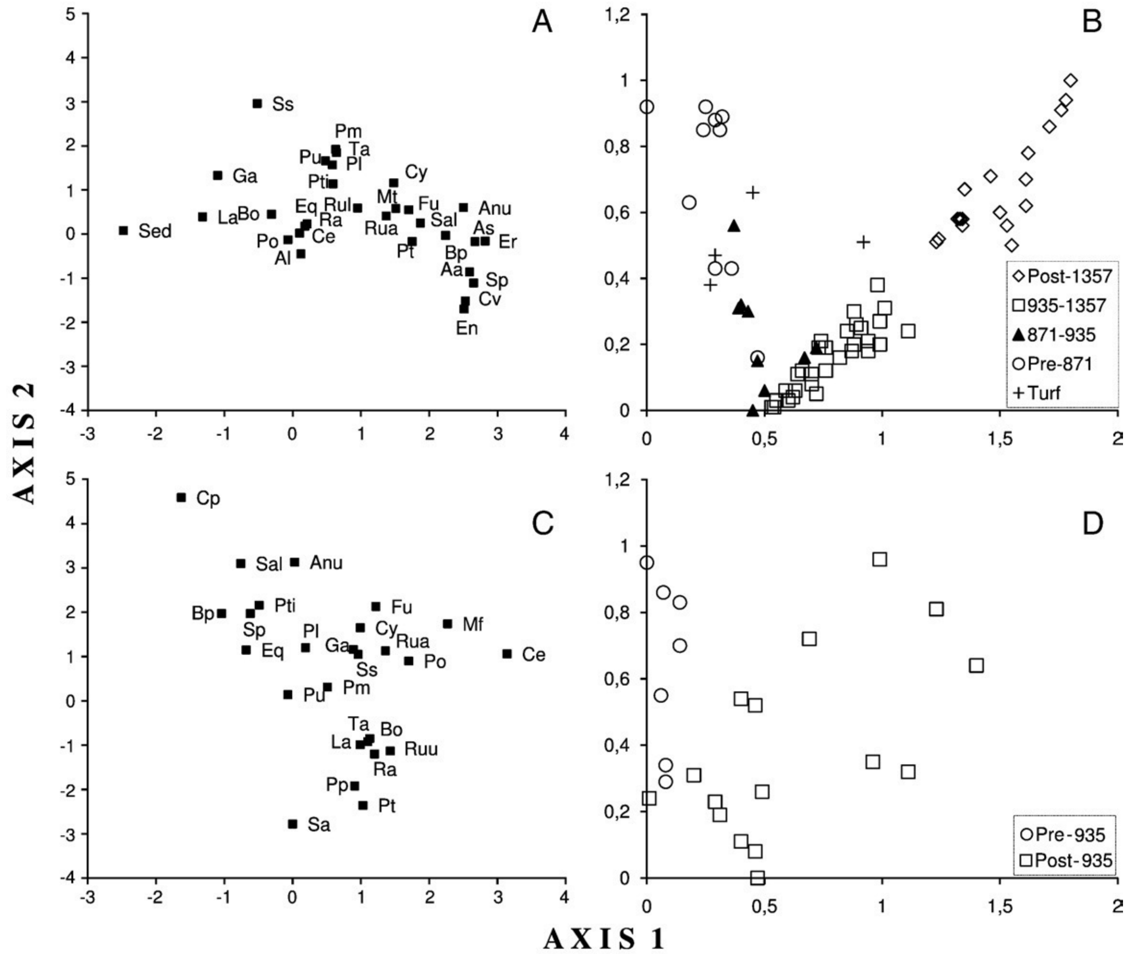

Figure 7. DCA axis 1 and 2 scores plot. Taxa reaching ≥1% TLP are presented in variable score plots. (A) KET1 variable scores; (B) KET1 sample scores; (C) KET2 variable scores; (D) KET2 sample scores. Key to labels: Aa *Angelica archangelica*; Al Alchemilla; As *Angelica sylvestris*; Au Apiaceae undiff.; Bp *Betula pubescens*; Bo Botrychium; Ct Cerastium-type; Cv *Calluna vulgaris*; Cy Cyperaceae; En *Empetrum nigrum*; Eq Eqisetum; Eu Ericales undiff.; Fu *Filipendula ulmaria*; Ga Galium; La Lactuceae; Mf *Montia fontana*; Mt *Menyanthes trifoliata*; Pl *Plantago lanceolata*; Pm *Plantago maritima*; Pmi *Pterosida monolete* indet.; Po Poaceae; Pp *Parnassia palustris*; Pt Potentilla; Pu Plantago undiff.; Ra *Rumex acetosa*; Rac *Rumex acetosella*; Rt *Ranunculus*-type; Ru *Rumex* undiff.; Sa *Salix*; Sag Sagina; Se *Sedum*; SS *Selaginella selaginoides*; Sp *Sphagnum*.

separation of this part of the profile in both DCA sample and variable scores reinforces the abrupt ecological change across the massive Katla tephra from AD 1357 (cf. Buckland et al., 1986). Despite being adaptive, the expanding taxa are most common in sparsely vegetated, nutrient-poor and gravelly environments (cf. Steindórsson, 1981) and although present in the pollen assemblages before AD 1357 (Figs. 4 and 5), their considerably improved representation and the concomitant dwindling of damp-loving taxa such as the Cyperaceae (sedge family), demonstrate the effect of drainage and the habitat changes associated with the massive deposition of tephra.

There is a strong chrono- and biostratigraphical correspondence between the datasets available for the study area (Fig. 8). The lower temporal resolution of KET2 (Fig. 6) prohibits the detection of a comparably detailed pattern of vegetation changes seen at KET1 (Figs. 4 and 5), particularly for the period AD 871 to 935. The macrofossil and insect data from Buckland et al. (1986) correspond well with the palynological record in terms of major synchronous environmental changes (Fig. 8).

Vegetation history

Pre-landnám (AD ca. 730–871)

The pre-*landnám* period at Ketilsstaðir reflects a different vegetational landscape than can be found in many other lowland pollen diagrams from Iceland, most of which contain a fairly strong representation for *Betula* spp. (*B. pubescens* where separated) (Einarsson, 1963; Hallsdóttir, 1987; Erlendsson, 2007). The very limited relative and absolute values for tree or shrub taxa at both KET1 and KET2 indicate the openness of the landscape, which accords with results from the palaeoentomological research of Buckland et al. (1986). The pollen influx (accumulation rate) values for *B. pubescens* over this period are much lower (30–60 grains cm^{-2} yr^{-1}) than would be expected within or near wooded areas, as suggested threshold values for presence/absence (not present within 1 km) of birch in northern Scandinavia are 500–600 grains cm^{-2} yr^{-1} (Hicks, 2001; Hicks and Sunnari, 2005). Comparable influx values for downy birch for the period ~AD 500–870, also obtained from peat profiles, are available from Stóra-Mörk in South Iceland and Reykholtsdalur in West Iceland, where the presence of open woodland has been demonstrated by macro-remains of Coleoptera (Vickers, 2006) and plants (Bending, 2007). These influx values are considerably higher than at Ketilsstaðir – 40–650 and 500–1250 grains cm^{-1} yr^{-1} at Stóra-Mörk and Reykholtsdalur respectively – with phases of lower values probably reflecting episodes of pollination suppression by climatic harshness (Erlendsson, 2007; Erlendsson and Edwards, unpublished) associated with the early medieval period (Geirsdóttir et al., 2009). It is probable that the limited values for pollen of *B. pubescens* at Ketilsstaðir reflect a background component, perhaps from distant woodlands in more sheltered areas of Mýrdalur, such as Hrífunes, an elevated location east of Mýrdalsjökull where woodlands still remain. The plant macrofossil study of Buckland et al. (1986) also suggested an open pre-*landnám* environment with pools bounded by

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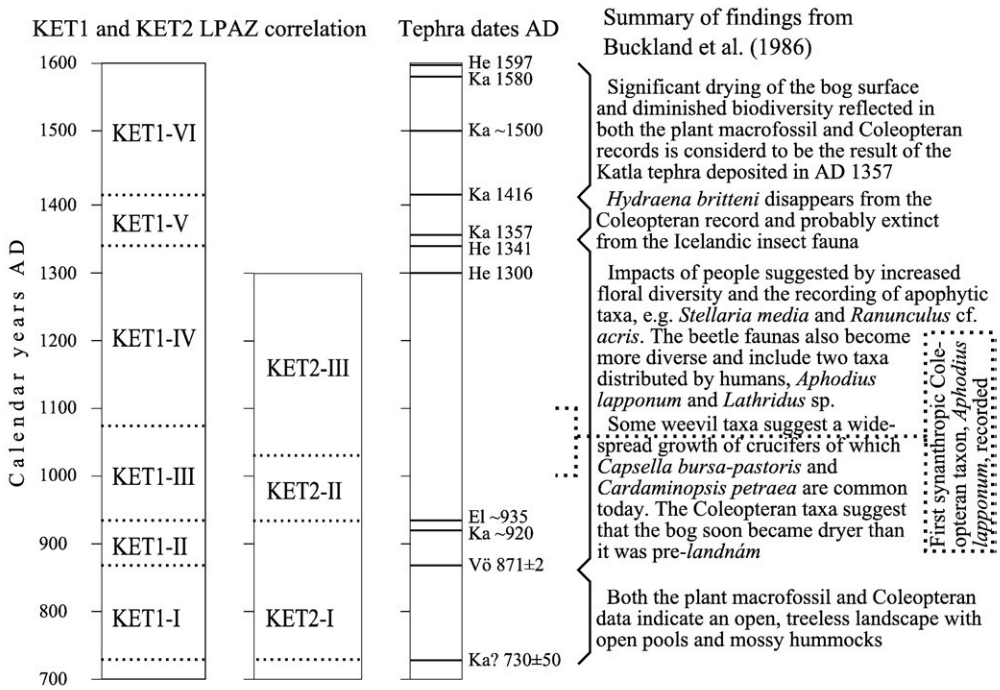

Figure 8. Summary of available palaeoenvironmental data for Ketilsstaðir.

cushions of wet *Sphagnum* providing a suitable habitat for the water beetle *Hydraena britteni* which was found in abundance. As previously noted, the apparent lack of birch woodland is probably the result of proximity and exposure to the open Atlantic Ocean. This produces high levels of moisture and salinity, both of which would have detrimental effects upon the growth of *B. pubescens*, together with climate and climatically-influenced edaphic factors which in modern times present an obstacle to its growth (cf. Einarsson, 1975).

The vegetation did not remain static pre-*landnám*, and some clear changes can be seen in both relative (KET1 and KET2) and absolute (KET1) profiles, across the undated Katla tephra layer (123.5–122 cm) of ca. AD 800. Taxa that respond positively to wetness, most noticeably *Sphagnum*, together with heath taxa commonly growing on mossy hummocks in boggy habitats (Kristinsson, 1986), suffered from the apparent drying of the bog surface. Taller herbs, most of which are less reliant upon wet substrates than *Sphagnum* (e.g. *Angelica* spp., *F. ulmaria*) seem to have either benefited or been less affected by tephra deposition (cf. Edwards and Craigie, 1998; Edwards et al., 2004).

Early Norse times (AD 871–mid-11th century)

Some indications of cultural impact can be seen in the palynological record in the *landnám* period from AD 871, as seen in the reduction of *Angelica* spp. and *F. ulmaria*. The near-disappearance of *Sphagnum* and heath taxa (including *E. nigrum*) soon after AD 871 is perhaps the combined result of bog drainage (e.g. from peat cutting), tephra deposition, increased soil erosion and trampling from domestic mammals. The signals for the heaths and *Sphagnum* are likely to be quite local, as these taxa are only sparsely represented in the KET2 sample. Some apophytic elements of the flora appear or expand slightly at both sampling locations (for example, species of *Plantago*, Polygonaceae and Caryophyllaceae). The rarefaction values (Figs. 4 and 6), however, indicate diminished palynological diversity over this period, implying that taxa are being more rapidly extinguished locally than being introduced, as Poaceae and Cyperaceae become increasingly dominant. The possible anthropogenic indicators are probably too weakly represented to infer the definite existence of a nearby permanent settlement. It seems that the local environment at Ketilsstaðir had evolved without the sheltering effect and shade provided by tall woody species and thus did not suffer the shock of losing these elements, being to a large extent dominated by taxa common in the contemporary open landscapes (e.g. Cyperaceae, Poaceae, *Rumex acetosa* [common sorrel], *Ranunculus* spp. [buttercups] and *Equisetum* [horsetails]). The impact of frequent tephra deposition during this period (ca. AD 871, 920 and 935) is best seen in the increase in Poaceae at the expense of Cyperaceae as a result of the drying of the bog surface (cf. Edwards et al., 2004).

The palynological signals towards the mid-11th century AD are quite muted with regard to anthropogenic indicators, although both KET1 and KET2 record some *Hordeum*-type pollen grains above the Eldgjá tephra (~AD 935). The thick tephra deposit could have provided prime conditions for the growth of *Leymus arenarius*. The latter was formerly used in Mýrdalur as a cereal substitute (Guðmundsson, 1996) and it is frequently employed in the re-vegetation of denuded coastal and volcanic areas of southern Iceland, which serves to indicate its habitat preference.

Whilst Buckland et al. (1986) note an increase in diversity of beetle taxa at Ketilsstaðir immediately after *landnám*, suggesting it to be consequent upon habitat diversification created by human activity, there is no commensurate pollen signal. It is difficult to determine why settlement of the site would have been delayed, but the impact of the Katla and Eldgjá eruptions in AD ~920 and ~935 respectively may have discouraged colonisation. In particular, the Eldgjá eruption would have had a major impact. This eruption resulted in greater acidity peaks in the Greenlandic ice-core records than the Skaftá fires in the late 18th century AD, including the Laki eruption of 1783–84, which devastated farms, people and livestock over a large area of Iceland (Vasey, 1991). Although settlers are unlikely to have been aware of the impact of eruptions, the lack of woodland resources and contamination of peat with tephra, reducing its organic content and suitability as a fuel, may have contributed to delays in settlement, although the slightly warmer and wetter climate of the region would have increased hay productivity.

Permanent settlement (ca. mid-11th century–AD-1341)

The anthropogenic signals evident in the pollen assemblages from KET1 and KET2 for the period ca. AD 1075–1341 imply that a permanent settlement, perhaps at or close to the modern Ketilsstaðir,

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had been established. The prime indicator for the intensification of agricultural activity at the onset of this period is the marked rise in *P. lanceolata*. The species is known to thrive in and around cultivated areas (Sagar and Harper, 1964). The expansion of *Plantago maritima* (sea plantain) follows a near identical pattern to that of *P. lanceolata*. It is a stress-tolerant species that thrives on nitrogen-rich soils (Sheehy Skeffington and Jeffrey, 1988) and at Lambi in the Faroe Islands the plant increases in abundance in association with cultivation from what appears to be the onset of the settlement period (Jóhansen, 1979). It seems likely, therefore, that this species could expand in both arable and pastoral situations. The sustained representation of *F. ulmaria* is more difficult to explain, as it is generally considered vulnerable to land-use activities (Kristinsson, 1986). It could have grown within areas inaccessible or unattractive to grazing animals, like ditches, abandoned peat cuttings and damp localities within hayfields, from which stock would have been excluded.

Later, between ca. AD 1200 and 1341, apophytic taxa, first Lactuceae and *Ranunculus acris*-type and then *S. selaginoides*, accompany the apparent ruderals. This could reflect a vegetational succession of abandoned cultivated areas where *P. lanceolata* decreases slightly while *R. acris*-type and Lactuceae invade abandoned fields and are themselves succeeded by *S. selaginoides* and *Equisetum* (cf. Austrheim and Olson, 1999). Abandonment of cultivated areas is by no means a prerequisite for the flourishing of these taxa, however, as they are all commonly found within present grazed natural grass- or heathlands (Steindórsson, 1964).

The diminished flowering of *P. lanceolata* around AD 1300 may have been linked to late medieval cooling (cf. Geirsdóttir et al., 2009). The plant is close to its northern limits in Iceland and could have experienced reduced flowering under climatic and/or grazing stress. This might have led to it becoming increasingly restricted to the most favourable areas, just as it is mostly confined to south-facing slopes in the warmer districts of Iceland today (Kristinsson, 1986). It is also possible that abandonment of cultivated areas diminished its favoured habitat. The recording of *Avena*-type pollen from a level dated to ~AD 1195 in KET2, perhaps represented an attempt to grow more damp-loving and climatically tolerant cereals at the site as the climate deteriorated and as imported grain became an increasingly attractive option (Einarsson, 1963; Sveinbjarnardóttir et al., 2007). What should be emphasised, however, is the uncertainty in inferring the termination of cereal growing on the basis of an absence of cereal-type pollen. Low pollen productivity and poor dispersal of most cereal-type pollen could obscure the evidence of cultivation in the palynological record (Erlendsson et al., 2006).

No large-scale tephra deposits from the Katla volcanic system, or more distant eruptions, affected the area around Ketilsstaðir between ~AD 935 and 1300, and settlement appears to have been continuous. As the insect evidence suggests some local disturbance from *landnám* onwards (Buckland et al., 1986), it is possible that primary land use in this region reflected utilisation as a shieling (a seasonal grazing outpost; cf. Sveinbjarnardóttir, 1991), perhaps from the farm at Fell on the eastern edge of Sólheimarsandur, where there is archaeological evidence for early settlement (Þórarinsson, 1971); only later did this slightly elevated treeless area support a full farm. In the entomological record there are problems in identifying the relative permanence of occupation (Buckland and Sadler, 1991). The obligate herbivore dung feeder *Aphodius lapponum*, which must rapidly have dispersed throughout Iceland shortly after its introduction (Buckland et al., 1991), first appears in a sample probably from the 11th century AD (Fig. 8), and the more strongly synanthropic *Latridius minutus* (grp), often characteristic of indoor hay deposits (Amorosi et al., 1998), is only present immediately before the 1357 tephra. Judging by the limited data from elsewhere in Iceland, woodlands had by this time been significantly reduced (e.g. Hallsdóttir, 1987; Erlendsson, 2007; Lawson et al., 2007), perhaps allowing peat-rich and climatically milder areas, like those around Ketilsstaðir, to become increasingly important, even if the peat was low in organic content (typically <50% in the analysed profile) (Figs. 4 and 6) and therefore not of the best quality.

Settlement and environmental disruption (AD 1341–1597)

The sediment stratigraphy between the tephra layers Hekla 1341 and Katla 1416 (LPAZ KET1-V) contains clear indications of anthropogenic activity. Pits, afterwards filled with tephra, were dug between AD 1341 and 1357 (Fig. 2) presumably for peat extraction, although other activities, such as flax-retting, should not be ruled out (cf. Þórarinsson, 1944, 171–172). Given the high sediment accumulation rates (Fig. 2) and the palynological record which contains increased quantities of e.g. *Betula*, *Empetrum*, Ericales undiff. and *Sphagnum* (cf. KET1-I), underscoring a pre-settlement origin as already suggested by the DCA sample scores (Fig. 7B), it appears that the deposits became contaminated by debris from the displaced material from the pit. This was filled with tephra from the Katla eruption of AD 1357, either as a result of natural mass movement processes and/or from intentional filling. A layer of subfossil turves situated between the 1357 and 1416 Katla tephras clearly indicates the exploitation of peat resources within the Ketilsstaðir area, although their immediate location above the tephra may reflect an attempt to provide a fresh surface upon which plants could colonise. This suggests that the eruption did not force the abandonment of the farm or that it became re-established soon after the eruption.

Between the Katla 1416 and Hekla 1597 tephra, the sediments appear intact and the pollen assemblages in KET1-VI suggest a dramatic drying of the bog. This may have been a consequence of the 1357 tephra deposition and/or the more localised setting of turves upon the peat surface. Those taxa generally more common in heaths, meadows and in disturbed areas than in boggy environments (Poaceae, Lactuceae, *R. acris*-type, *Galium*, *Sedum*, *Alchemilla*, *Equisetum* and *S. selaginoides*), attain high influx values (Fig. 5), even if overshadowed in percentage terms (Fig. 4) by Poaceae. This trend changes across an undated Grímsvötn tephra at 46.5–46.0 cm (probably deposited in the mid-15th century AD) where, in relative terms, Cyperaceae start to increase, suppressing the values for the taxa which favour drier habitats. This pattern can also been seen in the influx diagram, but this suggests that the rise in the relative values for Cyperaceae is more driven by the decline in other taxa than an actual increase in the flowering of sedges around the sampling site. It seems that by the time of the deposition of the Grímsvötn tephra, the peat deposits had become thicker and waterlogged beyond the tolerance level of the dry-loving taxa. The LOI values and sediment accumulation rates also suggest a high degree of tephra reworking and/or increased soil erosion between AD 1416 and ~1500, a likely consequence of substantial tephra fall. The environmental alteration caused by the 1357 eruption is also noted in the macrofossil work of Buckland et al. (1986) who recorded a lower abundance of Cyperaceae seeds and poorer taxonomic diversity of Coleopteran species (Fig. 8).

The drying effect of the Katla 1357 tephra could have a bearing on the extinction of the water beetle *H. britteni*. This species is close to its northern distributional limits in southern Iceland. It is an inhabitant of wet *Sphagnum* cushions and flooded grasslands and is also known from pools within woodlands (Hansen, 1987; Buckland et al., 1991). *H. britteni* is fairly common in early medieval contexts at Ketilsstaðir (Buckland et al., 1986), but it has not been unambiguously recorded in Icelandic contexts post-dating AD 1500 (Buckland and Wagner, 2001). Buckland et al. (1983) estimated that a cooling of about 1°C during the so-called Little Ice Age (LIA) sufficed to cause the extermination of this species, a similar temperature fall to that proposed for the LIA by a recent chironomid-inferred temperature reconstruction from western Iceland (Gathorne-Hardy et al., in press). The relationship between ocean temperature, sea ice and growing season has been noted (e.g. Friðriksson, 1969), although a direct impact on the invertebrate fauna is less evident. Whether such cooling, also evident from the sea ice record (e.g. Ogilvie and Jónsson, 2001), can be superimposed on the south coast is uncertain. Regardless of the exact level of cooling, the area in which *H. britteni* could have survived is likely to have diminished.

Conclusions

Climate change may have been responsible for pre-settlement tree birch suppression and, less certainly, later minor vegetational changes. The data from Ketilsstaðir allow greater confidence in the elucidation of volcanic and human influences upon the flora. Eight of the visible tephra layers have an apparent floristic response as inferred from the palynological records, viz. Ka ~800, Vö 871 ± 2 (Landnám ash), Ka ~920, El ~935, Ka 1357, Ka 1416, Gr unknown and He 1597 (Fig. 2). Tephra deposition seems to have largely controlled the short-term development of the vegetation, primarily with the replacement of damp-loving taxa by more dryland ones, as is evident across all tephra except the undated (~15th century AD) Grímsvötn layer. The situation, however, is not always straightforward. The changes following the deposition of the Landnám ash may have been the result of several causes such as tephra fall, peat drainage, increased soil erosion and trampling from domestic mammals. The position is complicated in that a layer of turves was placed over the Katla 1357 tephra deposit and this may have been intended to facilitate land surface drying or to mitigate the affects of tephra pollution.

Unlike some areas of Iceland, the landscape within the Ketilsstaðir pollen catchment area was largely unwooded, even prior to initial settlement. The limited signal for woody taxa is considered to be the result of the wet, exposed location, unfavourable for the growth of *B. pubescens*. Accordingly, the study area would perhaps never be a fair test of Ari the Wise's claim in the 12th century *Íslendingabók* (Book of the Icelanders; Benediktsson, 1968) that woodland at the time of *landnám* stretched from the mountains to the seashore. Along with saga evidence (Gunnarsdóttir, 2001), however, it demonstrates the variability in Iceland's past arboreal cover.

The period conventionally referable to *landnám* (at and following ~AD 871) was quantitatively characterised by the disappearance of many taxa rather than by the colonisation of new ones: first Cyperaceae and then Poaceae dominate the pollen spectra. Despite the reduction in floristic diversity (a pattern seen elsewhere in the North Atlantic [Edwards et al. 2005c], but not always [Edwards et al. 2008; Schofield et al. 2008]), some anthropogenic indicators become more prominent at low numbers, indicating that although a permanent settlement was perhaps not established locally, the impacts of the Norse settlement in the wider area left its imprint on the palynology of the bog at Ketilsstaðir.

Neither the historical record nor the environmental data are conclusive as to the date when permanent settlement occurred. Historically, the high economic value of the farm and its associated half-church would suggest that settlement was established early, in contrast to what its name and first documented occurrence would imply. The environmental record is similarly equivocal, with circumstantial palynological evidence for arable activity perhaps supported by the adjacent cultivated field terraces and the reduction in taxa palatable to grazing animals. The relatively late expansion of weed taxa and the synchronous non-tephra-influenced rise in Poaceae, classic indicators of human activity (Hallsdóttir, 1996), would suggest that settlement permanence came later, perhaps in the mid-11th century. It is conceivable that both the historical and the palynological records indicate that Ketilsstaðir was not founded as an early-*landnám* farm. It is unfortunate that the exercise in cereal-type scanning did not produce more conclusive results given the potential confusion in distinguishing between domesticated and natural species within the *Hordeum* group.

There is no doubting the direct evidence for human impact demonstrated by the pits and turves sandwiched between tephras dating to AD 1341 and 1416. It can be assumed that there was only a short-term abandonment of the farm, if any, in the wake of the Katla 1357 eruption. After AD 1416 at least, there was a major transformation of the hydrology and floristic composition of the mire with the expansion of dryland taxa, most notably Poaceae. This, rather than simply a late- and post-medieval cooling period, is likely to have contributed to the demise of the water beetle *H. britteni* which probably became extinct sometime during the 14th or 15th centuries AD, although both the timing and nature of its extinction need further exploration.

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References

Amorosi, T., Buckland, P.C., Edwards, K.J., Mainland, I., McGovern, T.H., Sadler, J.P., Skidmore, P., 1998. They did not live by grass alone: the politics and palaeoecology of fodder on the North Atlantic islands. Environmental Archaeology 1, 41–54.

Andersen, S.T., 1979. Identification of wild grass and cereal pollen. Danmarks Geologiske Undersøgelse Årbok 1978, 69–92.

Andrews, J.T., Caseldine, C., Weiner, N.J., Hatton, J., 2001. Late Holocene (ca. 4 ka) marine and terrestrial environmental change in Reykjafjörður, north Iceland: climate and/or settlement? Journal of Quaternary Science 16, 119–132.

Austrheim, G., Olson, E.G.A., 1999. How does continuity in grassland management after ploughing affect plant community patterns. Plant Ecology 145, 59–74.

Bending, J.M., 2007. The economy of the Norse settlement of the North Atlantic islands and its environmental impact: an archaeobotanical assessment. Unpublished PhD thesis, University of Sheffield.

Benediktsson, J. (Ed.), 1968. Íslendingabók. Landnámabók (Book of Icelanders, Book of Settlements). Íslenzk fornrit 1. Hið íslenzka fornritafélag, Reykjavík.

Bennett, K.D., 2009a. Catalog of pollen types. Queen's University Belfast. Belfast. http://www.chrono.qub.ac.uk/pollen/pc-intro.html (last accessed March 2009).

Bennett, K.D., 2009b. *Psimpoll* and *pscomb* programs for plotting and analysis. http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html (last accessed March 2009).

Birks, H.J.B., Line, J.M., 1992. The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. The Holocene 2, 1–10.

Borthwick, D.M., 2007. The timing and impact of the Norse *landnám* on the vegetation of Hovsdalur, Faroe Islands. Unpublished PhD thesis, University of Aberdeen, Scotland.

Buckland, P.C., Sadler, J., 1991. Farm or shieling: an entomological approach. In: Sveinbjarnardóttir, G., Shielings in Iceland — an archaeological and historical survey. Acta Archaeologica 61, 93–96.

Buckland, P.C., Wagner, P.E., 2001. Is there an insect signal for the “Little Ice Age”? Climatic Change 48, 137–149.

Buckland, P.C., Perry, D.W., Sveinbjarnardóttir, G., 1983. *Hydraena britteni* Joy (Coleoptera, Hydraenidae) fundin á Íslandi í setlögum frá því seint á nútíma. Náttúrufræðingurinn 52, 37–44.

Buckland, P.C., Gerrard, A.J., Larsen, G., Perry, D.W., Savory, D.R., Sveinbjarnardóttir, G., 1986. Late Holocene palaeoecology at Ketilsstaðir in Mýrdalur, South Iceland. Jökull 36, 41–55.

Buckland, P.C., Dugmore, A.J., Sadler, J., 1991. Faunal change or taphonomic problem? A comparison of modern and fossil insect faunas from south east Iceland. In: Maizels, J.K., Caseldine, C. (Eds.), Environmental Change in Iceland. Past and Present. Kluwer, Dordrecht, pp. 127–145.

Buckland, P.C., Edwards, K.J., Blackford, J.J., Dugmore, A.J., Sadler, J.P., Sveinbjarnardóttir, G., 1995. A question of Landnám: pollen, charcoal and insect studies on Papey, eastern Iceland. In: Butlin, R., Roberts, N. (Eds.), Ecological Relations in Historical Times. Human Impact and Adaptation. Blackwell, Oxford, pp. 245–264.

Calib (2009). Radiocarbon calibration program: version Calib 5.0.2html. http://calib.qub.ac.uk/calib/ (last accessed March 2009).

Caseldine, C., 2001. Changes in the Holocene record from Iceland — a palaeoclimatic record or evidence for early Holocene hybridisation? Review of Palaeobotany and Palynology 117, 139–152.

D.I., 1867–1972. Diplomatarium Islandicum. Hið íslenzka bókmenntafjelag, Copenhagen and Reykjavík.

Dugmore, A.J., Buckland, P.C., 1991. Tephrochronology and late Holocene soil erosion. In: Maizels, J.K., Caseldine, C. (Eds.), Environmental Change in Iceland. Past and Present. Kluwer, Dordrecht, pp. 147–161.

Dugmore, A.J., Larsen, G., Newton, A.J., 1995. Seven tephra isochrones in Scotland. The Holocene 5, 257–266.

Dugmore, A.J., Newton, A.J., Larsen, G., Cook, G.T., 2000. Tephrochronology, environmental change and the Norse settlement of Iceland. Environmental Archaeology 5, 21–34.

Dugmore, A.J., Church, M.J., Buckland, P.C., Edwards, K.J., Lawson, I., McGovern, T.H., Panagiotakopulu, E., Simpson, I.A., Skidmore, P., Sveinbjarnardóttir, G., 2005. The

Norse *landnám* on the North Atlantic islands: an environmental impact assessment. Polar Record 41, 21–37.
Edwards, K.J., 1989. The cereal pollen record and early agriculture. In: Milles, A., Williams, D., Gardner, N. (Eds.), The Beginnings of Agriculture. British Archaeological Reports, International Series, Oxford, pp. 113–135.
Edwards, K.J., Craigie, R., 1998. Palynological and vegetational changes associated with the deposition of Saksunarvatn ash in the Faroe Islands. Fróðskaparrit 46, 245–266.
Edwards, K.J., McIntosh, C.J., 1988. Improving the detection rate of cereal-type pollen grains from *Ulmus* decline and earlier deposits from Scotland. Pollen et Spores 30, 179–188.
Edwards, K.J., Dugmore, A.J., Blackford, J.J., 2004. Vegetational response to tephra deposition and land-use change in Iceland: a modern analogue and multiple working-hypothesis approach to tephropalynology. Polar Record 39, 1–8.
Edwards, K.J., Lawson, I.T., Erlendsson, E., Dugmore, A.J., 2005a. Landscapes of contrast in Viking age Iceland and the Faroe Islands. Landscapes 6, 63–81.
Edwards, K.J., Whittington, G., Robinson, M., Richter, D., 2005b. Palaeoenvironments, the archaeological record and cereal pollen detection at Clickimin, Shetland. Journal of Archaeological Science 32, 1741–1756.
Edwards, K.J., Borthwick, D., Cook, G., Dugmore, A.J., Mairs, K.-A., Church, M.J., Simpson, I.A., Adderley, W.P., 2005c. A hypothesis-based approach to landscape change in Suðuroy, Faroe Islands. Human Ecology 33, 621–650.
Edwards, K.J, Schofield, J.E., Mauquoy, D., 2008. High resolution paleoenvironmental and chronological investigations of Norse *landnám* at Tasiusaq, Eastern Settlement, Greenland. Quaternary Research 69, 1–15.
Einarsson, Þ., 1963. Pollen analytical studies on the vegetation and climate history of Iceland in late and post-glacial times. In: Löve, Á., Löve, D. (Eds.), North Atlantic Biota and their History. Pergamon Press, Oxford, pp. 355–365.
Einarsson, E.H., 1975. Mýrdalur. Árbók Ferðafélags Íslands 1975, 11–123.
Einarsson, M.Á., 1976. Veðurfar á Íslandi. Iðunn, Reykjavík.
Einarsson, E.H., Larsen, G., Þórarinsson, S., 1980. The Sólheimar tephra layer and the Katla eruption of ~1357. Acta Naturalia Islandica 28, 1–24.
Erlendsson, E., 2007. Environmental change around the time of the Norse settlement of Iceland. Unpublished PhD thesis, University of Aberdeen.
Erlendsson, E., Edwards, K.J., Lawson, I.T., Vésteinsson, O., 2006. Can there be a correspondence between Icelandic palynological and settlement evidence? In: Arneborg, J., Grønnow, B. (Eds.), Dynamics of Northern Societies. Publications from the National Museum, Studies in Archaeology and History, Vol. 10. Copenhagen, pp. 347–354.
Erlendsson, E., Vickers, K.A., Gathorne-Hardy, F., Bending, J.M., Gunnarsdóttir, B., Gísladóttir, G. and Edwards, K.J., in press. Late-Holocene environmental history of the Reykholt area, Borgarfjörður, Western Iceland. In Þorgeirsson, B. (ed), Mellan Text och Materiell Kultur. Snorrastofa, Reykholt.
Friðriksson, S., 1959. Korn frá Gröf í Öræfum. Árbók Hins Íslenzka Fornleifafélags 1959, 88–91.
Friðriksson, S., 1960. Jurtaleifar frá Bergþórshvoli á söguöld. Árbók Hins íslenzka fornleifafélags 1960, 64–75.
Friðriksson, S., 1969. The effects of sea ice on flora, fauna and agriculture. Jökull 19, 146–157.
Gathorne-Hardy, F.J., Erlendsson, E., Langdon, P.G. and Edwards, K.J., in press. Lake sediment evidence for late Holocene climate change and landscape erosion in western Iceland. Journal of Paleolimnology, doi:10.1007/s10933-008-9285-4.
Geirsdóttir, Á., Miller, G.H., Thordarson, Th., Ólafsdóttir, K.B., 2009. A 2000 year record of climate variations reconstructed from Haukadalsvatn, West Iceland. Journal of Paleolimnology 41, 95–115.
Grimm, E.C., 1991. TILIA and TILIA.GRAPH 1. Illinois State Museum, Springfield.
Grimm, E.C., 2004. TGView 2.0.2. Illinois State Museum, Springfield.
Grönvold, K., Óskarsson, N., Johnsen, J., Clausen, H.B., Hammer, C.U., Bond, G., Bard, E., 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. Earth and Planetary Science Letters 135, 149–155.
Guðmundsson, G., 1996. Gathering and processing of lyme-grass (*Elymus arenarius*) in Iceland: an ethnohistorical account. Vegetation History and Archaeobotany 5, 13–23.
Guðmundsson, G., Snæsdóttir, M., Simpson, I.A., Hallsdóttir, M., Sigurgeirsson, M., Árnason, K., 2004. Fornir akrar á Íslandi: meintar minjar um kornrækt á fyrri öldum. Árbók Hins íslenska fornleifafélags 2002–2003, 79–106.
Gunnarsdóttir, B., 2001. Gróðurfarslýsingar í Íslendingasögum bornar saman við núverandi gróðurfar. Skógræktarritið 2001, 63–77.
Gunnarsson, G., 1980. Landskuld í mjöli. Saga 18, 31–48.
Hafliðason, H., Larsen, G., Ólafsson, G., 1992. The recent sedimentation history of Thingvallavatn, Iceland. Oikos 64, 80–95.
Hallsdóttir, M., 1982. Frjógreining tveggja jarðvegssniða úr Hrafnkelsdal. Áhrif ábúðar á gróðurfar dalsins. Árbók Hins íslenska fornleifafélags 1982, 253–265.
Hallsdóttir, M., 1987. Pollen analytical studies of human influence on vegetation in relation to the Landnám tephra layer in Southwest Iceland (PhD thesis). Lundqua Thesis 18, Lund University, Lund.
Hallsdóttir, M., 1996. Frjógreining. Frjókorn sem heimild um landnámið. In: Grímsdóttir, G.Á. (Ed.), Um landnám á Íslandi — fjórtán erindi. Vísindafélag Íslendinga, Reykjavík, pp. 123–124.
Hansen, M., 1987. The Hydrophiloidea (Coleoptera) of Fennoscandia and Denmark. Scandinavian Science Press, Leiden.
Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25, 101–110.
Hermannsson, J., 1993. Kornrækt á Íslandi. Rannsóknastofnun landbúnaðarins, Reykjavík.
Hicks, S., 2001. The use of annual arboreal pollen deposition values for delimiting tree-lines in the landscape and exploring models of pollen dispersal. Review of Palaeobotany and Palynology 117, 1–29.
Hicks, S., Sunnari, A., 2005. Adding precision to the spatial factor of vegetation reconstructed from pollen assemblages. Plant Biosystems 139, 127–134.
Jóhansen, J., 1979. Cereal cultivation in Mykines, Faroe Islands AD 600. Danmarks Geologiske Undersøgelse Årbog 1978, 93–103.
Karlsdóttir, L., Thórsson, Æ.Th., Hallsdóttir, M., Sigurgeirsson, A., Eysteinsson, Th., Anamthawat-Jónsson, K., 2007. Differentiating pollen of *Betula* species from Iceland. Grana 46, 78–84.
Kristinsson, H., 1986. The Flowering Plants and Ferns of Iceland. Örn og Örlygur, Reykjavík.
Lawson, I.T., Gathorne-Hardy, F.J., Church, M.J., Newton, A.J., Edwards, K.J., Dugmore, A.J., Einarsson, Á., 2007. Environmental impacts of the Norse settlement: palaeoenvironmental data from Mývatnssveit, Northern Iceland. Boreas 36, 1–19.
Lawson, I.T., Edwards, K.J., Church, M.J., Newton, A.J., Cook, G.T., Gathorne-Hardy, F.J., Dugmore, A.J., 2008. Human impact on an island ecosystem: pollen data from Sandoy, Faroe Islands. Journal of Biogeography 35, 1130–1152.
Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis, 2nd edn. Blackwell Science, Oxford.
Newton, A.J., Dugmore, A.J., Gittings, B.M., 2007. Tephrabase: tephrochronology and the development of a centralised European database. Journal of Quaternary Science 22, 737–743.
Ogilvie, A.E.J., Jónsson, T., 2001. "Little Ice Age research": a perspective from Iceland. Climatic Change 48, 9–52.
Óladóttir, B.A., Larsen, G., Þórðarson, Þ., Sigmarsson, O., 2005. The Katla volcano, S-Iceland: Holocene tephra stratigraphy and eruption frequency. Jökull 55, 53–74.
Ólafsdóttir, R., 2001. Land Degradation and Climate in Iceland: A Spatial and Temporal Assessment (PhD thesis). Meddelanden från Lunds Universitets Geografiska Institutioner, avhandlingar 143. Lund University, Lund.
Ólafsson, H., Helgadóttir, Á., Sigurgeirsson, A., Hermannson, J., Rögnvaldsson, Ó., 2007. Líkleg þróun veðurfars á Íslandi með tilliti til ræktunar. Fræðaþing landbúnaðarins 4, 29–36.
Sagar, G.R., Harper, J.L., 1964. *Plantago major* L., *P. media* L. and *P. lanceolata* L. The Journal of Ecology 52, 189–221.
Schofield, J.E., Edwards, K.J., Christensen, C., 2008. Environmental impacts of Norse *landnám* in the Qorlortoq valley, Eastern Settlement, Greenland. Journal of Archaeological Science 35, 1643–1657.
Sheehy Skeffington, M.J., Jeffrey, D.W., 1988. Response of *Armeria maritima* (Mill.) Wild. and *Plantago maritima* L. from an Irish salt marsh to nitrogen and salinity. New Phytologist 110, 399–408.
Sicre, M.-A., Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eríksson, J., Knudsen, K.L., Jansen, E., Turon, J.-L., 2008. Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. Earth and Planetary Science Letters 268, 137–142.
Smith, K.P., 1995. Landnám: the settlement of Iceland in archaeological and historical perspective. World Archaeology 26, 319–347.
Steindórsson, S., 1964. Gróður á Íslandi. Almenna bókafélagið, Reykjavík.
Steindórsson, S., 1981. Vegetation classification in Iceland. Journal of Agricultural Research in Iceland 12, 11–57.
Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 614–621.
Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon 35, 215–230.
Sveinbjarnardóttir, G., 1991. Shielings in Iceland — an archaeological and historical survey. Acta Archaeologica 61, 73–96.
Sveinbjarnardóttir, G., Erlendsson, E., Vickers, K., McGovern, T.H., Milek, K., Edwards, K.J., Simpson, I.A., Cook, G., 2007. The palaeoecology of a high status Icelandic farm. Environmental Archaeology 12, 187–206.
Tweddle, J.C., Edwards, K.J., Fieller, N.R.J., 2005. Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset. Vegetation History and Archaeobotany 14, 15–30.
Vasey, D.E., 1991. Population, agriculture and famine: Iceland 1784–85. Human Ecology 9, 1–28.
Vésteinsson, O., 1998. Patterns of settlement in Iceland: a study in prehistory. Saga-Book 25, 1–29.
Vilmundarson, Þ., 1971. -stad. Island. Kulturhistorisk Leksikon for Nordisk Middelalder fra Vikingertid til Refomationstid 16, 378–384.
Vickers, K.A., 2006. The palaeoentomology of the North Atlantic islands. Unpublished PhD thesis, University of Sheffield.
Þórarinsson, S., 1944. Tefrokronologiska Studier på Island (Þjórsárdalur och dens Förödelse). Geografisker Annaler 26, 1–217.
Þórarinsson, S., 1961. Uppblástur á Íslandi í ljósi öskulagarannsókna. Ársrit Skógræktarfélags Íslands 1960–1961, 17–54.
Þórarinsson, S., 1971. Forn saumnál finnst á Felli í Mýrdal. Árbók Hins íslenzka fornleifafélags 1971, 95–99.
Þórarinsson, S., 1975. Katla og annáll Kötlugosa. Árbók Ferðafélags Íslands 1975, 125–149.
Þórhallsdóttir, Þ.E., 1996. Áhrif búsetu á landið. In: Grímsdóttir, G.Á. (Ed.), Um landnám á Íslandi — fjórtán erindi. InVísindafélag Íslendinga, Reykjavík, pp. 149–170.