Published article:

Plunkett, G, McDermott, C, Swindles, GT and Brown, DM (2013) *Environmental indifference? A critique of environmentally deterministic theories of peatland archaeological site construction in Ireland.* Quaternary Science Reviews, 61. 17 - 31.

http://dx.doi.org/10.1016/j.quascirev.2012.11.002

Environmental indifference? A critique of environmentally deterministic theories of peatland archaeological site construction in Ireland

G. Plunkett[a*], C. McDermott[b], G.T. Swindles[c] and D.M. Brown[a]

[a]School of Geography, Archaeology and Palaeoecology, Queen's University Belfast, Belfast BT7 1NN, Northern Ireland; g.plunkett@qub.ac.uk; d.brown@qub.ac.uk; +44 (0)28 90973184

[b]School of Archaeology, Newman Building, University College Dublin, Belfield, Dublin 4, Ireland; conor.mcdermott@ucd.ie; +33 (0)1 7168668

[c]School of Geography, University of Leeds, Leeds LS2 9JT, England; g.t.swindles@leeds.ac.uk; +44 (0)113 3439127

(*author for correspondence)

Abstract: Climate change, whether gradual or sudden, has frequently been invoked as a causal factor to explain many aspects of cultural change during the prehistoric and early historic periods. Critiquing such theories has often proven difficult, not least because of the imprecise dating of many aspects of the palaeoclimate or archaeological records and the difficulties of merging the two strands of research. Here we consider one example of the archaeological record – peatland site construction in Ireland – which has previously been interpreted in terms of social response to climate change and examine whether close scrutiny of the archaeological and palaeoenvironmental records uphold the climatically deterministic hypotheses. We evaluate evidence for phasing in the temporal distribution of trackways and related sites in Irish peatlands, of which more than 3,500 examples have been recorded, through the examination of ~350 dendrochronological and ^{14}C dates from these structures. The role of climate change in influencing when such sites were constructed is assessed by comparing visually and statistically the frequency of sites over the last 4,500 years with well-dated, multi-proxy climate reconstructions from Irish peatlands. We demonstrate that national patterns of "peatland activity" exist that indicate that the construction of sites in bogs was neither a constant nor random phenomenon. Phases of activity (i.e. periods in which the number of structures increased), as well as the 'lulls' that separate them, show no consistent correlation with periods of wetter or drier conditions on the bogs, suggesting that the impetus for the start or cessation of such activity was not climatically-determined. We propose that trigger(s) for peatland site construction in Ireland must instead also be sought within the wider, contemporary social background. Perhaps not surprisingly, a comparison with archaeological and palynological evidence shows that peatland activity tends to occur at times of more expansive settlement and land-use, suggesting that the bogs were used when the landscape was being more widely occupied. Interestingly, the lulls in peatland site construction coincide with transitional points between nominal archaeological phases, typically defined on the basis of their material culture, implying that there may indeed have been a cultural discontinuity at these times.

Keywords: Peatland archaeology, Holocene climate change, Environmental impact, Environmental determinism, Summed probability functions, Ireland

.

1.0 Introduction

The pending threat of future climate change to human societies has stimulated considerable interest in looking at how past populations have coped with climate variability and the last two decades have seen major debates emerge regarding the vulnerability and response of past societies to environmental change (e.g. Buckland et al., 1996; deMenocal, 2001; Hassan, 2001; Haug et al., 2003; Brooks, 2006; Oram and Adderley, 2008; McAnany and Yoffee, 2010; Roberts et al., 2011). With reference to the recent past, for which detailed and precisely-dated historical records exist, Zhang et al. (2011) argue that 'golden' and 'dark' ages in both Europe and N. America were determined by changes in temperature, which, through their impact on bioproductivity, resulted in fluctuations in agricultural production that ultimately led to economic, social and demographic changes. Similar scenarios have been proposed for prehistoric and early historic periods, with human responses to climate change ranging from full-scale social collapse/transformation and population crashes/spurts, to more subtle shifts in settlement patterns, economic regimes or ritual/ceremonial practices (e.g. Bryson et al., 1974; Burgess, 1974; 1989; Weiss, 1982; van Geel et al., 1996; 2004; An et al., 2004; Munoz et al., 2010; Büntgen et al., 2011). In the absence of precise chronicles and instrumental records, however, ascertaining causal links between climate change and social response is a considerably intricate process, not least due to the difficulties of achieving sufficient chronological control to establish a secure temporal framework for the observed events. Even when temporal coincidence provides a basis for considering cause-and-effect, there is a danger that undue consideration of the wider archaeological record will lead to contentious hypotheses (e.g. Baillie, 1989; 1993; Turney et al., 2006; Turney and Brown, 2007). This paper examines one instance of human activity that took place in a climatically-sensitive environmental setting and for which climate change has been invoked as an influential factor that highlights some of the limitations of even the most plausible climatically-determined theories.

1.1 Archaeological activity in Irish peatlands

Irish peatlands are well known to be an important repository of palaeoclimatic data in the form of oak and pine timbers that have been used to construct a long dendrochronological series for the last 7,000 years (Pilcher et al., 1995; 1996b; Brown and Baillie, 2012), and multiple peat-based proxies for Holocene palaeohydrological and -environmental change (e.g. Barber et al., 2000; 2003; Plunkett, 2006; Swindles et al., 2007a; 2007b; 2010; Blundell et al., 2008). Abundant archaeological remains (amounting to >3,500 sites) from these peatlands (mainly raised bogs but including their underlying minerotrophic horizons) also reveal a long history of human activity, stretching back to at least 4000 BC and probably before (Raftery, 1996; Brindley and Lanting, 1998; McDermott, 2001), with site concentrations often far exceeding the frequency of known archaeological sites in their dry hinterlands. The sites comprise mainly a large number of trackways (known in Ireland as toghers) that facilitated movement onto, within and across the peatlands and 'platforms' that may have served as working surfaces and habitations, but also includes a substantial number of indeterminate, typically less substantial ‘structures’ (McDermott, 2007). The sites most probably served a range of purposes: aiding communications, maintaining networks, providing access to specific resources and quite likely at times fulfilling non-utilitarian needs. With a large subset of sites (~10% of the total known record) independently dated by ^{14}C or dendrochronology, distinct 'phases' of peatland use have previously been suggested (Baillie and Brown, 1996; Raftery, 1996; Brindley and Lanting, 1998). These phases have in turn been interpreted in terms of their palaeoenvironmental significance, either as evidence for wetter periods (Baillie, 1993) in which such sites were necessary for the maintenance of existing communications and activities, or drier periods during which the peatlands became more accessible environments (Baillie, 1999; Baillie and Brown, 2002). In these scenarios, it is the impact of environmental change directly on the bogs that is thought to have influenced human activity. The close relationship between the start of clusters of dendro-dated peatland sites and growth anomalies in Irish oaks has prompted Baillie (1993; Baillie and Brown, 2002) to surmise that environmental crises could have instigated social responses that subsequently gave rise to peatland site construction. In this instance, climate is deemed to have had an impact beyond the immediate bog environment.

In reality, palaeoenvironmental studies of numerous trackways demonstrate that the features frequently cross a range of hydrological environments on the peat surface, including hummocks, hollows and pools, and encompass different types of wetland including ombrotrophic *Sphagnum* bogs, fens and carr-woodland (Casparie and Moloney, 1996; Cross May et al., 2005a), suggesting that such environmentally-deterministic interpretations are overly simplistic. In an examination of multiple sites in Kilnagarnagh Bog, Co. Offaly, Bermingham (2005) found that trackways were not built during particularly wet or dry phases, but tended to occur during transitional phases as the bog surface changed from wet to dry, or dry to wet. Such studies have tended to emphasise the potential role of autogenic hydrological changes in influencing when individual bogs were exploited (Bermingham, 2005; Casparie, 2005; Caseldine et al., 2005). In Derryville Bog, sites were constructed at times to take advantage of certain environmental conditions, at other times in response to localised changes to wetter or drier bog surfaces (Cross May et al., 2005b) but tended to be less common during very wet intervals (Gearey and Caseldine, 2006). These findings do not account, however, for the apparently episodic nature of peatland activity at extra-local scales, nor do they adequately establish the role of climate in determining phases of peatland use. The latter failing is due in part to many of the sites being situated in fen peats, from which palaeoclimatic reconstructions are more complex, and in part to the possible influence of site construction on the hydrology of bogs with long histories of human interference (Casparie, 2005).

This investigation examines whether regional climate change is a plausible explanation for peatland activity that can be supported by both the archaeological and palaeoenvironmental records. First, we explore whether there are identifiable phases of activity within the archaeological record through an examination of the probability density function (PDF) of ^{14}C-dated peatland sites, and a stacked record of their dendro-dated counterparts. We consider how these patterns compare to PDFs that might be produced if the sites were constructed randomly or constantly through time, or if the dendro-dated sites reflected the "true" phases of activity. Secondly, we compare the frequency of the archaeological sites with published, peatland-based proxy climate records to assess whether increases and declines in the level of peatland site construction can be firmly associated with specific climatic conditions or transitions.

2.0 Methods

2.1 Archaeological data compilation and analysis

Most of the sites known from Irish ombrotrophic peatlands have been discovered since the initiation of dedicated archaeological surveys and excavations of Republic of Ireland bogs since the late 1980s, and the complete dataset includes indeterminate structures (~53%), short trackways (Class 3 toghers, ~30%), lengthy trackways (Classes 1 and 2 toghers, ~8%) and an array of less frequent site types. Fig. 1 shows the location of the four main regions in the Irish Midlands which have been subject to survey. We collated dating information for all site types (excluding habitations, burnt mounds, artefacts and bog body findspots) from published datasets, the Irish Archaeological Wetland Unit Database (University College Dublin) and Queen's University Belfast Dendrochronological Database (see Supplementary Table 1 for details of all the ^{14}C dataset, Supplementary Table 2 for dendro-dated sites and Supplementary Note A for official site classifications). Generally, any sites which contained dendro-datable oak timbers have been dated, and the dendro-database therefore contains a virtually complete record of such sites, mainly (~70%) from lengthy trackways. Of the remaining structures, a subset, equating to ~7% of the known archaeological record, were dated using ^{14}C dating; within this dataset, there is bias towards the more substantial sites, with dates from ~12% of all trackway types and ~65% of platforms (nonlinear features), but from only ~1% of the more enigmatic ‘structures’. The last mentioned category includes sites that may have been significantly destroyed before discovery, untraceable in extent during survey, or originally ephemeral. There is an inherent taphonomic bias in the recovery of sites, as drainage and peat milling will have been carried out in all the bogs surveyed, resulting, on the one hand, in the destruction of the youngest sites, and the extent of loss will vary from bog to bog according to the length of time for which each peatland has been commercially exploited. Drainage ditches rarely exceed 1m in depth and therefore at the time of an archaeological survey, the peat strata exposed at any location seldom exceeds a ~2000 yr period of growth (estimate based on average accumulation rates of modified raised bogs in Ireland [Plunkett et al. 2004]). The relative paucity of Neolithic sites (>2500 BC), on the other hand, is due at least in part to the fact that these levels have not yet been exposed or surveyed in many bogs.

The resulting dataset includes a complete list of 124 dendro-dated sites, the dating precision of which falls into three categories: a) felling dates with annual precision; b) felling estimates with a precision of ±9 yr, where the outer ring of the timber was absent from the dated sample but the heartwood-sapwood boundary present (the error margin being based on an empirical sapwood estimate of Irish oaks [Baillie 1982]); and c) *termini post quem* (from timbers in which the heartwood-sapwood boundary was not present and a only minimum date could be established). Where multiple dates were available from any one site, a single best date (the most precise, or the latest in the series) was selected to represent the site, unless multiple, discrete phases of construction or repair were evident. To facilitate comparison with the ^{14}C dataset, the data were distributed into 25 yr bins (e.g. 1499-1475 BC, 1474-1450 BC). For category b dates that spanned two bins (e.g. 1492±9 BC), a value of 0.5 was given to each relevant bin, assuming an equal likelihood that that site could have been constructed in either age range. For category c dates, a maximum likely age error of 280 yr was estimated using the average age plus one standard deviation of trees felled for trackways in categories a and b (i.e. 207±73 yr) and, with consideration of the age of each timber, establishing the range of bins across which a felling date was likely. A *pro rata* value to a total of one for each date was then attributed to each of the relevant bins. This maximum age calculation is considered reasonable in view of the observations by Baillie and Brown (1995) that the ages of parkland and bog oaks from Ireland seldom exceeded *c.* 250 yr, although oak timbers used in trackways were typically less mature (~100-200 yr old). Nevertheless, 12 sites in this dataset (representing 10% of sites) contain oaks that exceed 280 yr, the longest lived being a 471-year-old specimen from Baunmore platform, Derryville Bog, Co. Tipperary.

Our dataset includes ^{14}C dates for 230 peatland sites (Supplementary Table 1). Nine sites that had ^{14}C determinations older than ~4100 BP were excluded from analysis as their calibrated age ranges are beyond the limits of most of the palaeoclimate proxy records from Ireland. The vast majority of sites were dated using samples of identified, short-lived wood or wood with outer rings/bark identified, minimising the risk that an 'old wood effect' could skew the data, and the mean error (ΔT) on the dataset is ±47 yr. The dates were calibrated using Calib v.6.10 (Stuiver and Reimer, 1993) and the INTCAL09 calibration dataset (Reimer et al., 2009), and their probabilities summed to provide a probability density function (PDF) with which to explore the frequency of peatland site construction. One date per site was used for the analysis except where the original excavators identified more than one distinct phase of construction or repair, or where this could be clearly inferred by a disparity in the dates. Where dendrochronological and ^{14}C dates were available for the same site or phase of construction within a site the dendrochronological date was used for the analysis. Where multiple ^{14}C dates were available for a site, the date with the narrower calibrated age span was selected where their probabilities overlapped significantly; in the case of sites with discrepant pairs of dates with little or no overlap in their 95% confidence intervals and for which multiphased activity was unlikely given the form of the structure, the position of the site in relation to adjacent peatland sites was used to determine which date was more likely.

PDFs are increasingly used as a tool, albeit an imperfect one, for identifying major changes in past human activity (e.g. Gamble et al., 2005; Kerr et al., 2009). Although this approach invariably produces scattered date ranges that extend beyond the true start and end date of the phenomenon being dated (Bayliss et al., 2007; Chiverrell et al., 2011), peaks and troughs within PDFs can potentially be underpinned by real fluctuations in the frequency of activity, particularly if sufficiently large datasets are available to minimise variability arising from sampling bias and ^{14}C statistical smearing (Williams, 2012). Some of the potential pitfalls of this technique (see Williams, 2012) are circumvented in the context of this study by 1) a large sample size (n=221) spanning a relatively short time interval (4,500 yr) that should provide a robust and reliable PDF; 2) a low ΔT (±47) within the dataset; 3) a reasonably representative subsample of the archaeological record, notwithstanding the under-representation of the ambiguous and more ephemeral ‘structures’ and the taphonomic issues described above; and 4) the dating of material that by and large directly relates to the initial construction of the sites (only a small proportion of sites showing evidence of long term usage or re-use), which is the specific activity under consideration.

To test whether the PDF from the peatland sites reflects real phasing, we used OxCal (Bronk Ramsey, 1995; 2001) to simulate ^{14}C datasets from calendar dates representing constant (i.e. regular) and random site construction over the last 4,500 years with activity weighted more heavily between 1700 BC-AD 1650 (as in the dataset). "Constant" calendar years were calculated on the basis of 221 evenly spaced dates spanning the period ~AD 1750-2500 BC, with the bulk of dates (n=200) more tightly constrained within the period 1700 BC-AD 1650; 221 "random" calendar years were calculated using the random function in Excel, with the same bias applied (cf. Riede et al., 2009). These calendar "dates" were converted to simulated ^{14}C determinations using the simulation function in OxCal, and each simulated determination was attributed a random error (generated again in Excel) of between ±20 and ±80 yr. The simulated determinations were then calibrated and their probabilities summed (as above). We similarly simulated ^{14}C dates for all category a and b dendro-dated tracks, applied random errors to each and summed their calibrated age ranges, to examine the potential extent of spread within this tightly-dated subset of the dataset. Correlations between the resultant summed probabilities and the calendar dates on which the simulations were assessed using Pearson correlation analysis.

2.2 Palaeoclimate records from Ireland

Regionally-relevant palaeoclimate reconstructions are undoubtedly requisite for examining the potential impact of climate change on past societies. In Ireland, a $\delta^{18}O$ record from a speleothem at Crag Cave, Co. Limerick, is thought to reflect mainly changes in air temperature but chronological control on the record is poor with, for example, errors of ±200 years stated for the Medieval Warm Period c. 1,000 years ago (McDermott et al., 1999; 2001). A precisely-dated palaeoclimatic index inferred from mainly bog oak population dynamics in Ireland (Turney et al., 2005) has been shown to be unreliable (Swindles and Plunkett, 2010), although growth anomalies in the oak chronologies signify extreme, rapid environmental events at 2345 BC, 1628 BC, 1159 BC, 207 BC and AD 540 (Baillie and Munro, 1988), the nature of which has yet to be firmly identified. Other palaeoclimate reconstructions for the mid- to late Holocene have generally been performed using peat-based proxies, such as peat humification, plant macrofossils and/or testate amoebae-derived water table reconstructions. All three proxies provide indications of fluctuations in bog surface wetness (BSW) through time, which in ombrotrophic bogs are thought to reflect past changes in the length and intensity of the summer water deficit, most probably controlled by summer precipitation in oceanic northwest Europe (Charman, 2007). As such, these records are highly apt for considering the palaeoclimatic context of peatland site construction to ascertain if climate, through BSW, influenced when such sites were constructed. This is true whether or not the sites were built on ombrotrophic bogs, as the hydrology of fens will also have been affected ultimately by climate changes.

From the published literature, we have selected the testate amoebae water table reconstructions as the primary proxy with which to compare the peatland archaeology datasets. These include palaeohydrological records from three ombrotrophic bogs in the north of Ireland that extend back to ~2500 cal BC (Swindles, 2006; Swindles et al., 2010) and three sites in central Ireland (referred to here as the Irish Midlands), one of which extends back >5,000 years (Langdon et al., 2012) and two of which mainly span the last two millennia (Blundell et al., 2008) (see Fig. 1 for site locations). The north of Ireland sites have been dated using a combination of AMS ^{14}C dating, spheroidal carbonaceous particles (SCP) and tephrochronology, and their age models are based on linear interpolation (Swindles et al., 2010). Chronological precision in these records is strongest during the Medieval to recent period, the early first millennium cal BC and the later 3rd millennium cal BC where the records are dated by tephra isochrons. The Irish Midlands sites were dated using ^{14}C dating; the age model for Derragh Bog age was produced using the Bayesian depositional model (Langdon et al., 2012) and linear interpolation was used at Ardkill and Cloonoolish bogs (Blundell et al., 2008). The upper sections of the last two mentioned sites are thought to have been affected by peat cutting, and for the purposes of this paper, the records have therefore been truncated at cal AD 1400 and cal AD 1250 respectively. BSW data from Derryville, Co. Tipperary (Caseldine and Gearey, 2005; Caseldine et al., 2005; Gearey and Caseldine, 2006) and Kilnagarnagh, Co. Offaly (Bermingham, 2005), are excluded as both sequences show evidence for autogenic processes (including bog bursts) and considerable human impact that obscure their climatic signals.

We include also for comparison six peat humification records from ombrotrophic bogs in north and western Ireland (Plunkett, 2006; see Fig. 1 for site locations). Although peat humification analysis has been down-played as an effective means of reconstructing relative BSW due to the potential influence of different plant components within the peat on the results (Yeloff and Mauquoy, 2006), the studies presented here have demonstrated sufficient regional coherency to suggest that they reflect to some extent wider palaeoclimatic shifts. These sites have been dated using tephrochronology, which provides strong chronological ties between the records in the early first millennium BC. Plant macrofossil studies have also formed the focus of palaeohydrological studies in northeast and central Ireland (Barber et al., 2000; 2003). We have not included these records in this synthesis as the one dimensional summaries (e.g. DCA Axis 1 scores) of their ecological significance are complex and variable.

To facilitate identification of any major trends in the palaeohydrology records, all data were combined and sorted by age, detrended by linear regression and standardised. A Loess smooth function (span = 0.02) was applied as a useful exploratory tool to assess overall trends in the data but the interpretation of wet and dry shifts in BSW is based on a consideration of the individual bog records.

3.0 Results

3.1 Identifying phasing in the archaeological datasets

The PDF and dendro-date age distributions of peatland sites are shown in Fig. 2, alongside examples of PDFs from simulated datasets representing ‘constant’ activity, ‘random’ activity and ‘dendro’ sites. The actual distribution of dendro-dated sites separates into four distinct clusters, and a fifth, more diffuse group whose features are obscured by tails arising from the category c dendro-dates. The PDF of the precisely and near-precisely dendro-dated sites indicates that the summing probability approach captures these clusters very well (all yielding strong positive correlations), but the age ranges of the phases are unevenly scattered either side of the binned dendro-dates, and probability values are especially augmented between closely spaced clusters. The PDF of the ^{14}C dated peatland sites is characterised by numerous peaks and troughs that clearly distinguish it from the more evenly distributed probabilities that would be expected if activity had been constant. Sites that are built randomly through time are, however, capable of yielding PDFs with decadal to multi-centennial scale features that imply periods of increased or reduced activity, despite the simulated dates being spaced usually no more than a century apart. There are, nevertheless, significant positive correlations between the random PDFs and the calendar dates on which they are based. The dendro-dates and PDF of the ^{14}C-dated peatland sites similarly show a high positive relationship with each other and, notwithstanding the inherent smearing of dates, the combined results strongly point to phasing within the dataset, with activity concentrated in the periods between 2700-1900 cal BC, 1700-1375 cal BC, 1225-775 cal BC, 500 cal BC-cal AD 25, cal AD 400-900 and cal AD 1000-1650. These phases, and the lulls that separate them, are discussed in further detail below.

3.2 Bog surface wetness records

According to estimates of recent annual moisture deficit in Ireland, accumulated mainly in the summer months (Mills, 2000), the locations of the palaeohydrological records considered in this paper can seemingly be divided into two zones, one running northeast-to-west zone and the other in the Irish Midlands (Fig. 1). The deficit model implies that, in the present climate regime at least, peatlands in the Irish Midlands, and especially those in the archaeological survey regions, would be more sensitive to summer drought than the peatlands to the north and west, whilst the latter might be more vulnerable to increased effective moisture. From a palaeohydrological perspective, the different sensitivities of the northern/western and Midlands sites might be expected to reveal themselves as regional trends in the BSW records.

The juxtaposed palaeohydrology records (Fig. 3) indicate a great degree of variability in the apparent responsiveness of individual sites to BSW fluctuations. The Lowess climate compilation highlights possible trends in the data with a noticeable wet-shift occurring in the mid-first millennium BC and a long-term trend towards increasing wetness from the mid-first millennium AD until the end of the Little Ice Age. No consistent differences can be detected between the northern/western records and those of the Midlands, although inter-regional variability is apparent. Errors of ±100-200 yr on the individual site age models complicate the establishment of widespread climate shifts, although the timing of an apparently prevalent wet shift at ~750 BC is constrained by tephrochronology. The degree of consistency between the BSW records is therefore evaluated in relation to the timing of each phase and lull in peatland site construction.

3.3 Phases of peatland activity and their relationship to BSW records

The site age distributions strongly imply periods in which peatland activity was concentrated ('Activity Phases') or subsided ('Activity Lulls') (Fig. 4; Table 1), each of which will be discussed in turn (age brackets are rounded to the nearest quarter-century). In this analysis, a 'lull' in activity is not defined in quantitative terms, but is interpreted in light of the level of site construction that can be attributed to the preceding interval. The identification of changes is based on both data sources with emphasis placed on the more precise dendro-dataset in establishing the phase shift boundaries. Multiplots indicating the calibrated probability distribution of individual ^{14}C determinations (Supplementary Fig. 1) are referred to in order to aid interpretation of the phases and lulls. As a simple tool to compare fluctuating frequencies of sites between the defined periods, we have calculated average construction rates based on the number of dated trackways attributed to each period, which are presented in Table 1.

3.3.1 Activity Phase 1 (2700-1900 cal BC)

Nineteen sites, including mainly short trackways but also longer examples and platforms, have been ^{14}C dated to this interval, but only one dendro-dated trackway (dating to 2259±9 BC) falls within this phase. Overall, this represents a low frequency construction rate. Although the PDF peaks slightly between ~2150-2000 cal BC, the age distributions are well distributed across this period. The dated sites have a wide geographical distribution but are not found in the Littleton region.

From the beginning of this period, rising Lowess values are driven largely by the palaeohydrological data from Derragh Bog which suggest increasingly dry bog surfaces until ~2400 cal BC. On the basis of the Derragh Bog and Dead Island records, there appears to be a trend towards increasingly wet conditions after this time, but a similar change is only evident two centuries later at Slieveanorra. An oak growth anomaly occurs towards the middle of the phase at 2345 BC but wet shifts in Dead Island and Slieveanorra bogs begin, respectively, below and above a layer of Hekla 4 tephra, dated to 2395-2279 cal BC (Pilcher et al., 1996a), and are clearly asynchronous in these sites. The increasingly wet conditions do not appear to have instigated any changes in the frequency of peatland site construction during this phase.

3.3.2 Activity Lull A (1900-1700 cal BC)

The small probability distribution at this time derives mainly from four sites (Derryfadda 204, Ballykilleen 92a, Rattin 16a and Bunsallagh 2a), the first three of which were most likely constructed during the previous activity phase (Supplementary Fig. 1a). Only one of the dated sites, a short trackway, therefore seems to have been constructed during this period. The palaeohydrology records indicate some minor fluctuations in BSW, but overall the bogs appear to have remained wetter during this interval, though not appreciably different from the preceding phase.

3.3.3 Activity Phase 2 (1700-1375 cal BC)

There is a large increase in the number of sites that can be attributed to this phase. The ^{14}C dated sites include 21 sites that were most likely built prior to 1500 cal BC and at least 12 sites that were probably constructed between 1500-1375 cal BC. The dendro-dates reveal a concentration (n=29) of trackway construction mainly between ~1600-1375 BC, with only one site built before an oak growth anomaly at 1628 BC. Many of the sites in this group are short trackways found in Derryoghil Bog, in the Mountdillon region, but there is a good representation of more substantial sites in other parts of the Irish Midlands.

Water table depths at Derragh Bog and Dead Island Bog remain largely unchanged at this time, suggesting no major palaeohydrological shifts, and although the data from Slieveanorra oscillate quite considerably. The Lowess climate compilation suggests a shift towards drier conditions from the start of this phase, and appears to be influenced by relatively drier conditions suggested by the humification curves at Garry, Owenduff and Moyreen. On the whole, the BSW records do not signify any coherent wet or dry shift that could account for initiation of the widespread and intensive activity in peatlands at this time, and there are no consistent perturbations in the BSW records around the time of the 1628 BC oak growth anomaly. The condition of the wood recovered from Killoran 18 trackway in Derryville Bog, which was constructed in the latter part of this phase, suggested dry conditions during the site's use (Cross May et al., 2005a), which is consistent with the evidence suggested by the humification records.

3.3.4 Activity Lull B (1375-1225 cal BC)

A lack of precisely dendro-dated sites and a drop in the probability distribution of ^{14}C-dated sites suggest a fall-off in peatland activity at this time. The PDF remains rather elevated owing in part to at least five sites that were probably built during the preceding phase, and three sites that are possibly younger (Supplementary Fig. 1c). At least three, but up to possibly thirteen sites, were built during this interval. A variety of trackways from the four main survey regions are represented.

The peat humification records and the water table reconstructions from Glen West and Derragh indicate a shift to wetter conditions within this time interval but the Slieveanorra and Dead Island water table reconstructions suggest short-lived shifts to drier conditions, followed by increases in BSW. Essentially, the chronological precision of the age models is insufficient in all instances to determine whether there was a synchronous shift in BSW around this time that might have impacted upon peatland site construction. At Derryville Bog, however, a bog burst is thought to have lowered water tables in this system at ~1250 cal BC (Casparie 2005), after which two sites (Derryfadda 311, Cooleeny 64) are believed to have been constructed. This bog burst could conceivably have been triggered by an increasingly wet climate.

3.3.5 Activity Phase 3 (1225-775 cal BC)

From the later 13th century cal BC, the PDF curve starts to rise, and by the early 11th century, dendro-dated sites are certainly being built (total n=42 for this phase). Slightly more ^{14}C dated sites (n=26) fall within the two centuries before 1000 cal BC than the two centuries that follow (n=23) (Supplementary Fig. 1d), but dendro-dated sites peak during the 10th century BC and were constructed until at least the mid-9th century BC. The range of sites is dominated by short trackways but more substantial sites were also built, and after ~900 BC, post-rows are represented for the first time. The sites have a wide geographical distribution.

The start of this phase would appear to be marked by continuing wet conditions, registered at six of the palaeohydrological sites. The timing of an oak growth anomaly starting at 1159 BC falls within the 95% confidence interval of age ranges from the earliest ^{14}C-dated sites, whose construction cannot, therefore, be demonstrated with certainty either to precede or follow the tree-ring event. A shift to drier conditions is subsequently observed at Slieveanorra, Sluggan, Claraghmore (where it occurs shortly before the Hekla 3 tephra isochron, dating to 1087-1003 cal BC [van den Bogaard et al., 2002]) and Glen West in contrast to increasing BSW at Garry, Dead Island, Owenduff and Moyreen. These discrepant trends may be indicating differential responses to climate at a subregional scale, with the Irish Midlands experiencing warmer/drier conditions at this time. A more consistent picture emerges at the very end of the phase, as eight, tephra-linked BSW records point to drier conditions on the bogs at the start of the 8th century BC. Lower water tables are recorded at the start of this interval in Derryville Bog attributed to the effects of the bog burst at ~1250 cal BC, but BSW increases after ~1055 cal BC, culminating in a bog burst dated to ~820 cal BC (Casparie, 2005; Caseldine and Gearey, 2005). Here at least, more sites seem to have been built when the bog was drier.

3.3.6 Activity Lull C (775-500 cal BC)

Both the dendro- and ^{14}C-dated datasets point to a break in peatland activity from the beginning of the early 8th century cal BC, perhaps as early as ~800 cal BC. Due to the extended plateau in the ^{14}C calibration curve at this time, the dating precision is very poor for the ^{14}C dated sites, and 13 sites have high probabilities spanning the interval (Supplementary Fig. 1e). Three dendro-dated sites from three different bogs can be firmly attributed to the first half of the 7th century BC, coinciding with a small rise in PDF. Sites include a range of trackways, a platform and perhaps one indeterminate structure, and are found in all survey regions except the Blackwater group.

This lull occurs during a period in which many of the palaeohydrology records indicate a shift to wetter conditions, the start date of which (~750 cal BC) is constrained by the presence of two well-dated tephra horizons in several of the sites (Plunkett, 2006; Swindles et al., 2007a; 2007b). In at least six sites, a wet-shift took place after the deposition of the GB4-150 tephra (dated to 800-760 cal BC; Plunkett et al*.,* 2004) and before the eruption of the Microlite/OMH-185 tephra (dated to 755-680 cal BC; Plunkett et al*.,* 2004), and has been interpreted as a widely synchronous event in Ireland (Plunkett, 2006; Swindles et al., 2007b). Despite the close timing of the two changes, it seems likely that the reduction in peatland activity began just before bog surfaces got wetter. Most of the palaeohydrological records suggest that wet conditions persisted throughout this interval. At Derryville Bog, water tables rise during this interval up until the time of a bog burst which is dated to ~600 BC and attributed to the impact of the construction of a large trackway, Cooleeny 31 (Casparie, 2005; Caseldine and Gearey, 2005).

3.3.7 Activity Phase 4 (500 cal BC-cal AD 25)

This phase includes two distinct clusters of dendro-dated sites, between which there is an extensive series of ^{14}C dated sites, and on this basis, three sub-phases are distinguished. Subphase 4a includes mostly long trackways (Class 2 and 3 toghers) mainly from two bog systems, Edercloon and Derryville. Four dendro-dated sites were constructed in the early to mid-5th century BC, and five ^{14}C dated sites were most probably constructed within this century. A hiatus in the representation of dendro-dated sites can be seen in the latter half of the fifth century BC, but a substantial increase in PDF is evident after ~400 cal BC which would not be expected if there had been a major fall-off in site construction. As many as 21 sites have well-spread age probabilities across the period ~400-200 cal BC (Subphase 4b) that suggest continuous peatland use during this time, but the bimodal probability distributions could potentially mask a hiatus in activity (Supplementary Fig. 1f). The majority of sites are found in Derryville and Edercloon bogs, but other areas are also now represented. After ~200 BC, the PDF curve declines, but continued construction is demonstrated by seven dendro-dated sites, including the most renowned Irish trackway, Corlea 1 (Raftery, 1996), and at least eight ^{14}C -dated sites, and a further five sites have high ^{14}C probabilities in this bracket (Subphase 4c). Sites in this subgroup are much more widely distributed geographically, and include five major trackways, four platforms and a range of less substantial sites.

The BSW records provide fairly consistent impressions of increasingly drier bog surfaces through this period, with some minor wetter episodes. An oak growth anomaly dated to 207 BC occurs towards the end of this phase, and its environmental origin clearly had no influential role in determining peatland site construction.

3.3.8 Activity Lull D (cal AD 25-400)

This prominent lull is characterised by an almost complete absence of sites. Only one indeterminate structure, ^{14}C-dated to cal AD 1-220, can be ascribed to this interval. The water table reconstructions suggest that this was a prolonged phase of generally drier conditions on the bogs, again interrupted periodically by some wet shifts. At Derryville Bog, in contrast, wetter conditions seemed to have prevailed until a further bog burst at ~cal AD 250 (Casparie, 2005; Caseldine et al., 2005).

3.3.9 Activity Phase 5 (cal AD 400-900)

This phase is marked by a resurgence of activity and features 28 dendro- and at least 22 ^{14}C-dated sites. The majority of the dendro-dated sites cluster between ~AD 550-750. The PDF rises rapidly at ~cal AD 400, peaking between ~cal AD 650-750, mirroring the increase in dendro-dated sites. At least four of the ^{14}C-dated sites predate the start of the dendro-site cluster, and two almost certainly are later. Sites include a wide range of trackways, post rows, and for the first time, paved ways and a gravel road, indicating a greater effort to create solid communication routes across the bogs. The sites are very widely distributed throughout the four main surveyed zones. Both PDF and dendro-dated sites decline unequivocally at ~cal AD 900.

A shift to increased BSW is seen at Slieveanorra, Glen West, Cloonoolish and, to a lesser extent, Derragh at the start of this phase. By ~cal AD 500, this is particularly marked at Cloonoolish and Glen West, and at AD 536 and AD 540, growth anomalies are recorded in the oak dendrochronological record (Baillie, 1999). The dating precision is not sufficient to enable the synchroneity of the wet shift and the start of this phase of activity to be established, but site construction certainly began before the oak growth anomalies (Supplementary Fig. 1g). There appears to be a return to drier bog surfaces at Glen West and Cloonoolish by ~cal AD 700, although the Ardkill record is at its wettest at this time, and Slieveanorra and Dead Island also experience wet shifts. The timing of drier conditions at Glen West and Dead Island is better restrained by the presence of the 'AD860B' tephra (dating to AD 847, Coulter et al., [in press]) towards the end of this interval.

3.3.10 Activity Lull E (cal AD 900-1000)

There is only one ^{14}C-dated site, a short trackway, with a substantial probability range within this interval, although it could have been constructed during the preceding phase (Supplementary Fig. 1g). No dendro-dated sites are known at this time. The palaeohydrological records suggest a shift to wetter conditions, and at Dead Island, this can clearly be seen to occur after the 'AD860B' tephra.

3.3.11 Activity Phase 6 (cal AD 1000-1650)

The last millennium AD is characterised by continual peatland activity of varying intensity, represented by a fluctuating PDF. The ^{14}C-dated sites are fairly well-dispersed in time, with a large peak in probability in the 15th century when at least eight sites are likely to have been built. No dendro-datable sites can be firmly identified prior to the mid-12th century or after the mid-13th century, although ^{14}C dates indicate activity before and after this time bracket. A large number of sites dating to this period are likely to have been destroyed by industrial peat extraction, with only individual examples recorded in Derryville Bog and in the Mountdillon region, for instance. There are a large proportion of gravel roads/stone trackways recorded during this time interval, and their survival may be due in part to their greater visibility and the obstacle they pose to peat milling, but also to a greater investment of effort in the construction of communication routes across areas of peatland.

Both Slieveanorra and Dead Island show an overriding trend during this interval towards increasingly wet bog surfaces, although at the former site, water levels fall again at ~cal AD 1500. At Derragh Bog, a similar drop in water levels seems to take place at ~cal AD 1400. The Ardkill and Cloonoolish records display contrasting conditions at the start of this phase, with Ardkill registering very wet bog surface while the water table is at its lowest in Cloonoolish. Reduced BSW is subsequently recorded at Ardkill at ~cal AD 1210-1350 (Blundell et al., 2008). These divergent stories make it impracticable to disentangle a consistent climate influence on the peatlands and on site construction.

3.3.12 Early Modern to Present (cal AD 1650-2000)

Although ^{14}C dating precision of the peatland sites after ~cal AD 1600 is very poor, it is likely that many sites younger than this would have been destroyed during the early stages of peat extraction during the course of the last century. Three sites, two of which are indeterminate structures, can be considered recent. The Slieveanorra, Dead Island and Derragh water table reconstructions all provide a picture of very wet bog surfaces until the 19th century, followed by a steady falling of water levels, but the impact on peatland site construction cannot be gauged given the taphonomic bias in the archaeological record.

4.0 Discussion

Drawing from the largest compilation of dates from Irish peatland sites until now, this analysis confirms previous findings (Baillie and Brown, 1996; Raftery, 1996; Brindley and Lanting, 1998) that there are discrete episodes of increased human activity on Irish peatlands recognisable within the dataset. Although the ^{14}C-dated sites tend to provide a smoother and more extended record of peatland use than the dendro-dated examples, a detailed examination of their age probability distributions shows that they generally follow the same patterning evident in the dendro-dataset, a relationship upheld by statistical analysis at a multi-decadal timescale. In some instances (notably for much of Activity Phase 1, in the 5th, 9th and 11th centuries AD and after the 14th century AD), the ^{14}C dates provide incontrovertible evidence (i.e. not merely an artefact of ^{14}C smearing) of activity in periods not well-represented by dendro-dated sites that highlights the fact that the latter dataset does not offer a complete reflection of peatland activity. Of the 39 dated indeterminate ‘structures’, the most poorly represented category of peatland site, all but one fall clearly within an activity phase, suggesting that these sites too are more common during periods of high frequency peatland use.

The activity phases correspond in an Irish archaeological framework to the Later Neolithic-Early Bronze Age (Activity Phase 1), the Middle Bronze Age (Phase 2), the Late Bronze Age (Phase 3), the Early-Developed Iron Age (Phase 4), the Early Medieval period (Phase 5) and the Medieval to Post-Medieval periods (Phase 6). Activity Phases 2 and 3 stand out as being the most pronounced periods of peatland site construction, and Activity Phases 4 and 5 are also characterised by a high frequency of sites but will have been affected to a greater extent by taphonomic loss. Each phase is generally represented by sites from more than one area, suggesting that peatland activity at these times was part of widespread cultural phenomena; sites dating to the initial centuries of Activity Phase 4 are restricted mainly to two peatlands, but these peatlands are located in two discrete regions indicating that this is an extra-local phenomenon. Although at Derryville, Co. Tipperary, peatland sites constructed after ~1250 cal BC and ~820 cal BC were seen to be a response to autogenic reductions in bog surface wetness (Cross et al., 2001; Cross May et al., 2005b), these sites fit within the wider pattern of peatland use in other Irish bogs, although ‘unusually’ wet (in the context of the palaeohydrological records discussed in this paper) conditions at Derryville may have hindered site construction during the latter part of Activity Phase 3. Thus, the general prevalence of a 'national pattern', so described by Raftery (1996, p. 411), implies that local bog development and autogenic processes alone cannot have played a leading role in determining when peatlands were utilised in the past, and wider, external factors – whether they be climate or cultural – need to be sought to explain the observed trends.

It is evident from a visual comparison of the peatland sites' date distributions and the palaeohydrological records that there is no coherent correlation between past climate and the construction of sites in bogs, and this is upheld by a statistical test of the correlation between the archaeological datasets and the Lowess climate compilation. Activity Phases 1, 2, 3 and 4 span periods in which bog surfaces were largely drier, but the hydrology of the bogs during these periods was evidently variable, and sites are also represented during wet intervals, particularly during Activity Phases 5 and possibly 6. Notwithstanding some level of chronological uncertainty in the palaeohydrological records, the starts of the phases are not consistently linked to specific wet/cool or dry/warm shifts, implying that climate change was not the over-arching impetus for the initiation of peatland use (*contra* Baillie, 1993; 1999) and that the sites were not constructed merely during periods of palaeohydrological transitions (*contra* Bermingham, 2005). The results also show that although there is indeed a close temporal relationship between oak growth anomalies and the start of building phases in Irish bogs (Baillie, 1993; Baillie and Brown, 2002), the activity usually commences categorically before the tree-ring events (Activity Phases 1, 2, 4 and 5). The start of Activity Phase 3 cannot, however, be certainly disassociated with the environmental event that gave rise to the 1159 BC growth anomaly.

The lulls in peatland activity are of variable length, ranging from one century (Activity Lull E) to four centuries (Activity Lull D). As with the activity phases, the lulls cannot be equated consistently with any specific bog surface conditions, occurring as they do at times of lower (Lull D), higher (Lulls A and E) and variable (Lulls B and C) water levels. It is particularly noteworthy that the lulls do not – as far as it is possible to say with the available dating precision –consistently occur at times of changes in palaeohydrological conditions. The start of Activity Lull C begins at ~800-775 cal BC, coinciding with dry conditions on many bogs whose timing is constrained by the presence of the GB4-150 tephra, dated to 800-760 cal BC (Plunkett et al., 2004). The start of Activity Lull D is closely associated with a wet shift whose timing in at least one bog (Dead Island) can be placed in the latter half of the 9th century AD. This strongly suggests that *on the whole* lulls were not prompted by palaeoclimate transitions. Curiously, apart from Activity Phase 1/Lull A (which only includes two sites of Later Neolithic date) and the spread of sites across the last millennium, the lulls between the activity phases occur at transitions between nominal archaeological periods, namely the Early/Middle Bronze Age (Activity Lull A), the Middle/Late Bronze Age (Lull B), the

Late Bronze Age/Developed Iron Age transition (now termed the Early Iron Age but until recently regarded as a cultural dark age [Becker at al., 2008]) (Lull C), the Late Iron Age (also regarded as a cultural hiatus) (Lull D), and the Viking town era of the Early Medieval Period (Lull E). Although scholars of Irish archaeology may debate the timing of these periods, or indeed whether they constitute discernible cultural units at all, the lulls tend to indicate a discontinuity in certain human activities at these times.

Activity Phase 2 can be correlated with a major expansion in the number of recorded settlement sites across Ireland between ~1700-1325 cal BC (Ginn, 2012), including a good number in wetland areas (e.g. Pollack and Waterman, 1964; Bradley, 1997), and it is towards the end of this period that the highly productive Bishopsland industry emerges amid the context of strong trade links with various areas in Britain (Eogan, 1964; 1984). Whether or not the settlement record implies increased population pressure, the association of some wetland settlements with ‘fine’ objects negates the idea that peatlands were marginalised environments (Ó Néill and Plunkett, 2007) and the archaeological record as a whole illustrates the incorporation of peatlands into the general social landscape. There is a marked change in burial practices, as formal burials with grave goods decline, and the artefact record signifies a period of prosperity, certainly towards the end of the phase (Becker, 2006). Beginning before the 1628 BC growth anomaly, there is no clear climatic stimulus for these changes, although the palaeohydrology records suggest that relatively warmer/drier conditions prevailed that may have helped support a thriving subsistence economy. During this period, therefore, extensive settlement conceivably gave rise to a greater use of the landscape, incorporating peatlands and giving rise to a need or desire to build structures in these environments. These changes can be seen in the context of developments in neighbouring areas of Europe. Kristiansen (2007) identifies the period 1700-1500 cal BC as one of landscape transformation in northwest Europe associated with agricultural expansion possibly linked to the widespread availability of metal. In Britain, settlement expansion settlement expansion is also noted from ~1500 cal BC (Jones 2008) and in the Netherlands, there is evidence that, there too, peatland trackway construction was a cultural feature at this time (Casparie, 1987).

The end of this phase (Activity Lull B) may have coincided with increasingly cold/wet conditions, the timing of which is uncertain but evidence for which has also been put forward from Britain (e.g. Langdon and Barber, 2005). Indeed, climate deterioration around this time is thought to have been a contributing factor to the abandonment of field systems in southern Britain (Amesbury et al., 2008). Juxtaposed pollen and humification records from sites discussed in this paper indicate, however, continuity in the nature and extent of land-use following the wet shift (Plunkett, 2006; 2009a), which suggests that, irrespective of the *precise* timing of any widespread wet/cold shift around this time, the subsistence economy in Ireland was not notably altered in the wake of a climate deterioration. Thus, although the decline of peatland site construction in the early 14th century BC and a more general reduction in the settlement record both hint at a possible demographic crisis, neither phenomenon can be categorically attributed to agricultural failure in the wake of a climate deterioration, and indeed the pollen and artefactual evidence (the rise of the Bishopsland industry) appears to counter the idea of a population decline. An ability to withstand climatic fluctuations could have been facilitated in some part by the practice of mixed agriculture through much of the Middle and Late Bronze Age, in which relatively hardy barley was the predominant cereal component (Johnston, 2007) and the mode of production was seemingly one of self-sufficiency (Ginn, 2012). Whether or not peatland activity diminished before or after a climate shift cannot presently be ascertained, but it is seems likely linked primarily to a retraction of settlement.

The earlier half of Activity Phase 3, on the other hand, is characterised in many pollen records by a period of woodland regeneration, and in the archaeological record by the start of hillfort occupation and a curtailment in hoard deposition and burnt mound construction (Ó Néill, 2005; Plunkett, 2009a; 2009b), pointing to a different cultural milieu of which peatland use was a component. The precise dating of sites during this period is hampered by a plateau in the calibration curve that tends to smear dates across several centuries, but it would appear that there is the beginning of an expansion of activity in the wider archaeological record from the 12th century BC (Armit et al., 2013), from which time first swords in Ireland start are recorded (Matthews, 2011). Wet/cold conditions appear to have continued as this activity phase emerged, but the palaeohydrological records then indicate intra-site variability that hampers reliable climate reconstruction but that may denote the onset of warmer/drier conditions in the Irish Midlands in the 11th century, when dendro-dated sites begin to emerge. From around the same time, the artefactual record demonstrates the emergence of far-reaching trade links, and expansions in metalwork production and hoard deposition in peatlands, mirroring developments in Britain; the following two centuries are recognised as a pinnacle of technological and aesthetic creativity in later prehistoric Ireland (Eogan, 1994; 1995) and there is a further expansion in general activity (Armit et al., 2013). This latter period can again be associated, through palynological studies, with a high level of land clearance (Plunkett, 2009a; 2009b), presumably associated with agricultural output, but the start of the peatland activity pre-empts these developments and does not appear to be simply a response to a burgeoning economy or expanding population. Occupation sites, some of which are associated with fine objects, are again found in wetland areas (e.g. Raftery, 1942; Grogan et al., 1999; Hencken, 1942; Raftery, 1994), which together with the many peatland hoards imply that these environments were an integral part of the cultural landscape. Demographic expansion and intense agricultural activity have similarly been proposed for other regions of continental Europe within this same period (Kristiansen, 1994).

The decline of peatland site construction through the 9th century BC, ceasing perhaps as early as 800 cal BC, echoes the downturn in the wider archaeological record (Armit et al., 2013). In the absence of the tephra-dated palaeohydrological records, it would be very tempting and plausible to interpret these changes as responses to the onset of wetter/colder conditions observed in many sites in Ireland ~750 BC. As already noted, however, the tephra-dated palaeohydrological records indicate drier bog surface conditions at the start of this century. The peatland activity phase almost certainly comes to an end, therefore, during a period characterised by a drier/warmer climate when discontinuities are noted in numerous pollen records, including those from Garry, Sluggan, Claraghmore and Glen West (Plunkett, 2006; 2009a; 2009b), and the fall-off in site construction can be disassociated with the inferred climate event. Alternative triggers for the essential demise of the Irish Bronze Age *floruit* may then lie internally within an increasingly complex socio-political arena or an unsustainable culture of metal production and consumption, or externally by way of destabilised exchange networks with Britain and mainland Europe, where cultural discontinuities are also observed at this time (e.g. Needham, 2007).

The ensuing Activity Lull C is the least well defined discontinuity identified in this study as a large number of sites have high probabilities during this interval, and some dendro-dated sites were certainly constructed. In this instance, the lull is interpreted from the lower frequency of activity. Other contemporary archaeological sites dated by ^{14}C tend to suffer from the same imprecision resulting from the shape of the ^{14}C calibration curve at this time, and the understanding of the phase in wider terms is therefore restricted. The metalwork evidence, which ceases to show signs of exchange with Britain and continental Europe from ~700 BC, may signify economic stagnation (Raftery, 1994).

Activity Phase 4 emerges within a wider context of general woodland regeneration in pollen records from many areas of Ireland, but few archaeological sites of any kind (with the exception of dendro-dated peatland sites) can be firmly attributed to the period before ~300 cal BC (e.g. Raftery, 1994). This phase encompasses the end of what has traditionally been perceived as a cultural ‘dark age’, and which has only recently – mainly since the identification of dendro-dated peatland sites (Cross et al., 2001; Cross May et al., 2005a) – begun to emerge as a period of low visibility archaeology whose recognition has been greatly hampered by the long ^{14}C calibration plateau between ~800-400 cal BC. Certainly from a material culture perspective, there is little with which to define the period ~500-300 cal BC, as the artefact record is largely devoid of objects certainly post-dating ~700 BC and pre-dating ~300 BC. The peatland sites can be seen to fit within an increasing body of non-distinctive site types that can be now attributed to this period (Becker et al*.,* 2008), extending into the more developed stage of the Irish Iron Age which is renowned for its major ceremonial/political centres, linear earthworks and fine metalwork with British affinities, as well as lakeside settlement. The prevailing climatic conditions seem to have been warmer/drier throughout the phase. Although many pollen records show only very minor evidence of human impact on the landscape before ~300 cal BC (e.g. Molloy and O'Connell, 1991; Plunkett, 2009b), there are exceptions (Molloy, 2005), and the peatland sites provide reliable evidence for a human presence that surpasses the "dryland" archaeological or palynological records. Indeed, at both Derryville and Edercloon, where much of the early Phase 4 activity is concentrated, there is only limited evidence for farming activity in the surrounding area until ~200 cal BC (Caseldine et al*.,* 2005; Plunkett, forthcoming). Again, it seems that the increase in peatland site construction occurs intriguingly in the absence of any overt changes in climate, demography or economic productivity, although drier bog surfaces may have facilitated activity. Interestingly, this appears to be a period of trackway building in Dutch bogs too (Casparie, 1987).

The subsequent Activity Lull D stands out as a prolonged period in which little or no peatland activity took place. This reflects a lacuna in the general archaeological record, the cultural significance of which continues to be a matter of conjecture, although a major population crash has been hypothesised (Weir, 1993; 1995). Pollen records variously show signs of woodland clearance from as early as ~cal AD 200-300 (Weir, 1993), demonstrating human presence during this time, but the precise timing of the evidence has not yet been thoroughly assessed. More recent research suggests continued representation of human presence in the archaeological record through undiagnostic, low visibility sites (Becker et al*.,* 2008). An alternative explanation to a demographic decline may lie in part in the economic impact of the Roman occupation of Britain and adjacent Europe and its affects on the socio-political structure of Late Iron Age Ireland (Newman, 1998), although this does not account for the decline in peatland activity. While it may be argued that the bog surface conditions were generally drier at this time, and that constructions were not needed to facilitate activity on and around the bogs, a gap in the peatland archaeology record is also recorded at this time at Derryville Bog during a period of high water table (Caseldine et al*.,* 2005).

Activity Phase 5 occurs during a period of generally wetter/colder conditions, but coincides with the start of the Early Medieval period in Ireland, which is characterised by major changes in the settlement record, including an upsurge in the number of domestic farmsteads (known in Ireland as raths) and lake settlements, and the emergence of monasticism and the vast creative industry that accompanied it. Baillie (1995) has argued that a short-lived catastrophe at AD 540, interpreted from the tree-ring record, provided impetus for the spread of the Christian faith, more traditionally credited to the efforts of St Patrick in the mid-fifth century AD. The siting of some early churches and monasteries on bog islands certainly played a role in the proliferation of large trackways through bogs during this phase (McDermott, 1998) but peatland activity undoubtedly began sometime in the century and a half before the hypothesised environmental catastrophe. Post-rows that are cross areas of peatlands during this phase possibly relate to the emergence of formalised land divisions (Cross et al*.,* 2001), and the reasons for peatland activity are, in this phase, more explicitly multifarious. The archaeological, literary and palynological evidence together provide an overwhelming impression that this was a 'golden age' in Ireland that was supported by a thriving, mixed subsistence economy (Kelly, 1997; Hall, 2000; 2003). Dendro-dates from horizontal mills indicate intensive agricultural output between the 8th and early 10th centuries at least (Brady, 2006). It may be no coincidence that the dendro-dated peatland sites decline from the mid-8th century after which trackways continued to be constructed from other building material, including short-lived oak and non-oak planks, until ~cal AD 900. Potentially, intensive land-use may have impacted on the extent and/or age structure of native woodland, limiting the availability of mature oaks for 'mundane' purposes.

Peatland site construction in Activity Phase 5 ostensibly continues through wet and dry phases on the bogs, regardless of whether or not climate impacted on other aspects of society at this time, but it may have come to an end as conditions got wetter around the end of the 9th century. The exact timing of the wet shift cannot be ascertained, but at Dead Island Bog, it can be demonstrated to occur immediately after the deposition of the 'AD860B' tephra, suggesting a date in the latter half of the 9th century. The hiatus represented by Activity Lull E represents a short interlude which corresponds a period of major social and economic re-organisation, following the rise of Viking Dublin as an economic hub (Edwards, 2005), and the decline in peatland sites from ~cal AD 900 could quite possibly be linked to a general change in socio-political or economic activity.

The re-emergence of site construction in Activity Phase 6 can be seen against a backdrop of BSW records whose variability hinders the reconstruction of a consistent palaeoclimate record, but which should arguably encompass the Medieval Warm Period and the early stages of the Little Ice Age. Whether or not these climate fluctuations impacted in any coherent way on bog surface conditions, there seems to be little suggestion in the peatland archaeological record, notwithstanding the certain taphonomic loss of sites, of an associated response in human activity. The relative confinement of dendro-dated sites to the period between mid-12th century or after the mid-13th century may again reflect over-exploitation of oak woodland and/or restricted timber resources, as peatland sites are certainly built from other materials over a much more extended timeframe.

Overall, the peatland archaeological sites provide a valuable record of changes in the levels of past human interactions with these environmentally-sensitive environments. Our results indicate that periods of intensive and reduced activity show no linear relationship with periods of climate change, or to local-scale responses to autogenically-driven BSW levels at individual bogs. In many instances, it seems that this activity took place at times in which other wetland constructions, namely lakeside settlements, are frequent, for which there are prolific artefactual records that indicate extensive external trade links, and during which there is palynological evidence for extensive woodland clearance (Hall, 2000; 2003; Plunkett, 2009a). Together, these elements point to widespread settlement patterns, productive subsistence and craft economies, and presumably, considerable movement through the landscape, and may even reflect periods of increased populations. It is no surprise, then, that structures would be constructed within Ireland's extensive bog systems to aid the exploitation of these environments and movement across them. More intriguing, however, are the periods between ~1225-1100 cal BC and ~500-300 cal BC when peatland site construction appears to pre-empt the cultural expansions of the Late Bronze Age and Iron Age, respectively, and reveal a degree of continuity at least in terms of landscape use that is not otherwise explicit in the archaeological record. Caution must therefore be applied in interpreting the activity lulls in terms of demographic crashes, and wider economic impacts, including developments beyond Ireland, must be given due consideration.

5.0 Conclusions

The evidence presented here suggests that human activity took place on Irish bogs during specific phases of the last five millennia mainly irrespective of the influence of the prevailing climate conditions. Although excessively wet conditions may have served as a barrier to site construction in certain bogs at certain times, there are clearly extra-local trends in the periods of peatland site construction that suggest that the impetus for such activity has a wider relevance. Similarly, the suggestion that trackways reflect "opportunistic ventures" on the part of the peatland users, building sites when conditions on the bog facilitated or necessitated them (Bermingham, 2005, p. 273), cannot explain the existence of a national pattern of peatland use, which seems to be significantly culturally-determined. Rather, it seems that cultural reasons were the prime motivators for changing levels of human interaction with these environments through time, and there is unlikely to be any single interpretation to account for increased or decreased activity associated with each phase. Thus, although activity at any one bog may have at times been limited by local bog surface wetness levels, the main periods of increased peatland usage were governed by wider cultural trends characterised in the main (though not exclusively) by what seem to have been general expansions in settlement and burgeoning economies, and perhaps population levels. Furthermore, at least two of the phases recognised in this paper appear to have counterparts in other parts of Europe, namely Activity Phases 2 and 4 (Casparie, 1987), further pointing to a social impetus for these undertakings. The peatland sites, both in their acme and hiatuses, quite clearly highlight the interconnectedness of communities on a range of scales, from the local to the inter-regional.

We do not suggest that climate had no impact on past Irish societies. Literary and historical records provide ample evidence that human populations were at times at the mercy of their environment: bad winters decimated livestock, bad summers led to crop failure, and human populations invariably suffered as a consequence (e.g. Kelly 1997). For the most part, these events left no appreciable mark on the cultural record (see, for example, the frequent annalistic references to extreme weather events sometimes leading to significant mortality rates which did not ostensibly alter the nature of Early Medieval and Medieval societies or economies [Corpus of Electronic Texts: http://www.ucc.ie/celt/publishd.html]), but sustained environmental crises could well have stimulated an enduring social response (e.g. Kerr et al., 2009). Instead, we draw attention to the potential pitfalls of interpreting cause-and-effect on the basis of close temporal proximity of cultural and climate changes. The peatland archaeological record from Ireland provides an excellent illustration of the need for tight dating control if the relationship between climate and cultural changes is to be established. Understanding of the ^{14}C- and dendro-dated archives has been greatly enhanced through their mutual comparisons, and the phases identified in this paper provide a well-dated framework with which to examine changes in other aspects of the archaeological record. Identifying coherent palaeoclimate changes in proxy records is in itself fraught with difficulties, as this paper shows, mitigated to some extent through the identification of tephra isochrons, and there is a clear need for a more critical approach to drawing correlations between closely-dated events. Where they exist, combined palaeoclimatic proxies and palynological records can be used to bridge the chronologically murky gulf between the palaeoenvironmental and archaeological records, and to test whether reconstructed climate events had a perceptible impact on agricultural productivity.

Acknowledgements

We are grateful to Catríona Moore, CRDS Ltd., for making available forthcoming archaeological data from Edercloon, Co. Longford, and to Pete Langdon, University of Southampton, and Antony Blundell, University of Leeds, for kindly providing published palaeohydrological data.

References

Amesbury, M.J., Charman, D.J., Fyfe, R.M., Langdon, P.G., West, S., 2008. Bronze Age settlement decline in southwest Britain: testing the climate change hypothesis. Journal of Archaeological Science 35, 87-98.

An, C.B., Feng, Z.D., Barton, L., 2004. Environmental change and cultural response between 8000 and 4000 cal. yr BP in the western Loess Plateau, northwest China. Journal of Quaternary Science 19, 529-35.

Armit, I., Swindles, G.T., Becker, K., 2013. From dates to demography in later prehistoric Ireland? Experimental approaches to the meta-analysis of large ^{14}C data-sets. Journal of Archaeological Science 40, 433-438.

Baillie, M.G.L., 1982. Tree-ring Dating and Archaeology. Croom Helm, London.

Baillie, M.G.L., 1989. Hekla 3: how big was it? Endeavour 13, 78-81.

Baillie, M.G.L., 1993. Dark Ages and dendrochronology. Emania 11, 3-12.

Baillie, M.G.L., 1995. Patrick, comets and Christianity. Emania 13, 69-78.

Baillie, M.G.L., 1999. Exodus to Arthur. B.T. Batsford, London.

Baillie, M.G.L., Munro, M.A.R., 1988. Irish tree rings, Santorini and volcanic dust veils. Nature 332, 344-346.

Baillie, M.G.L., Brown, D.M., 1995. Some deductions on ancient Irish trees from dendrochronology. In: Pilcher, J.R., Mac an tSaoir, S. (Eds.), Wood, Trees and Forests in Ireland.. Royal Irish Academy, Dublin, pp. 35-50.

Baillie, M.G.L., Brown, D.M., 1996. Dendrochronology of Irish bog trackways. In: Raftery, B., Trackway Excavations in the Mountdillon Bogs, Co. Longford, 1985-1991, Irish Archaeological Wetland Unit Transactions 3, Crannóg Publication, Dublin, pp. 395-402.

Baillie, M.G.L., Brown, D.M., 2002. Oak dendrochronology. some recent archaeological developments from an Irish perspective. Antiquity 76, 497-505.

Barber, K.E., Maddy, D., Rose, N., Stevenson, A.C., Stoneman, R., Thompson, R., 2000. Replicated proxy-climate signals over the last 2000 yr from two distant UK peat bogs: new evidence for regional palaeoclimate teleconnections. Quaternary Science Reviews 19, 481-487.

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.

Bayliss, A., Bronk Ramsey, C., van der Plichet, J., Whittle, A., 2007. Bradshaw and Bayes: towards a timetable for the Neolithic. Cambridge Archaeological Journal 17 (suppl.), 1-28.

Becker, K., 2006. Hoards and deposition of the Bronze and Iron Age in Ireland. Unpublished PhD thesis, University College Dublin, Dublin.

Becker, K., Ó Néill, J., O'Flynn, L., 2008. Iron Age Ireland: Finding an Invisible People. Unpublished report to the Heritage Council (http://www.ucd.ie/t4cms/IRON_AGE_IRELAND_Project_16365_PilotWeb.pdf, accessed 11 October 2012).

Bermingham, N.C., 2005. Palaeohydrology and archaeology in raised mires: a case study from Kilnagarnagh. Unpublished PhD thesis, University of Hull (accessible through http://ethos.bl.uk/)

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, J., 1997. Archaeological excavations at Moynagh Lough, Co. Meath 1995-96. Ríocht na Midhe 9 (3), 50-60.

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, Arizona, 39-68.

Brindley, A.L., Lanting, J.N., 1998. Radiocarbon dates for Irish trackways. Journal of Irish Archaeology IX, 45-68.

Bronk Ramsey, C., 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. Radiocarbon 37, 425-430.

Bronk Ramsey, C., 2001. Development of the radiocarbon program OxCal. Radiocarbon 43, 355-363.

Brooks, N., 2006. Cultural responses to aridity in the Middle Holocene and increased social complexity. Quaternary International 151, 29-49.

Brown, D.M., Baillie, M.G.L., 2012. Confirming the existence of gaps and depletions in the Irish oak tree-ring record. Dendrochronologia 30, 85-91.

Bryson, R.A., Lamb, H.H., Donley, D.L., 1974. Drought and the decline of Mycenae. Antiquity 48, 46-50.

Buckland, P.C., Amorosi, T., Barlow, L.K., Dugmore, A.J., Mayewski, P.A., McGovern, T.H., Ogilvie, A.E.J., Sadler, J.P., P. Skidmore, P., 1996. Bioarchaeological and climatological evidence for the fate of Norse farmers in medieval Greenland. Antiquity 70, 88-96.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J., 2011. 2500 years of European climate variability and human susceptibility. Science 331, 578-582.

Burgess, C., 1974. The Bronze Age. In: Renfrew, C. (Ed.), British Prehistory. Duckworth, London, pp. 165-232.

Burgess, C., 1989. Volcanoes, catastrophe and the global crisis of the late second millennium BC. Current Archaeology 117, 325-329.

Caseldine, C., Geary, 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, 1-18.

Caseldine, C., Hatton, J., Gearey, B., 2005. Pollen and palaeohydrological analyses. In: Gowen, M., Ó Néill, J., Phillips, M. (Eds.), The Lisheen Mine Archaeological Project, 1996-98, Wordwell, Bray, pp. 83-136.

Casparie, W.A., 1987. Bog trackways in the Netherlands. Palaeohistoria 29, 35-65.

Casparie, W.A., 2005. Peat morphology and bog development. In M. Gowen, J. Ó Néill & M. Phillips (Eds.), The Lisheen Mine Archaeological Project, 1996-98, Wordwell, Bray, 13-54.

Casparie, W.A., Moloney, A., 1996. Corlea 1: palaeo-environmental aspects of the trackway. In: Raftery, B., Trackway Excavations in the Mountdillon Bogs, Co. Longford, 1985-1991, Irish Archaeological Wetland Unit Transactions 3, Crannóg Publication, Dublin, pp. 367-377.

Charman, D.J., 2007. Summer water deficit controls on peatland water table changes: implications for Holocene palaeoclimate reconstructions. The Holocene 17, 217-227.

Chiverrell, R.C., Thorndycraft, V.R., Hoffmann, T.O., 2011, Cumulative probability functions and their role in evaluating the chronology of geomorphological events during the Holocene. Journal of Quaternary Science 26, 76-85.

Coulter, S.E., Pilcher, J.R., Plunkett, G., Baillie, M., Hall, V.A., Steffensen, J.-P., Vinther, B., Clausen, H.B., Johnsen, S.J. in press. Holocene tephras highlight complexity of volcanic signals in Greenland ice cores**.** Journal of Geophysical Research – Atmospheres.

Cross, S., Murray, C., Ó Néill, J., Stevens, P., 2001. Derryville Bog: a vernacular landscape in the Irish Midlands. In: Raftery, B., Hickey, J. (Eds.), Recent Developments in Wetland Research, Seandálaíocht Monograph 3, Department of Archaeology, University College Dublin and WARP Occasional Paper 14, University College Dublin, Dublin, pp. 87-97.

Cross May, S., Murray, C., Ó Néill, J., Stevens, P., 2005a. Catalogue of wetland sites. In: Gowen, M., Ó Néill, J., Phillips, M. (Eds.), The Lisheen Mine Archaeological Project, 1996-98, Wordwell, Bray, pp. 223-282.

Cross May, S., Murray, C., Ó Néill, J., Stevens, P., 2005b. Terrain sensitivity. In: Gowen, M., Ó Néill, J., Phillips, M. (Eds.), The Lisheen Mine Archaeological Project, 1996-98, Wordwell, Bray, pp. 341-350.

deMenocal, P. 2001. Cultural responses to climate change during the late Holocene. Science 292, 667-673.

Edwards, N. 2005. The archaeology of Early Medieval Ireland, c.400-1169: settlement and economy. In: Ó Cróinín, D. (Ed.), A New History of Ireland, Volume 1, Prehistoric and Early Ireland. Oxford University Press, Oxford, pp. 235-300.

Eogan, G., 1964. The Later Bronze Age in Ireland in the light of recent research. Proceedings of the Prehistoric Society 14, 268-351.

Eogan, G., 1994. The Accomplished Art: Gold and Gold-Working in Britain and Ireland During the Bronze Age (c.2300-650 B.C.). Oxbow Monographs in Archaeology 42, Oxford.

Eogan, G., 1995. Ideas, people and things: Ireland and the external world during the Later Bronze Age. In: Waddell, J., Shee Twohig, E. (Eds.), Ireland in the Bronze Age. The Stationery Office, Dublin, pp. 128-135.

Gamble, C., Davies, W., Pettitt, P., Hazelwood, L., Richards, M., 2005. The archaeological and genetic foundations of the European population during the late glacial implications for 'agricultural thinking'. Cambridge Archaeological Journal 15, 193-223.

Gearey, B.R., Caseldine, C.J., 2006. Archaeological applications of testate amoebae analyses: a case study from Derryville, Co. Tipperary, Ireland. Journal of Archaeological Science 33, 49-55.

Ginn, V. 2012 Settlement structure in Middle-Late Bronze Age Ireland. Unpublished PhD thesis, Queen's University Belfast.

Grogan, E., O'Sullivan, A., O'Carroll, F., Hagen, I., 1999. Knocknalappa, Co. Clare: a reappraisal. Discovery Programme Reports 5, 111-123.

Hall, V.A., 2000. The documentary and pollen analytical records of the vegetational history of the Irish landscape AD 200-1650. Peritia, Journal of the Medieval Academy of Ireland 14, 342-369.

Hall, V.A., 2003. Vegetation history of mid- to western Ireland in the 2nd millennium A.D.; fresh evidence from tephra-dated palynological investigations. Vegetation History and Archaeobotany 12, 7-17.

Hassan, F.A. 2001. The collapse of the old kingdom: low floods, famine and anarchy. Monsoon 3, 39.

Haug, G.H., Günther, D., Peterson, L.C., Sigman, D.M., Hughen, K.A., Aeschlimann, B., 2003. Climate and the collapse of Maya civilization. Science 299, 1731-1735.

Hencken, H.O'N., 1942. Ballinderry Crannog No. 2. Proceedings of the Royal Irish Academy 47C, 1-76.

Johnston, P., 2007. Analysis of carbonised plant remains. In: Grogan, E., O'Donnell, L., Johnston, P., The Bronze Age Landscapes of the Pipeline to the West. Wordwell, Bray, pp. 70-79.

Jones, A.M., 2008. Houses for the dead and cairns for the living; a reconsideration of the Early to Middle Bronze Age transition in south-west England. Oxford Journal of Archaeology 27, 153-174.

Kelly, F., 1997. Early Irish Farming. School of Celtic Studies, Dublin Institute for Advanced Studies, Dublin.

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

Kristiansen, K., 1994. The emergence of the European world system in the Bronze Age: divergence, convergence and social evolution during the first and second millennia BC in Europe. In: Kristiansen, K., Jensen, J. (Eds.), Europe in the First Millennium B.C. (Sheffield Archaeological Monographs 6). J.R. Collis, Sheffield, pp. 7-30.

Kristiansen, K., 2007. Household economy, long-term change, and social transformation: the Bronze Age political economy of northwestern Europe. Nature and culture 2, 71-86.

Langdon, P.G., Barber, K.E., 2005. The climate of Scotland over the last 5000 years inferred from multiproxy peatland records: inter-site correlations and regional variability. Journal of Quaternary Science 20, 549-566.

Langdon P.G., Brown, A.G., Caseldine, C.J., Blockley, S.P.E., Stuijts, I., 2012. Regional climate change from peat stratigraphy for the mid- to late Holocene in Central Ireland. Quaternary International 268, 145-155.

Matthews, S., 2011. Chelsea and Ballintober swords: typology, chronology and use. In: Mödlinger, M., Uckelmann, M., Matthews, S. (Eds.), Bronze Age Warfare: Manufacture and Use of Weaponry (British Archaeological Reports International Series 2255). Archaeopress, Oxford, pp. 85-105.

McAnany, P.A., Yoffee, N. (Eds.), 2010. Questioning Collapse. Cambridge University Press, Cambridge.

McDermott, C., 1998. The prehistory of the Offaly peatlands. In: Nolan W., O'Neill, T.P. (Eds.), Offaly History and Society. Geography Publications, Dublin, pp. 1-28.

McDermott, C., 2001. Trekkers through time: recent archaeological survey results from Co. Offaly, Ireland. In: Raftery, B., Hickey, J. (Eds.), Recent Developments in Wetland Research. Seandálaíocht Monograph 3, Department of Archaeology, University College Dublin and WARP Occasional Paper 14, University College Dublin, Dublin, pp. 13-25.

McDermott, C., 2007. ''Plain and bog, bog and wood, Wood and bog, bog and plain!': Peatland archaeology in Ireland'. In: Barber, J., Clark, C., Cressey, M., Crone, A., Hale, A., Henderson, J., Housley, R., Sands, R., Sheridan, A. (Eds.), Archaeology from the Wetlands: Recent Perspectives. Proceedings of the 11th WARP Conference, Edinburgh 2005. Society of Antiquaries of Scotland, Edinburgh, pp. 17-30.

McDermott, F., Frisia, S., Huang, Y., Longinelli, A., Spiro, B., Heaton, T.H.E., Hawkesworth, C.J., Borsato, A., Keppens, E., Fairchild, I.J., van der Borg, K., Verheyden, S., Selmo, E., 1999. Holocene climate variability in Europe: evidence from $\delta^{18}O$, textural and extension-rate variations in three speleothems. Quaternary Science Reviews 18, 1021-1038.

McDermott, F., Mattey, D.P., Hawkesworth, C., 2001. Centennial-scale Holocene climate variability revealed by a high-resolution speleothem $\delta^{18}O$ record from SW Ireland. Science 294, 1328-1331.

Mills, G., 2000. Modelling the water budget of Ireland – evapotranspiration and soil moisture. Irish Geography 33, 99-116.

Molloy, K., 2005. Holocene vegetation and land-use history at Mooghaun, south-east Clare, with particular reference to the Bronze Age. In: Grogan, E., The North Munster Project, Vol. 1: The Later Prehistoric Landscape of South-East Clare. Discovery Programme Reports No. 6, Wordwell, pp. 255-287.

Molloy, K., O'Connell, M., 1991. Palaeoecological investigations towards the reconstruction of woodland and land-use history at Lough Sheeauns, Connemara, western Ireland. Review of Palaeobotany and Palynology 67, 75-113.

Munoz, S.E., Gajewski, K., Peros, M.C., 2010. Synchronous environmental and cultural change in the prehistory of the northeastern United States. Proceedings of the National Academy of Sciences 107, 22008–22013.

Needham, S., 2007. 800 BC, the great divide. In: Haselgrove, C., Pope, R. (Eds.), *The earlier Iron Age in Britain and the near Continent*. Oxbow Books, Oxford, pp. 39-64.

Newman, C., 1998. Reflections on the making of a ‘royal site’ in early Ireland. World Archaeology 30, 127–141.

Ó Néill, J., 2005. The historical burnt mound tradition in Ireland. Journal of Irish Archaeology 13, 77-84.

Ó Néill, J., Plunkett, G., 2007. A Middle Bronze Age occupation site at Ballyarnet Lake, Co. Derry: the site and its wider context. In: Barber, J., Clark, C., Cressey, M., Crone, A., Hale, A., Henderson, J., Housley, R., Sands, R., Sheridan, A. (Eds.), Archaeology from the Wetlands: Recent Perspectives. Proceedings of the 11th WARP Conference, Edinburgh 2005, Society of Antiquaries of Scotland, Edinburgh, pp. 175-181.

Oram, R., Adderley, W.P., 2008. Lordship and environmental change in Central Highland Scotland c.1300-c.1400. Journal of the North Atlantic 1, 74-84.

Pilcher, J.R., Baillie, M.G.L., Brown, D.M., McCormac, F.G., MacSweeney, P.B., McLawrence, A.S., 1995. Dendrochronology of subfossil pine in the north of Ireland. Journal of Ecology 83, 665-671.

Pilcher, J.R., Hall, V.A., McCormac, F.G., 1996a. An outline tephrochronology for the Holocene of the north of Ireland. Journal of Quaternary Science 11, 485-494.

Pilcher, J.R., Baillie, M.G.L., Brown, D.M., McCormac, F.G., 1996b. Hydrological data from the long Irish subfossil oak records. In: Dean, J.S., Meko, D.M., Swetman, T.W. (Eds.), Tree Rings, Environment and Humanity. Proceedings of the International Conference, Tucson, Arizona, 17-21 May 1994, Radiocarbon 1996, pp. 259-264.

Plunkett, G., 2006. Tephra-linked peat humification records from Irish ombrotrophic bogs question nature of solar forcing at 850 cal. BC. Journal of Quaternary Science 21, 9-16.

Plunkett, G., 2009a. Land-use patterns and cultural change in the Middle to Late Bronze Age in Ireland: inferences from the pollen record. Vegetation History and Archaeobotany 18, 273-295.

Plunkett, G., 2009b. Socio-political dynamics in later prehistoric Ireland: insights from the pollen record. In: Salisbury, R.B., Thurston, T., (Eds.), Reimagining Regional Analyses: The Archaeology of Spatial and Social Dynamics. Cambridge Scholars Press, Cambridge, pp. 42-66.

Plunkett, G., forthcoming. Vegetation history at Edercloon, Co. Longford. In: Moore, C., The results of the Edercloon excavations on the N4 Dromod-Roosky By-Pass. NRA Scheme Monograph Series, National Roads Authority, Dublin.

Plunkett, G.M., Pilcher, J.R., McCormac, F.G., Hall, V.A., 2004. New dates for first millennium BC tephra isochrones in Ireland. The Holocene 14, 780-786.

Pollock, A.J., Waterman, D.M., 1964. A Bronze Age habitation site at Downpatrick. Ulster Journal of Archaeology 27, 31-58.

Raftery, B., 1994. Pagan Celtic Ireland. Thames & Hudson, London.

Raftery, B., 1996. Trackway Excavations in the Mountdillon Bogs, Co. Longford, 1985-1991. Irish Archaeological Wetland Unit Transactions 3, Crannóg Publications, Dublin.

Raftery, J., 1942. Knocknalappa crannóg, Co. Clare. North Munster Antiquarian Journal 3, 53-72.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0-50,000 years cal BP. Radiocarbon 51, 1111-1150.

Riede, F., Edinborough, K., Thomas, M., 2009. Tracking Mesolithic demography in time and space and its implications for explanations of culture change. In: Crombé, P., van Strydonck, M., Sergant, J., Bats, M., Boudin, M. (Eds.), Chronology and Evolution within the Mesolithic of North-West Europe, Proceedings of an International Meeting, Brussels, May 30th-June 1st 2007. Cambridge Scholars Press, Newcastle, pp. 177-194.

Roberts, N., Eastwood, WJ., Kuzucuoglu, C., Fiorentino, G., Caracuta, V., 2011. Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition. The Holocene 21, 147-162.

Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon 35, 215-320.

Swindles, G.T., 2006. Reconstruction of Holocene climate change from peatlands in the north of Ireland. Unpublished PhD thesis, Queen’s University Belfast (accessible through http://ethos.bl.uk/).

Swindles, G.T., Plunkett, G., 2010. Testing the palaeoclimate significance of the Northern Irish bog oak record. The Holocene 20, 155-159.

Swindles, G.T., Plunkett, G., Roe, H., 2007a. A delayed climatic response to solar forcing at 2800 cal. BP: multi-proxy evidence from three Irish peatlands. The Holocene 17, 177-182.

Swindles, G.T., Plunkett, G., Roe, H., 2007b. A multi-proxy climate record from a raised bog in County Fermanagh, Northern Ireland: a critical examination of the link between bog surface wetness and solar variability. Journal of Quaternary Science 22, 667-679.

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.

Turney, C.S.M., Brown, H. 2007. Catastrophic early Holocene sea level rise, human migration and the Neolithic transition in Europe. Quaternary Science Reviews 26, 2036-2041.

Turney, C., Baillie, M., Clemens, S., Brown, D., Palmer, J., Pilcher, J., Reimer, P., Leuschner, H.H., 2005. Testing solar forcing of pervasive Holocene climate cycles. Journal of Quaternary Science 20, 511-518.

Turney, C.S.M., Baillie, M., Palmer, J., Brown, D., 2006. Holocene climatic change and past Irish societal response. Journal of Archaeological Science 33, 34-38.

van den Bogaard, C., Dörfler, W., Glos, R., Nadeau, M.-J., Grootes, P.M., Erlenkeuser, H., 2002. Two tephra layers bracketing Late Holocene paleoecological changes in Northern Germany. Quaternary Research 57, 314-324.

van Geel, B., Buurman, J., Waterbolk, H.T., 1996 Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological teleconnections around 2650 BP. Journal of Quaternary Science 11, 451-460.

van Geel, B., Bokovenko, N.A, Burova, N.D., Chugunov, K.V., Dergachev, V.A., Dirksen, V.G., Kulkova, M., Nagler, A., Parzinger, H., van der Plicht, J., Vasiliev, S.S., Zaitseva, G.I., 2004. Climate change and the expansion of the Scythian culture after 850 BC: a hypothesis. Journal of Archaeological Science 31, 1735-1742.

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

Weir, D.A., 1995. A palynological study of landscape and agricultural development in County Louth from the second millennium BC to the first millennium AD. Final report. Discovery Programme Reports 2, 77-126.

Weiss, B., 1982. The decline of Late Bronze Age civilization as a possible response to climatic change. Climatic Change 4, 173-198.

Williams, A.N., 2012. The use of summed radiocarbon probability distributions in archaeology: a review of methods. Journal of Archaeological Science 39, 578-589.

Yeloff, D., Mauquoy, D., 2006. Influence of vegetation composition on peat humification: implications for palaeoclimatic studies. Boreas 35, 662-673.

Zhang, D.D., Lee, H.F., Wang, C., Li, B., Pei, Q., Zhang, J., An, Y., 2011. The causality analysis of climate change and large-scale human crisis. Proceedings of the National Academy of Sciences 108, 17296-17301.

List of captions

Fig. 1. Location of main regions in which archaeological surveys of peatlands have been carried out in Ireland (*i*, Mountdillion; *ii*, Derrygreenagh; *iii*, Blackwater; *iv*, Littleton) and the three bogs (Corlea, Derryville and Edercloon) which have been the subject of major archaeological research projects. The locations of the bogs from which palaeohydrological records referred to in this study are also shown (SL, Slieveanorra; GA, Garry; DI, Dead Island; SG, Sluggan; CL, Claraghmore; GW, Glen West; OW, Owenduff; DE, Derragh; LL, Lough Lurgeen; AR, Ardkill; CO, Cloonoolish; MO, Moyreen). The contours indicate the average annual moisture deficit (9 mm) for the period 1961-1990 based on Mills (2000).

Fig. 2. Probability density functions (PDFs) of a) the ^{14}C dates from the peatland sites, alongside 25 yr bins of the dendro-dated sites. Also shown are simulated ^{14}C datasets representing: b) constant peatland site construction (weighted towards the period 1700 BC-AD 1650) (related calendar dates not shown due to their even distribution); c-e) random peatland site construction; and f-h) dates simulated from the precise and nearly precise dendro-dates from peatland sites. The Pearson correlation values of each set of data are indicated.

Fig. 3. Testate-amoebae-derived water table (WT) reconstructions (expressed as water table depth (cm) below surface) and humification (HU) records (standardised data expressed as arbitrary units, a.u.) from Ireland (see text for references). WT reconstructions error ranges have been removed for diagrammatic clarity. The locations of tephra isochrons are shown by boxes (grey boxes indicating tephra identity confirmed by geochemistry, white boxes indicating Microlite tephra identified visually on basis of feldspar inclusions, and circles indicating tephra identity inferred through morphology and stratigraphic position). Data from the individual records have been added together and ranked in chronological order to provide an overall compilation. A Lowess function is used to identify main trends in the records, whose significance is nevertheless assessed in the text on the basis of the individual palaeohydrology records. Dates of growth anomalies in Irish oaks are shown on the extreme left of the figure (Baillie and Munro, 1988), and approximate cultural divisions are indicated on the extreme right (LNeo: Late Neolithic; EBA: Early Bronze Age; MBA: Middle Bronze Age; LBA: Late Bronze Age; EIA: Early Iron Age; DIA: Developed Iron Age; LIA: Late Iron Age; EMed: Early Medieval Period; Med: Medieval and Post-Medieval Period; Mod: Modern Period). Green bands indicate the Peatland Activity Phases described in the text.

Fig. 4. The probability density function (PDF) and dendro-dates of archaeological sites in Irish peatlands, indicating the activity phases (AP) and lulls (AL) described in the text. Approximate cultural divisions (see Fig. 3 for abbreviations) and notably events are also indicated.

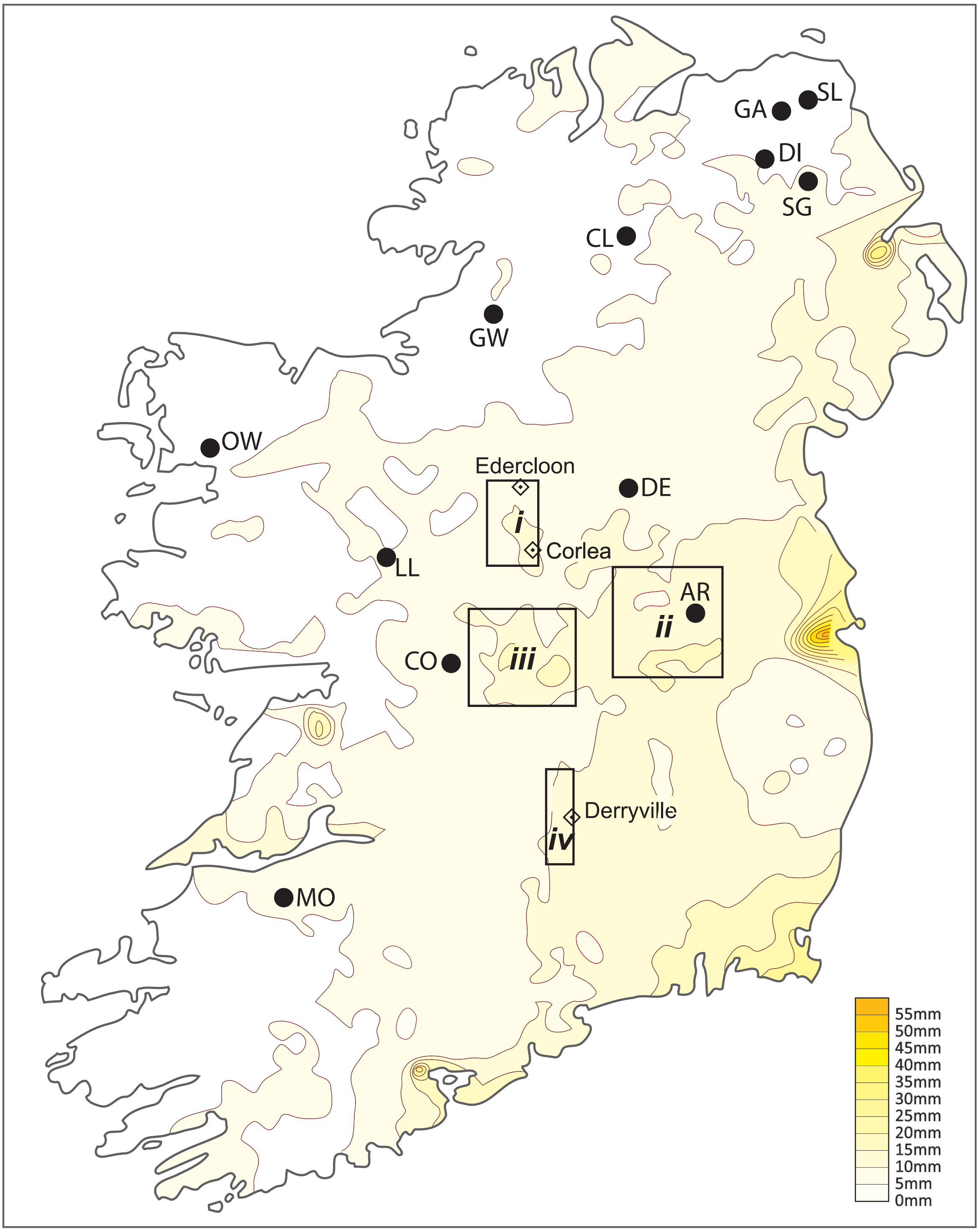
Supplementary Figure 1. Multiplots of the calibrated age ranges of individual ^{14}C-determinations used in this analysis. Green screens indicate the dates which are attributed to Activity Phases; orange screens indicate dates possibly attributed to Activity Lulls. Red lines indicate the timing of growth anomalies in Irish oaks (Baillie and Munro, 1988).

Table

Table 1: Summary of the Activity Phases and Lulls in peatland site construction identified in this paper.

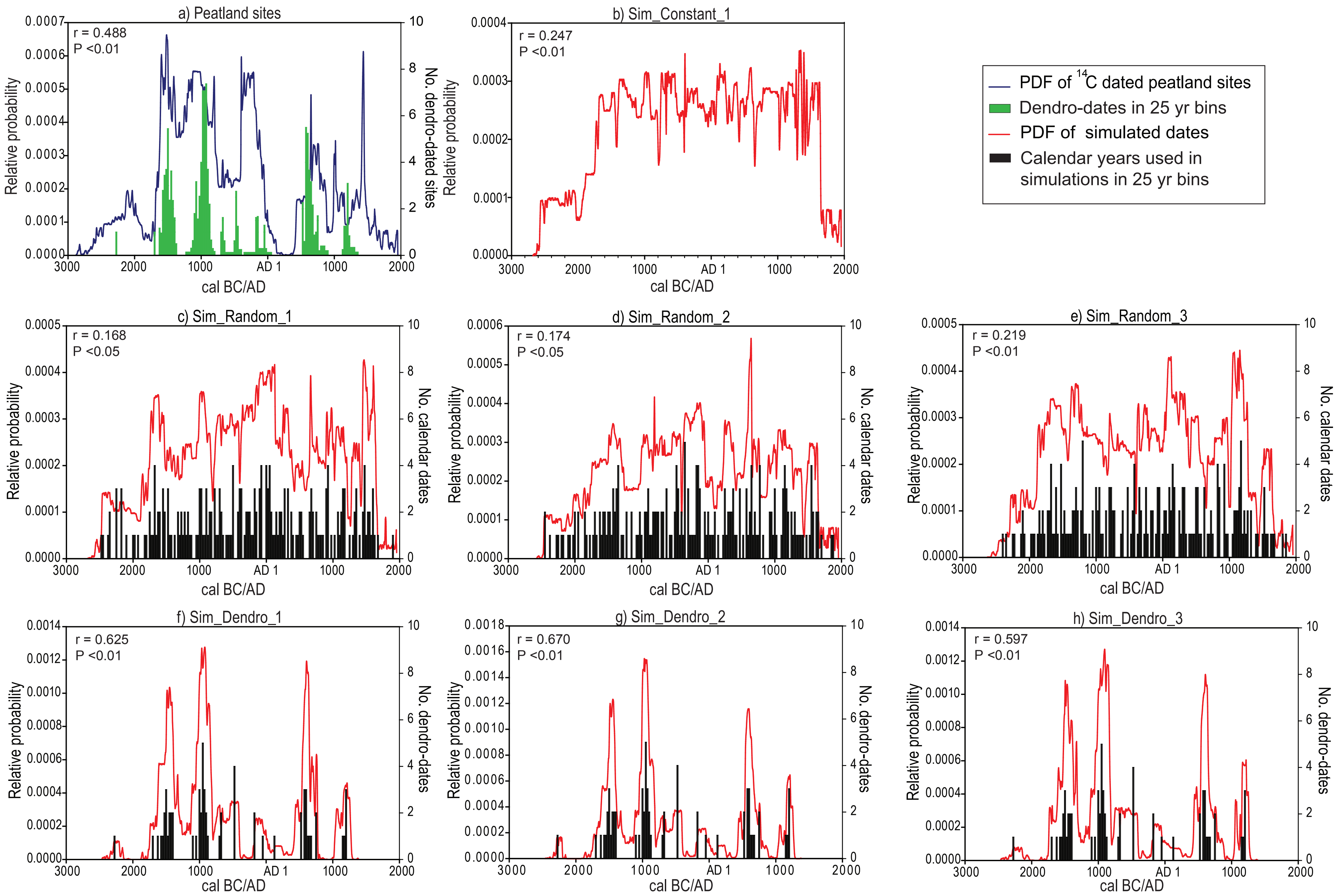
Activity Phase (AP)/ Lull (AL)	Age span (~calendar years)	No. sites	Average construction rate (yr per site)	Palaeohydrology summary
AP-1	2700-1900 BC	20	40	Drier conditions initially, but progressively wetter after ~ 2400 cal BC
AL-A	1900-1700 BC	1	200	Wet, similar to previous phase
AP-2	1700-1375 BC	62-66	5	Variability between records, but overall, slightly drier bog surfaces
AL-B	1375-1225 BC	3-13	12-50	Possible widespread wet shift during this period, but precise timing uncertain
AP-3	1225-775 BC	91-98	5	Wet at the start of the phase, followed by BSW fluctuations, but drier periods ~1100 cal BC and ~800 cal BC
AL-C	775-500 BC	16-17	14	Strong evidence from multiple sites for widespread wet period across this interval
AP-4	500 BC-AD 25	54-55	10	Increasingly drier bog surfaces
AL-D	AD 25-400	1	375	Generally drier conditions on the bogs, interrupted periodically by some wet shifts.
AP-5	AD 400-900	50-51	10	A shift to wetter conditions at the start of the phase, followed by fluctuating BSW, and culminating in possibly a drier period
AL-E	AD 900-1000	0-1	100	Possible widespread wet shift during this period, but precise timing uncertain
AP-6	AD 1000-1650	34	19	Overall trend towards increasing wetness, but considerable variability between sites

Figure

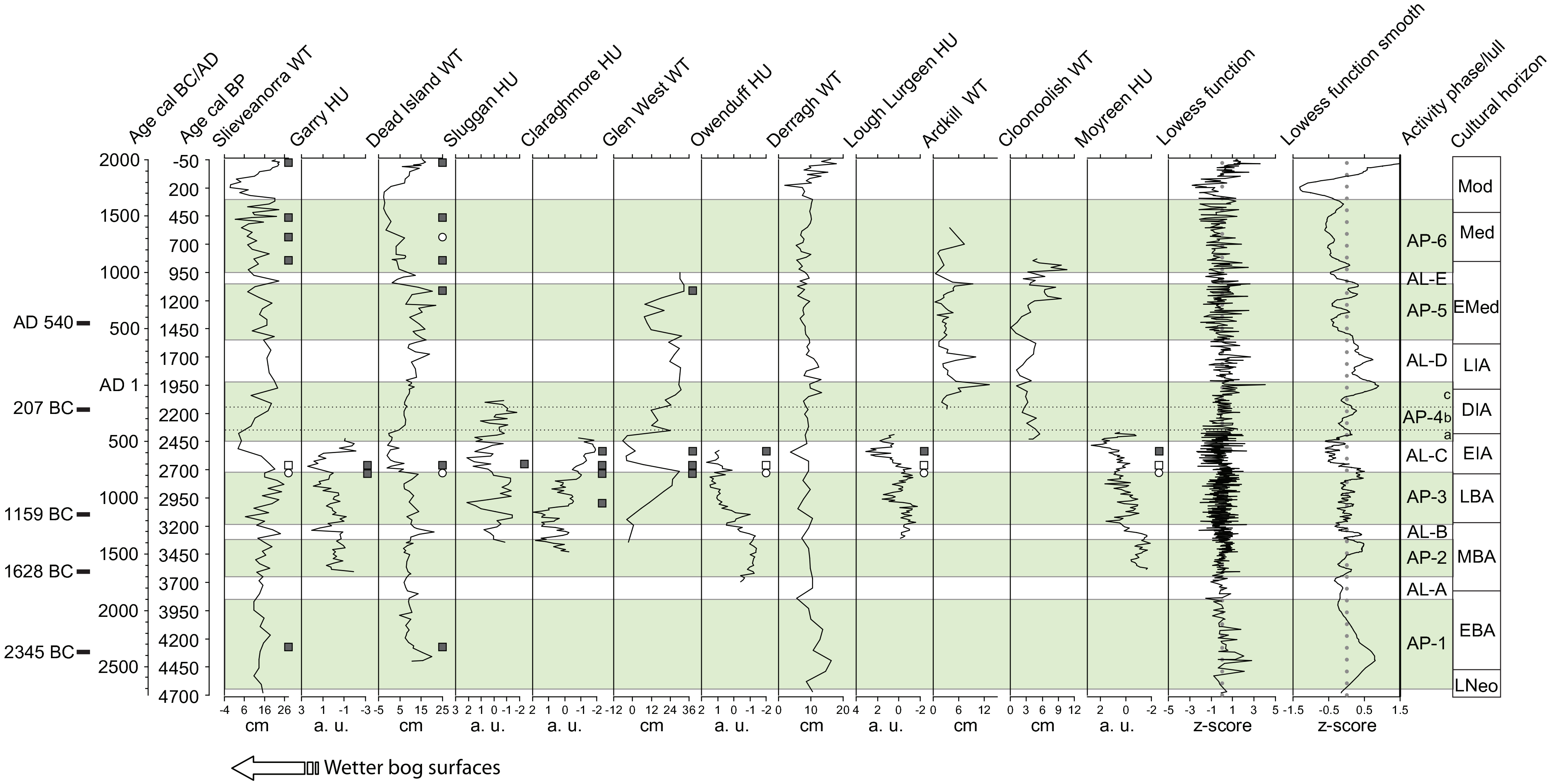


SL
GA
DI
SG
CL
GW
OW
Edercloon
i
Corlea
DE
LL
AR
ii
iii
CO
Derryville
iv
MO
55mm
50mm
45mm
40mm
35mm
30mm
25mm
20mm
15mm
10mm
5mm
0mm

Figure

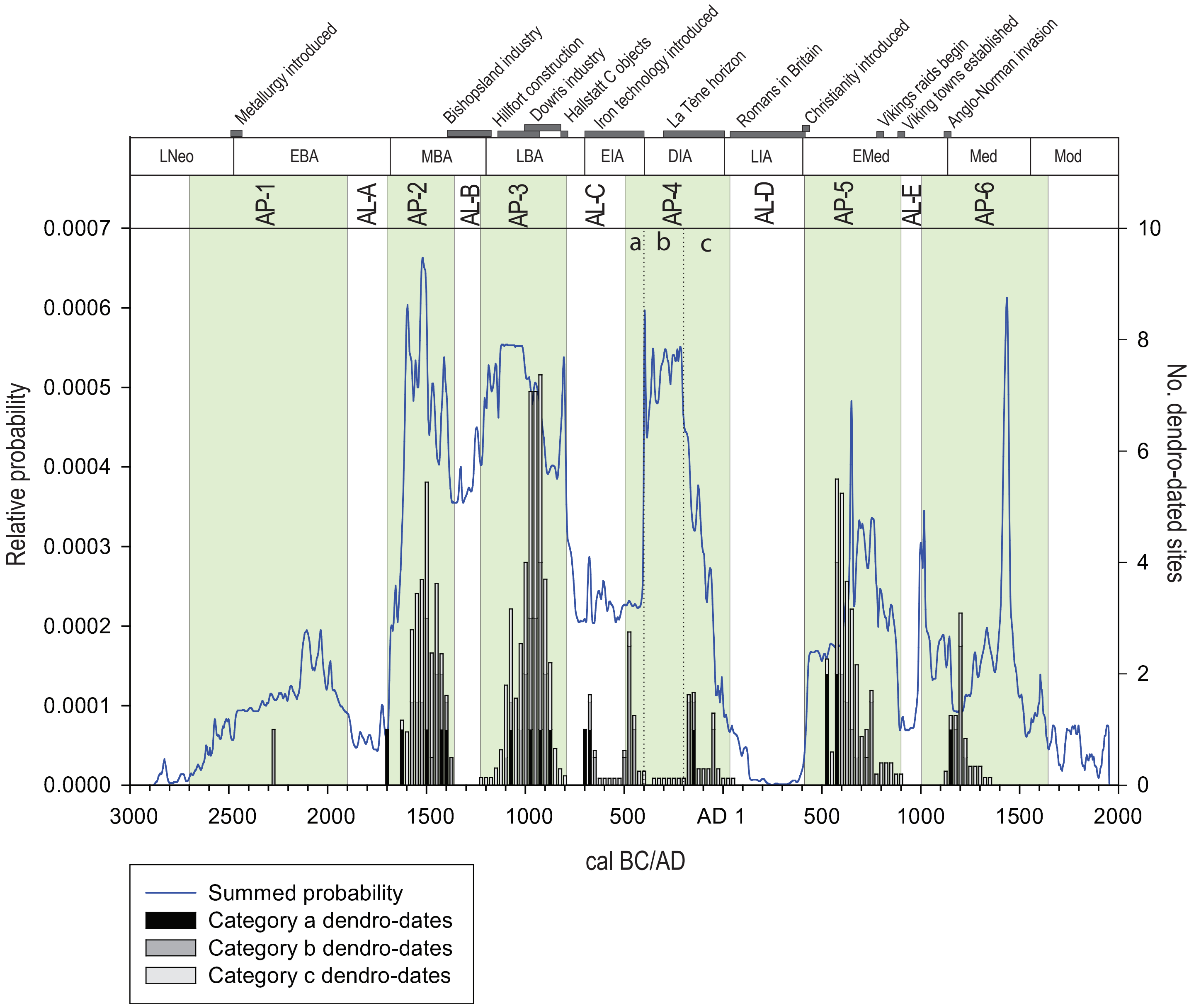

a) Peatland sites
r = 0.488
P <0.01
b) Sim_Constant_1
r = 0.247
P <0.01
PDF of ^{14}C dated peatland sites
Dendro-dates in 25 yr bins
PDF of simulated dates
Calendar years used in simulations in 25 yr bins
c) Sim_Random_1
r = 0.168
P <0.05
d) Sim_Random_2
r = 0.174
P <0.05
e) Sim_Random_3
r = 0.219
P <0.01
f) Sim_Dendro_1
r = 0.625
P <0.01
g) Sim_Dendro_2
r = 0.670
P <0.01
h) Sim_Dendro_3
r = 0.597
P <0.01
Relative probability
No. dendro-dated sites
No. calendar dates
No. dendro-dates
cal BC/AD
3000
2000
1000
AD 1
1000
2000

Figure



Age cal BC/AD
Age cal BP
Slieveanorra WT
Garry HU
Dead Island WT
Sluggan HU
Claraghmore HU
Glen West WT
Owenduff HU
Derragh WT
Lough Lurgeen HU
Ardkill WT
Cloonoolish WT
Moyreen HU
Lowess function
Lowess function smooth
Activity phase/lull
Cultural horizon
AD 540
AD 1
207 BC
1159 BC
1628 BC
2345 BC
cm
a. u.
z-score
AP-6
AL-E
AP-5
AL-D
AP-4
AL-C
AP-3
AL-B
AP-2
AL-A
AP-1
Mod
Med
EMed
LIA
DIA
EIA
LBA
MBA
EBA
LNeo
Wetter bog surfaces

Figure



Metallurgy introduced
Bishopsland industry
Hillfort construction
Dowris industry
Hallstatt C objects
Iron technology introduced
La Tène horizon
Romans in Britain
Christianity introduced
Vikings raids begin
Viking towns established
Anglo-Norman invasion
LNeo
EBA
MBA
LBA
EIA
DIA
LIA
EMed
Med
Mod
AP-1
AL-A
AP-2
AL-B
AP-3
AL-C
AP-4
AL-D
AP-5
AL-E
AP-6
a
b
c
Relative probability
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
No. dendro-dated sites
10
8
6
4
2
0
3000
2500
2000
1500
1000
500
AD 1
500
1000
1500
2000
cal BC/AD
Summed probability
Category a dendro-dates
Category b dendro-dates
Category c dendro-dates

Supplementary Data

Click here to download Supplementary Data: Suppl Note A.pdf

Supplementary Data

Click here to download Supplementary Data: Suppl Table 1.pdf

Supplementary Data
Click here to download Supplementary Data: Suppl Table 2.pdf