University of Stavanger

Link to official URL: DOI: 10.1016/j.revpalbo.2010.10.008
(Access to content may be restricted)
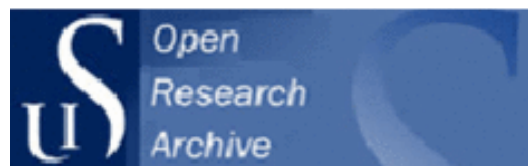
Open Research Archive

UiS Brage
http://brage.bibsys.no/uis/

New insights into late Holocene farming and woodland dynamics in western Ireland with particular reference to the early medieval horizontal watermill at Kilbegly, Co. Roscommon

by Anette Overland, Michael O'Connel

Key words:

- pollen analysis;
- moss polsters;
- horizontal watermill;
- medieval farming;
- Iron Age;
- Ireland

Abstract

An early medieval horizontal watermill, discovered during archaeological survey preparatory to motorway construction, at the edge of a small mire in Kilbegly Townland, County Roscommon, provided the opportunity for palaeoecological investigations of peat and fossil moss-polster samples in a part of western Ireland where there have been few detailed pollen analytical investigations. While the data – pollen and macrofossil (moss) identifications and 14C dating – relate mainly to the early medieval period, analyses of a peat core from the mire, and a moss sample that was used as caulk in the trough of a burnt mound (fulacht fiadh), extend the environmental record well into the Bronze Age (c. 1850 cal. BC). Woodland and farming dynamics in the late Holocene are reconstructed on the basis of the investigations at Kilbegly and other sites in the region. An overview of human impact, and the intensity and nature of farming, since the mid Iron Age (c. 350 cal. BC) in Ireland is presented, based on a review of fossil pollen evidence from key sites, with due consideration being given to factors such as climate change, and cultural and related developments. The history of pine (Pinus sylvestris) and yew (Taxus baccata) is considered in some detail. The final demise of these species in the study area had occurred by the 10th century AD.

1. Introduction

Large-scale construction works, and in particular road construction, in Ireland during recent years, have led to much new information on past settlements and long-term human impact (O'Sullivan and Stanley, 2008, Corlett and Potterton, 2009, Stanley et al., 2009 and McKeon and O'Sullivan, in press). One of the more spectacular finds was the discovery of a well preserved, horizontal watermill at Kilbegly, to the east of Ballinasloe on the footprint of the about-to-be constructed M6 motorway (Fig. 1 and Plate I, 1; Plate S1) (Jackman, 2007, Jackman, 2009 and Jackman et al., in press). In a European context, Ireland is noted for the early introduction of both horizontal and vertical watermills, both types being present in Ireland from at least the early seventh century AD (Brady, 2006 and Rynne, 2000a; BC and AD dates are quoted in calibrated years or, in the case of AD dates, calendar years depending on the context). The introduction and spread of water-powered mills, which were particularly common in the fertile southern midlands and county Cork, represented a major technological advance over hand-operated rotary quern stones introduced in the preceding Iron Age (Watts, 2002).

- Plate I. 1. Overview towards south-west of the horizontal-mill site during excavation (Kilbegly 2; 24/07/2007). A recent drain runs diagonally across the photograph. An arrow points to a dot that marks the location of core KLB-U2. A mire once occupied the basin, including the area with forestry in the background. 2. Sampling peat (mainly mosses) from beneath the flume. The flume and part of undercroft are shown (view from east side; 22/08/2007).
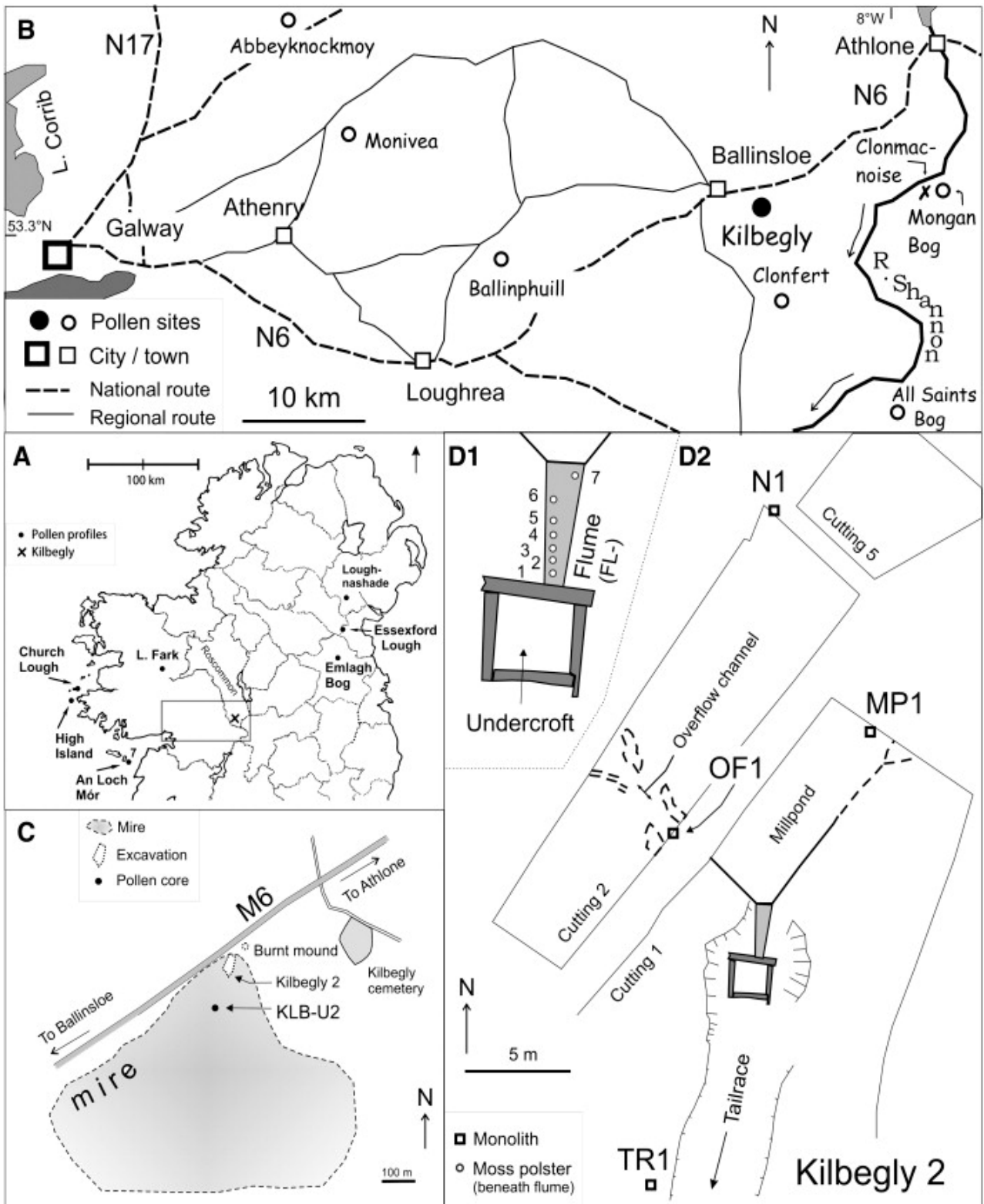
- Fig. 1.
- A. Overview map with county boundaries. The study region is delineated by a rectangle and selected pollen sites from outside the study region are indicated; B. Study region showing pollen sites, main road network (prior to M6 motorway) and other geographical features; C. Excavation site Kilbegly 2, the burnt mound and coring site KLB-U2. The original extent of the mire (approximate) is delineated; D1. The excavation site, Kilbegly 2, showing monolith locations with respect to the mill (post and wattle structures to the east of the millpond have been omitted); D2. A detail of the mill showing where samples FL1–7 were taken from beneath the flume.

The context of the find at Kilbegly, namely a small mire within an otherwise fertile landscape, provided a rare opportunity to carry out palaeoecological investigations, in the context of excavations at an intact mill site. While the palaeo-records from Kilbegly extend from *c.* 1850 BC to AD 1200, in this paper the main focus is on woodland dynamics, and the intensity and nature (pastoral versus arable) of farming in Iron Age and medieval Ireland.

The mill site (Kilbegly 2) is situated at the edge of a modest-sized mire (Fig. 1C; Plate I, 1; Plate S1) that occupies a shallow basin to the west of a low ridge with fertile farmland (maximum elevation: 98 m asl). This gently undulating landscape drains, via the river Suck, into the river Shannon. The bedrock consists of Lower Carboniferous limestone overlain by drift deposits of Weichselian (Midlandian) age. Pastoral farming (cattle and sheep) predominates today on both the dry mineral soils and peaty low-lying areas, which have been reclaimed and partly planted with conifers. On higher ground, the occasional field carries cereals.

The mire, which covered and preserved the mill site, was reclaimed to give a wet pasture, probably in the last century (it is noted as wetland in the 1st edition of the Ordnance Survey (OS) maps, *c.* 1838). Mire rather than bog is advisedly used since fen/reedswamp, rather than *Sphagnum*-dominated raised bog, seems to have prevailed throughout much of the post-glacial at this site (see Discussion).

2. Methods

2.1. Fieldwork

In July 2007 four short peat monoliths, TR1, OF1, MP1 and N1, were collected from within the mill site where archaeological excavations were being carried out (details in Table 1; locations indicated in Fig. 1 and Fig. 8). These monoliths relate to the tailrace, the so-called overflow channel, the millpond and a point located 22 m to the north of the mill croft, respectively.

Table 1.   Samples for palaeoenvironmental investigations.

Sample no.	Contexts	Sample details	Lat./long.
Core			
U1, U2	Peat cores	Parallel cores from reclaimed bog in basin. Coring location *c.* 110 m south of the mill	N53° 19.195′ W08° 09.036′
Short monoliths			
TR1	C70; tailrace	A peat layer (>30 cm) sealed by spoil (stony drift; *c.* 40 cm thick) placed on top of the peat during construction of the tailrace	N53° 19.249′ W08° 09.016′
OF1	C13, C22; overflow	Mainly the basal peat (*c.* 40 cm of a total of 80 cm removed). Lowermost, fluid-like peat (*c.* 10 cm) was not completely removed	N53° 19.258′ W08° 09.015′
MP1	C2, C3, C69; millpond	From a peat section in the millpond near that part of the millpond wall made of wattle (otherwise wall made of oak planking) The deposit consisted of peat (incl. sand/silt and flecks of marl), topped by 15 cm of marl; peat and base of marl (3 cm) was sampled.	N53° 19.260′ W08° 09.007′
N1	C1, C3, C69	Peat from beside a recent drain to the north-east of the mill-pond, 22 m north of the mill croft. Uppermost *c.* 10 cm of peat (modern rooting zone) not included in the 55 cm-long monolith	N53° 19.267′ W08° 09.010′
Moss samples (flume and burnt mound)			
FL1–FL7	C68; flume	Samples FL1–FL7 from beneath the flume (sample sequence bottom to top); sample FL3 was a short monolith	N53° 19.255′ W08° 09.011′
FF1	C17	Sample from between timbers of trough of burnt mound (*fulacht fiadh*)	N53° 19.267′ W08° 09.010′

Context numbers are as defined during the course of the excavations.

Seven moss samples (referred to as moss polsters) were collected in August 2007 from beneath the flume of the mill prior to lifting of the flume (samples FL1–7; Fig. 1, D2; Plate I, 2). A moss sample had been collected (FF1) earlier from between the timbers that lined the trough of a burnt mound (*fulacht fiadh*).

The shallow peat basin, in which the horizontal mill was preserved, was investigated using a gouge corer. In November 2007, parallel cores U1 and U2 (1 m-long core segments with overlap of 20 cm) were taken using an Usinger corer where the deposits were deepest (Table 1 and Fig. 1C). Core U2 was subsampled, core U1 being somewhat disturbed due to woody remains at ca. 90 cm depth. The resulting pollen profile KLB-U2 was expected to provide a long-term record of vegetation change and human activity in the general area (a pollen source area of about a kilometre radius of the sampling site is postulated) and hence complement the more localised records from the monoliths and the moss polsters.

The prefixes KLB1-, KLB2- and KLB- were used in the designation of samples from the burnt mound, horizontal-mill site and the core from the peat basin, respectively. The prefixes are generally omitted in the text for the sake of brevity but it is recommended that they be used if the data are being referenced elsewhere.

2.2. Laboratory methods

2.2.1. Stratigraphy

The stratigraphical descriptions of the monoliths relate to the exposed section as cleaned and photographed in the field prior to sampling. The stratigraphy of the peat core was described after splitting the core longitudinally in half. Depths in the monoliths and core are with respect to the tops of the monoliths and the present ground surface, respectively.

2.2.2. Pollen and macrofossil analysis

Sub-sampling was carried out in the laboratory. Samples of 1 cm^3 and 1 cm thick were taken from the monoliths at approximately equal intervals. The upper part of core U2 was similarly sub-sampled using a sample volume of 3 cm^3. In the case of the moss samples, *c.* 10–15 g of wet material was used.

Samples were prepared for pollen analysis using standard procedures as implemented in Galway (cf. Overland and O'Connell, 2008). The procedure included initial sieving using a 100 μm-mesh sieve, treatments with KOH, HCl and HF followed by acetolysis, and sieving the final pellet using a 5 μm-mesh sieve in an ultra-sonicator. *Lycopodium* tablets (batch 483216), supplied by the Department of Geology/Quaternary Sciences, University of Lund, were added at the beginning of the procedure, except in the case of the moss samples. The addition of this spike enabled pollen concentration to be subsequently estimated. The samples were mounted in glycerol, and counted using a Leica DM LB2 microscope fitted with a phase contrast Planapo 63/1.4 objective lens (magnification used ×630). Pollen and spore identification followed mainly Fægri and Iversen (1989). Other authorities consulted included Moore et al., 1991, Beug, 2004, Reille, 1992 and Reille, 1995. Cereal-type pollen were distinguished following the criteria in Beug (2004) and categorized according to size classes (length of longest axis of grain cited): 40–44 μm, 45–49 μm and ≥ 50 μm. Cereal-type pollen of size ≥ 37–39 μm are included in the Poaceae curve because of the likelihood that this category consists mainly of pollen of non-cultivated grasses. Selected non-pollen palynomorphs (NPP) were also counted, including fungal spores, *Pinus* stomata and *Erica tetralix* epidermis fragments and charcoal (fragments > 30 μm counted; referred to as micro-charcoal).

Material retained during pollen preparation on a 100 μm-mesh sieve after KOH treatment were examined using a Leica MZ125 stereo-microscope for macrofossils, charcoal (referred to as macro-charcoal) and other identifiable material. Photomicrographs were taken using a Leica DFC32 digital camera attached to the stereo-microscope. Estimates of abundance were generally recorded as follows: rare (+); occasional (1); frequent (2) and abundant (3). Seeds, fruits and nutlets were identified using Beijerinck, 1976, Schoch et al., 1988 and Cappers et al., 2006. Higher plant nomenclature follows Stace (1997). Smith, 1978 and Watson, 1981 were consulted in connection with moss identification. Moss nomenclature follows the former.

For pollen data handling, including plotting of diagrams, the program CountPol (I. Feeser, unpublished) was used. Percentage data from the monoliths and core are expressed relative to total terrestrial pollen (TTP). Taxa excluded from the pollen sum include wetland/bog taxa, corroded and unknown grains (generally few), *Sphagnum* spores, micro-charcoal and NPP, including fungal spores. The percentage representation of these taxa was calculated relative to TTP and the sum of taxa pertaining to the component in question. Pollen assemblage zone (PAZ) boundaries are indicated where major changes occur in the percentage pollen curves.

The percentage values in the case of the moss samples are also based on a TTP but here wetland/bog taxa are included in the pollen sum since, in this instance, the wetland/bog taxa are presumed to be predominantly of regional rather than local origin.

2.2.3. Loss-on-ignition

Ash content was determined at regular intervals in the monoliths and peat core on the basis of dry weight, by burning samples that had been dried to constant weight for six hours in porcelain crucibles at 550 °C.

2.2.4. Radiocarbon dating

Slices of peat, 1 cm thick, were sieved using a 125 μm-mesh sieve to obtain identifiable plant remains suitable for AMS ^{14}C dating. Sample volumes of *c.* 35 and 15 cm^3 were used in the case of the monoliths and core, respectively. The materials retained in the sieve were scanned using a Leica MZ125 stereomicroscope; identifications were carried out as far as possible and fruits/seeds, charcoal and wood were selected for dating. Moss samples – two from the flume and one from the burnt mound – were also submitted for dating. Preparation involved washing using distilled water in a 500 μm-mesh sieve.

3. Results and interpretation

The ^{14}C dates are presented in Table 2a and age/depth curves for the peat and tailrace profiles (U2 and TR1, respectively) are shown in Fig. 2. The pollen diagrams, including macrofossil data, ash dry weight and other details, are presented in Fig. 3, Fig. 4, Fig. 5, Fig. 6 and Fig. 7. Details of the stratigraphy of core U2 are given in Table 3, and the results of the moss identifications from the flume and burnt-mound samples are presented in Table 4.

Table 2a.

Radiocarbon dates from short monoliths, core and moss samples.

Monolith/core, depth (cm), context	Dated material[a]	$\delta^{13}C$ (‰)	Age (BP)	Age[b] (BC/AD)	^{14}C lab. no. (UBA-)
Short monoliths					
MP1, 4–5, C3	Wood (several small pieces), fruits, seeds[c]	−22.6	2556 ± 20	793–675 BC	9263
MP1, 48–49, C69	Wood, charcoal, *Rumex* fruit (11) *Carex* nutlet (1), other plant parts[c]	−28.5	1662 ± 29	AD 348–420	8764
OF1, 34–35, C22	*Achillea millefolium* fruit (*c.* 95), other Asteraceae (incl. *Crepis biennis*) fruit (16), *Raphanus* sp. (7)[c]	−30.7	1190 ± 30	AD 781–882	8765
TR1, 0–1, C70	Wood (6 pieces), *Rubus* fruit (4), *Rumex* fruit (6), *Juncus* seed (7), unknown seed (1), charcoal (1)	−26.9	1289 ± 19	AD 677–766	9264
TR1, 5–6, C70	Wood, charcoal, *Juncus* seed (1), *Rumex* fruit (5), *Rubus* fruit (1), cf. unknown seed (1)	−35.9	1713 ± 36	AD 259–384	8759
TR1, 16–17, C70	Wood (several small pieces), *Potentilla* fruit (6–7), *Rumex* fruit (5), charcoal (1)	−28.5	2871 ± 27	1112–1005 BC	9265
TR1, 25–26, C70	Wood (*Betula* bark and wood; microscopically identified; several large pieces) Wood (*Betula* twigs, <1 cm diameter)	−25.5	2928 ± 21	1194–1056 BC	9266
TR1, 31–32, C70	Wood (diffuse porous; cf. *Betula*)	−30.1	3151 ± 30	1487–1404 BC	8760
N1, 15–16, C3	Wood (cf. *Betula*)	−29.4	2818 ± 29	1005–928 BC	8761
N1, 31–32, C3		−32.7	2528 ± 30	787–569 BC	8762
Core					
U2, 35–36	*Rumex* cf. *acetosa* fruit (*c.* 24), *Juncus* seed (1), unknown seed (3)	−29.3	1005 ± 18	AD 999–1031	9267
U2, 46–47	*Rumex* fruit (7), unknown fruit (4); black, *c.* 3 m m	−25.6	1152 ± 22	AD 830–962	8769
U2, 53–54	*Menyanthes trifoliata* seed (3), *Rumex* cf. *acetosa* fruit (20), *Potentilla* fruit (1/2), unknown seed (4), charcoal (1)	−30.8	1228 ± 17	AD 720–859	9268
U2, 69–70	Wood (4 fragments), unknown fruit (3); black, *c.* 3 mm, unknown seed (2); 0.5 mm, *Rubus* fruit (1/2)	−30.2	3331 ± 33	1665–1535 BC	8770
Moss samples					
FL1	11.8 g of mosses submitted from material with *Drepanocladus revolvens* (A)	−30.9	1260 ± 29	AD 689–775	8766
FL7	12.1 g of mosses submitted. In the remaining material, a variety of woodland mosses recorded[c]	−29.6	1220 ± 29	AD 729–869	8767
FF1	4.6 g of mosses submitted from material with *Thuidium tamariscinum* (A), *Neckera crispa* (A), *Hylocomium brevirostre* (F), *Sphagnum* (+)	−34.6	3487 ± 42	1879–1755 BC	8768

Sample from MP1 at depth 31–32 cm (context C69; UB-8763), consisting of *Carex* nutlet (6), *Betula* fruit (1) and a few unknown seeds, was too small to date.

a Quantities of mosses designated as follows: A, abundant; F, frequent; O, occasional; and +, rare. Actual numbers of seeds, nutlets, fruits, etc. are given (all values in parentheses). An asterisk indicates that there was further material in the sample, details of which are given in Table 2b.

b Calibrated age range (1σ range, i.e. 68.3% confidence level); calibration carried out using CALIB ver. 5.0.1 and the IntCal04 calibration curve (Reimer et al. 2004).

c Details of additional material in Table 2b.

Table 2b.

Additional material included in samples (marked with asterisk in <u>Table 2a</u>) that were ^{14}C dated.

Sample[a]	Additional material included in the dated sample
MP1, 4–5, C3	*Juncus* seed (3), *Carex* nutlet (1), *Rumex* cf. *acetosa* fruit (4),
	Potamogeton fruit (1), *Potentilla erecta* fruit (1), cf. *Rhynchospora*
	alba fruit (2), part of *Rubus* fruit, unknown seed (1)
MP1, 48–49, C69	*Potentilla erecta* fruits (3), *Betula* seed (1), *Ranunculus* seed (1),
	part of cf. *Alchemilla* seed (1), a few unknown seeds, charred cf. *Erica tetralix* leaf, unidentified leaves
OF1, 34–35, C22	*Cerastium* seed (13), *Rumex* nutlets (7), *Potentilla erecta* fruit
	(4), *Persicaria maculosa* (*Polygonum persicaria* L.) nutlet (2),
	Poaceae caryopsis (1), unknown seed, two types (6)
FL7	*Hylocomium splendens* (A)*; Rhytidiadelphus triquetrus* (A);
	Thuidium tamariscinum (F)*; Pseudoscleropodium purum* (O); cf. *Rhynchostegium confertum* (O)*; Mnium rostratum* (+)

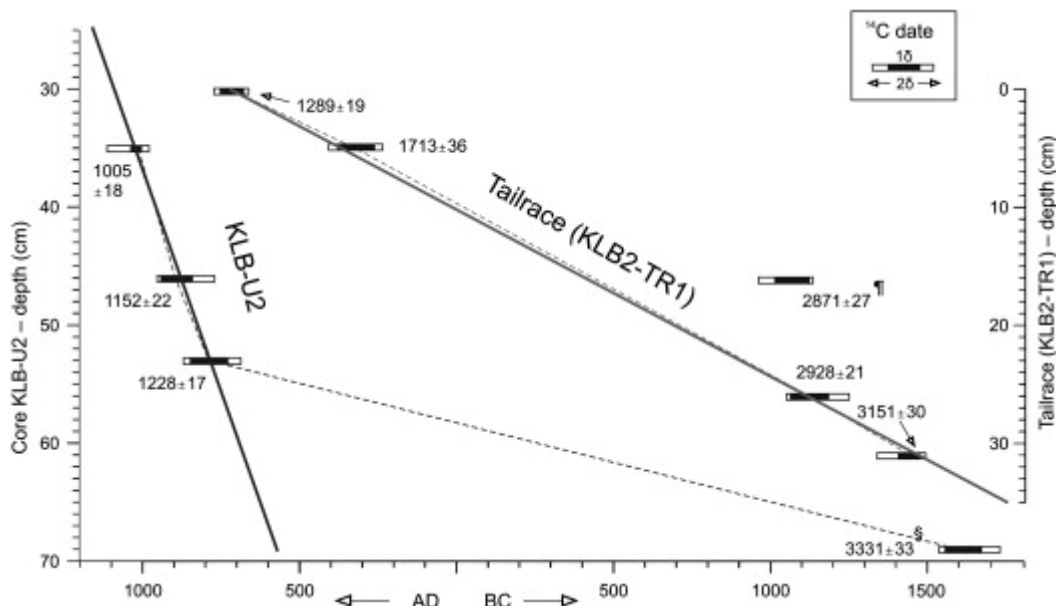[a] Monolith/core, depth (cm), context; numbers/quantities designated as in Table 2a.

Fig. 2.

Age/depth relationships in core KLB-U2 and tailrace monolith KLB2-TR1. Broken lines join the median probability value of the calibrated ^{14}C dates; solid lines (straight lines fitted by linear regression) show the age-depth relationships used for the respective chronologies. Dates with symbols '¶' and '§' (tailrace and core, respectively) are regarded as outliers and are not used in constructing the age-depth models.
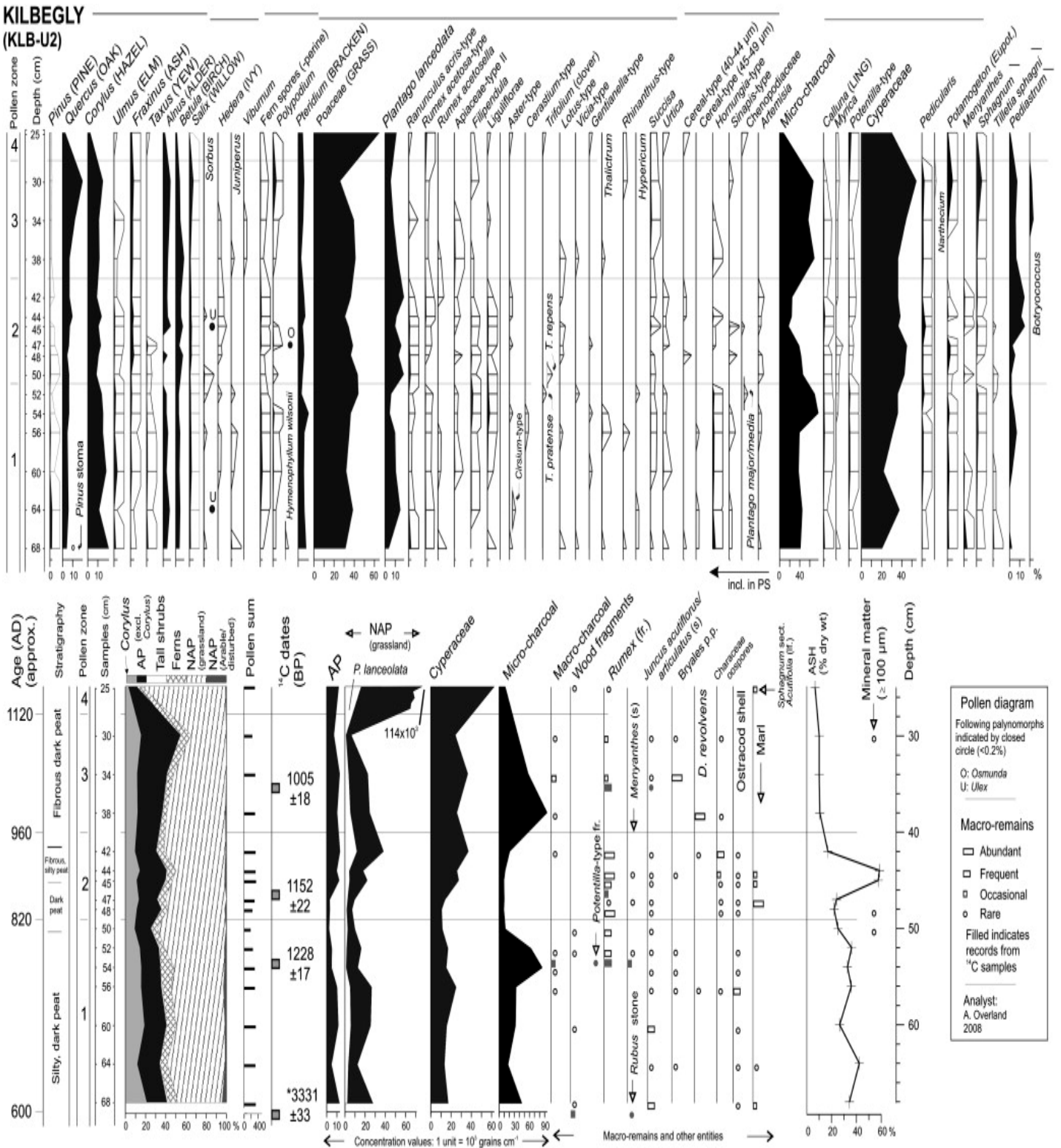
Fig. 3.

Profile KLB-U2: pollen, macrofossil and other data. Pollen and related curves are drawn to the same scale. The scale for micro-charcoal is reduced by two. Silhouettes show values magnified ×10. The ^{14}C date marked by an asterisk is not used in constructing the chronology. Abbreviations used in Figs. 3–6: ach.: achene; fr.: fruit; lf.: leaf; s: seed.

Fig. 4.

Profile KLB2-TR1 (tail race): pollen, macrofossil and other data. Conventions are as in Fig. 3. Abbreviations for palynomorphs (values mostly < 0.5%): L: *Lonicera*; M: *Melampyrum*; O: *Osmunda*; Po: *Polygonum maculosa*; S: *Sambucus*; Se: *Selaginella*; V: *Viburnum lantana*. In a few instances, where there are macroremains from pollen-sample and ^{14}C-sample sievings that relate to the same depth, the results are plotted as deriving from the ^{14}C sample; most of the records derive from the much larger ^{14}C sample.
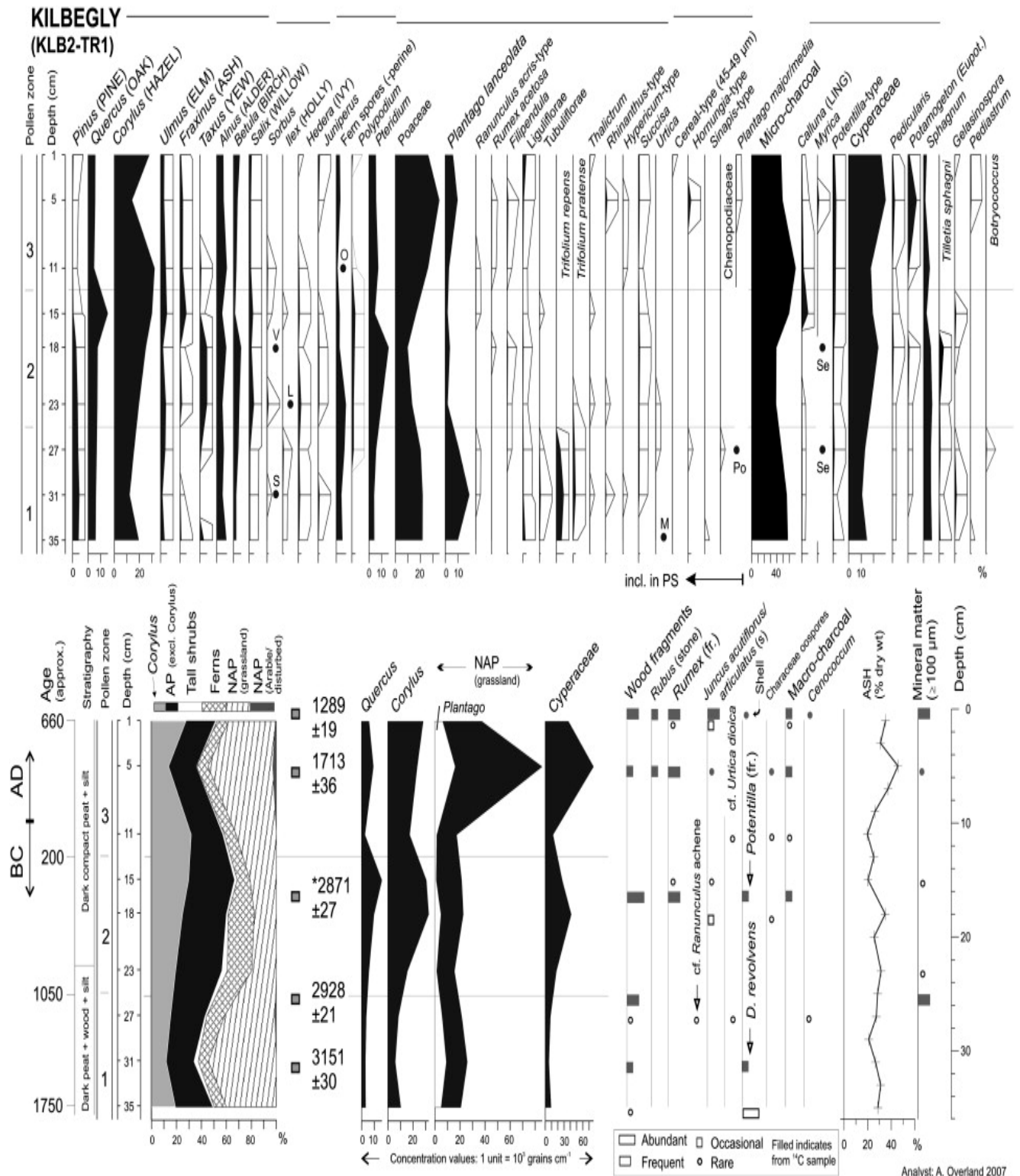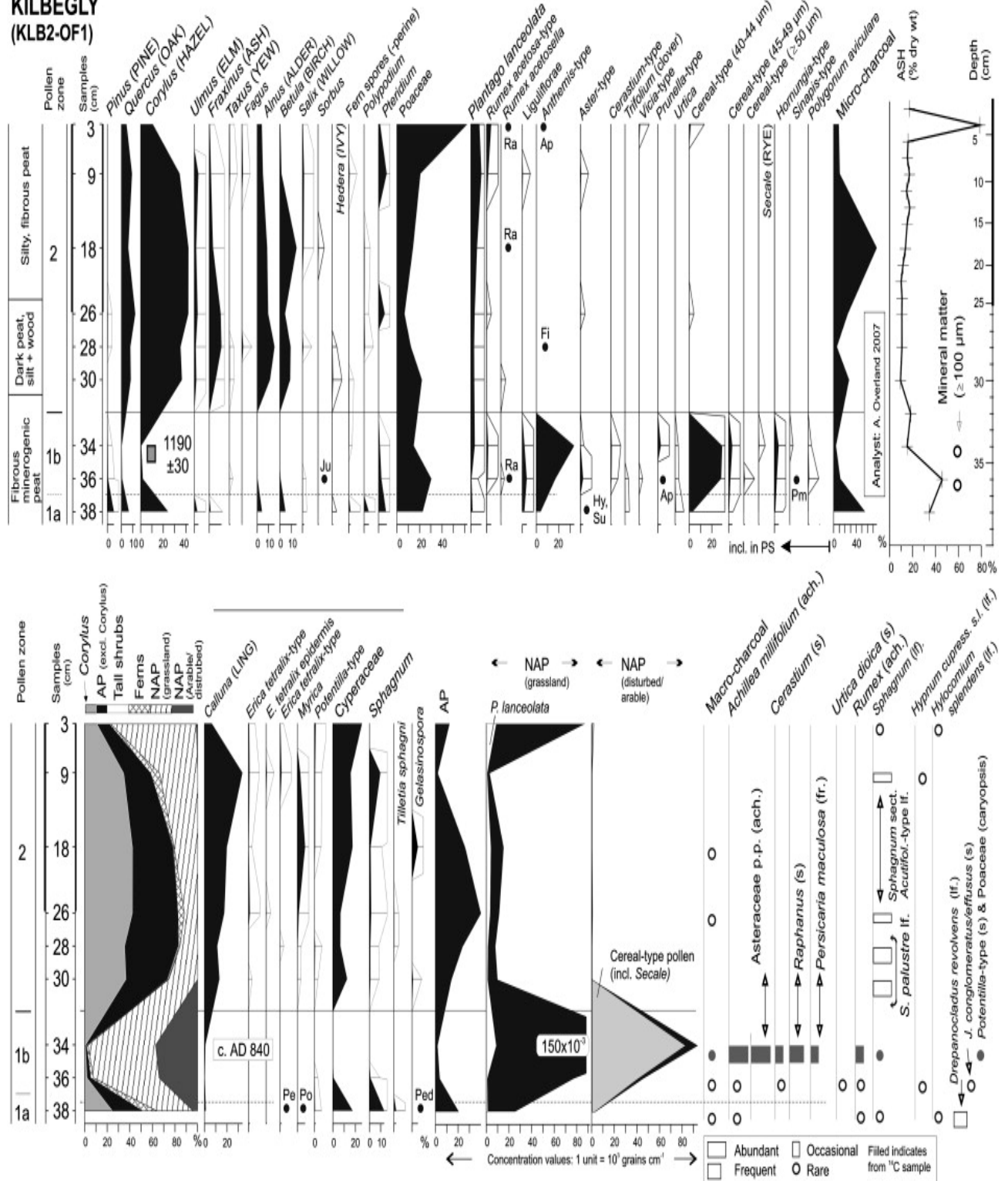
Fig. 5.

Profile KLB2-OF1: pollen, macrofossil and other data. Conventions are as in Fig. 3 and Fig. 4. Abbreviations for palynomorphs (values mostly < 0.5%): Ap: Apiaceae-type II; Fi: *Filipendula*; Hy: *Hypericum*-type; Ju: *Juniperus*; Pe: *Pedicularis*; Ped: *Pediastrum*; Pm: *Plantago major/media;* Po: *Potamogeton* sect. *Eupotamogeton*; Ra: *Ranunculus acris*-type; Su: *Succisa*. From 26 cm to the top of the profile, the vertical scale is halved.
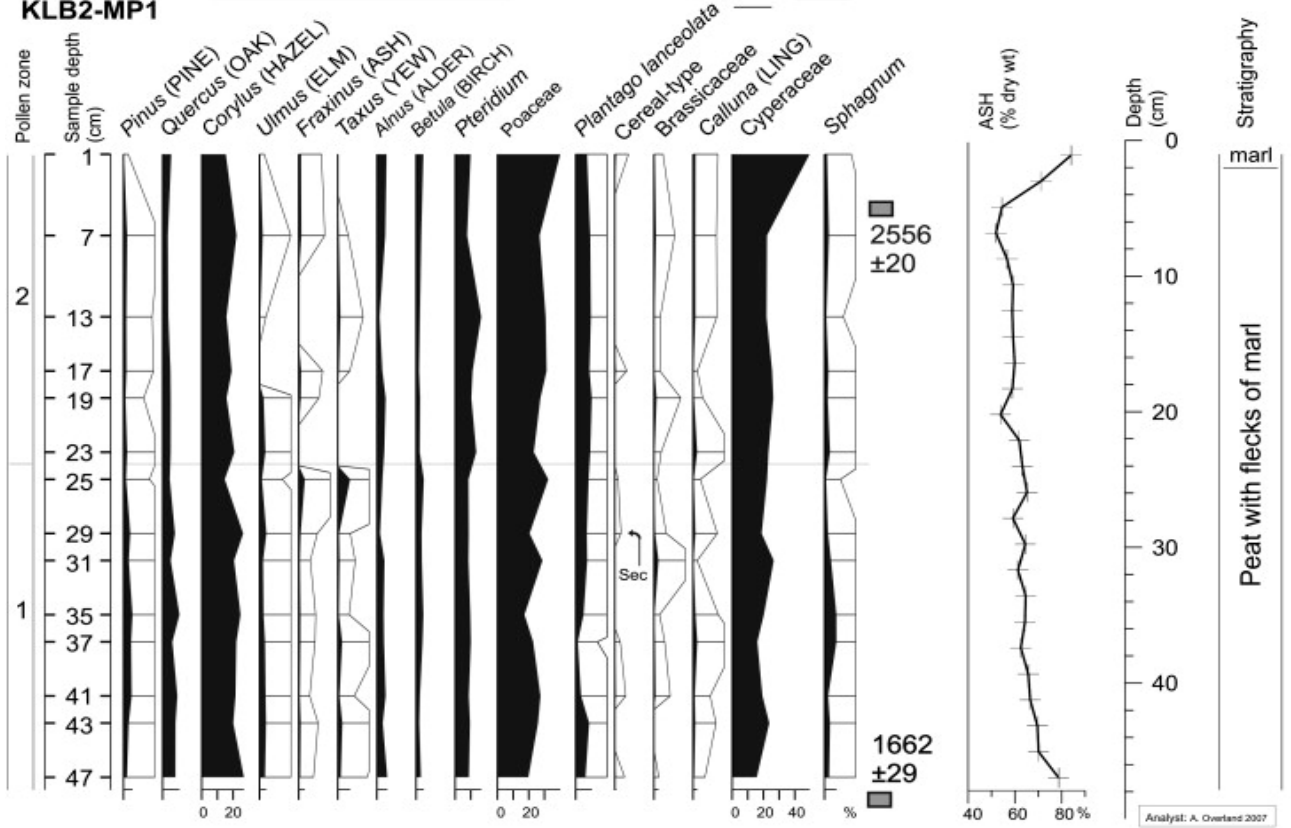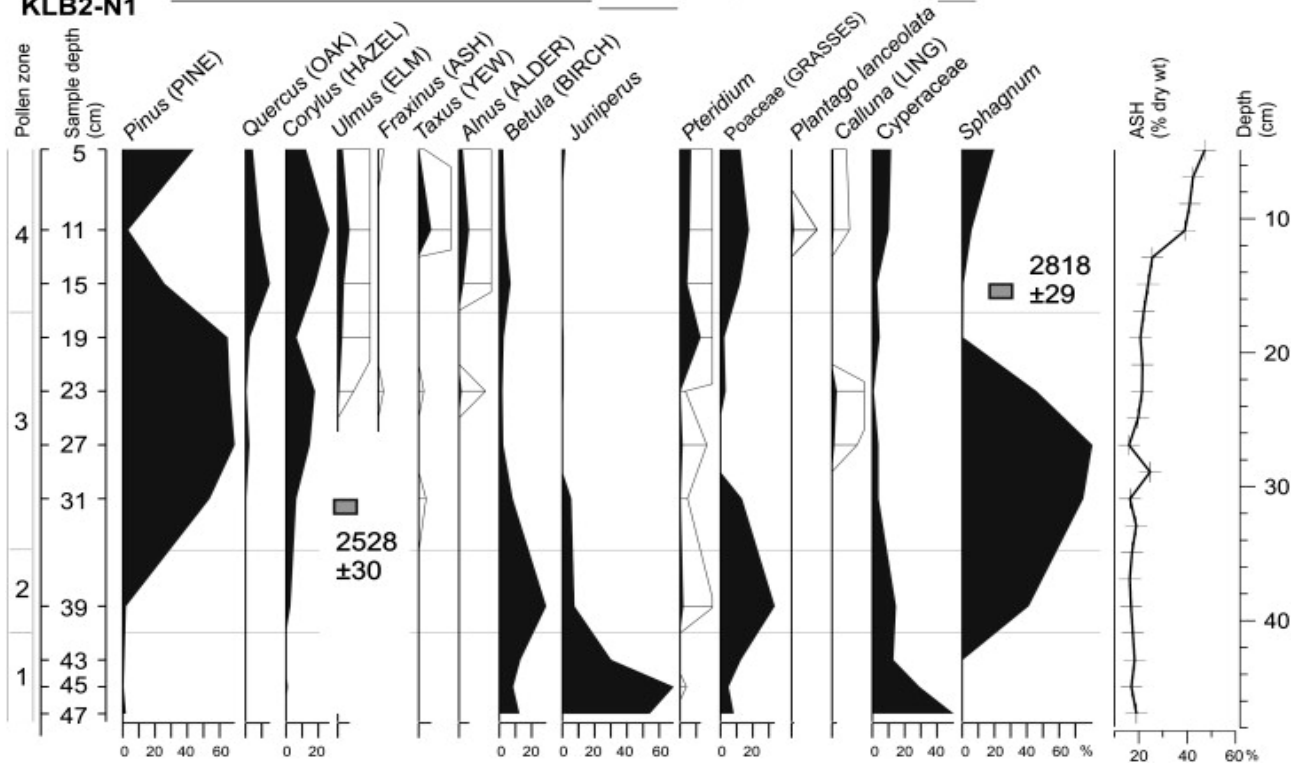
Fig. 6.

Profiles KLB2-MP1 and KLB2-N1. Curves for the main pollen taxa, ash values and ^{14}C dates (regarded as not reliable) are shown. The stratigraphy is shown for MP1; the deposit at location N1 consisted of dark, well decomposed peat. Abbreviation: Sec: *Secale*.

KILBEGLY (moss polsters)
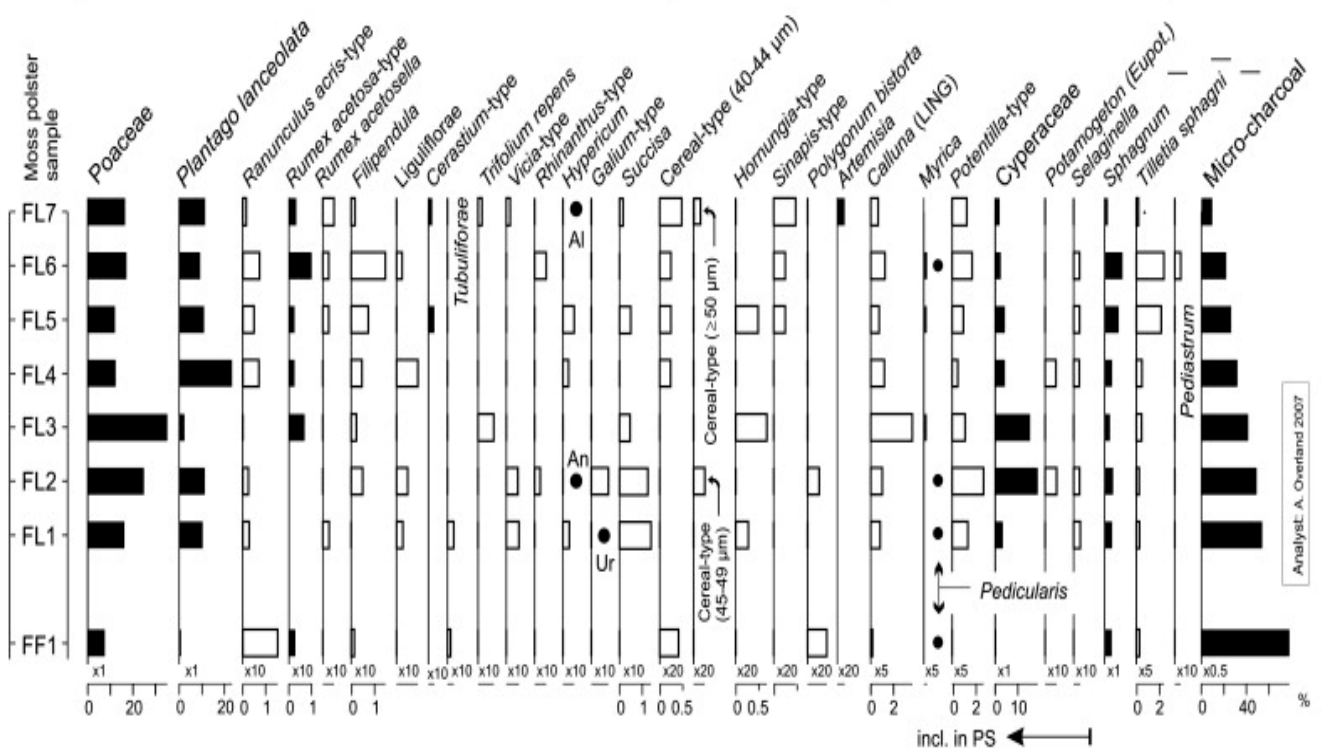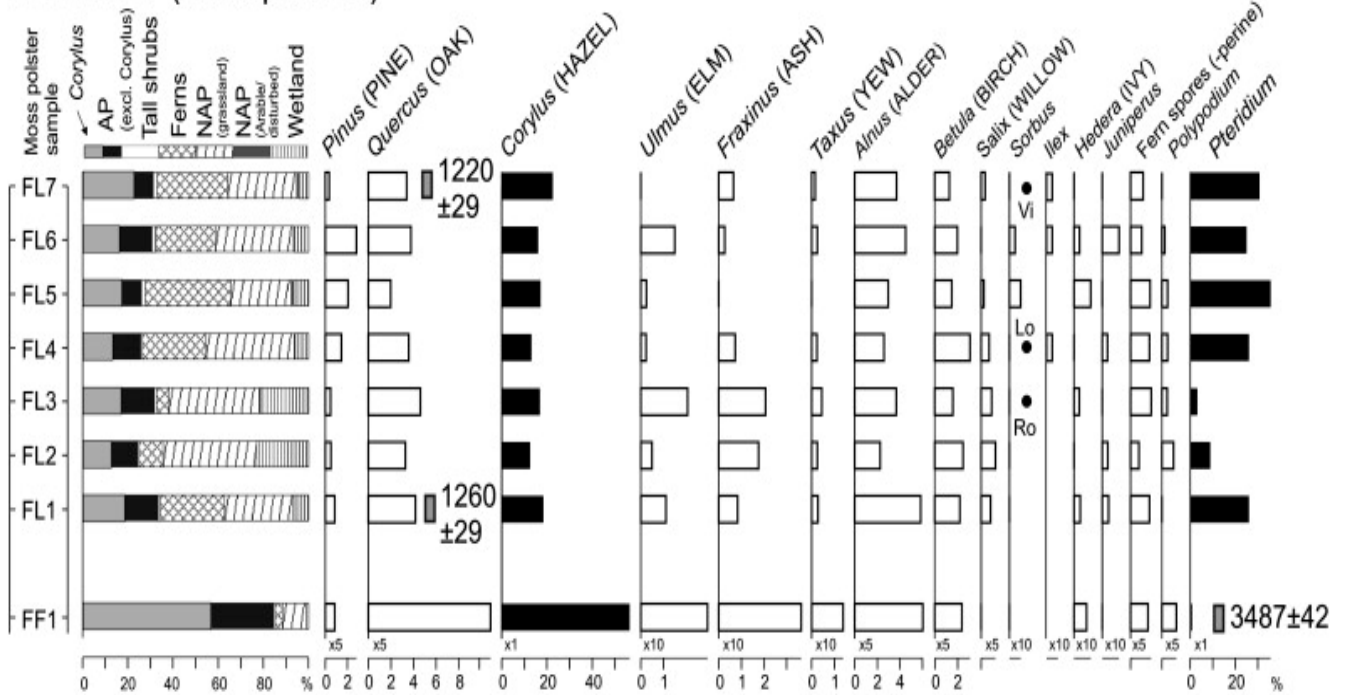
Fig. 7.

Pollen spectra from moss samples (burnt mound and flume). Open histograms used to highlight exaggerated x-scales (exaggeration shown at the base of each curve). A closed circle is used to indicate the following taxa (values mostly < 0.5%): Al, *Allium*-type; An, *Anemone*-type; Lo, *Lonicera*; Ro, *Rosa*-type; Ur, *Urtica*; Vi, *Viburnum opulus*.

Table 3.

Stratigraphical description, core KLB-U2.

| Depth (cm)	Stratigraphy
17–42	Undisturbed, stratified, fibrous, dark peat; lighter in colour between 17 and 27 cm. Some thin darker layers (ribbon like). Note: peat above 17 cm was not sampled; it was assumed to be disturbed due to reclamation
42–46	Light coloured, fibrous peat. Some mineral matter and/or marl
46–51	Well decomposed dark peat
51–97	Silty, somewhat greasy, well decomposed peat but with sedge and moss (non-*Sphagnum*) remains
97–215.5	Decomposed dark peat. Some sedge and wood remains. Darker band at 108–112 cm, and paler between 209 and 215.5 cm
215.5–218.5	Yellowish marl with silt/clay; some dark fine string-like inclusions and fibres
218.5–230.5	Yellow/grey marl with silt/clay. Some fibres.
230.5–232	Light grey fine sand with silt/clay
232–247	Darker grey coarse sand with silt/clay

Table 4.

Moss samples from beneath flume (FL) and burnt mound (FF), Kilbegly.

Moss polster no. =>	FL2	FL3	FL4	FL5	FL6	FL7	FF1
No. of bryophyta taxa=>	5	1	5	4			
Taxon name							
Neckera crispa	.	.					
Sphagnum	.	.					
Hylocomium brevirostre	.	1	3	.	.		
Thuidium tamariscinum	3	2	1				
Rhytidiadelphus triquetrus	1	3		3	3		
Pseudoscleropodium purum	*	*	2	.	2	1	.
Hylocomium splendens	*	.	*	1	3	3	.
cf. *Rhynchostegium confertum*	.	*	.	2	*	1	.
Plagiomnium rostratum	.	1	.	.	.	*	.
Eurhynchium striatum	.	1	.	.	1	.	.
Isothecium myosuroides	.	1	.	.		.	.
Other entities							
Isoetes lacustris (megaspores)	.	(1)	.	.	(1)	.	.
Wood fragments[a]	.	2	.	1	1	*	.
Scales (cf. *Betula* buds)	.	.	.		2	1	.
Rubus thorn	.	(1)	.	.	(2)	.	.
Quartz	.	3	.	2	3	.	.

Abundance/occurrence indicated as follows: 3, Abundant; 2, Frequent; 1, Occasional; , Rare; numbers of entities recorded are given in parentheses. Sample FL1: a small sample with a few Drepanocladus revolvens branches and leaves, some Sphagnum leaves, a Juncus seed, a wood fragment and Poaceae epidermis. Additional taxa (not listed in tabular form above).

FL2: cf. Drepanocladus fluitans 1; Non-identi ed seed.

FL3: Eurhynchium; cf. Plagiothecium; cf. Brachythecium sp.; cf. Calliergon cuspidatum (all occasional leaves).

FL4: Polytrichum sp. ; FL5: dicotyledonous leaf fragment; FL6: Mnium sp. ; Juncus articulatus/acutiflorus 2.

FL7: Hypnaceous moss (undet.) ; Betula (fr) 1; Fern sporangia 2.

[a] Bold indicates that fragments of diffuse porous wood were noted.

3.1. Mire profile, KLB-U2

The mire from which this core was taken is relatively shallow; a maximum thickness of 250 cm was recorded near core U2. A marl layer, *c.* 20–30 cm thick in the vicinity of core U2, indicates the former presence, presumably in the early Holocene, of a small body of open water. Otherwise, the deposits consist of peat, containing *Phragmites* and wood remains, that rests directly on mineral ground. Loss of the uppermost peat due to reclamation is estimated to be in decimetres rather than metres (see ^{14}C dating below) and so does not impinge on the present investigations. The basin appears to have remained under minerotrophic influence throughout the Holocene (see Discussion) so that typical, *Sphagnum*-dominated raised-bog vegetation was never widespread. This is not altogether surprising given the proximity of carbonate-rich mineral ground and the presence of springs.

As regards dating, the upper three ^{14}C AMS dates fall more or less in a straight line ($r^2 = 0.99$) and are accepted as reliable indicators of age (Fig. 2). The lowermost date (3331 ± 33 BP), however, is considerably older than expected. Accepting it would imply that peat accumulated at 0.07 mm year^{-1} between 53 and 69 cm, i.e. an order of magnitude lower than in the interval spanned by the dates above (0.8 mm year^{-1}). This has the further implication that the basal peat accumulated rapidly which is unlikely. The date 3331 ± 33 BP is therefore regarded as unreliable and is rejected. The linear age–depth relationship is assumed to also apply in the lower part of the profile (*c.* AD 600–1150; Fig. 2).

Given that the pollen diagram is from a rather large basin (though mineral ground was < 150 m distant), it is assumed to be regional in character. The relevant pollen source area (RPSA *sensu* Sugita, 1994; see also Hellman et al., 2009), is probably about a kilometre in radius. Four PAZs are distinguished as follows (Fig. 3).

3.1.1. PAZ U2-1 (68–52 cm; c. AD 600–820)

Arboreal pollen (AP) are at *c.* 40% and non-arboreal pollen (NAP) values are high which suggest a rather open landscape. Hazel was the main woody species and there were small populations of oak, elm, yew and ash. Initially, pine was probably locally present (*Pinus* was recorded at > 2%; *Pinus* stoma noted; Fig. 3). Later, it was either very rare or extinct (*Pinus* remains mainly at ≥ 0.4% in most samples until 42 cm; above this only single *Pinus* pollen were recorded). Strong NAP representation (Poaceae and *Plantago lanceolata* average 36.5% and 8.5%, respectively) indicates species-rich

grasslands. Indicators of arable/disturbed biotope are rather poorly represented. The *Hornungia*-type curve may consist mainly of wetland crucifers, e.g. *Cardamine pratense*. Cereal-type pollen are recorded mainly as single grains and so the evidence for cereal cultivation is not strong.

Records for the alga *Pediastrum*, aquatic flowering plants such as *Potamogeton* and *Menanythes* (pollen and macroremains) and ostracod shell suggest wet, calcareous conditions. High ash content (average 35%) indicates much mineral input derived presumably from springs and surface waters in the catchment.

3.1.2. Zone U2-2 (50–42 cm; c. AD 820–960)

This PAZ is characterised mainly by high *Plantago lanceolata* values and rather low *Corylus* values. This points to less woody vegetation with hazel scrub particularly adversely affected. An increase in *Fraxinus* representation may reflect more ash trees but increased pollen production, stimulated by open conditions, probably also contributed. The *Taxus* curve ceases which suggests local extinction of yew presumably due to human impact (*c.* AD 900; see Discussion, and Summary and conclusions). The decline in AP, combined with high *P. lanceolata* values, suggests substantial pastoral-based farming. Cereal growing seems to have been of only minor importance, at least in the vicinity of the mire (only four cereal-type pollen recorded, size range 40–44 μm, 0.2% of TTP).

Pediastrum values are high in the upper half of the zone. This suggests increased mineral input (cf. high ash content, Fig. 3), presumably due to soil erosion. Marl and ostracod shell records point to increased input of calcareous waters. Both macro- and micro-charcoal have decreased representation. There was presumably less firing of the mire due possibly to increased mire wetness which would have favoured taxa such as Cyperaceae, *Menyanthes* and *Potamogeton*.

3.1.3. Zone U2-3 (38–30 cm; c. AD 960–1120)

Plantago lanceolata representation is lower and the NAP component is less diverse (both grassland and arable/disturbed biotope indicators). Ash content is also much lower which suggests less soil erosion. There seems to be a decline in farming. Woodland regeneration registers rather slowly however and involved mainly oak.

3.1.4. Zone U2-4 (25 cm; c. AD 1150)

This single spectrum, characterised by low AP and high NAP values, indicates increased farming and woodland clearance.

3.2. Tailrace, TR1

This pollen profile (Fig. 4) pre-dates the construction of the tailrace. Four of the five ^{14}C dates lie more or less on the straight line ($r^2 = 1$; Fig. 2) that is used to construct the age–depth model. The remaining date, 2871 ± 27 BP, is much older than expected (statistically, it is inseparable from the date immediately beneath; see Fig. 2) and is rejected. Accumulation rate, at 0.14 mm y^{-1}, is low but the peat deposit is undoubtedly affected by compression due to heavy overburden and water loss as a result of recent drainage. Three PAZs are recognised as follows (Fig. 4).

3.2.1. PAZ TR1-1 (35–27 cm; 1740–1050 BC)

AP average 42%, NAP are well represented and especially Poaceae, *Plantago lanceolata* and *Trifolium repens*. This suggests that as peat accumulation began here in the mid Bronze Age, open, herb-rich grasslands prevailed locally (the site is near the edge of the mire and so the profile is assumed to be local in character). Woody plants present, though not necessarily nearby, included hazel, oak and pine, and possibly also elm, ash and yew.

3.2.2. PAZ TR1-2 (23–15 cm; 1050–200 BC)

There is some expansion of hazel and yew (*Taxus* at *c.* 6%) in the context of reduced farming. In the final spectrum, woodland composition shifts in favour of oak, ash and elm, to the detriment of yew.

3.2.3. PAZ TR1-3 (11–1 cm; 200 BC–AD 650)

Pine and yew appear to be either absent or exceedingly scarce. Grasslands expand and woodland/shrub (including hazel) was less important. Ash content of the peat increases which suggests soil erosion (downwash from the overlying spoil, derived from the tailrace, may also contribute) but evidence for cereal cultivation remains weak.

3.3. Overflow, OF1

This short profile is the closest to the mill undercroft (< 10 m distant; Fig. 5). It derives from a shallow channel that probably served as an overflow in connection with regulation of water supply to the mill.

The single ^{14}C date 1190 ± 30 BP (AD 781–882, 1σ range) from near the base of the profile is accepted as indicative of age in that part of the profile, a conclusion supported by the pollen assemblage. Unfortunately, there are no features in the mid and upper parts of the profile that give a good age fix. It is reasonable to assume, however, that the profile spans a few centuries, i.e. it extends to at least Norman times (late 12th/early 13th century) and possibly later. The possibility that the upper peat is partly disturbed cannot be excluded (see Discussion).

PAZ OF1-1 is characterised by exceptionally low AP and high NAP. Cereal-type pollen representation is very high at 31% and 33% in spectra 36 and 34 cm, respectively (subzone OF1-1b). Given the severe under-representation of cereal pollen (other than rye) in pollen records, these exceptionally high values are best ascribed to special circumstances. Proximity to the mill site is one possibility, particularly as most cereal pollen are liberated in the course of grain handling and milling (Vuorela, 1973 and Hall, 1989). The explanation may also be found in the nature of the basal peat. This was quite different in texture (fibrous but relatively uncompacted) and of lighter colour compared with the overlying peat. It may derive from debris arising from cereal processing (discussed later in the context of the macroremains), which was deposited directly or by flowing water in the channel. This seems to be the most plausible explanation for the high values of cereal-type pollen and other NAP.

The pattern of punctae on the exine surface of the cereal-type pollen was mainly *Hordeum* type (see Beug, 2004) which suggests that barley was the main crop. Rye probably also grew locally but perhaps as a weed rather than a crop (see Discussion).

Macroremains recorded in the sample sieved for ^{14}C dating included many fruit/seed of Asteraceae (mainly *Achillea millefolium*; also *Crepis*). *Raphanus raphanistrum*, *Cerastium* and a few *Persicaria maculosa* (*Polygonum persicaria* L.) nutlets were also noted (Table 2a and Table 2b). The pollen spectra include pollen that potentially arise from these and other species of arable situations and grassland. *Hornungia*-type may include pollen of Brassicaceae species such as *R. raphanistrum*; *Achillea*-type potentially includes pollen of *Achillea millifolium* (yarrow) and also *Chrysanthemum segetum* (corn marigold, regarded by Preston et al. (2002) as a common archaeophyte in Britain from the Iron Age onwards); and the taxon Liguliflorae consists of pollen of ligulate composites such as dandelion (*Taraxacum*) and hawkweeds (*Crepis*). The disturbed conditions associated with the maintenance and working of the mill would have provided suitable conditions for some of these weedy plants. However, it is more likely that, as postulated for the cereal-type pollen, these pollen and fruit/seed may have been present in the organic material that accumulated or that was deposited in the overflow channel. Whatever the origin of the deposit, there can be little doubt but that PAZ OF1-1 relates to a time when the mill was in operation (see Discussion).

In PAZ OF1-2, AP (especially *Corylus*) are relatively well represented. The sharp difference between this and PAZ OF1-1 suggests that very different taphonomic processes were operating. The peat and its pollen seem to have arisen through the usual processes associated with peat formation but the possibility that the stratigraphical integrity in this part of the profile is compromised cannot be ruled out (see profiles MP1 and N1 later). The pollen assemblage suggests mainly hazel scrub with small populations of tall-canopy trees. Farming is mainly pastoral-based and evidence for cereal cultivation is weak (four cereal-type pollen versus 224 in the previous PAZ). The mill had probably ceased to operate as PAZ OF1-2 opens or at least the depositional environment that gave rise to the exceptional pollen assemblage OF1-1 no longer existed.

3.4. Millpond, MP1

The overall similarity of the pollen spectra and the inverted ¹⁴C dates suggest that the deposit is poorly stratified (Fig. 6). The relatively smooth pollen curves may be indicative of rapid deposit accumulation during a period with little variation in vegetation. It is more likely, however, that smoothing has occurred as a result of input of reworked pollen and deposit mixing. The consistent records for *Pinus*, at a time when pine was extremely rare or extinct, point to reworked organic matter that originally accumulated when pine was present locally (cf. zones TR1-1 and TR1-2; also N1-3 later).

Though stratification is poor or absent, some features of the profile are informative. NAP values are high (*c.* 20–30%) and there is high diversity. This, in conjunction with the presumed secondary origin of much of the AP, suggests a largely open landscape. Wet calcareous conditions prevailed locally. This is indicated by records for the fen mosses *Drepanocladus revolvens* (recorded from most samples; also cf. *D. exannulatus*) and *Ctenidium molluscum*. Cyperaceae are well represented (also as macrofossils) so presumably the fen vegetation was sedge-rich. On the other hand *Calluna*, indicative of acidic conditions, is poorly represented. Leaves of *Sphagnum imbricatum* and other cucullate *Sphagnum* leaves were recorded at depth 43 cm and *Thuidium tamariscinum* was recorded at 25 cm. The *Sphagnum* records suggest raised bog while *T. tamariscinum* is a typical moss of calcareous woodlands (cf. the flume samples). These mosses are presumably either in-washed or carried to the site. The high ash content (*c.* 60% or greater) indicates substantial mineral inwash.

3.5. Monolith N1 (north of mill)

The main features of this short profile (Fig. 6) are as follows. Zone N1-1 (47–43 cm) is characterised by high *Juniperus* values (peak: 69%) and modest values for *Betula* (also *Betula* fruit). Megaspores of *Isoetes lacustris* (*c.* 20) were recorded in the two basal samples. This suggests shallow open water. Zone N1-2 is transitional in character (a single spectrum). Zone N1-3 (31–19 cm) has high *Pinus* values, low NAP values and generally high *Sphagnum* values. In zone N1-4, AP values (especially *Pinus*) are rather low and NAP are well represented.

The radiocarbon dates, 2528 ± 30 BP and 2818 ± 29 BP, derived from small fragments of diffuse porous wood (probably *Betula*), are inverted (Table 2a) and so are regarded as unreliable indicators of age.

The high *Juniperus* values at the base of the profile suggest the early Holocene when juniper expanded in response to rising temperatures. In Irish pollen records, expansion of *Betula* normally follows, then *Corylus* (usually pronounced) and after that the tall-canopy trees, but this pattern is not obvious here. This, and the anomaly in the ¹⁴C dates, suggest that the deposit is disturbed. High *Pinus* values suggest that pine was important in the area, possibly for a considerable time. Peats such as this are probably the source of much of the reworked *Pinus* pollen (cf. profile MP1).

The diversity of AP and NAP in zone N1-4 suggests a late Holocene age but the pollen record is regarded as unreliable due to disturbance. Interestingly, cereal-type and *Plantago lanceolata* are poorly represented. The peat and pollen are probably largely secondary and hence may derive mainly from a period prior to strong human impact, i.e. to a time considerably older than suggested by the upper ^{14}C date.

3.6. Samples from burnt mound and flume

3.6.1. Macroremains

Results from macrofossil analyses of samples collected from beneath the flume and the burnt mound are presented in Table 4. Ecological preferences of the recorded mosses are summarised in Table 5.

Table 5.

Table 5

Main mosses recorded in moss polsters, their growth form, habitat preferences and present-day distribution.

Taxon (and growth form)	Habitat preferences	Present-day distribution
Drepanocladus spp. (rather small but may give high cover, esp. *D. revolvens*)	This genus is mainly associated with wet, semi-aquatic habitats, esp. fen (alkaline) cf. *D. revolvens*. *D. fluitans* is ± confined to acidic pools but can tolerate periodic dry conditions[α, β].	*D. revolvens* common in fens and transitional fens in IRL and GB; dot distribution map suggests that *D. fluitans* is rare in IRL[β] but this an under-estimate[γ]
Eurhynchium striatum (medium-sized; may contribute substantial cover)	Calcareous woods; also calcareous grassland[α, β]	Very common, esp. in calcareous woodland in IRL[κ]; In GB, particularly conspicuous in 1° and 2° woodland and scrub[β]
Hylocomium brevirostre (large moss; may give substantial cover)	Weak calcicole, characteristic of calcareous woodland; occurs also in acid oakwoods and damp exposed habitats[β]	Distinctly western distribution in GB and also IRL[β];
H. splendens (weft growth; may give high cover)	Acid woodland, heath; also calcareous grassland, etc. especially if leached[β, α]	Common in IRL and GB esp. where conditions are acidic
Isothecium myosuroides (small to medium-sized; does not give high cover)	Common in oak woodland (rock, stumps and trees), both acid and base-rich; also on boulders in rather open conditions[α]	Common esp. in western IRL and GB; recorded from H15[β]; wide EUR distribution[δ]
Neckera crispa (robust moss)	Moist calcareous rock ledges, chalk grass (GB) and tree boles where humic[α]; calcicole but with some tolerance for acidic conditions[β]	Predominantly western distribution in IRL and GB[β] but no records from H15 and H25[β, γ]; wide EUR distribution[δ], but greatly reduced due to woodland removal[ε]
Plagiomnium rostratum (relatively large but usually not giving major cover)	Moist, shaded habitats in woods, on riverbanks and sometimes grassland[β]	Common in GB but only a scatter of records from IRL[β, γ]
Pseudoscleropodium purum (medium-sized, conspicuous but not bulky)	Common acidophile (heath and woodland clearings on acid soils); also in calcareous grasslands[α]; avoids deep shade[β]	Common esp. in heathy habitats[β]
Rhynchostegium confertum (small moss)	Lowland, shaded, damp situations; grows on rocks, soils and base-rich bark, esp. *Alnus*[β, α]	Few records from IRL (probably under-recorded); common in England and Wales[β]
Rhytidiadelphus triquetrus (large, spreading growth form)	Woodland clearances, esp. on calcareous clay soils; also many open situations incl. grassy banks; wide acid/base tolerance[α, β, δ]	Common in IRL and GB (esp. western parts); decrease in central and SE England possibly partly connected with less coppice[β]
Thuidium tamariscinum (weft growth form; provides good cover)	Woods on clayey soils and a variety of open habitat, incl. grassland; tends to avoid acidic conditions[α, β]	Common; major contributor to bryophyte flora of ash/hazel woodland on limestone in IRL[κ]

Habitat preferences and distribution based on a variety of sources including: Watson (1981); Hill et al. (1994); Holyoak (2003); Dierßen (2001); Kelly and Kirby (1982); Kuijper (2000).

Note: unless otherwise indicated, wide distribution at an European scale can be assumed; H15 and H25: vice-counties south-east Galway and Roscommon, respectively.

Preservation was generally excellent (see Plate S2). In most samples mosses were abundant and constituted the bulk of the material. Sample FL1, taken from near the point where the flume abutted onto the undercroft, was the main exception. This sample contained mainly only leaves and stems of *Drepanocladus revolvens*. This distinctive and slender moss is normally associated with wet, calcareous fens (recorded also near the base of profile OF1). It probably grew at/near where collected. Similar considerations apply in the case of cf. *Drepanocladus fluitans* (sample FL2).

The sample from the burnt mound was distinctive in having low species diversity. Apart from the calcareous woodland moss, *Thuidium tamariscinum*, the sample included *Neckera crispa* and a few leaves of *Sphagnum*. The *Sphagnum* probably derived from nearby bog vegetation while *N. crispa* was more than likely purposefully collected in nearby woodland. Kuijper (2000, p. 31) notes that, in the past, the favoured habitat for *N. crispa* in the Netherlands was "well-sheltered deciduous woods with many old trees and high humidity and permanently high air humidity". The many records from archaeological sites suggest that it was preferentially collected because of local abundance, and its bulky growth habit and durability made it ideal for caulking and various domestic uses (Kuijper, 2000). In this instance, the mosses were used to caulk the trough of the *fulacht fiadh*.

The mosses recorded in the flume samples suggest that, in general, they derive from a woodland context though many also occur today in calcareous grasslands (see Table 5). The luxuriance and high abundance of typical woodland mosses such as *Thuidium tamariscinum* and *Rhytidiadelphus triquetrus* (also *Hylocomium brevirostre* though recorded in only three samples) suggest that these mosses were locally abundant and were growing in near optimum conditions. Many, while calcicole, are tolerant of mildly acidic conditions and indeed *Hylocomium splendens* (also *Polytrichum*) is generally regarded as a calcifuge.

It is quite likely that these mosses were differentially collected locally because of their bulky growth form and ready availability. They were placed beneath the flume, presumably to cushion and support the flume as it was put into position between the millpond and undercroft timbers (Plate S1, D).
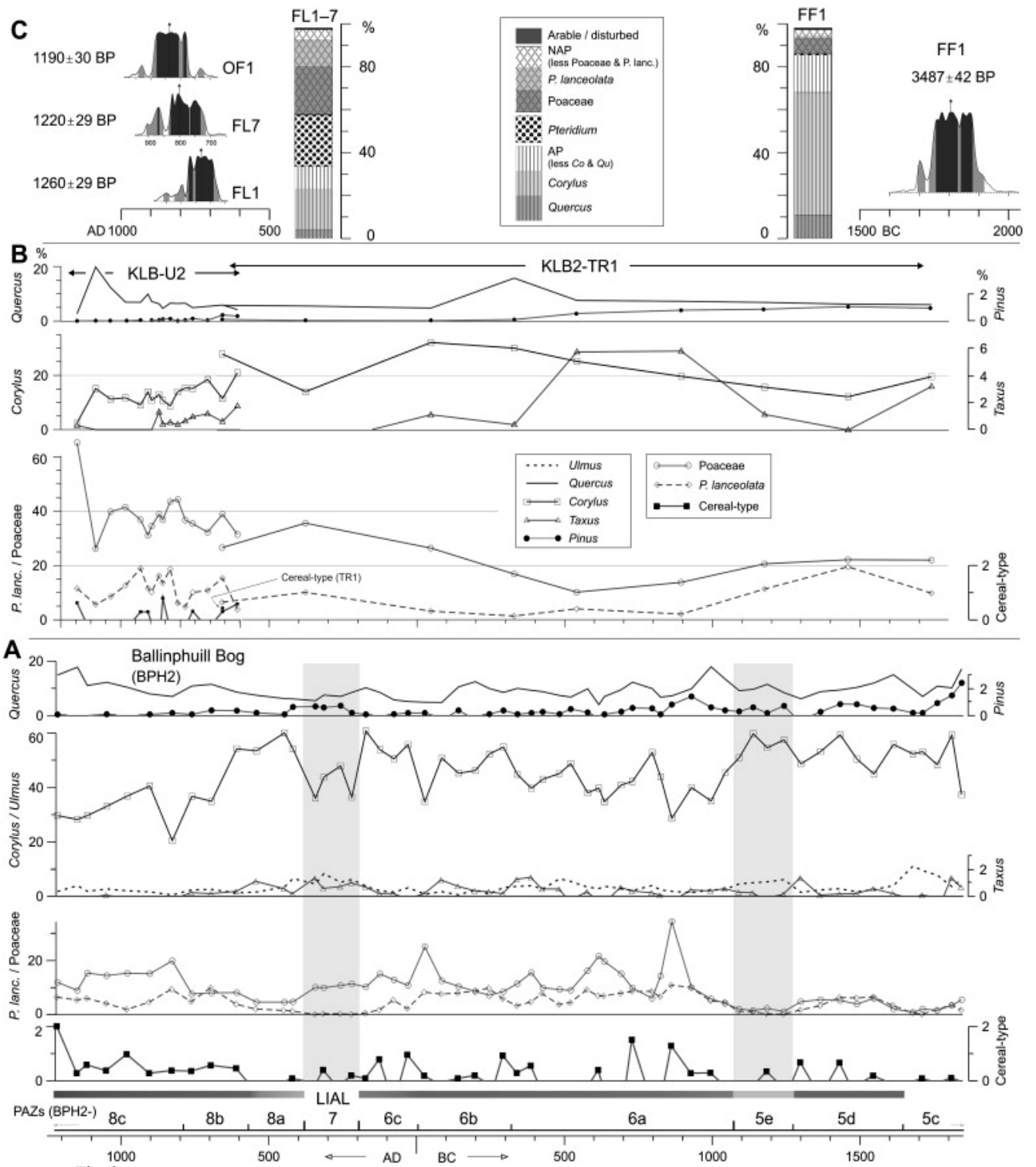
Fig. 8.

Summary plots of palaeoecological data from east County Galway that relate to the interval c. 1800 cal. BC to cal. AD 1200. Data are plotted to a common time scale. A. Selected pollen curves, profile BPH2, Ballinphuill Bog. At the base, the time scale, PAZs distinguished in profile BPH2 and schematic representation of farming activity (low levels are indicated by less dense or no shading) are shown. In the plots, periods with reduced farming activity, i.e. the Late Iron Age Lull (LIAL) and subzone BPH2-5e, are indicated by shading. B. Selected pollen curves from profiles KLB-U2 (core) and KLB2-TR1 (tailrace). C. histograms showing average pollen values in the seven moss polsters from the flume (Fl1–Fl7) and the burnt mound (*fulacht fiadh;* FF1), respectively. Minor taxa, mainly ferns and tall shrubs, are omitted. Calibration plots, derived from CALIB ver. 5.0.2, of selected ^{14}C dates are also shown as follows: two dates from moss samples from beneath the flume (Fl1, Fl7), a date from near the base of monolith OF1 (overflow channel), and a date from a moss sample from the burnt mound (1σ and 2σ ranges are indicated by the intensity of the shading; an arrow indicates the median calibrated age).

Items listed under 'Other entities' in Table 4 include material that may have been imported with the mosses, e.g. *Rubus* (blackberry) thorns and wood fragments (diffuse porous wood only noted; the flume, on the other hand, was made of oak which is ring porous).

Megaspores of *Isoetes lacustris* were also recorded. This quillwort presumably grew in the millpond. Today, it is mainly confined to upland non-calcareous lakes in western Ireland and the western uplands of Britain, especially western Scotland. *Isoetes lacustris* seems to have become extinct in the Irish midlands, presumably as a result of human impact and especially eutrophication (Preston et al., 2002 and Webb et al., 1996). Bud scales (cf. *Betula*) and *Juncus* seed presumably derive from plants that grew on nearby wet ground.

3.6.2. Pollen analytical data

The pollen spectrum from the moss sample FF1 (burnt mound; Fig. 7 and Fig. 8C) suggests that tall-canopy trees, including mainly oak, ash, elm and yew, were present but in low numbers, hazel scrub was dominant (*Corylus* 57%) and pine was scarce or more than likely locally absent. The ^{14}C date 3487 ± 42 BP, derived from mosses, suggests mid Bronze Age (*c.* 1800 BC). *Ranunculus* pollen probably derive from the vernal woodland species, *Ranunculus ficaria* (lesser celandine), rather than buttercups growing in grassland. Cereal-type pollen at 0.4% suggest limited cereal growing. Overall farming impact is low. Bog taxa are poorly represented in the pollen record though some *Sphagnum* leaves were noted (Table 2a; also *Sphagnum* spores; Fig. 7) that presumably derive from the nearby mire. As expected, given the burnt-mound context, charcoal was abundant.

The moss spectra from the flume have an overall similarity and contrast sharply with sample FF1 (Fig. 7 and Fig. 8C) in having distinctly lower AP values, and much higher *Pteridium* and *Plantago lanceolata* representation (*P. lanceolata* averages 12% vs. 0.7% in sample FF1). Cereal-type pollen are poorly represented, especially given the sampling location (the samples were probably effectively sealed by the flume; Plate I, 2). Arable weed indicators have rather low representation and some of these (especially *Hornungia* and *Sinapis*-types) probably derive from habitats other than arable ground. Overall, the pollen spectra are indicative of pastoral rather than arable farming.

Inter-sample variation in the flume samples (e.g. low *Plantago lanceolata* and *Pteridium* values in FL3) is probably ascribable largely to variation in species composition close to the point of collection of the mosses (RPSA is probably in the range 20–100 m radius; see, for example, Bradshaw, 1981, Bunting, 2002 and Mazier et al., 2008). Given the open aspect that prevailed, extra-local pollen are probably well represented (cf. high *P. lanceolata* values).

Since the sample material derives from within the mill complex close to substantial water movement, flushing out of the original pollen content or incorporation of pollen present in the waters that powered the mill is a possibility. The mosses, however, derive from beneath the flume and hence were probably effectively sealed, a view supported by the overall pollen composition. The consistent *Pinus* pollen records are noteworthy in that they point to the possibility that pine was still surviving locally. *Pinus* stomata, however, were not recorded. The lack of records for pine wood from archaeological contexts along the route of the M6, and very low *Pinus* values in most of the profiles presented here, also suggest that it is probably incorrect to interpret these pollen records as evidence for late survival of pine at Kilbegly.

The two ^{14}C dates from the flume mosses provide useful indicators as to when the flume was placed in position. Considering the 1σ age range (Table 2a), the date 1260 ± 29 BP from FL1 points to the eighth century but the 2σ age range extends this well into the ninth century (AD 689–752, 787–823 and 841–861) as well as backwards as far as the late seventh century (Fig. 8C). The older end of the age range may be accounted for by the context of the sample (base of flume and hence the material dated may have preceded the placement of the flume), and also the material dated which included

Drepanocladus revolvens, a semi-aquatic moss, the age of which may be influenced by the 'hard-water' effect.

The date 1220 ± 29 BP from FL7 has a largely comparable 2σ age range (AD 729–735, 772–832 and 765–886) as does the date 1190 ± 30 BP from the basal peat in OF1 (the 2σ age range includes a short interval in the 10th century, i.e. 921–944 AD but the probability that the age falls in this interval is low, i.e. 0.038; Fig. 8C). Oak wood from the flume returned a date of 1199 ± 20 BP (UBA-12857) and a yew wood chipping from the millpond gave the date 1202 ± 27 BP (UBA-12860; for details of these and other dates from various archaeological contexts see Jackman et al., 2010). In summary, the evidence points to the eighth century for placement of the flume and use of the mill extending well into the ninth century AD.

4. Discussion

4.1. Land-use and vegetation dynamics at Kilbegly

The palaeoecological data provide several insights into the environmental contexts before, during and after construction, use and abandonment of the horizontal watermill at Kilbegly. The ^{14}C-dated profile U2, in conjunction with results from the exploratory coring (see Results and interpretation), provides information on the formation of the relatively shallow deposits that fill the basin. The basal marl probably formed at/shortly after the Late-glacial/Holocene transition (*c.* 9500 BC), the underlying basal silt/clay presumably having been deposited near the end of the last glaciation (Midlandian, i.e. Weichselian; typical Late-glacial deposits were not noted). Infilling of the small body of open water occurred in the early Holocene (cf. early Holocene deposits, profile N1; Fig. 6). Reedswamp and fen conditions persisted until well into the medieval period (*c.* 12th century AD; upper limit of the U2 record) and perhaps later. Minerogenic influence, as a result of input of carbonate-rich waters from runoff and springs in the catchment, presumably prevented, or at least restricted, widespread development of *Sphagnum*-dominated raised bog.

Profile TR1 (tailrace) provides a record of vegetation and land-use that spans the mid Bronze Age to the early medieval period (*c.* 1750 BC–AD 650). Profile U2 serves to extend the vegetational record well into the medieval period (to *c.* AD 1150; Fig. 3; summary data in Fig. 8B). Additional evidence for both local and regional environments is provided by the short profiles, OF1, MP1 and N1, and moss-poster samples from the burnt mound and beneath the flume (Fig. 4, Fig. 5, Fig. 6, Fig. 7 and Fig. 8).

Profile TR1 (Fig. 4 and Fig. 8B) suggests open conditions due to pastoral-based farming during the mid and late Bronze Age (*c.* 1750–1000 BC; PAZ TR1-1). Hazel scrub was common, oak was the main tall-canopy tree, and pine, elm and ash were minor components.

Insight into local conditions, at about the same time as profile TR1 opens, is provided by moss sample FF1 from the burnt mound (*fulacht fiadh*) (Table 4; Fig. 7 and Fig. 8B). The main mosses suggest well-developed woody vegetation, which was presumably present nearby. The pollen data suggest hazel scrub rather than well-developed tall-canopy woodland. Open habitats, including grasslands, seem to have been unimportant. This contrasts with the reconstruction based on profile TR1 but the very different taphonomic processes should be borne in mind. The mosses were taken from a woodland context. As caulk in the burnt-mound trough, they were probably not exposed for sufficiently long to integrate several years of pollen production from open habitats as in the case of the TR1 peat samples, and, furthermore, the pollen spectrum reflects largely the local environment where the mosses were gathered.

The date 3487 ± 42 BP (*c.* 1800 BC) from the burnt-mound moss sample lies in the early part of the age range for burnt mounds from Ireland (cf. Brindley et al., 1990). Four dates derived from hazel

wood collected from the trough 3653 ± 26, 3645 ± 23 BP, 3615 ± 24 and 3587 ± 23 BP (UBA-12826 to UBA-12829; Jackman et al., 2010) suggest that the trough may have been constructed several years prior to the caulk being added (possibly up to 200 years earlier). The trough may have been used over many years; the mosses that were sampled may have been added towards the end of the use-cycle.

During the final phases of the Bronze Age and throughout much of the Iron Age, profile TR1 records low values for *Plantago lanceolata* and other anthropogenic indicators, and *Corylus* representation increases (PAZ TR1-2). In the mid Iron Age, farming declined and regeneration involving yew and also oak, ash and hazel scrub, follows. By *c.* 300 BC (depth 15 cm), pine seems to have become exceedingly scarce or even extinct. The profile shows no trace of a Late Iron Age Lull (LIAL) but the sampling intervals may be too large to record what is expected to be a relatively short-lived feature (further discussion on the LIAL later). The uppermost two spectra (early medieval period; *c.* AD 380 and 660, respectively) suggest clearances that involved hazel and yew (the *Taxus* record ceases), and an increase in pastoral farming. Locally, there was increased disturbance (elevated ash content) and the mire surface was wet (cf. *Potamogeton* and *Pediastrum*; Fig. 4) for a considerable time prior to construction of the tailrace.

The base of profile U2 (PAZ U2-1; *c.* AD 600–820), which may briefly overlap the top of profile TR1, indicates a landscape similar to that recorded at the top of TR1, i.e. rather open with much pastoral farming. Tall woody vegetation consisted mainly of hazel scrub, with oak the main tall-canopy tree. Continuous, even if slender, curves for *Ulmus*, *Fraxinus* and *Taxus* suggest that these trees still persisted, probably both locally and in the region.

The mid part of the profile (PAZ U2-2; *c.* AD 820–960) indicates substantial increase in pastoral farming or at least a change in the farming system that greatly favoured *Plantago lanceolata* (*P. lanceolata* averages 14.5%, compared with 9.6% and 8.5% in the PAZs above and below, respectively). Ribwort plantain often flourishes where grasslands follow tillage in the rotational cycle (Behre, 1981; also personal observations in western Ireland), so that the *P. lanceolata* curve may be indirectly reflecting tillage. As regards AP, the cessation of the *Taxus* curve is noteworthy. It suggests that yew became locally extinct at *c.* AD 870.

Zone U2-2 coincides with mill construction and it presumably also spans the period when the mill was in use. Even allowing for poor pollen production and dispersal, cereal-type pollen values are surprisingly low. Pollen indicative of arable weed communities are also very poorly represented. Cereal growing appears not to have been important. On the other hand, the exceptionally high cereal-type pollen representation at the base of profile OF1 (PAZ OF1-1) and the strong representation of arable weeds (pollen and macroremains) show, beyond doubt, that the mill was indeed used for processing cereals. *Hordeum*-type pollen predominated which supports the idea that barley was the main crop (six-rowed barley, *H. vulgare/hexastichum,* was the main cereal recorded as a macrofossil; *Avena* (both *S. sativa* and *A. strigosa* probably present) was also recorded; S. Lyons in Jackman et al., 2010). In general, barley seems to have been the main cereal in early medieval Ireland, with wheat, oats and rye being generally much less abundant (Monk, 1986, McClatchie, 2007 and Kyle et al., 2009). At Kilbegly, rye seems to have been unimportant. It was not recorded as a macrofossil at Kilbegly (S. Lyons in Jackman et al., 2010). Indeed, it may have been present merely as a weed among other cereals; in all, 224 cereal-type pollen were counted in PAZ OF-1 and of these only two were *Secale*.

The mosses beneath the flume (Table 4) include several robust species such as *Thuidium tamariscinum*, *Rhytidiadelphus triquetrus* and *Hylocomium brevirostre* that are typical of the luxuriant, ground-floor (rather than epiphytic) moss flora of woodland/scrub communities, especially in calcareous habitats in western Ireland today (cf. Kelly and Kirby, 1982). Given the large quantities of moss used, it is assumed that these species were readily available within easy reach of the mill. The pollen spectra from the flume samples, which have generally high NAP and *Pteridium* values, contrast with the burnt-mound spectrum, FF1, in which woody taxa dominate (Fig. 7 and Fig. 8C). The flume

mosses were probably collected in a small woodland grove or in a patch of a semi-open woodland in an otherwise open landscape (cf. high *Plantago lanceolata* values). Indicators of arable farming are poorly represented, which is surprising given the proximity of the sample material to the milling operation. As already suggested, the flume seems to have formed an effective seal with respect to the supporting material beneath.

If, as seems to be the case, cereal growing was unimportant in the general vicinity of the mill, the exceptionally high representation of cereal-type pollen and other arable indicators recorded in PAZ OF1-1 is best explained by assuming that the basal peat derives mainly from material that arose from storage and processing of cereals rather than from mire species. It may include cereal straw used on-site, for instance, as thatch (horizontal mills in Ireland were commonly thatched; Rynne, 2000a and Watts, 2002).

If, as argued earlier, the local farming economy was predominantly pastoral rather than arable based, then the site for the mill was probably chosen, not on the basis of local availability of cereals, but rather overall suitability for a watermill. The presence of a reliable water supply that could be easily regulated may have been crucial. Close proximity to the early medieval church site at Kilbegly, and the economic and other activities associated with that site, were undoubtedly also important considerations.

As regards the dates relating directly to the mill construction and use, the date from the top of monolith TR1 (1289 ± 19 BP; AD 668–728 AD and 736–772; 2σ ranges) gives a *terminus post quem* for the construction of the tailrace. This points to the eighth century, though the late seventh century cannot be excluded. Of immediate relevance are the two dates from the moss samples from beneath the flume (1260 ± 29 and 1220 ± 29 BP; median calibrated ages: AD 736 and 804; Tables 2a and 2b and Fig. 8C). These point to the late eighth and early ninth centuries for placement of the flume. The ^{14}C date 1190 ± 30 BP (median calibrated age: AD 835) from near the base of monolith OF1 is also highly relevant in that the material dated (seeds and fruits of anthropore plants) most likely relates to the time when the mill was operating. This suggests that the mill was in use in the ninth century and probably also over some decades at either side of that century.

In core U2, PAZ 2 encompasses the interval *c.* AD 820 to AD 960 during which human impact was greatest. While it is not possible to firmly connect this with mill construction and use, it is reasonable to assume that there was substantial farming prior to mill construction and that this, in itself, provided the demand for a mill. The introduction of this advanced piece of technology to the area can, in turn, be expected to have triggered a further increase in farming and human impact generally.

Land-use and vegetation in the mid medieval period, presumably after the mill ceased operation, is reflected mainly in PAZs U2-3 and 4. During the 10th century, there is limited woodland regeneration (mainly oak) that was facilitated by a decline in farming, a trend that is reversed in the uppermost spectrum. The age model suggests mid 12th century for this latter development, but a 13th-century date cannot be excluded. By the mid 13th century, the Normans were well established in south Roscommon (Graham, 1988) and especially in neighbouring east Galway where they had already constructed several tower houses or castles (Holland, 1996) and so, presumably, strongly influenced farming.

The profiles MP1, N1 and OF1 provide further palaeoenvironmental information, albeit of limited value because of disturbance (see Results and interpretation). Profile N1 shows that peaty deposits formed close to the periphery of the present-day peat-filled basin in the early Holocene and that marl deposition took place in relatively recent times. Profile MP1 shows that the peat that accumulated in the millpond, during and after the period when the mill was in use, is highly disturbed. The pollen evidence, even though of limited value, supports the idea of an open landscape with woody vegetation limited mainly to hazel scrub and local farming being predominantly pastoral rather than arable based.

PAZ OF1-2, on the other hand, suggests that woody vegetation, especially hazel, was important after abandonment of the mill but the possibility that this deposit is also disturbed cannot be excluded.

4.2. Land-use and vegetation dynamics at Ballinphuill Bog

To set the information relating to Kilbegly in a wider regional context, the detailed regional pollen profile from Ballinphuill Bog (profile BPH2; Molloy et al., 2010), which lies 24 km to the west, is now considered. In Fig. 8A, selected pollen curves from Ballinphuill relating to the interval *c.* 1800 BC–AD 1200 are plotted together with pollen data from Kilbegly.

The most striking overall difference is the much higher contribution that *Corylus* makes in the Ballinphuill profile. Over most of the interval plotted in Fig. 8A, i.e. *c.* 1800 BC–AD 600, *Corylus* averages close to 50%, while during the corresponding period at Kilbegly, values are at *c.* 20%. The difference is probably partly attributable to the more regional character of the BPH2 profile. Nevertheless, the impression remains of a more open landscape at Kilbegly. *Plantago lanceolata* and Poaceae are well represented in the profiles from both areas and indeed these pollen taxa are much more strongly represented in the medieval period in the U2 profile. On the other hand, cereal-type pollen are better represented in the BPH2 profile which suggests that cereal growing was part of the farming economy at Ballinphuill throughout more or less the entire period represented in Fig. 8A.

As regards the contribution of the various tall-canopy trees, the two areas are broadly comparable throughout most of the period under consideration (Fig. 8A, B). Oak was the main tree, while ash, elm, yew and pine were minor components.

The records for yew and pine are of particular interest given the uncertainties regarding survival of these trees in Ireland into the late Holocene. Yew is a rather strong, though variable, producer of wind-dispersed pollen (Bradshaw, 1981) so firm conclusions are difficult to arrive at based on pollen evidence alone. Local and regional presence, however, is supported by several records of yew wood. At Kilbegly, the plate that regulated water output from the flume was yew (Jackman, 2007; E. O Carroll in Jackman et al., 2010). Yew wood from the base of the millpond yielded the ^{14}C date 1202 ± 27 BP (median probability: AD 825). Yew wood has also been recorded from medieval contexts further west along the route of the M6 (cf. Dillon et al., 2007). At both Kilbegly and Ballinphuill, there are more or less continuous *Taxus* pollen curves (Fig. 8A and B) until *c.* AD 800 (somewhat later at Kilbegly). Yew was probably present but rare in both areas until the ninth century AD, when it seems to have become extinct as a result of being sought out for its flexible and durable timber. In this regard, the high frequency of yew in artefacts from a medieval urban context in Dublin is noteworthy (Stuijts, 2007; given the context, the possibility that the wood was imported cannot be excluded).

As regards pine, its pollen is consistently recorded, but mainly at < 2%, in the profiles from Kilbegly and Ballinphuill. It cannot, however, be assumed that such percentage values reflect local or indeed extra-local presence given that pine is a high pollen producer with strong dispersal (Bunting, 2002). The available evidence suggests that pine survived in at least parts of western Ireland until well into the medieval period (as late as the 14th century AD; Molloy and O'Connell, 2007). Whether it survived in east Galway/Roscommon remains uncertain in view of the lack of macrofossil evidence. The slender curves for *Pinus* in the Kilbegly and Ballinphuill profiles, however, point towards survival in the wider region until about the ninth century AD.

As regards the farming economy, the peat-derived records relating to the Bronze Age and the Iron Age from Kilbegly have poor temporal resolution and so give only broad pointers. Over much of the Bronze Age (*c.* 1750–1050 BC; PAZ TR1-1), pastoral farming was important. In the late Bronze Age and Iron Age, farming continued but at a reduced level (cf. a similar pattern has been recorded in north Offaly; Plunkett et al., 2009). A strong upturn in farming, including cereal growing, may have commenced as early as AD 400 with the highest levels of activity in the ninth and early part of the

10th centuries AD. At Ballinphuill, where the record has a better temporal resolution, the more intensive phases of prehistoric farming (mainly pastoral but including cereal growing) are recorded between 1650 and 1300 BC (subzone BPH2-5d) and 1050 BC–AD 200 (zone BPH2-6). Farming activity picks up as the LIAL ends (*c.* AD 400), a strong upsurge with a distinct arable component begins at *c.* AD 600 (BPH2-8b), and an *Artemisia* (mugwort) curve is initiated by AD 800 (details in Molloy et al., 2010). Mugwort is favoured by fallow ground. Its expansion probably signifies more extensive cultivation and thus more fallow. Mitchell (1965) suggested that the rise in the *Artemisia* curve during early medieval times resulted from a change in ploughing practice following the introduction of the mouldboard plough to Ireland. However, the archaeological evidence suggests that the mouldboard plough was not a feature of Irish farming prior to the 10th century (Brady, 1993, Kelly, 1997 and Ryan, 2000). Rynne (2000b), however, questions this, citing the importance of cereal-growing in the farming economy as evidenced by the high frequency of watermills (most date to between the early eighth and the early 10th centuries; Fig. 9C). Whatever the role played by technological change, the *Artemisia* curve appears to closely track the increasing importance of cereal growing during the medieval and subsequent periods in Irish farming (cf. Fig. 9A; Kelly, 1997 and Ó Corráin, 2005).

Figure with multiple panels. Top panels labeled D2 and D1 show "Increased wetness" curves plotted against a timescale of 2000, 1500, 1000, 500, AD/BC, with markers for 'Draught phases', 'Irish Annals wet, cold shift', 'Oak narrow-ring events', AD 540, 207 BC. Period labels: LIA, MWP, RWP, and LIAL.

Panels B4, B3, B2, B1 show pollen percentage curves for Grassland, Cereal (excl. Secale), Secale, Cannabis sativa, and Linum usitatissimum at sites: Essexford Lough Co. Louth (B4); Lough Fark (LFC) Mayo Abbey, Co. Mayo (B3); Abbeyknockmoy East Galway (AKM '99) (B2); Ballinphuill East Galway (BPH2) (B1). Panel C is an inset bar chart showing Number of mills.

Panel A shows detailed pollen diagrams for three sites: Emlagh Bog, Co. Meath (EML I); Church Lough, Inishbofin (CHU I); An Loch Mór (MOR). Taxa include Urtica, Chenopodiaceae, Brassicaceae, Artemisia, Secale, Cereal-type, Rumex, L*guliflorae, Tubuliflorae, P. lanceolata, Poaceae, Corylus (HAZEL), Taxus, Fraxinus, Ulmus (ELM), Quercus, Anthoceros, Plantago maritima, Polypodium, Rumex acetosella, Linum usitatissimum, Betula (BIRCH), Salix (WILLOW), Juniperus, Fraxinus (ASH), Taxus (YEW), Quercus (OAK).

Age axis (AD/BC): 1800, 1600, 1400, 1200, 1000, 800, 600, 400, 200, AD, BC, 200.
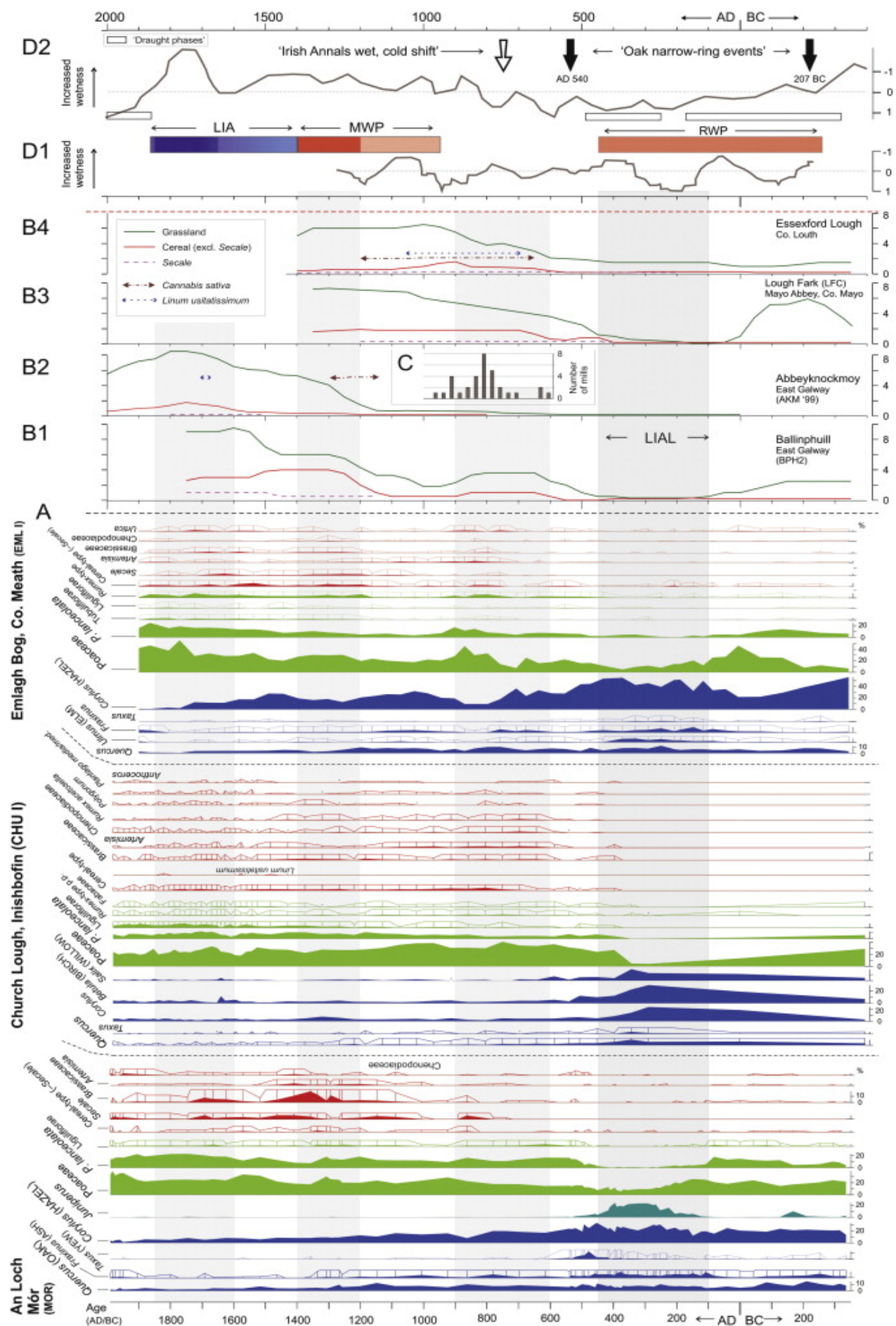
Fig. 9.

Environmental change and farming dynamics in the late Holocene (late Iron Age to recent times) with particular reference to western Ireland. A. Selected percentage pollen curves for the following profiles: MOR (Inis Oírr, Aran Islands); the age–depth model is based on a variety of evidence (^{14}C, tephra and geochemical analyses; cf. Chambers et al., 2004); CHU I (Church Lough, Inishbofin); the age–depth model is as in O'Connell and Ní Ghráinne (1994), but the upper of the two dates, 1700 ± 60 and 1760 ± 80 BP, has been omitted as this shows reversal (in the original publication these were averaged to give a single point in the age/depth curve); EML I (Emlagh Bog); the age–depth model is based on AMS ^{14}C dates and geochemically characterised tephra layers including Hekla 1 (AD 1104), AD 860 tephra and Helka 1947 (cf. Newman et al., 2007); B. Curves indicating levels of farming activity (pastoral and arable) in the pollen source areas of: Ballinphuill, east Galway (Molloy et al., 2010); Lough Fark, Mayo Abbey (monastic site with similar history to monastic site at Church Lough) (Fuller, 2002); Abbeyknockmoy, east Galway (Lomas-Clarke and Barber, 2004 and Lomas-Clarke and Barber, 2007); Essexford Lough, Co. Louth (Weir, 1995). C. Frequency plot of horizontal and vertical medieval watermill constructions in Ireland based on ^{14}C and dendrological evidence (after Brady, 2006, as modified by Kerr et al., 2009); D. Climate change indicators. Compiled bog-surface-wetness curves, based on proxies derived from raised bogs near Cloonoolish, east Galway and Ardkill, Co. Kildare (D1; Blundell et al., 2008) and a compiled record based on two raised-bog sites from Northern Ireland (D2; after Swindles et al., 2010) (in both instances, a 100-year running mean is plotted); 'draught phases' suggested by Swindles et al. (2010) are indicated. The climate intervals, Roman Warm Period (RWP), Medieval Warm Period (MWP) and the Little Ice Age (LIA) are indicated (denser shading used to suggest greater shift) (after several sources including Desprat et al., 2003, Bradley et al., 2003 and Glaser, 2001). Narrow-ring events in the Irish dendrochronological oak record (Baillie, 1995), and more frequent reference to stormy conditions and severe winters beginning in the mid eighth century in the Irish Annals (cf. Kerr et al., 2009), are highlighted.

4.3. Overview of other records from the wider east Galway/mid Shannon-basin region

At 12 km to the east of Kilbegly lies the important monastic sites of Clonmacnoise. Two pollen profiles are available from Mongan Bog, a nearby raised bog. Near the top of the profile by H. Parkes, i.e. at *c.* AD 800, anthropogenic indicators, including *Plantago lanceolata* and cereal-type, show increased representation (Parkes and Mitchell, 2000). *Corylus* values are exceptionally high throughout (*c.* 60%) and *Taxus* has low values in a few samples near the top of the profile. Pollen and macrofossil investigations carried out at high-temporal resolution on another core from Mongan Bog by Hall and Mauquoy (Hall, 2005 and Hall and Mauquoy, 2005; contiguous sampling using 1 cm-thick samples) provide a record that spans the historical period (*c.* AD 400 onwards). Arboreal pollen representation varies little until substantial clearances are recorded in the early 19th century. Anthropogenic indicators remain remarkably steady with *P. lanceolata* generally not exceeding 5% and cereal-type pollen poorly represented. Indeed, the records for the latter are often interrupted, especially before the mid 12th century, though this may be due, at least partly, to low pollen counts. It is also noteworthy that the period *c.* AD 750–1350, which includes the heyday of the monastic site, has the lowest representation of anthropogenic indicators. The profile may be too regional in character to give a good reflection of monastic farming, the monastic site lying *c.* 2 km distant but upwind of the coring site (Fig. 1B). Changes in the composition of the bog flora suggest that bog-surface wetness decreased between the late 10th and the late 13th century. This points to less rainfall and/or higher temperatures. As regards woodland composition, oak is the main tall-canopy tree, there is little ash or elm, *Pinus* pollen is rare and there are no pollen records for *Taxus*.

There is a high-temporal-resolution pollen profile from All Saints Bog, *c.* 19 km to the south of Clonmacnoise and equidistant from Kilbegly, that extends back to *c.* AD 900 (Cole and Mitchell, 2003). It suggests broadly similar woodland and land-use history to that described by Hall (2005) from Mongan Bog. Expansion of medieval farming, which included an arable component, appears to have been delayed until the mid 12th century when there was an appreciable impact on woody vegetation, including hazel scrub.

A high-temporal-resolution pollen profile from Clonfert Bog (near the monastic site of Clonfert; 8 km south-east of Kilbegly; Fig. 1B) spans most of the last two millennia (Hall, 2005). At a level dated by the AD 860 tephra there is a distinct increase in *Plantago lanceolata* and cereal-type is consistently represented, though with low values. Distinctly elevated *P. lanceolata* values are recorded for about

two centuries (almost 10%; based on a pollen sum that included bog taxa) beginning at *c.* AD 860 (base of tephra layer) and then tailing off to reach more usual values of < 5% by AD 1150. The cereal curve, however, shows little response. Here too, hazel is the main woody species, oak is the main tall-canopy tree and there are no records for *Taxus.*

A pollen profile from Moneyveagh Bog (presumed to be Monivea Bog), 36 km north-west of Kilbegly, spans the last *c.* 1000 years (Hall, 2005). It suggests considerable pastoral-based farming, with major clearances beginning at about AD 1500. Again, evidence for cereal growing is weak throughout the profile and representation of tall-canopy trees is exceptionally low throughout.

Abbeyknockmoy Bog, 43 km north-west of Kilbegly, lies beside a Cistercian monastery founded in AD 1189. From here, there are detailed records of vegetation, land-use and climate history that span the last two millennia (Lomas-Clarke and Barber, 2004, Lomas-Clarke and Barber, 2007 and Barber et al., 2003; Fig. 9B2). At about AD 800 (or earlier if the straight-line, age–depth model rather than the ^{14}C date in that part of the profile is taken into account), anthropogenic indicators (e.g. Poaceae, *Plantago lanceolata*, *Rumex*-type) begin a slow increase, with a distinct increase in the late 12th century; highest values are recorded between *c.* AD 1600–1800. Indicators of arable farming are modest throughout (occasional *Secale* pollen), highest representation being achieved in the last mentioned interval. A titanium curve, indicative of soil erosion, follows a similar pattern (Lomas-Clarke and Barber, 2004). Noteworthy are the elevated Ti values that persist for about a century at *c.* AD 800 and again in the post-medieval period until *c.* AD 1800. Occasional records of *Cannabis sativa*-type and *Linum bienne* pollen are indicative of local hemp and flax cultivation (it is assumed that *L. bienne* derives mainly, and perhaps exclusively, from *Linum usitatissimum*).

4.4. Late Holocene land-use and vegetation dynamics: overview within an Ireland context

The only pollen analytical investigation reported prior to this that had the specific aim of investigating vegetation change and farming at the site of a horizontal mill in Ireland is that from High Island, off the west Connemara coast (Molloy et al., 2000). This small island (*c.* 33 ha) is famed for its important early medieval monastery (established in the late seventh/early eighth century; main activity relates to the interval ninth to the 12th century; White Marshall and Rourke, 2000). The horizontal mill is unambiguously associated with an early monastic site (Rynne et al., 1996 and White Marshall and Rourke, 2000). The pollen diagram, from a small peat basin located *c.* 100 m from the monastery and *c.* 150 m from the mill site, suggests that, in the early Iron Age (550 BC), tall woody vegetation became more or less extinct, presumably as a result of human impact. The curve for *Pinus*, the main tree pollen, ends shortly after this; *Corylus*, the main shrubby species, falls to < 5%, and NAP, including *Plantago lanceolata*, increase substantially. At *c.* AD 640, *P. lanceolata* expands to give a peak of *c.* 20% and cereal-type pollen are recorded with rather low values (< 0.6%). *Secale* is recorded for the first time but only as a single grain; subsequently, values for cereal-type pollen remain low. Though cereal-type pollen are rather poorly represented and the dating might be better constrained, there is little doubt but that cereals were grown on the island in the early medieval period (Molloy et al., 2000).

Pollen cores from Church Lough on Inishbofin and An Loch Mór on Inis Oírr, provide what are probably the strongest pollen analytical evidence for medieval farming with a substantial cereal growing component from western Ireland and indeed Ireland generally (Fig. 9A). Both islands had important medieval monastic settlements and are situated in geographical regions noted for medieval monastic settlements (cf. Gosling, 1993). These island sites, lying upwind from the main landmasses, have the advantage that the pollen records are probably little influenced by long-distance-transported pollen derived from the mainland. Furthermore, the coring basins are small and are optimally located for documenting farming activity associated with the monastic settlements and indeed the island settlements generally. An Loch Mór lies 270 m south-east of Teampall Chaomháin (medieval church site) while at Church Lough, the monastic settlement, founded in AD 665, lies immediately to the east

of the lake. There is a mill site (date unknown) near to where the outflow from Church Lough reaches the sea (Gibbons, 1994).

The pollen record from An Loch Mór (Fig. 9A) shows a pronounced Late Iron Age Lull (AD 100–450; Molloy and O'Connell, 2004). This was followed by substantial farming and clearances in the medieval and later periods. Between AD 450 and 800, farming was pastoral based. As this interval ends, the first *Secale* pollen are recorded (*c.* AD 750) and the *Artemisia* curve begins shortly before that. These features signal the beginning of cereal growing as an important part of the farming economy on the island. Interestingly, rye was probably the first cereal cultivated and subsequently continued to be the most favoured cereal (in recent times, and presumably also earlier, oats – *Avena sativa* and *A. strigosa* – was also important). After *c.* AD 800, cereal cultivation assumed greater importance with the most intensive cultivation between AD 1050–1700 and especially AD 1150–1500. Brassicaceae pollen, which have particularly high values (maximum: 18.4%), probably derive mainly from *Raphanus raphanistrum*, a common weed of rye crops. On Inis Oírr, where *R. raphanistrum* is still common, the species is probably favoured by the maritime conditions and sandy soils. The *Artemisia* curve, though slender, parallels the Brassicaceae curve.

At Church Lough, the late Iron Age record has poor temporal resolution and dating control is rather weak (O'Connell and Ní Ghráinne, 1994; Fig. 9A). The LIAL is represented by only three spectra that show considerable regeneration of tall scrub. This feature has been dated to the first three and half centuries AD. The subsequent part of the record is much more detailed, but the ^{14}C-based dating control is complicated by inwash of organic-rich soils (O'Connell and Ní Ghráinne, 1994). The inwash, combined with strong representation of anthropogenic indicators in the pollen record (Fig. 9A), points to intensive farming in the lake catchment. After an initial phase of largely pastoral-based farming that resulted in considerable clearances (AD 350–550), arable farming expanded strongly in the mid sixth to the early eighth centuries (cf. *Artemisia*, Chenopodiaceae, *Rumex acetosella* and *Anthoceros*; the latter two taxa, sheep's sorrel and hornwort, were probably favoured by bare, organic-rich soils associated with arable farming). The most intensive arable activity relates to *c.* AD 750–1200 and coincides largely with the period when the monastery was most active. Interestingly, only occasional *Secale* pollen were recorded. Low but consistent records for *Taxus* until *c.* AD 1200 suggest that yew may have survived on the island into the late medieval period. A profile from Lough Fark, Mayo Abbey (the monastery was founded in AD 664 by Saxon monks who had been in Inishbofin) shows a broadly similar pattern to that from Church Lough. Medieval farming, beginning in the fifth century and more intensive from *c.* AD 600 onwards, included a sizeable arable component (Fuller, 2002). Rye was grown but it was of minor importance (maximum *Secale* value: 0.6%).

Pollen records from further afield include those from Emlagh Bog, Co. Meath (Fig. 9A; cf. Newman et al., 2007) and Essexford Lough, Co. Louth (Fig. 9B4; Weir, 1995). These are of particular interest in that they give a detailed record of arable farming in fertile parts of eastern Ireland. A LIAL is distinguishable in both profiles. Though NAP decline substantially, cereal-type pollen continue to be recorded which suggests that there was farming activity, though greatly reduced (LIAL: *c.* AD 100–500 at Emlagh Bog; *c.* 200 BC–AD 200 at Essexford Lough but the beginning and end are not sharply defined and the profile lacks independent dating). By *c.* AD 500, substantial cereal-type curves are initiated in both profiles. A *Secale* curve begins at about this time at Essexford Lough and later (*c.* AD 1000; occasional pollen from *c.* AD 600) at Emlagh Bog. The importance of arable farming at Essexford Lough is further emphasised by a sizeable curve for *Cannabis sativa* (*c.* AD 700–1000; it continues to be recorded until *c.* AD 1200) and several records for *Linum usitatissimum* which is very much under-represented in pollen records (Fig. 9B4; Weir, 1995). At Emlagh Bog, the main increase in arable farming begins at *c.* AD 1200. The extraordinary high values for cereal-type pollen (up to 20%; *Secale* a minor contributor) recorded at Loughnashade, near Navan Fort, in the early first millennium AD (prior to AD 200 and reaching a maximum by AD 300; independent dating is lacking) serve to emphasise the importance of arable farming in particular areas at the late Iron Age/early medieval transition (Weir, 1993).

The records reviewed above and presented in Fig. 9 serve to emphasise the significant increase in farming that marked the transition from the Iron Age to the medieval period (*c.* fifth century AD) in many parts of Ireland. By the beginning of the seventh century, arable farming had assumed greater overall importance than probably at any time heretofore. This more or less coincides with the spread of knowledge regarding the construction and operation of water-powered mills (Fig. 9C) which, in itself, is a good indicator of the increasing importance of cereals in the farming economy. The importance of watermills, in the medieval economy and society in Ireland (cf. Brady, 2006, Rynne, 2000a and Watts, 2002), is further emphasised by the recent discovery, near Ashbourne, Co. Meath, of up to eight watermills, mostly the horizontal type and dating to between the seventh and 10th century AD (Seaver, 2006). Another important farming phase, with an even greater arable component, begins at about AD 1200. This seems to be connected with increased Norman influence in Ireland.

4.5. Climate change and farming

Climate change is an external factor that impinges directly on several aspects of human activity, and especially farming and associated activities such as water-powered milling. At Kilbegly, the climate may be particularly critical given the location of the mill in a wet, boggy environment which would have made the milling operation difficult, or indeed impossible, in wet periods. On the other hand, a reliable, year-round water supply to power the mill was essential given the requirement for regular milling because of the limited shelf-life of cereals once ground (Rynne, 2000b). Unseasonal flooding undoubtedly had the potential to impinge negatively on mill operations but droughts, especially if of short duration, may not have been over-critical in view of the presence of active springs along the mire margin.

Evaluating the possible effects of climate change is not easy, especially given the uncertainties associated with long-term climatic reconstructions. Historical sources have provided much information on climate patterns and weather events during the last millennium (e.g. Glaser, 2001 and Pfister and Brazdil, 1999) and prior to instrumental measurements. Prior to *c.* AD 1000, however, reliable documentary evidence is scarcer and so various proxies are relied on. Bog wetness indicators constitute such a proxy. The indicators of past bog-surface wetness are assumed to largely reflect shifts in climate. Though these records and their interpretation are not always straightforward (cf. fig. 5 in Barber, 2006), they have the advantage that much of the data derives from the climatic region that is of particular interest — in this instance, Britain and Ireland including sites in east Galway. A summary of the records and other climatic information are presented in Fig. 9 (parts D1 and D2; explanatory notes in the figure legend).

On the basis of the climate data shown in Fig. 9, it appears that the upsurge in farming in Ireland, including cereal growing, that marks the early medieval period took place against a background of poor climatic conditions relative to the preceding Roman Warm Period (*c.* 250 BC–AD 450) and the Medieval Warm Period (*c.* AD 950–1400) that followed. Furthermore, construction of water-powered mills appears to have peaked at, or shortly after, a shift towards distinctly wetter and colder conditions that set in at *c.* AD 750 (based on documentary evidence gleaned from the Irish Annals and bog-surface-wetness reconstructions; Swindles et al., 2010 and Kerr et al., 2009; for evidence from south-western Ireland for wetter and cooler conditions see Overland and O'Connell, 2008). The enigma is that the increased expansion in cereal production and farming generally, as well as high levels of cultural achievements (cf. Ireland's Golden Age; Ó Cróinín, 1995) and presumably population expansion, took place in the context of apparently unfavourable climate. This has led to suggestions that cereal growing in medieval Ireland may have had advantages over pastoral-based systems during climatic downturns (Kerr et al., 2009). The complexities associated with these climatic reconstructions in the first instance should not, however, be overlooked (Caseldine and Gearey, 2005). While there is general agreement that bogs and bog communities (animal and plant) respond to large climatic shifts, there is often rather poor agreement between peat-based reconstructions from sites in similar climatic regions, including sites that are geographically close.

At Kilbegly, where the mill was constructed in a basin at the edge of a mire, it is difficult to envisage construction and operation of the mill if conditions were exceptionally wet over a considerable period. Ultimately, disease and communal strife which were both common in early medieval Ireland (Ó Corráin, 2005), as well as various other social and economic factors, may have been more important in determining population levels and the nature and intensity of farming, than climate change which was more long-term and probably quite subdued.

5. Summary and conclusions

Palaeoecological investigations, involving mainly pollen analyses of short peat monoliths from at and near the archaeological sites at Kilbegly, a peat core from nearby, and moss-polster samples from beneath the flume of the horizontal watermill and a nearby burnt mound, are reported on. These provide information on environmental change and human impact between the mid Bronze Age (*c.* 1800 BC) and late medieval times. During the medieval period, and particularly during the 9th and first half of the tenth century, i.e. coinciding broadly with the period when the mill operated, the pollen data suggest a rather open landscape, devoted mainly to pastoral farming. Woody vegetation consisted mainly of hazel (probably pockets of hazel scrub) with a good variety of tall-canopy trees though rather few in number (mainly oak; also ash, elm, alder and birch; yew still survived locally and perhaps pine). Surprisingly, strong evidence for cereals is available only from the basal pollen spectra of a peat profile from near the mill (overflow channel). It is concluded that, while the mill was used to process cereals, cereal growing was not important in the immediate vicinity of the mill site. Grain was probably brought from more distant parts that may have been associated with ecclesiastical lands connected to the church site at Kilbegly.

The palaeoecological investigations at Kilbegly are set within wider regional and national contexts. Palaeoecological data from other sites, mainly in western Ireland, are reviewed and presented in summary form. Several of these sites are located at or beside important medieval ecclesiastical settlements, including that on High Island, off Connemara, where there was a horizontal watermill in a spectacular siting. The data that are reviewed span, in several instances, the interval *c.* 350 BC to recent times. The main trends in farming activity are discussed next.

In the three centuries immediately before the AD/BC transition, several sites show strong human impact in the form of pastoral-based farming. Between *c.* AD 100 and 450 there is a distinct lull in human activity and regeneration of woody vegetation at many sites; this is the so-called Late Iron Age Lull. Subsequent to this, early medieval impact registers strongly in most pollen profiles. Initially, the impact was mainly due to pastoral farming. By the sixth century, cereal growing had assumed considerable importance at many sites. During the seventh century, considerable expansion of pastoral and arable farming took place. Rye (also flax and hemp, but less frequently) is recorded at several sites. It is only on the Aran Islands, however, that rye assumes considerable importance (from the late eighth century onwards).

The pollen data show that the interval AD 650–950, which coincides with the construction of water-powered mills, was also the main period of arable farming prior to late medieval/Norman times (AD 1200–1400) when there was an distinct expansion in farming (arable and pastoral), and the early modern era (*c.* AD 1600–1800) when cereal growing expanded again and human impact greatly increased to create the present-day open landscape.

The following are the supplementary materials related to this article.

Plate S1.

A. View towards north-east showing tailrace which leads to the flume (mill undercroft has been removed), and the ridge carrying fertile pasture in the background. Monolith TR1 was taken from the left-hand side of the tailrace near the foreground (22/08/2007). B1. Monolith OF1, overflow channel; B2. Archaeological section with monolith OF1 removed; C. Peat buried by tailrace spoil; this peat was sampled as monolith TR1; D. Flume and undercroft largely excavated; long oak planks that formed part of wall of millpond are visible at top left. Scale divisions: 5 cm; photographs B1–D taken on 24/07/2007.
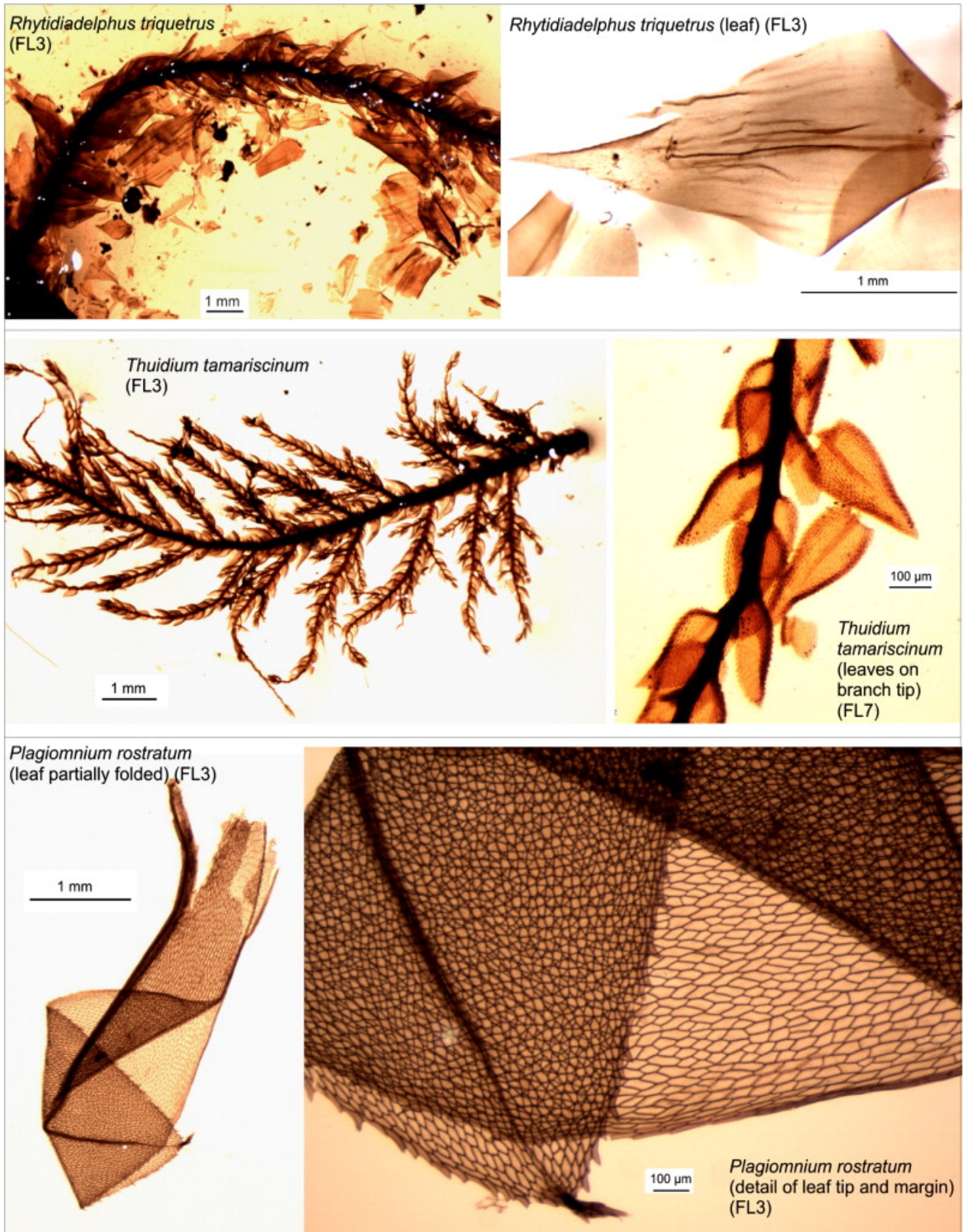
Plate S2.

Photomicrographs of mosses from samples collected from beneath the flume. New insights into late Holocene farming and woodland dynamics in western Ireland with particular reference to the early medieval horizontal watermill at Kilbegly, Co. Roscommon.

Acknowledgements

References

Baillie, M.G.L., 1995. A Slice through Time. Dendrochronology and Precision Dating, Batsford, London.

Barber, K.E., 2006. Peatland records of Holocene climate change. In: Elias, S.A. (Ed.),   Encyclopedia of Quaternary Science. Elsevier, Amsterdam, pp. 1883–1894.

Barber, K.E., Chambers, F.M., Maddy, D., 2003. Holocene palaeoclimates from peat stratigraphy: macrofossil proxy climate records from three oceanic raised bogs in

England and Ireland. Quaternary Science Reviews 22, 521–539.

Behre, K.-E., 1981. The interpretation of anthropogenic indicators in pollen diagrams. Pollen et Spores 23, 225–245.

Beijerinck, W., 1976. Zadenatlas. Der nederlandische flora. Ten behoeve van de botanie, palaeontologie, bodemcultuure en warenkennis. Backhuys and Meesters, Amsterdam.

Beug, H.-J., 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Friedrich Pfeil, Munich.

Blundell, A., Charman, D.J., Barber, K., 2008. Multiproxy late Holocene peat records from Ireland: towards a regional palaeoclimate curve. Journal of Quaternary Science 23, 59–71.

Bradley, R.S., Briffa, K.R., Cole, J., Hughes, M.K., Osborn, T.J., 2003. The climate of the last millennium. In: Alverson, K.D., Bradley, R.S., Pedersen, T.F. (Eds.), Paleoclimate, Global Change and the Future. Springer, Berlin, pp. 105–141.

Bradshaw, R.H.W., 1981. Modern pollen-representation factors for woods in south-east England. Journal of Ecology 69, 45–70.

Brady, N., 1993. Reconstructing a medieval Irish plough. I Jornadas Internacionales sobre Technología Agraria Tradicional, pp. 31–44.

Brady, N., 2006. Mills in medieval Ireland: looking beyond design. In: Walton, S.A. (Ed.), Wind and Water in the Middle Ages. Fluid Technologies from Antiquity to the Renaissance. Arizona Center for Medieval and Renaissance Studies, Tempe, pp. 39–68.

Brindley, A.L., Lanting, J.N., Mook, W.G., 1990. Radiocarbon dating from Irish Fulachta Fiadh and other burnt mounds. Journal of Irish Archaeology 5, 25–33.

Bunting, M.J., 2002. Detecting woodland remnants in cultural landscapes: modern pollen deposition around small woodlands in northwest Scotland. The Holocene 12, 291–301.

Cappers, R.T.J., Bekker, R.M., Jans, J.E.A., 2006. Digitale zadenatlas van Nederland. Digital Seed Atlas of the Netherlands (Groningen Archaeological Studies 4). Barkhuis Publishing, Eelde.

Caseldine, C., Gearey, B., 2005. A multiproxy approach to reconstructing surface wetness changes and prehistoric bog bursts in a raised mire system at Derryville Bog, Co. Tipperary, Ireland.
The Holocene 15, 585–601.

Chambers, F.M., Daniell, J.R.G., Hunt, J.B., Molloy, K., O'Connell, M., 2004. Tephrostratigraphy of An Loch Mór, Inis Oírr, W. Ireland: implications for Holocene tephrochronology in the northeastern Atlantic region. The Holocene 14, 703–720.

Cole, E.E., Mitchell, F.J.G., 2003. Human impact on the Irish landscape during the late Holocene inferred from palynological studies at three peatland sites. The Holocene 13, 507–515.

Corlett, C., Potterton, M. (Eds.), 2009. Rural Settlement in Medieval Ireland. Wordwell, Bray.

Desprat, S., Goni, M.F.S., Loutre, M.F., 2003. Revealing climatic variability of the last three millennia in northwestern Iberia using pollen influx data. Earth and Planetary Science Letters 213, 63–78.
Dierßen, K., 2001. Distribution, Ecological Amplitude and Phytosociological Characterization of European Bryophytes (Bryophytorum Bibliotheca, Bd 56). Cramer, Berlin.

Dillon, M., Johnston, P., Tierney, M., 2007. Reading the ashes: charred plant material from two ringforts in County Galway. Seanda 2, 27–29.

Fuller, J.L., 2002. Past vegetation and land-use dynamics in Mayo Abbey, central Mayo. Archaeology Ireland 16 (3), 20–23.

Fægri, K., Iversen, J., 1989. In: Fægri, K., Kaland, P.E., Krzywinski, K. (Eds.), Textbook of Pollen Analysis, 4th ed. Wiley, New York.

Gibbons, M., 1994. Archaeology and history [of Inishbofin]. In: Coxon, P., O'Connell, M. (Eds.), Clare Island and Inishbofin Field Guide No. 17. Irish Quaternary Research Association, Dublin, pp. 54–59.

Glaser, R., 2001. Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen. Primus Verlag, Darmstadt.

Graham, B.J., 1988. Medieval settlement in County Roscommon. Proceedings of the Royal Irish Academy 88C, 19–38.

Gosling, P., 1993. Archaeological Inventory of County Galway, Vol. 1. West Galway. Government Stationery Office, Dublin.

Hall, V.A., 1989. A study of the modern pollen rain from a reconstructed 19th century farm. Irish Naturalists' Journal 23, 82–92.

Hall, V.A., 2005. The vegetation history of monastic and secular sites in the midlands of Ireland over the last two millennia. Vegetation History and Archaeobotany 15, 1–12.

Hall, V.A., Mauquoy, D., 2005. Tephra-dated climate- and human-impact studies during the last 1500 years from a raised bog in central Ireland. The Holocene 15, 1086–1093.

Hellman, S., Gaillard, M.J., Bunting, J.M., Mazier, F., 2009. Estimating the relevant source area of pollen in the past cultural landscapes of Southern Sweden — a forward modelling approach. Review of Palaeobotany and Palynology 153, 259–271.

Hill, M.O., Preston, C.D., Smith, A.J.E. (Eds), 1994. Atlas of the Bryophytes of Britain and Ireland. Vol 3. Mosses (Diplolepideae). Harley Books, Colchester.

Holland, P., 1996. The Anglo-Normans and their castles in County Galway. In: Moran, G.(Ed.), Galway. History and Society. Interdisciplinary Essays on the History of an Irish County. Geography Publications, Dublin, pp. 1–26.

Holyoak, D.T., 2003. The Distribution of Bryophytes in Ireland. An Annotated Review of the Occurrence of Liverworts and Mosses in the Irish Vice-counties, Based Mainly on the Records of the British Bryological Society. Broadleaf Books, Dinas Powys (Vale of Glamorgan).

Jackman, N., 2007. Kilbegly mill: work in progress. Seanda 2, 34–35.

Jackman, N., 2009. Early medieval food-processing technology at Kilbegly, Co. Roscommon: the miller's tale. In: Stanley, M., Danaher, E., Eogan, J. (Eds.), Dining and Dwelling. Archaeology and theNational Roads AuthorityMonograph Series No. 6. Wordwell, Bray, pp. 9–18.

Jackman, N., Moore, C., Rynne, C., Devane, C., 2010. The Mill at Kilbegly. Archaeological Investigation of an Early Medieval Horizontal Mill and other Excavations on the N6 Ballinasloe to Athlone Road Scheme. National Roads Authority Archaeology Scheme Monograph Series. National Roads Authority, Dublin (in press).

Kelly, D.L., Kirby, E.N., 1982. Irish native woodlands over limestone. Journal of Life Sciences, 3. Royal Dublin Society, pp. 181–198.

Kelly, F., 1997. Early Irish Farming (Early Irish Law Series), Vol. IV. Dublin Institute of Advanced Studies (School of Celtic Studies), Dublin.

Kerr, T.R., Swindles, G.T., Plunkett, G., 2009. Making hay while the sun shines? Socioeconomic change, cereal production and climatic deterioration in Early Medieval Ireland. Journal of Archaeological Science 36, 2868–2874.

Kyle, A., Stewart, K., Tourunen, A., 2009. Excavating a meal: a multidisciplinary approach to early medieval food economy. In: Stanley, M., Danaher, E., Eogan, J. (Eds.), Dining and Dwelling. Archaeology and the National Roads Authority Monograph Series, No. 6. Wordwell, Bray, pp. 73–84.

Kuijper, W.J., 2000. The former occurrence of Neckera crispa Hedw. in the Netherlands. Lindbergia, 25, pp. 28–32.

Lomas-Clarke, S.H., Barber, K.E., 2004. Palaeoecology of human impact during the historic period: palynology and geochemistry of a peat deposit at Abbeyknockmoy, Co. Galway, Ireland. The Holocene 14, 721–731.

Lomas-Clarke, S.H., Barber, K.E., 2007. Human impact signals from peat bogs — a combined palynological and geochemical approach. Vegetation History and Archaeobotany 16, 419–429.

Mazier, F., Brostrom, A., Gaillard, M.J., Sugita, S., Vittoz, P., Buttler, A., 2008. Pollen productivity estimates and relevant source area of pollen for selected plant taxa in a pasture woodland landscape of the Jura Mountains (Switzerland). Vegetation History and Archaeobotany 17, 479–495.

McClatchie, M., 2007. The study of non-wood plant macro-remains: investigating past societies and landscapes. In: Murphy, E.M., Whitehouse, N.J. (Eds.), Environmental Archaeology in Ireland. Oxbow Books, Oxford, pp. 194–220.

McKeon, J., O'Sullivan, J., 2010. (Eds.), The Quiet Landscape: Archaeological and Palaeoecological Investigations on the M6 Galway to Ballinasloe National Road Scheme. National Roads Authority Excavations Monograph. National Roads Authority, Dublin (in press).

Mitchell, G.F., 1965. Littleton Bog, Tipperary: an Irish agricultural record. Journal of the Royal Society of Antiquaries of Ireland 95, 121–132.

Molloy, K., O'Connell, M., 2004. Holocene vegetation and land-use dynamics in the karstic environment of Inis Oírr, Aran Islands, western Ireland: pollen analytical evidence evaluated in the light of the archaeological record. Quaternary International 113, 41–61.

Molloy, K., O'Connell, M., 2007. Fresh insights into long-term environmental change on the Aran Islands based on palaeoecological investigations of lake sediments from Inis Oírr. Journal of the Galway Archaeological and Historical Society 59, 1–17.

Molloy, K., Feeser, I., O'Connell, M., 2010. A new pollen record from east Galway: fresh insights into farming and woodland dynamics in mid-western Ireland from the Neolithic to recent times. In: Schulting, R.J., Whitehouse N.J., McClatchie, M. (Eds.), Living Landscapes: Exploring Neolithic Ireland and its Wider Context. Archaeopress (BAR), Oxford. (in press).

Molloy, K., Fuller, J.L., Conaghan, J., 2000. Vegetation and land-use history on High Island: the results of preliminary investigations. In: White Marshall, J., Rourke, G.D. (Eds.), Town House and Country House, Dublin, pp. 233–243.
Monk, M.A., 1986. Evidence from macroscopic plant remains for crop husbandry in prehistoric and early historic Ireland: a review. Journal of Irish Archaeology 3, 31–36.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis, 2nd ed. Blackwell, London.

Newman, C., O'Connell, M., Dillon, M., Molloy, K., 2007. Interpretation of charcoal and pollen data relating to a late Iron Age ritual site in eastern Ireland: a holistic approach. Vegetation History and Archaeobotany 16, 349–365.

O'Connell, M., Ní Ghráinne, E., 1994. Palaeoecology [of Inishbofin]. In: Coxon, P., O'Connell, M. (Eds.), Clare Island and Inishbofin. Field Guide No. 17. Irish Association for Quaternary Studies, Dublin, pp. 60–103.

Ó Corráin, D., 2005. Ireland c. 800: Aspects of Society. In: Ó Cróinín, D. (Ed.), A New History of Ireland. I. Prehistoric and Early Ireland. Oxford University Press, Oxford, pp. 549–608.

Ó Cróinín, D., 1995. Early Medieval Ireland. Longman, London, pp. 400–1200.

O'Sullivan, J., Stanley, M., 2008. Roads, Rediscovery and Research. Archaeology and the National Roads Authority Monograph Series No. 5. National Roads Authority, Dublin.

Overland, A., O'Connell, M., 2008. Fine-spatial paleoecological investigations towards reconstructing late Holocene environmental change, landscape evolution and farming activity in Barrees, Beara Peninsula, southwestern Ireland. Journal of the North Atlantic 1, 37–73.

Parkes, H.M., Mitchell, F.J.G., 2000. Vegetation history at Clonmacnoise, Co. Offaly. Biology and Environment (Proceedings of the Royal Irish Academy) 100B, 35–40.

Pfister, C., Brazdil, R., 1999. Climatic variability in sixteenth-century Europe and its social dimension: a synthesis. Climatic Change 43, 5–53.

Plunkett, G., Whitehouse, N.J., Hall, V.A., Charman, D.J., Blaauw, M., Kelly, E., Mulhall, I., 2009. A multi-proxy palaeoenvironmental investigation of the findspot of an Iron Age bog body from Oldcroghan, Co. Offaly, Ireland. Journal of Archaeological Science 36, 265–277.

Preston, C.D., Pearman, D.A., Dines, T.D. (Eds.), 2002. New Atlas of the British and Irish Flora. Oxford University Press, Oxford.

Reille, M., 1992. Pollen et spores d'Europe et d'Afrique du nord. Laboratoire de Botanique Historique et Palynologie, Faculté des Sciences et Techniques Saint-Jérôme, Marseille.

Reille, M., 1995. Pollen et spores d'Europe et d'Afrique du nord. Supplement 1. Laboratoire de Botanique Historique et Palynologie, Faculté des Sciences et Techniques Saint-Jérôme, Marseille.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G.Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, G., Manning, S., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., Weyhenmeyer, C.E., 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46, 1029–1058.

Ryan, M., 2000. Furrows and browse: some archaeological thoughts on agriculture and population in early medieval Ireland. In: Smyth, A.P. (Ed.), Seanchas. Studies in Early and Medieval Irish Archaeology, History and Literature in Honour of Francis J.Byrne. Four Courts Press, Dublin, pp. 30–36.

Rynne, C., 2000a. Waterpower in medieval Ireland. In: Squatriti, P. (Ed.), Working with Water in Medieval Europe. Brill, Leiden, pp. 1–50.

Rynne, C., 2000b. The early medieval monastic watermill. In: White Marshall, J., Rourke, G.D. (Eds.), High Island. An Irish Monastery in the Atlantic. Town House and Country House, Dublin, pp. 185–212.

Rynne, C., Rourke, G., White-Marshall, J., 1996. An early Medieval monastic watermill on High Island. Archaeology Ireland 10 (3), 24–27.

Schoch, W.H., Pawlik, B., Schweingruber, F.H., 1988. Botanical Macro-remains. Haupt, Bern. Seaver, M., 2006. Through the mill — excavation of an early medieval settlement at Raystown, County Meath. In: O'Sullivan, J., Stanley, M. (Eds.),
Settlement, Industry and Ritual. Proceedings of a Public Seminar on Archaeological Discoveries on National Road Schemes, September 2005. National Roads Authority, Dublin, pp. 73–87.

Smith, A.J.E., 1978. The Moss Flora of Britain and Ireland. Cambridge University Press, Cambridge. Stace, C., 1997. New Flora of the British Isles, 2nd ed. Cambridge University Press, Cambridge. Stanley, M., Danaher, E., Eogan, J. (Eds.), 2009. Dining and Dwelling. Archaeology and the National Roads Authority Monograph Series No. 6. Wordwell, Bray.

Stuijts, E., 2007. Wood and charcoal research in Ireland. In: Murphy, E.M., Whitehouse, N.J. (Eds.), Environmental Archaeology in Ireland. Oxbow Books, Oxford, pp. 179–193.

Sugita, S., 1994. Pollen representation of vegetation in Quaternary sediments: theory and method in patchy vegetation. Journal of Ecology 82, 881–897.

Swindles, G.T., Blundell, A., Roe, H.M., Hall, V.A., 2010. A 4500-year proxy climate record from peatlands in the North of Ireland: the identification of widespread
summer 'drought phases'? Quaternary Science Reviews 29, 1577–1589.

Vuorela, I., 1973. Relative pollen rain around cultivated fields. Acta Botanica Fennica 102, 1–27. Watson, E.V., 1981. British Mosses and Liverworts, 3rd ed. Cambridge University Press, Cambridge. Watts, M., 2002. The Archaeology of Mills and Milling. Tempus, Stroud (Gloucestershire).

Webb, D.A., Parnell, J., Doogue, D., 1996. An Irish Flora, 7th ed. Dundalgan Press, Dundalk.

Weir, D.A., 1993. Dark Ages and the pollen record. Emania 11, 21–30.

Weir, D.A., 1995. A palynological study of landscape development in County Louth from the second millennium BC to the first millennium AD.
Discovery Programme Reports: 2. Project Results 1993. Royal Irish Academy/Discovery Programme, Dublin, pp. 77–126.

White Marshall, J., Rourke, G.D., 2000. High Island. An Irish Monastery in the Atlantic. Town House and Country House, Dublin.