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TREE-RING ANALYSIS OF OAK TIMBERS FROM DORE ABBEY, ABBEY DORE, HEREFORDSHIRE

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Summary

Tree-ring analysis of oak timbers from Dore Abbey, now the Church of St Mary, was undertaken in order to date the ambulatory roof and assess the importance of timbers re-used from early phases. Sixteen samples were obtained and all but one dated. Two chronologies were produced, dating to AD 1073-1195 and AD 1363-1612. The first chronology was produced from re-used timbers felled in AD 1205-1238. The second site chronology included two phases of timbers, one felled in the late sixteenth or early seventeenth century and the other probably relating to the extensive restoration programme of AD 1633.

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Introduction

This document is a technical archive report on the tree-ring analysis of timbers from Dore Abbey, Herefordshire (NGR S0387304). It is beyond the dendrochronological brief to describe the building in detail or to undertake the production of detailed drawings. As part of a multifaceted and multidisciplinary study of the building, elements of this report may be combined with detailed descriptions, drawings, and other technical reports at some point in the future to form either a comprehensive publication or an archive deposition on the building. The conclusions presented here may therefore have to be modified in the light of subsequent work.

Dore Abbey, now the parish church of St Mary, is located at Abbey Dore in the Golden Valley, Herefordshire. The history of the abbey has been recently documented by Shoesmith and Richardson (1997). A Cistercian monastery was founded on the site *c* AD 1147 and the nucleus of the church is thought to have been constructed *c* AD 1170-1185. After the dissolution of the monastery in AD 1537, the land was given to the Scudamore family. The monastic buildings fell into disrepair, and only the crossing, transepts, and chancel of the abbey church remain. From AD 1633 the surviving structure was extensively renovated by John, Viscount Scudamore and the church was rededicated as the parish church in AD 1634 (Shoesmith and Richardson 1997). The church is renowned for the timberwork put in during this time by John Abel. The high roof that covers the crossing, transepts, and chancel, consists of fifteen trusses (numbered I-XV), all thought to be part of this phase.

Tree-ring analysis was commissioned by English Heritage in order to aid conservation decisions associated with forthcoming repair work. The objectives of the analysis were to date the timbers of the lower ambulatory roof, which had been remodelled in AD 1633/4, and identify any re-used material. The ambulatory roof is comprised of a series of shore-type trusses abutting the chancel and numbered XVI-XXXVI (Figs 1 and 2). The financial accounts for the AD 1633 restoration program include mention of the re-use of 'old timber' (Tonkin 1997). This is supported by redundant joints and peg holes on some of the timbers. The re-used timbers may be from the original roof of the ambulatory, chancel, or nave, or from elsewhere in the original abbey precinct. Tree-ring analysis of the extant ambulatory roof was requested to enable the re-used material to be identified and its historical importance to be assessed in advance of restoration work.

The timing of the sampling programme was dependent on the management requirements of the protected bat colonies that roost in both the ambulatory and the roofs of the crossing, transept, and chancel.

Methodology

The timbers from the ambulatory roof were assessed to identify those which were suitable for dendrochronological analysis. Sampling was focused on those timbers which may have been from earlier phases as well as the seventeenth-century restoration. Samples with over 50 rings are required for tree-ring dating in order to ensure that the growth pattern is unique. Samples with long ring sequences were looked for as these improve the potential for chronology building. In addition, samples with sapwood and bark edge were particularly sought, as these improve the precision of the results.

The timbers were sampled using a 15mm diameter corer attached to an electric drill. The cores were taken from the timbers in the most suitable direction for maximising the numbers of rings for subsequent analysis. The core holes were left open. The ring sequences in the cores were revealed by sanding and those samples with less than 50 rings were rejected. The growth rings in the samples that were selected for dating purposes were measured to an accuracy of 0.01mm using a computer based travelling stage. The ring sequences were plotted onto semi-log graph paper to enable visual comparisons to be made between them. In addition cross-correlation algorithms (Baillie and Pilcher 1973; Munro 1984) were employed to search for positions where the ring sequences were highly correlated. These positions were checked using the graphs and, where they were satisfactory, new mean sequences were constructed from the synchronised sequences. The *t*-values reported below are derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t*-value of 3.5 or over is usually indicative of a match, although this is with the proviso that high *t*-values at the same relative or absolute position must be obtained from a range of independent sequences, and that these positions are supported by satisfactory visual matching (Baillie 1982, 82-5).

All the measured sequences from the assemblage were compared with each other and any found to cross-match were combined to form a site master curve. These, and any remaining unmatched ring sequences, were tested against a range of reference chronologies, using the same matching criteria: high *t*-values, replicated values against a range of chronologies at the

same position, and satisfactory visual matching. Where such positions are found they provide calendar dates for the ring-sequence.

The tree-ring dates produced by this process date only the rings present in the timber. The interpretation of these dates relies upon the nature of the final rings in the sequence. If the sample ends in the heartwood of the original tree, a *terminus post quem (tpq)* for the felling of the tree is indicated by the date of the last ring plus the addition of the minimum expected number of missing sapwood rings. This is the earliest possible felling date but it may be many decades prior to the real felling date, depending on how many heartwood rings have been lost during timber conversion. Where some of the outer sapwood or the heartwood/sapwood boundary survives on the sample, a felling date range can be calculated using the maximum and minimum number of sapwood rings likely to have been present. The sapwood estimates applied throughout this report are a minimum of 10 and maximum of 55 annual rings, where these figures indicate the 95% confidence limits of the range. These figures are applicable to oaks from the British Isles (Hillam *et al* 1987). If bark edge survives, then a felling date can be directly utilised from the date of the last surviving ring. The season of felling can sometimes be identified based on the presence or absence of late spring/summer growth in the final ring. This will indicate whether the tree was felled during the growing period (incomplete ring), or in winter during dormancy (complete ring).

The dates obtained by the technique do not necessarily indicate the construction date of the structure from which they are derived. Considerations should be given to the delayed use of timber caused by seasoning, stockpiling, or re-use as these factors may affect the interpretation of tree-ring results. The possibility of repairs being made to the structure should also be taken into account. In general, timber was used while still green and easily worked, so that structures using primary timbers would have been built soon after felling (Rackham 1990). Tree-ring dating provides precise dates for the tree-ring sequences and is a completely independent process but the interpretation of the results may be refined through study of other archaeological and documentary evidence.

Results

Sixteen samples were obtained from the ambulatory roof, including three (**5**, **7**, and **9**) which were from obviously re-used timbers (Table 1). All three samples had redundant pegs and/or joint housings. Sample **9** may also have the remains of a notched-lap joint. Figure 2 shows the location of the roof trusses which were sampled. All the samples were of oak (*Quercus* spp.).

Halved and quartered trees were used for the majority of the principal timbers, such as the arcade posts and aisle rafters, as well as the purlins and struts. Two samples, **1** from an aisle rafter and **7** from an arcade post, were boxed hearts. Many of the timbers retained sapwood but it was often impossible to core successfully because of the dampness of the wood.

After preparation all the samples were found to be suitable for analysis. The ring sequences were measured and the number of rings ranged between 84 and 197. Samples, **1**, **3**, and **9**, crossmatched and these were combined to form a site chronology, DORE1 (Table 2; Fig 3). The remaining samples, except **7**, crossmatched against each other and a second site chronology, DORE2 was established (Table 3; Fig 3). The two site masters and **7** were tested against independent reference chronologies from the last millennia. DORE1 dated to AD 1073-1195 (Table 4) and DORE2 to AD 1363-1612 (Table 5). Ring width data for each chronology are presented in Tables 6 and 7. Sample **7** could not be dated against either site chronology or independent reference curves.

Interpretation

Phase 1: twelfth/thirteenth century timbers

Two samples, **1** and **9**, had heartwood only and were felled after AD 1203 and AD 1205 respectively. Sample **3** had a heartwood-sapwood boundary dating to AD 1183, giving a felling date range of AD 1193-1238. Assuming that the timbers were from the same building phase, a combined felling date range of AD 1205-1238 is obtained. The early date for sample **9** is supported by clear evidence of re-use, including the remains of a possible notch-lap joint. The other two timbers showed no obvious signs of re-use which probably indicates that there are more 'old timbers' remaining than are identifiable by the redundant joint housings.

Phase 2: late sixteenth-seventeenth century timbers

Twelve samples were dated from this phase (Fig 3). Nine samples retained some sapwood or had heartwood-sapwood boundary. Two of these, **8** and **15**, originally had bark at the position of sampling, but the sapwood shattered during coring. Felling dates ranges are presented in Table 1. More precise ranges for some of the timbers can be estimated by looking at the amount of sapwood known to be lost. Using the average ring widths of the whole ring sequence and of the last 20 measured rings allows a more refined, but approximate, felling date range to be produced:

Sample	Average ring width mm/year (whole sequence)	Average ring width mm/year (last 20 rings)	Amount of sapwood lost (mm)	Approx. no of missing rings
5	1.09	0.75	*c* 40mm + bark	37-53
13	1.22	1.37	*c* 35mm	at least 26
15	0.83	0.68	*c* 10-15mm + bark	12-22

The approximate felling date ranges obtained by this method are given in brackets in Fig 3 and Table 1. These results indicate that there at least two groups of timbers present in Phase 2. Samples **5** and **10** have felling date ranges of *c* AD 1602-1618 and AD 1570-1615 respectively (hereafter referred to as Phase 2a). Samples **8**, **11**, **13**, and **15** all have felling date ranges after *c* AD 1620 and are thus a few decades more recent than samples **5** and **10**. These four samples are probably from timbers original to the documented AD 1633 restoration (hereafter referred to as Phase 2b). The presence of timbers with slightly earlier felling dates, the Phase 2a samples, was an unexpected result.

Samples **4**, **6**, and **16** each have a few surviving sapwood rings and each have the same felling date range of AD 1610-1655. Although the date ranges of these samples straddle the interpreted range of both Phase 2a and 2b, the dates of the heartwood-sapwood boundaries are more similar to the timbers assigned to Phase 2b, which is the presumed AD 1633 phase, it seems likely but cannot be proven that these timbers belong with this phase. Samples **2**, **12**, and **14** have no sapwood and cannot be assigned to either Phase 2a or 2b without further sampling of detailed external examination of the timbers. Visual inspection of such factors as surface tool marks and redundant joist housings may assist in the separation of this material in the roof.

Discussion

Tree-ring analysis has resulted in three phases of building timber being identified in the ambulatory roof at Dore Abbey. The three Phase 1 samples are from a building constructed with timber felled between AD 1205 and AD 1238. It is not certain if they are from an Abbey building. The timber known to be re-used (**9**) was the lower purlin between trusses XXII and XXIII. The two Phase 1 timbers which had not been identified by external characteristics prior to the tree-ring analysis were both in truss XVIII, one as a strut and the other as an aisle rafter. The early timbers are therefore not confined to one area of the ambulatory.

The two Phase 2a timbers (**5** and **10**) are located in, or abutting, truss XX. They may have been re-used from a minor repair made just before the major rebuild of AD 1633/4, or they may have been salvaged from elsewhere. The timber from which sample **5** was derived is

clearly re-used since it has three pegs 420 and 460 mm apart in the timber with no function in the present structure. This clearly implies the difference in date between the Phase 2a and 2b timbers is not due to the presence of a mixture of seasoned and unseasoned timbers. Further examination of the timbers for surface tool marks and redundant joints, plus additional dendrochronological sampling, may indicate whether the Phase 2a timbers are widespread in the structure.

Phase 2b is assumed here to be timber associated with the AD 1633 rebuilding of the church. The restoration work undertaken by John Abel on behalf of John, Viscount Scudamore is well documented with the survival of financial accounts for the acquisition of materials and payment of craftsmen who carried out the refurbishment. Fifty-one newly felled trees are recorded as being used for the framing and furnishings in the church with smaller trees required over a four year period to produce laths (Shoesmith and Richardson 1997).

Correlation between the ring sequences tended to be low, and there was no evidence of any same-tree matches. It is therefore possible that, although the timbers were from the same region, a variety of sources may have been exploited. The presence of two groups of late sixteenth- or seventeenth-century timbers may exaggerate this difference.

Conclusion

The dendrochronological analysis supports the documentary evidence that 'old timber' was used in the restoration. The unexpected result is that there are two groups of 'old' material in the roof. One is from an early thirteenth-century structure, and the other dates to a few decades before the AD 1633 restoration. It is therefore recommended that all the timbers are carefully re-examined during restoration. Further sampling, particularly of timbers with bark edge, might help to further refine the differences between the three groups of timbers. Precise dates may be obtained especially if slices can be obtained from any timbers that are replaced.

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Figure 1

Typical truss type from the ambulatory roof, based on Truss XX (not to scale). Note, there is considerable variation in the design of each truss, for example some trusses had three purlins, some had more struts, whilst some had different alignments of the struts.

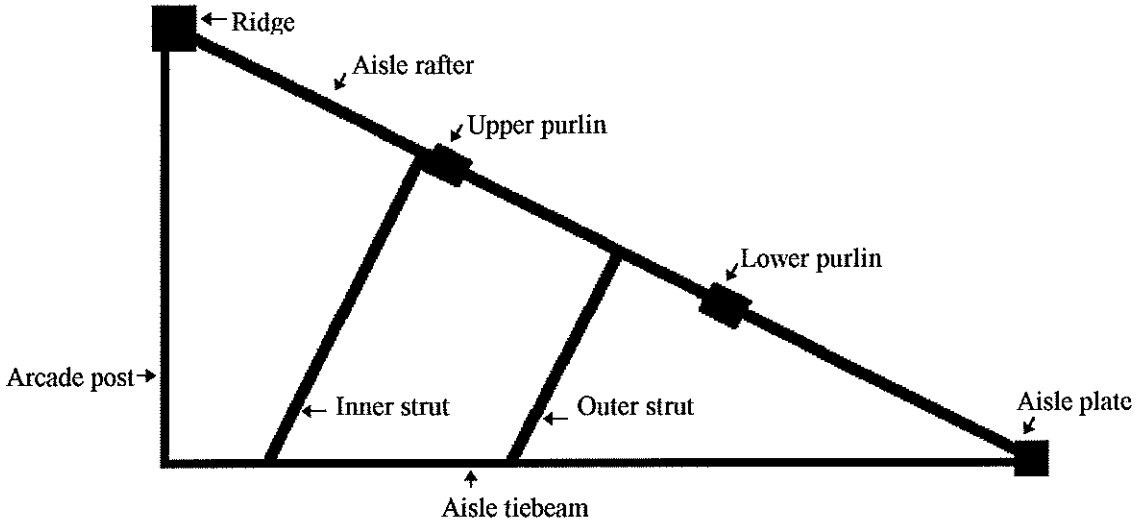


Figure 2

Plan of Dore Abbey Church showing the ambulatory roof trusses, numbered with Roman numerals eg XX. The tree-ring samples are shown in arabic numerals (eg 1) next to the relevant truss but not in the exact sampling location. Samples with double arrows are from purlins linking the trusses.

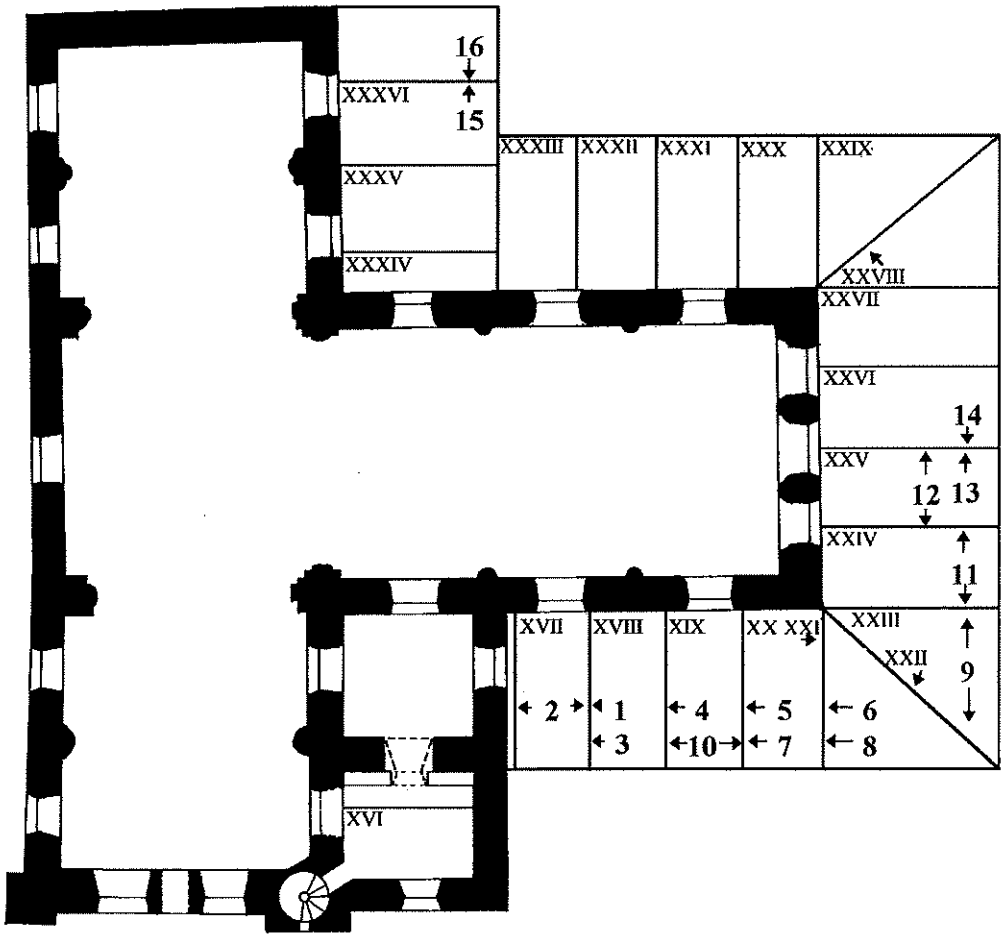
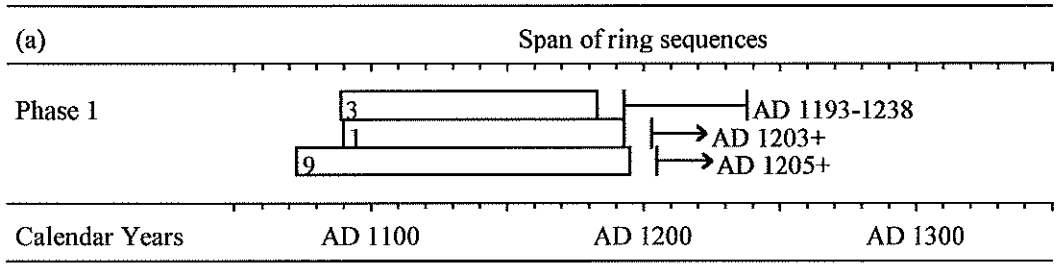
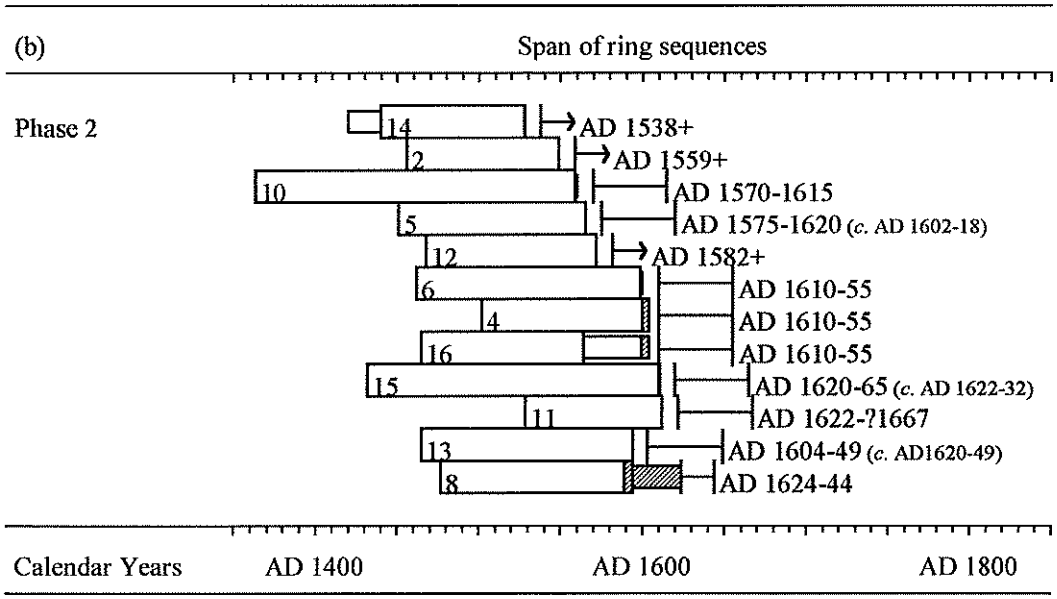


Figure 3

Bar diagram showing the relative positions of the dated timbers from (a) Phase 1 and (b) Phase 2. Note that no attempt has been made here to split the latter into Phase 2a and 2b. A sapwood estimate of 10-55 rings was used to estimate the felling date ranges. Felling date ranges in brackets were obtained by estimating the approximate number of rings in the sapwood lost during coring (see text). + - earliest possible felling date.





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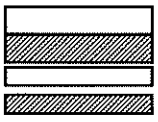

heartwood
sapwood
unmeasured heartwood
unmeasured sapwood

Table 1

Details of samples obtained from Dore Abbey. Felling date ranges in brackets are obtained by estimating the approximate number of rings in the sapwood lost during coring (see text).

Core	Origin	Location (truss no.)	Total rings	Sapwood rings	mm/year	Date of sequence (AD)	Felling (AD)
1	aisle rafter	XVIII	140		1.45	1090-1193	after 1203
2	upper purlin	XVII-XVIII*	94		1.28	1456-1549	after 1559
3	strut	XVIII	95	h/s	1.53	1089-1183	1193-1238
4	arcade post	XIV	103	4	1.54	1502-1604	1610-1655
5	inner strut (re-used)	XX	115	h/s + *c* 40mm to bark	1.09	1451-1565	1575-1620 (*c* 1602-1618)
6	aisle rafter	XXI	138 + 1	+h/s	1.40	1462-1599	1610-1655
7	arcade post (re-used)	XX	82+5		1.03	undated	
8	arcade post	XXI	118 + 30	5 + 30	1.50	1477-1594	1624-1644
9	lower purlin (re-used)	XXII-XXIII*	123		1.07	1073-1195	after 1205
10	upper purlin	XIX-XX*	197 +1	+h/s	1.03	1363-1559	1570-1615
11	middle purlin	XXIII-XXIV*	84	?h/s	1.80	1529-1612	1622-?1667
12	middle purlin	XXIV-XXV*	105		1.66	1468-1572	after 1582
13	aisle rafter	XXV	130 +30	h/s + *c* 35mm	1.22	1465-1594	1624-1649 (*c* 1620-1649)
14	arcade post	XXV	109		1.55	1420-1528	after 1538
15	inner strut	XXXVI	180	1 + *c* 10-15mm to bark	0.83	1432-1611	1620-1665 (*c* 1622-1632)
16	aisle rafter	XXXVI	100 + 40	+ 4	1.09	1465-1564	1610-1655

Key: h/s = heartwood/sapwood boundary; ?h/s = possible heartwood/sapwood boundary; + = additional unmeasured rings: * sample taken from timber between these trusses

Table 2

t-value matrix for the Phase 1 timbers.

	1	3	9
1	*	3.94	6.87
3		*	6.32
9			*

Table 3

t-value matrix for the Phase 2 timbers. *t*-values less than 3.0 are not shown.

	4	5	6	8	10	11	12	13	14	15	16
2	-	3.78	4.92	-	3.12	4.26	3.47	8.81	4.27	3.02	7.55
4	*	-	5.50	3.14	-	3.14	-	5.13	-	-	-
5		*	-	-	-	-	4.24	3.40	3.42	4.06	-
6			*	4.29	4.17	7.68	5.32	6.12	3.32	6.27	3.83
8				*	3.81	3.26	4.43	-	-	5.54	-
10					*	3.07	3.16	5.05	-	3.48	-
11						*	3.40	4.80	\	4.33	-
12							*	5.39	3.25	7.88	3.63
13								*	3.47	6.66	7.05
14									*	3.14	4.03
15										*	3.44

Table 4

Dating the chronology DORE1. *t*-values with independent reference chronologies.

Area	Reference chronology	*t*-values
Essex	Essex chronology, 165 timbers (Tyers 1993)	6.48
Gloucestershire	Blackfriars Priory, Gloucester (Hillam and Groves 1993)	7.65
	Siddington Tithe Barn (Groves and Hillam 1992)	6.83
Herefordshire	Cathedral Barn, Hereford (Tyers 1996a)	10.44
London	Billingsgate (Hillam 1992)	6.64
Worcestershire	Droitwich, Upwich 2 (Groves and Hillam 1997)	5.30
	St John the Baptist Church, Mamble (Tyers 1996b)	6.08

Table 5

Dating the chronology DORE2. *t*-values with independent reference chronologies.

Area	Reference chronology	*t*-values
Essex	Essex chronology, 165 timbers (Tyers 1993)	8.62
Gloucestershire	Mercers Hall, Gloucester (Howard *et al* 1996)	8.86
Herefordshire	Farmers Club, Hereford (Tyers 1996a)	9.18
London	Hays Wharf (Tyers 1996c and d)	7.62
Staffordshire	Sinai Park, Burton-on-Trent (Tyers 1997)	8.62
Worcestershire	Droitwich, Upwich 3 (Groves and Hillam 1997)	9.97
Wales	Welsh borders (Seinbenlist-Kerner 1978)	9.50

Table 6

The DORE1 chronology, AD 1073-1195

Date	Ring widths (0.01mm)										Number of samples									
AD 1073			141	128	194	212	212	214	139	148			1	1	1	1	1	1	1	1
	118	108	181	137	210	185	163	139	318	173	1	1	1	1	1	1	1	1	2	3
	147	197	254	206	183	169	217	210	144	165	3	3	3	3	3	3	3	3	3	3
AD 1101	159	154	144	111	197	131	119	170	139	112	3	3	3	3	3	3	3	3	3	3
	91	95	141	105	108	91	114	170	123	135	3	3	3	3	3	3	3	3	3	3
	118	114	134	119	101	94	108	112	53	89	3	3	3	3	3	3	3	3	3	3
	83	93	114	87	99	97	82	91	92	113	3	3	3	3	3	3	3	3	3	3
	155	119	113	119	146	137	112	149	174	116	3	3	3	3	3	3	3	3	3	3
AD 1151	137	109	161	133	118	137	169	135	146	161	3	3	3	3	3	3	3	3	3	3
	121	137	95	110	166	141	127	118	133	108	3	3	3	3	3	3	3	3	3	3
	150	144	136	127	109	110	92	97	134	103	3	3	3	3	3	3	3	3	3	3
	135	128	100	94	132	128	173	96	96	144	3	3	3	2	2	2	2	2	2	2
	132	116	158	120	124						2	2	2	1	1					

Table 7

The DORE2 chronology, AD 1363-1612

Date	Ring widths (0.01mm)										Number of samples									
AD 1363			199	180	142	148	113	107	148	126			1	1	1	1	1	1	1	1
	126	156	145	113	97	72	70	103	119	137	1	1	1	1	1	1	1	1	1	1
	95	78	81	89	107	122	108	108	95	75	1	1	1	1	1	1	1	1	1	1
	68	79	78	75	68	109	86	83	94	116	1	1	1	1	1	1	1	1	1	1
AD 1401	99	80	106	91	82	72	61	81	76	94	1	1	1	1	1	1	1	1	1	1
	75	92	88	85	99	87	68	60	56	79	1	1	1	1	1	1	1	1	1	1
	87	78	85	90	55	65	60	68	88	68	1	1	1	1	1	1	1	1	1	1
	50	111	91	98	117	109	140	115	79	86	1	2	2	2	2	2	2	2	2	3
	96	92	89	107	102	116	112	111	110	101	3	3	3	3	3	3	3	3	3	3
AD 1451	144	125	120	138	121	154	136	130	97	129	4	4	4	4	4	5	5	5	5	5
	121	129	154	110	118	124	136	148	155	147	5	6	6	6	8	8	8	9	9	9
	136	130	103	125	178	152	166	138	187	155	9	9	9	9	9	9	10	10	10	10
	187	169	171	187	152	159	142	115	120	143	10	10	10	10	10	10	10	10	10	10
	128	102	126	128	114	191	142	111	162	137	10	10	10	10	10	10	10	10	10	10
AD 1501	100	123	119	117	131	131	150	137	169	139	10	11	11	11	11	11	11	11	11	11
	136	148	140	127	119	110	139	119	138	98	11	11	11	11	11	11	11	11	11	11
	115	134	122	111	112	114	113	126	128	110	11	11	11	11	11	11	11	11	11	11
	140	105	113	131	144	121	125	116	122	145	11	11	11	11	11	11	11	11	11	11
	139	112	115	107	117	96	102	122	117	124	11	11	11	11	11	11	11	11	11	10
AD 1551	142	102	113	118	138	112	100	113	138	136	10	10	10	10	10	10	10	10	10	9
	145	150	115	176	134	78	75	98	130	139	9	9	9	9	8	7	7	7	7	7
	155	152	142	169	165	128	129	96	115	146	7	7	6	6	6	6	6	6	6	6
	114	109	91	109	112	119	119	138	163	99	6	6	6	6	6	6	6	6	6	6
	120	116	112	121	139	113	116	123	110	100	6	6	6	6	4	4	4	4	4	3
AD 1601	115	139	140	126	89	92	86	118	115	81	3	3	3	3	2	2	2	2	2	2
	118	125									2	1								