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Article

'Pine Decline or pine declines?' Analysis and Interpretation of Bog-Pines from Wem Moss, Shropshire, UK

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Abstract: A dendrochronological investigation was undertaken on subfossil Scots pine (*Pinus sylvestris* L.) stumps following their discovery during conservation management at Wem Moss, a small (28 ha) former raised mire in Shropshire, UK. Two ring-width chronologies were constructed from 14 of the 17 trees sampled spanning 198 and 208 years, respectively. Whilst dendrochronological dating was not possible, radiocarbon assays provided an estimated age for this mire-rooting woodland of between 3015 and 2505 years cal. BCE, coinciding with the age traditionally associated with the widespread mortality of pine trees throughout much of the UK and Ireland, often referred to as the Pine Decline (ca. 4000 radiocarbon years BP). Placed in a wider geographical context, the Wem Moss pines are located within the lowland Meres and Mosses region, where previous studies on subfossil pine have demonstrated protracted declines in mire-rooting trees. These have included tree mortality significantly post-dating the Pine Decline, especially at larger peatland sites that exceed 5 km^2. Such macrofossil evidence for the presence of Scots pine into the late Holocene is supported by continuous *Pinus* pollen representation at peatland sites in the Welsh Marches (English–Welsh border), suggesting the possible survival of native Scots pine trees in this area up to the present day. The investigation of Wem Moss bog pines and their wider geographical context highlights the incomplete and patchy nature of palaeo-vegetational records and also the need for future genetic research on living Scots pine in possible refugial areas in Britain and Ireland.

Keywords: climate change; dendrochronology; peatland archives; Pine Decline; *Pinus sylvestris* L.; radiocarbon dating

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1. Introduction

Under natural environmental and climatic conditions, many tree species are capable of colonising peatlands, particularly during periods of dry or relatively dry surface conditions [1,2]. Research in the last decade has demonstrated that tree growth and survival in these often-extreme environments is predominantly regulated by hydrological conditions, with climatic parameters correlated less well with dendrochronological records [2–5]. Peatland drainage events in the twentieth century CE have been clearly shown to promote tree colonisation and tree growth [6–9].

Past tree growth on peatlands over many centuries is often demonstrated by finds of isolated tree stumps and fallen trunks or apparent forest 'layers' revealed by erosion events, peat cutting, drainage and other human-related activities in Britain, Ireland and further afield, e.g., [2,10–16]. Whilst these subfossil trees are thought to represent previous drier peat surfaces, their preservational state can indicate wet conditions immediately post-mortem (intact bark and vertical trunk components) or relatively dry conditions (little trunk component remaining), as observed in subfossil pine (Figure 1), supporting other evidence for rapid natural fluctuations in past mire–surface hydrology during the Holocene.


(**a**) (**b**)

Figure 1. Subfossil bog pine (*P. sylvestris*) at Lindow Moss, Cheshire, UK. (**a**) Ex situ small diameter tree removed from an upper 'regeneration layer' in ombrotrophic peat–note c 20 cm of vertical trunk component facilitating sampling for dendrochronology. (**b**) In situ stump demonstrating some damage caused during mechanised peat extraction, but also limited surviving trunk component. Scale length 23 cm.

Preservation of organic remains in waterlogged peatlands is exemplified by investigations of bog bodies, such as Tollund Man (Denmark) and Lindow Man (England), that have provided detailed insights into our prehistoric past [17]. Human remains preserved in peat can, in addition to subfossil trees, also demonstrate imperfect preservation, with for instance bone demineralisation in acidic ombrotrophic peats and bone survival in nutrient-rich fens [18]. A variety of subfossil trees have been found in peat ranging from birch (Betula spp.), pine (*Pinus sylvestris*), oak (Quercus spp.), alder (*Alnus glutinosa*), willow (Salix spp.), hawthorn (Crataegus spp.), and hazel (*Corylus avellana*) in southern Pennine blanket peats, northern England (UK) [11,19], to yew stumps (*Taxus baccata*) in the fenlands of eastern England [20]. Preservation and usefulness of these trees for palaeoecological investigations can, however, vary considerably, with, for instance, the frequently occurring macrofossils of alder (*Alnus glutinosa*) and birch (Betula spp) failing to provide robust samples with sufficient tree-ring series for dendrochronological investigation. By contrast, oak (Quercus spp.) and pine (*P. sylvestris*), due to their generally broad spatial and temporal occurrence, and comparatively better preservation, have been the focus of palaeoecological investigations since the 1960s [2,21–28].

Research utilising subfossil trees and other proxy records such as pollen has revealed natural developments in wetland sites progressing from open water to eutrophic fens, culminating in raised ombrotrophic bogs [29]. Whilst this hydroseral succession has been demonstrated at numerous sites throughout north-west Europe, the successional pathways for wetland environments are known to be more complex [30], and some regions such as the Lancashire Coastal Plain are thought to have remained at early successional stages for millennia, promoting the persistence of extensive and unique bog-oak woodlands [16,31–33] (Figure 2). Dendrochronological dating of bog-oak and bog-pine woodlands, notably in Germany and Poland, has revealed extensive tree colonisation of European bogs correlating with periods of climatic amelioration (e.g., Holocene Thermal Maximum), as well as mass mortality events associated with climatic deterioration. These studies have indicated possible synchronous climatic forcing throughout north-western Europe, particularly during the mid-Holocene [2,15,27,34,35].

(**a**) (**b**)

Figure 2. Contrasting preservational environments for subfossil bog-pine in north-west England: (**a**) Lindow Moss, (**a**) former raised peat bog, north Cheshire (image: 6 June 2012), (**b**) a low-lying arable field (5–10 m asl) adjacent to Curlew Lane, south-west of Rufford on the Lancashire Coastal Plain. Inland hills (near Parbold) approximately 6 km to the south-east can be seen in the distance (image: 16 October 2019).

A significant concentration of radiocarbon dates for *P. sylvestris* microfossils (sharply declining pine pollen representation in pollen diagrams) and widespread occurrence of macrofossils (tree trunks and stumps) from Britain and Ireland has previously been noted at around 4000 ^{14}C years before the present (BP) and has been termed the 'Pine-decline' [36] (pp. 145–146). Although the precise mechanisms involved in this apparent 'event' were initially a matter of conjecture, climatic deterioration was suspected, and was also corroborated by existing evidence from other proxy records such as lake sediments and peat stratigraphy [37–40] cited by [36]. The 'Pine Decline' has remained contested within palaeoecology, attributed to climate change, competition between coniferous and broadleaf tree species, humans, pathogens, and even the potential impacts of Icelandic volcanism. The latter, for instance, has included some quite heated debates relating to the application of dating techniques and palynological criteria for the presence of local pine woodland [41–47].

This research presents new palaeoecological data relating to a subfossil pine woodland that grew on Wem Moss, a former raised bog, located close to the border between Wales and England (UK). It examines the significance of these dendrochronological records in relation to previous research on Scots pine (*P. sylvestris*) from the broader Meres and Mosses region and from elsewhere in Britain and Ireland, providing a critical examination of existing palaeoecological evidence for the 'Pine Decline' at 4000 ^{14}C years BP. In doing so, this research highlights the spatially and temporally discontinuous nature of micro- and macrofossil records of Scots pine, as well as the need for future genetic research on living pine trees.

2. Study Area and Site

Wetlands and former wetlands within the UK counties of Cheshire, Staffordshire and Shropshire are collectively known today as the Meres and Mosses region, an area of predominantly low-lying topography sharing not only similar landscape characteristics, but also similarities in glacial, landscape, vegetation, and human history [48–50]. These wetlands and their environmental archives have been the focus of a considerable quantity of both ecological and palaeoecological research including seminal works on the terrestrialisation of wetland sites, development of *Schwingmoor*, and the definition of palynological 'events' such as the '*Tilia* Decline', e.g., [51–55]. The research reported here formed part of a wider Meres and Mosses Landscape Partnership Scheme (MMLPS) [56] building on the

UK Government's National Improvement Area initiative (2011) and focusing on improvements to wetland landscapes. Sub-project COMM2 Peat Coring & Archaeology involved highlighting the nature and value of the wetland archives in this region and included both detailed palynological investigations [57], as well as the analyses of subfossil pine trees that were excavated at Wem Moss.

Wem Moss is a small (28 ha), lowland raised bog in Shropshire, UK (National Grid Reference SJ 473 343) and forms part of a larger conservation area, Fenn's, Whixall and Bettisfield Mosses National Nature Reserve (Figure 3 and is noted for raft spiders, the Large Heath Butterfly (*Coenonympha tullia*), and the common European Viper or Adder (*Vipera berus*). It is owned and managed by the Shropshire Wildlife Trust [58]. In 2015, conservation management required the insertion of a linear hydrological barrier to further site re-wetting and necessitated the removal of a number of subfossil bog-pine trees (*P. sylvestris*) from within the peat. Following a request from the Shropshire Wildlife Trust to ascertain the age of these trees, disc samples were removed from 17 subfossil stumps for dendrochronological analyses (Figure 4a,b).

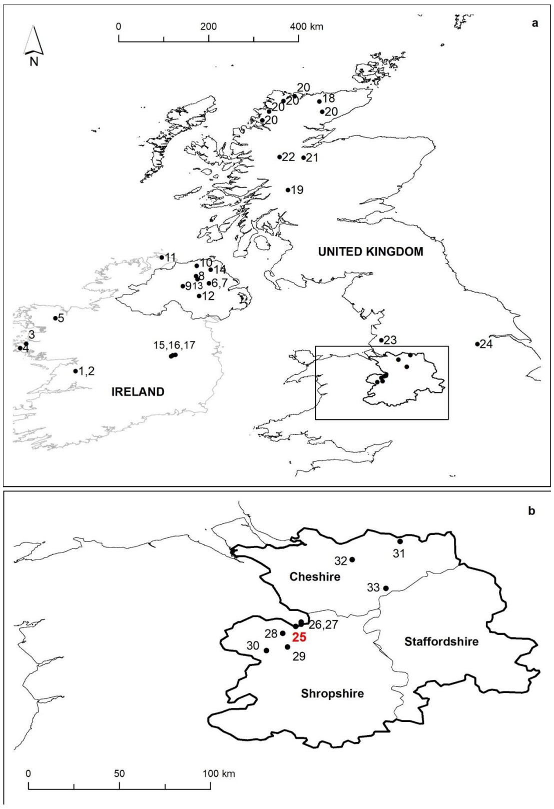

Figure 3. Locations of key palaeoecological studies undertaken on subfossil *P. sylvestris* in Britain and Ireland. (**a**) Sites in Ireland, Northern Ireland, Scotland, northern and eastern England. (**b**) Sites in the Meres and Mosses region (Shropshire—Cheshire—Staffordshire), including Wem Moss, site 25 (RED)—new dendrochronological data presented in this paper: 1–2 Aughrim Swamp, Rockforest Lough [59,60]; 3–5 Letterfrack, Derryeighter, Garrynagran [61]; 6–7 Sluggan, Sharvogues [62–64]; 8 Fallahogy [62]; 9 Ballynagilly [65,66]; 10 Garry Bog [62]; 11 Drumaville [D Brown pers. comm.]; 12 Derrycrow [62]; 13 Ballymacombs More [62,65]; 14 Altnahinch [62]; 15–17 Ballycon, Glashabaun, Timahoe [10]; 18 Loch Strathy [67]; 19 Rannoch Moor [68]; 20 N Scot—11 sites [69]; 21 Dubh Lochan [70]; 22 Loch an Amair [70]; 23 Curlew Lane [16]; 24 Hatfield Moors [71]; 26 Fenn's, Whixall & Bettisfield Mosses [53,72–76]; 27 Morris's Bridge [77]; 28 Crose Mere [78]; 29 Fenemere [79]; 30 Lin Can Moss [80]; 31 Lindow Moss [81]; 32 Davenham [82]; 33 White Moss [25].

(a) (b)

Figure 4. Recovering subfossil bog-pine trees from Wem Moss, Shropshire in March 2015. (**a**) Sampling tree discs using a chainsaw from well-preserved stumps close to the tree root crowns. Note corrugated plastic barrier inserted into the peat as a hydrological barrier. (**b**) Seventeen pine disc samples prior to transportation to the Dendrochronology laboratory at Manchester Metropolitan University.

3. Materials and Methods

3.1. Dendrochronology

Disc samples were allowed to air dry and then polished using progressively finer grades of sandpaper and a belt sander to make the wood structure and tree-ring patterns fully visible for measurement (examples of similar prepared subfossil pine discs can be seen elsewhere [16]). Ring-width measurements were made for each sample disc starting at or near the centre of the tree (pith) and progressing towards the youngest ring, as close as possible to the bark. Two ring-width series were made for each of the 17 disc samples using a binocular microscope, measuring stage, an electronic measuring device (measurement accuracy 0.01 mm), and data input software described in Tyers [83]. Ring-width series from these radial measurements were subsequently combined to create a mean ring-width record for each sample, and these were then compared for similarity using cross-matching software routines described by Tyers [83], Lageard et al. [25], and Lageard & Robinson [16]. Cross-matching and chronology-building followed standard dendrochronological procedures, utilising raw ring-width data [16,25]. The resultant Wem Moss ring-width chronologies were cross-matched against available subfossil pine reference chronologies from the Meres and Mosses region [25,81] to attempt dendrochronological dating. A detailed description of the methodology followed in this research and also recommended for the dendrochronology of subfossil pine, including cross-matching procedures and chronology-building, is described in further detail elsewhere [16].

3.2. Radiocarbon Dating

Following the creation of floating (un-dated) site ring-width chronologies, samples of wood were carefully removed from discs using a hammer and narrow-bladed chisel (avoiding any potential contamination from modern or older carbon). These samples comprised the youngest chronology components, e.g., rings 191–198 from disc Wem 01 from chronology Wem 2_2 (exceeding the minimum weight 3–100 mg required for AMS dating). Samples were sealed in laboratory sample bags and sent to Beta Analytic (Miami, USA) for ^{14}C assay. All ^{14}C date calibrations including for the Wem Moss wood samples utilised the IntCal20 atmospheric curve [84], and previously published ^{14}C dates included in the discussion were recalibrated using OxCal v. 4.4 [85].

4. Results

4.1. Dendrochronology

Ring-width measurements of the disc samples were undertaken in the Dendrochronology Laboratory at Manchester Metropolitan University, revealing mean ring counts of 49 to 269 years (see data in Supplementary Materials S4.1). Subsequent cross-matching [cf 16] demonstrated contemporaneity between 9 of the 17 mean ring-width series, indicated by *t* value correlations exceeding 5.0 in Table 1. Contemporaneity between three of these mean ring-width series (Wem01M, Wem06M, and Wem07M—each created using raw ring-width data) is illustrated in Figure 5. Wem01 and Wem07 (*t*-value correlation 8.14) were initially combined to form an interim site chronology, with Wem06 subsequently added following further cross-matching, forming site Chronology Wem 2_2 and illustrating the standard dendrochronological chronology-building process (Table 2). Note the variability in the sensitivity of these ring-width records (Wem01—0.39; Wem06—0.27; Wem07—0.37) possibly demonstrating variability in palaeohydrology on the bog surface over relatively short distances.

Table 1. Correlation matrix for Wem Moss samples Wem01–Wem14 showing *t* values exceeding 5.0. Site chronologies and their individual components are distinguished using the following colours: WEM2_2—lime green, WEM4_1—dark green.

	Wem01	Wem02	Wem03	Wem04	Wem05	Wem06	Wem07	Wem08	Wem09	Wem10	Wem11	Wem12	Wem13	Wem14
Wem01						5.38	8.14							
Wem02														5.74
Wem03									6.16					
Wem04					5.29				9.2					
Wem05									6.79					
Wem06							5.72							
Wem07											6.19			
Wem08										6.57				
Wem09														
Wem10														
Wem11														
Wem12														
Wem13														
Wem14														

Table 2. Details of Wem Moss site tree ring-width chronologies.

Site Chronology	Component Chronologies	Number of Samples	Length (Years)	Average Ring-Width (mm)	Sensitivity
WEM1_3	-	4	184	102.99	0.38
WEM2_2	-	3	198	90.48	0.31
WEM3_1	-	2	115	123.77	0.23
WEM4_1	WEM1_3 & WEM3_1	6	208	103.24	0.33

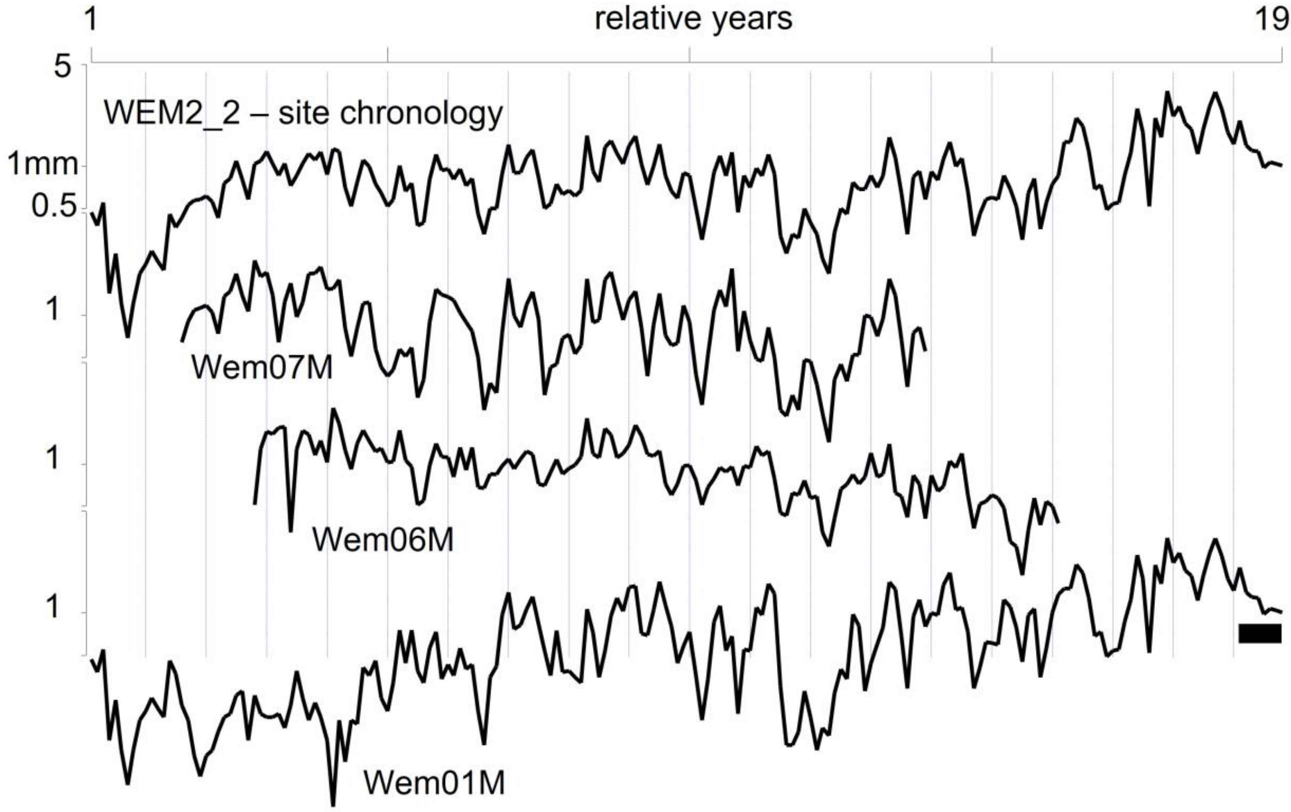

Figure 5. Contemporaneity and variability in subfossil pine growth from the same peat bog: *P. sylvestris* ring-width records Wem01M, Wem06M, and Wem07M, components of the 198-year site chronology Wem2_2. Black rectangle highlights wood sent for ^{14}C assay (Wem01 rings 191–197).

Three initial site ring-width chronologies were constructed (Table 2) and further cross-matching demonstrated the contemporaneity between Wem1_3 and Wem3_1. These chronologies were subsequently combined to form site chronology Wem4_1 (see Figure 6 & Supplementary Materials S4.2). Further sampling and analysis of bog-pines from Wem Moss are likely to extend the duration of this mire-rooting woodland and could also reveal protracted and staged decline as witnessed elsewhere in the Meres and Mosses region [25].

As cross-matching with other available regional subfossil pine reference chronologies was unsuccessful, age-estimation for samples from the two site chronologies (WEM2_2 and WEM4_1) was reliant on the results of the radiocarbon age determination.

4.2. Radiocarbon Dating

Youngest series of tree-rings were removed from subfossil pine disc samples emanating from both site chronologies (wood immediately proximate to tree bark: Wem2_2 rings 191–198; Wem4_1 rings 199–208) and sent for radiocarbon dating. Calibration (2 sigma) of the resultant ^{14}C dates suggest that the dendrochronological records are closely related and may relate to the same continuum of mire-rooting woodland centred on the period 3015–2505 Cal BCE (see Table 3).

Table 3. Radiocarbon dates associated with samples from chronologies Wem2_2 and Wem4_1.

Chronology	Tree	Chronology Years	Radiocarbon Age (^{14}C Years BP)	Calibrated Age Range–Years (2 Sigma)
WEM2_2	Wem01	191–198	4330 ± 30 (Beta–424347)	3015–2895 cal. BCE
WEM4_1	Wem10	199–208	4100 ± 30 (Beta–424348)	2860–2505 cal. BCE

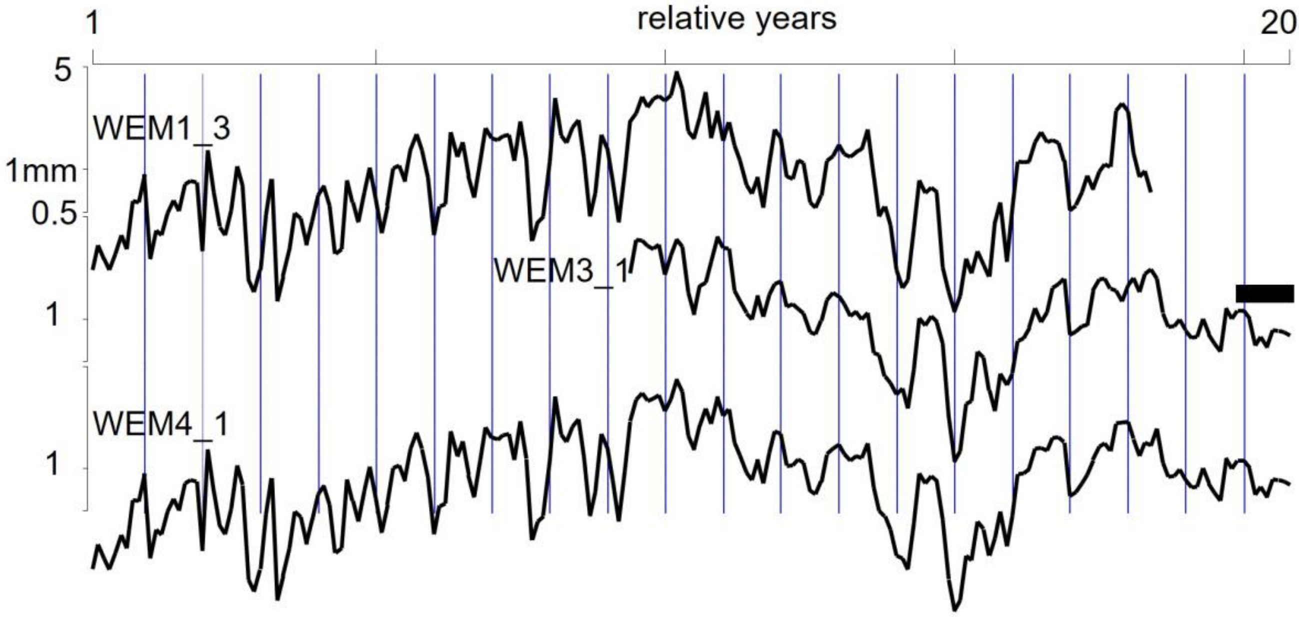

Figure 6. Ring-width records of interim site chronologies WEM1_3 (4 ring-width records) and WEM3_1 (2 records) and the resultant 208-year site chronology Wem4_1 (6 records), illustrating the chronology building process. Black rectangle highlights wood sent for ^{14}C assay (Wem10, individual sample component of chronology WEM3_1, rings 198–208).

5. Discussion

The similarity in the radiocarbon dates and the calibrated age ranges for the two floating pine ring-width chronologies from Wem Moss suggests that the trees sampled in this research comprised part of the same mire-rooting woodland probably extant for several centuries leading up to their mortality at or ca. 4000 ^{14}C years BP, 'typical' pine macrofossil evidence of the 'Pine Decline' [36]. More detailed investigations of similar subfossil woodland elsewhere in the Meres and Mosses region have however sometimes revealed a more complex picture of subfossil pine woodland decline with series of distinct temporal phases. At White Moss (45 km to the north-west in south Cheshire—Figure 3b), three phases of macrofossils were identified (see Figure 7A). White Moss Phase B was initially assayed by radiocarbon, but was subsequently dated precisely by dendrochronology to 2881–2559 BC [25]. The youngest tree layer/s from White Moss (Phase C) comprised an upper 'regeneration' layer(s) of small diameter stumps thought to represent the last attempts of woodland to re-establish in an increasingly wet environment, unsuited to tree growth (2484–2199 cal. BC & 1972–1740 cal. BCE) [25]. A similar 'regeneration' layer is currently under investigation at Lindow Moss (north Cheshire), and the morphology of many of its components provide further evidence implicating mire hydrology in tree mortality after 2569–2146 cal. BCE [2,15,81] (see Figure 8).

Whilst a number of mire-rooting pine woodland phases during the Holocene have now been dendrochronologically dated in Britain and, particularly, also in Ireland [25,62,69,71]—Figures 3 and 7—these contrast with temporally and geographically more extensive European records whose dating has benefitted from the widespread contemporaneity between bog-oak and bog-pine woodlands [2,15,34,35]. It is, however, possible to compare the radiocarbon dates for the Wem Moss subfossil pine woodland to palaeoecological investigations from the wider Meres and Mosses region, and also from the rest of Britain and Ireland (Table 4; Figures 3 and 7). Previously dated pine and oak macrofossil and microfossil (pine pollen) events from immediately adjacent peatlands in Shropshire are listed in Table 4 and these reveal a series of radiocarbon age-estimates post-dating the Wem Moss woodland and the age traditionally associated with the 'Pine Decline' (4000 ^{14}C years BP) (Figure 7A). These local investigations focussed primarily on a layer of pine stumps originally described by Hardy [72] at Whixall Moss (part of the larger Fenn's and Whixall Mosses peatland complex covering over 550 ha).

Table 4. Dating associated with subfossil Scots pine and subfossil oak macrofossils and sharp declines in *Pinus* (*P. sylvestris*) pollen from Whixall Moss and other sites in Shropshire, UK. Calibrations: [84,85]. See also Figure 3b.

Publication	Site	Bog-Oak/Bog-Pine/Pine Pollen	^{14}C Age (Years BP)	Calibrated Age Range (2 Sigma) (Years cal. BCE/CE)	Calendar Date (Years BCE)	Artefact Dating (Years BCE)	Undated Tree-Ring Series
[72]	Whixall Moss	Pine	-	-	-	1500–1000	-
[53]	Whixall Moss	Pine	2307 ± 110	761–106 BCE	-	-	-
[73]	Whixall Moss	Pine pollen	ca. 2000	-	-	-	-
[78]	Crose Mere	Pine pollen	2310 ± 85	753–164 BCE	-	-	-
[79]	Fenemere	Pine pollen	1890 ± 50	232–248 CE	-	-	-
[74]	Whixall Moss	Pine	2180 ± 50	397–3 BCE	-	-	✓
[75]	Whixall Moss	Pine	-	-	-	-	✓
[77]	Morris' Bridge	Oak	-	-	4596–4304	-	-
[76]	Whixall Moss	Pine	(6 x ^{14}C dates) Oldest: 3140 ± 45 Youngest: 2900 ± 40	1503–937 BCE	-	-	-
Current	Wem Moss	Pine	4330 ± 30 4100 ± 30	3015–2895 BCE 2860–2505 BCE	-	-	-

Hardy also recounted the discovery of a bronze looped palstave (axe) in 1927 CE by Mr George Saywell whilst 'digging turf', and 'lying on top of the roots of the old pine, about 8 ft. from the surface' [72] (p. 377). Typologically, this artefact dated to the Middle Bronze Age archaeological period, ca. 1500 to 1000 years BCE, and the find spot was also proximate to an earlier discovery (1889 CE) of a human 'bog body' [86]. The axe find, in particular, provides intriguing evidence of human presence contemporary with the bog-pine woodland, although to this author's knowledge, no direct human impacts, such as axe marks, have ever been found on pine macrofossils either here or further afield (UK or elsewhere).

Hardy's pine stump layer was initially dated to 2307 ± 110 BP (761–106 cal. BCE), although the specific nature of the organic sample and stratigraphic information were not provided [53]. Subsequently, dendrochronological investigations were undertaken by Haslam who made ring-width measurements for 14 subfossil trees and constructed a 96-year chronology, making observations on pine stump morphology, and also, on their proximity to overlying Sphagnum macrofossils (a *Sphagnum papillosum–Sphagnum cuspidatum* lawn community initiated ca. 2180 ± 50 BP or 397–3 cal. BCE), at a peat depth of 40–44 cm [74]. Further dendrochronological studies were undertaken on subfossil pine stumps revealed by peat cutting at varied locations throughout Fenn's and Whixall Mosses [13] and 6 radiocarbon assays on wood samples from dendrochronological records currently provide the best dating available for the Whixall Moss pine 'layer' (3140–2900 BP; 1505–930 cal. BCE) [76].

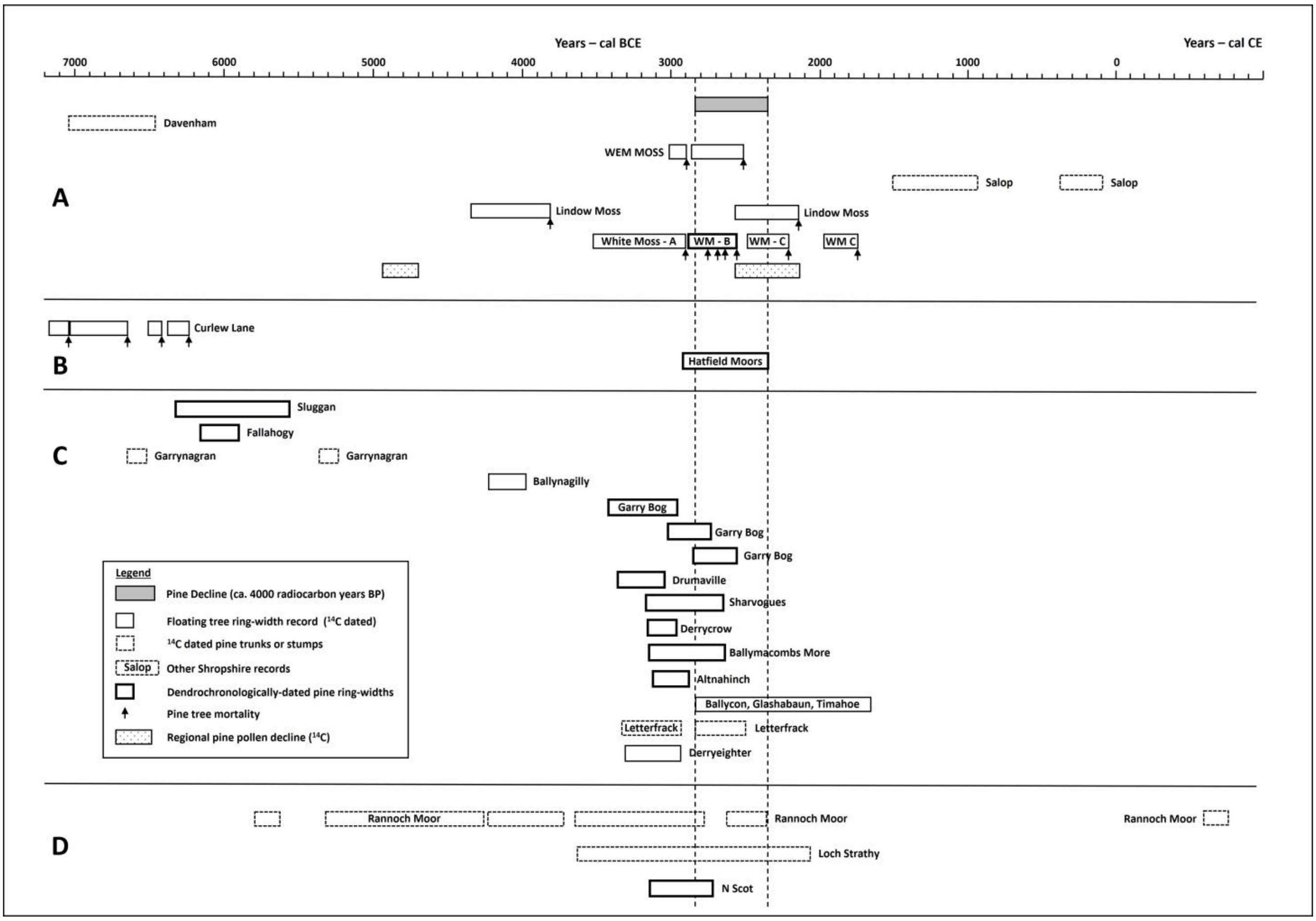

Figure 7. The 'classic' date often linked to the Pine Decline of 4000 ^{14}C years BP or ca. 2835–2346 cal. BCE [36] and the relative dating of *P. sylvestris* macro- and microfossils from (**A**) Shropshire (Salop) and Cheshire—the Meres and Mosses region, (**B**) Lancashire and south Humberside, (**C**) Ireland and (**D**) Scotland—N Scot refers to 11 sites providing dendrochronologically dated records from Moir et al. [69] (Dating sources: [10,16,25,53,61–64,67–69,71,76,81,82,87], Drumaville—D. Brown pers. comm., Wem Moss—this paper). ^{14}C dating at Curlew Lane, Wem, Lindow and White Mosses focussed on aging the youngest samples available; macrofossil analyses and dating were much more extensive at White Moss (4-year research project); small diameter pine stumps from upper stratigraphy at Lindow Moss (e.g., Figure 8—currently undated), are analogous to the final regeneration layers at White Moss (WM—C). Comparisons of average ring-width indicate: wider rings and faster growth in older tree-ring series (WM—A, oldest Lindow); narrower rings and more sensitive ring-width series (WM—B, WEM, oldest Salop). Site locations are illustrated in Figure 3.

Wider Context

The pollen record from White Moss (Cheshire—Figure 3b) demonstrated that boreal woodland dominated by *P. sylvestris* was likely to have occupied significant parts of the Meres and Mosses region between 8625 ± 50 BP (SRR 3881: 7761–7544 cal. BCE) and 5890 ± 45 BP (SRR 3880: 4897–4616 cal. BCE); see the vegetation history summary in reference [25] (Figure 5, p327), [87]. Discoveries of pine macrofossils at Davenham (mid-Cheshire—Figure 3b) and at Curlew Lane (Lancashire—Figure 3a) are remnants of these early-mid-Holocene woodlands, whose pre-eminence appeared to be checked shortly after 5890 ± 45 BP (4897–4616 cal. BCE) and again at 4280±45 (SRR 3879: 3022–2702 cal. BCE) (White Moss pollen record from core T3.75) [25,87] (see Figure 7A).

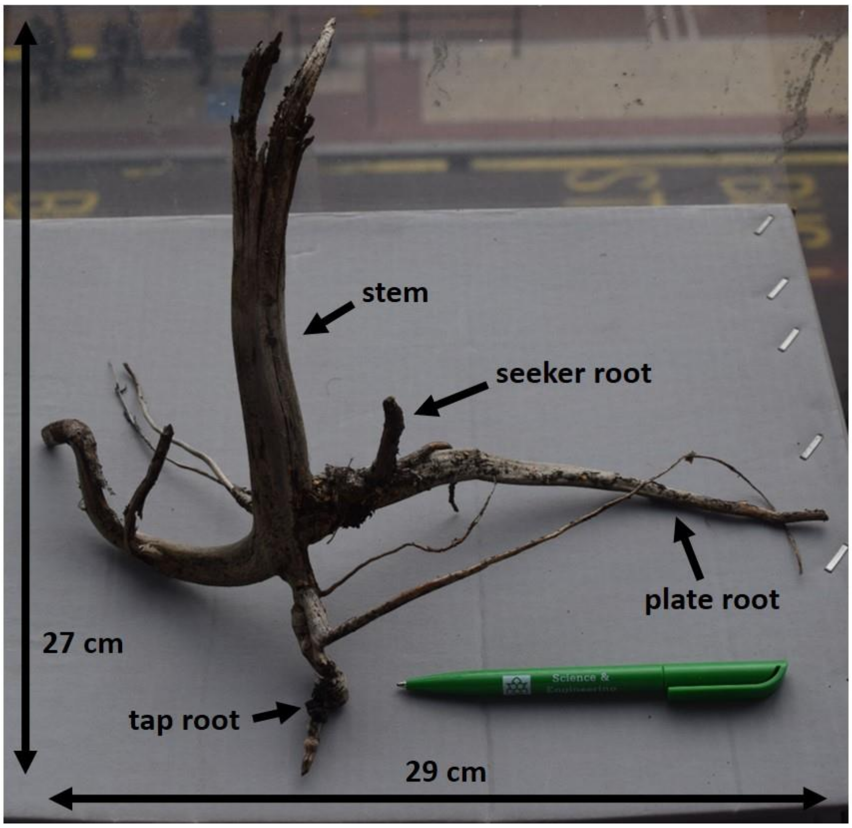

Figure 8. A small-diameter subfossil pine tree (*P. sylvestris*) recovered from the uppermost layers of peat containing bog-pine woodland at Lindow Moss, Cheshire (stem top broken by machinery during mechanised peat extraction). Note the presence of seeker roots, a likely response to prolonged waterlogging.

There has been considerable debate about the often-assumed extinction of native Scots pine woodland throughout most of Britain and Ireland, and this is exemplified in Shropshire. Pine pollen representation fell to background levels (ca. <1% TLP from 170 cm lake core depth upwards) at Crose Mere (5.5 km SW of Wem Moss—Figure 3b) after 2310 ± 85 BP (763–164 cal. BCE, Q-1233) [78], whilst at Fenemere (11.5 km SSE of Wem Moss—Figure 3b), a similar decline occurred at 1890 ± 50 BP (16–302 cal. CE, SRR-2920) [79]. It has been suggested that this represented a dating discrepancy, due to pine woodland persisting on more freely draining soils or 'erroneous [at Crose Mere] due to in-washed old carbon' [88] cited by [74] (p. 121). The ^{14}C age estimate (Q-1233), however, centred on a lower core depth (c 200 cm) where small quantities of pine pollen were still present [78] (p. 145), suggesting that the dates from Fenemere and Crose Mere might, in fact, be broadly complementary.

Precise stratigraphic comparisons of key events in the pollen record are not only compounded by the imprecision of ^{14}C dating, but also by debates surrounding the levels of pine pollen thought to be representative of local woodland. Initial criteria for the latter have varied from 20–30% total land pollen (TLP) [36,67], as pine trees are wind-pollenated and hence, copious producers of pollen [89,90]. Subsequently, these criteria have been progressively revised downwards, for instance, with 5% TLP suggested by Bennett [91], following the discovery of pine stomata in lake sediments with contemporaneous pine pollen levels at 3–18% TLP [92]. Hall et al. [42] also found <2–3% pine pollen in peat associated with in situ dendrochronologically-dated pine macrofossils, questioning the wider applicability of previous research linking a pine pollen decline in northern Scotland to the effects of Icelandic volcanism [41]. The volcanic impact debate was later elaborated in a comprehensive review of the palynological evidence, although this failed to provide definitive answers [47]. In contrast, a well-replicated study from Scotland provided tantalising evidence of local pine woodland demonstrated by the presence of pine stomata in sediment from Loch an Amair and Dubh Lochan (Figure 3b), coinciding with pine pollen abundance as low as 0.4% TLP, and as a result, potentially pushing back the date for the first expansion of the native Caledonian pinewoods [70].

Whilst *P. sylvestris* has persisted as a native tree in its Scottish heartland, despite human interference [93,94], a number of recent studies have thrown doubt on the complete Holocene extinction of Scots pine elsewhere in Britain and Ireland. Analysis of topography, pedology, and vegetation in northern England and southern Scotland suggested that pine trees could have persisted in parts of these regions, despite a lack of preservational environments, and therefore, of physical evidence [95]. In addition, palynological research in the Burren, County Clare (western Ireland—Figure 3a) has provided possible evidence of Scots pine survival throughout the later Holocene. An investigation of Aughrim Swamp (Figure 3a) revealed continuous pine pollen representation to the present day (with one small decline to 8% TLP) adjacent to mature pine woodland growing on limestone pavement [59]. A subsequent core from the nearby Rockforest Lough (Figure 3a) demonstrated sustained high levels of pine pollen (c. 40% TLP) from 1600 ^{14}C years BP to the present, supported by historical documentary and macrofossil evidence (lake shore macrofossils dating to ca. 3860 BCE, Neolithic; a lake core pine wood fragment and a pine needle (or peat from a similar core depth—the paper lacked clarity in this respect) dated to ca. 840 CE, early Medieval) [60]. Roche et al. concluded that the living trees were therefore likely to be native, sustained in their karstic environment (free-draining substrate combatting waterlogging elsewhere), and by local land ownership (Rockforest Estate) that prevented the intensity of land clearance and tree removal that occurred elsewhere on the Burren. These findings have, however, been questioned.

Other palaeoecological investigations from western Ireland have corroborated the presence of the early Holocene pine woodland (Garrynagran, Figure 7C), the mid-Holocene 'pine flush' (macrofossils from Letterfrack and Derryeighter, Figure 7C), and pine pollen ranging between 20–40% TLP, also noting the paucity of pine macrofossils after 4000 ^{14}C years BP [61,96,97]. These studies have, however, also specifically referenced the research at Rockforest, pointing out the possibility of long-distance pine pollen inputs, 'taphonomic processes' connected with karst hydrology that might have biased the pollen data and the limited macrofossil evidence (including possible discrepancies in the use of previous macrofossil ^{14}C dates). O'Connell and Molloy concluded that more substantive evidence is required to confirm the survival of pine trees and woodland up to modern times [96] (p. 23). Intriguingly, however, well-replicated palynological evidence from O'Connell et al. also suggests a more protracted pine decline, with regional extinction of pine woodland at ca. 3400 ^{14}C years BP and the 'demise of pine as a minor woodland component' after ca. 2300 ^{14}C years BP, post-dating the existing macrofossil evidence [61] (p. 272 & p. 284, Figure 7C).

In the Meres and Mosses region, a recent study of a peat core from Lin Can Moss (Shropshire—17 km SW of Wem Moss—Figure 3b) has also revealed a continuous pine pollen curve, although with low abundance (0.3–5.4% TLP), between 6060± (5198–4847 cal. BCE) and 270 ± 30 BP (1510–1798 cal. CE) [79]. Sassoon et al. demonstrated the similarity of Lin Can Moss pine record to previous palynological investigations in the Welsh Marches (north-east Wales and western Shropshire), in contrast to the intermittent or fragmentary representation of pine pollen elsewhere in Wales. As a consequence, Sassoon et al. speculated that neighbouring hills and rocky outcrops, and possibly the wider area of the Welsh Marches, could have been a refugial area for Scots pine, with 'isolated trees [surviving] in a mixed forest scenario' [80] (p. 9), for reasons analogous to Rockforest in western Ireland. These observations are of particular interest when considered alongside the macrofossil record from Shropshire that not only includes the subfossil pine woodland at Wem Moss, but also macrofossils post-dating 4000 ^{14}C years BP (Table 4, Figure 7A).

The discussion has highlighted evidence for pine declines considerably later than 4000 ^{14}C years BP in the Meres and Mosses region of England and in western Ireland, and also the possibility that living pine trees (in woodlands or as isolated individuals) in various localities in Britain and Ireland may in fact be remnants of native populations. The latter runs contrary to the standard interpretation that living pine trees (or increasing pine pollen in upper peat stratigraphies) represent 'romantic' and other planting during the later historic period, or twentieth century re-planting from imported stock [31,98]. The review in this paper of palaeoecological studies focusing on Scots pine in Britain and Ireland highlights the need for future genetic studies on living pine trees in possible refugial areas in Ireland, northern England and also the Welsh Marches. Modern ecological studies on seeds and saplings originating from native Caledonian pinewoods have not only generated genetic data, but also demonstrated subtle genetic variability, for instance, between tree populations in the maritime west and the drier east of Scotland (including better adaptations to waterlogging in wetter western areas) [99–101]. Despite the 'large and repetitive' nature of the Scots pine genome, recent research has also been able to differentiate Scottish and Finnish genotypes [102].

6. Conclusions

Analyses of subfossil pine stumps from Wem Moss produced two tree ring-width chronologies spanning 198 and 208 years, respectively (dated by radiocarbon to 3015–2505 cal. BCE), and these are likely to represent a continuum of mire-rooting woodland that died off around 4000 ^{14}C years BP in response to climatic deterioration—a classic 'Pine Decline' scenario encountered in Britain and Ireland.

The extinction of Scots pine in Britain and Ireland at the Pine Decline, outside the areas covered by today's native Caledonian pine woodlands, has, however, been questioned by ecological and palaeoecological studies from the Meres and Mosses region and further afield. Parallel palynological investigations and dating of associated macrofossils from western Ireland have demonstrated the possible survival of native pine trees at isolated sites and the continuous presence of pine pollen at other isolated sites in the Welsh Marches, has also highlighted this as a possible refugial area for pine. The review of previously dated pine macrofossils undertaken in this paper lends additional support to these views, with peatland complexes such as Fenn's, Whixall, and Bettisfield Mosses demonstrably well-suited to the persistence of bog pine woodland due to their larger geographical areas that were capable of supporting more varied mosaics of mire vegetation and hydrology. Future genetic comparisons of native Caledonian pine trees (Scotland) with other living trees from areas such as western Ireland, the Welsh Marches, northern England, and southern Scotland are recommended.

This research gives further credence to the survival of native Scots pine in isolated localities in Britain and Ireland throughout the later Holocene and up to the present day, also highlighting the difficulties associated in piecing together geographically disparate vegetational records.

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