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DAUNTSEY HOUSE, CHURCH LANE, DAUNTSEY, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Cathy Tyers, Matt Hurford, and Martin Bridge

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY

Dendrochronological analysis was undertaken on all 20 samples taken from the hall and cross-wing roofs. This resulted in the production of two site chronologies, DSDPSQ01 and DSDPSQ02, comprising eleven and nine samples respectively. DSDPSQ01 can be dated as spanning the years AD 1393–1580 and DSDPSQ02 as spanning the years AD 1122–1355.

The results indicate that the hall roof is constructed of timber that is likely to represent a single programme of felling dating to AD 1356–79, whilst the cross-wing was probably constructed just over two centuries later using timber, again representing a single felling programme, predominantly felled in the early, or possibly mid-, AD 1580s.

CONTRIBUTORS

Cathy Tyers, Matt Hurford, and Martin Bridge

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ARCHIVE LOCATION

Wiltshire and Swindon HER
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The Wiltshire and Swindon History Centre
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DATE OF INVESTIGATION

2009–11

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INTRODUCTION

In 2009 the Wiltshire Buildings Record (WBR) successfully obtained support through the English Heritage Historic Environment Enabling Programme for their project 'Wiltshire cruck buildings and other archaic roof types'. The detailed aims and objectives of the project are set out in the Project Design (Lloyd 2009). The overall aim was to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This would then facilitate detailed comparison with other counties allowing Wiltshire to be placed in a regional context. Investigation of these late medieval buildings (*c* AD 1200–*c* AD 1550) combined building survey, historical research, and dendrochronological analysis.

A series of 25 buildings identified by the WBR as having the potential to contribute to the aims and objectives of the project was assessed for dendrochronological suitability during 2009. In order to maximise the potential for dating the detailed dendrochronological and WBR assessments for the significance of each building informed the final selection of buildings, which were subsequently subjected to detailed study.

A single final Project Report produced by Lloyd (2012) summarises the overall results. However each building included in the project has an associated individual report on the structural analysis produced by the WBR, whilst the primary archive of the dendrochronological analysis is in the English Heritage Research Report Series.

A brief introduction to dendrochronology can be found in the Appendix. Further details can be found in the guidelines published by English Heritage (1998), which are also available on the English Heritage website (http://www.english-heritage.org.uk/publications/dendrochronology-guidelines/).

Dauntsey House

The Grade II* listed Dauntsey House (now known as Dauntsey Park) is located in close proximity to the Church of St James, about 1.5 miles west of the present village of Dauntsey in Wiltshire (Figs 1 and 2). The Dauntsey estate was granted to Malmesbury Abbey in AD 850 but by AD 1331 the manor was held by Sir Richard Dauntsey. Following the death of Sir Walter Dauntsey in AD 1420 the manor passed to the Stradlings and Dewall families through marriage, and subsequently to Sir John Danvers, with whom it remained until the Restoration.

The original plan is unclear, but it could have been a two-bay open hall with screen passages and service rooms to the south and a single-bay parlour to the north. This appears, on stylistic evidence, to date to the fourteenth century. This was extended with the addition of a cross-wing, aligned east-west, at the northern end of the hall, thought potentially to date to the later sixteenth century. Externally, there is no evidence for the medieval origins of the building as it has been so extensively extended that the original core is completely encased in later fabric (Fig 3).

The focus of this investigation is the surviving early core of the house, that is the open hall and cross-wing. Details given below are based on information provided in the WBR report (2012).

Hall

The original roof consists of three base-cruck trusses and two intermediate principal-rafter trusses. Base crucks C1 and C3 are the most complete of the trusses, with the others being very fragmentary. Truss C1 is an open truss with a cranked tiebeam and arch bracing, the spandrels being filled in with plaster (Figs 4 and 6); whilst truss C3 retains sections of its cruck blades, a cranked tiebeam, and evidence for lower purlins and two tiers of windbraces. Truss C2 is missing its base crucks but retains its chamfered tiebeam and arch bracing. Trusses C1 and C2 have peg holes and mortices for an upper structure set slightly in from the ends of the tiebeam, possibly for some form of upper cruck. Intermediate truss I1 has an arch-braced cranked collar which is chamfered on its lower edge. The remains of the principal rafters are still attached but cut off at the top and bottom. Intermediate truss I2 has a cambered rather than a cranked collar.

Cross-wing

The cross-wing is at the north end of the hall and is set on a lower level. The extant roof comprises three trusses, with principal rafters and collars, and twenty common-rafter frames (Figs 5 and 6). Based on the assembly marks present on the principal rafters it is thought that this roof was originally extended by a further truss to the west.

SAMPLING

Dendrochronological sampling and analysis of the timbers associated with the extant remains of the open hall and cross-wing was commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of the original medieval hall house and its subsequent early development, and hence inform the overall objectives of the 'Wiltshire Cruck Buildings and other archaic roof types' project. The dendrochronological study also formed a key component of the English Heritage-funded training programme for the second author, although the reporting was not completed within the duration of the training programme.

A total of nine timbers associated with the extant remains of the medieval hall house and eleven timbers from the cross-wing were sampled by coring by trainee Matt Hurford, supervised by Martin Bridge. Each sample was given the code DSD-P (for Dauntsey, Dauntsey Park) and numbered 01–20. The sampling encompassed as wide a range of elements as possible, whilst concentrating on those timbers with the best dendrochronological potential. Sampling focussed on the cruck blades, tiebeams, and collars in the hall as all other accessible timbers were reused and not thought to be associated with the primary construction of the hall. In the cross-wing the principal rafters and collars were predominantly sampled as the common rafters present were either derived from fast-grown oak trees, and considered highly unlikely to provide samples with sufficient numbers of rings for reliable dendrochronological analysis, or were relatively modern softwood replacements.

The location of samples was noted at the time of coring. No formal plans or drawings subsequently became available so the locations of the samples were marked on the sketch drawings made at the time of coring, these being reproduced here as Figures 6–14. Further details relating to the samples can be found in Table 1. In this table the timbers have been labelled following the scheme indicated in Figure 6. Truss C1 in the hall being the northernmost and truss C3 the southernmost. The trusses in the cross-wing have been numbered from the west to the east following the carpenters marks present on the principal rafters. Truss 1 is no longer extant so the westernmost truss is truss 2 and the easternmost truss 4.

ANALYSIS AND RESULTS

Each of the 20 cores obtained was prepared by sanding and polishing and the annual growth rings of each sample measured, the data of these measurements being given at the end of this report. The measurement and analysis was undertaken using a combination of the Litton/Zainodin grouping procedure (see Appendix) and software written by Tyers (2004). Tyers (2004) facilitates cross-matching and dating through a process of qualified statistical comparison and visual comparison. It uses a variant of the Belfast CROS programme (Baillie and Pilcher 1973). The analysis resulted in the production of two groups being formed, the samples of each group cross-matching with each as shown in Tables 2 and 3, and Figure 15.

The first group comprises eleven samples from the cross-wing which were combined to form site chronology DSDPSQ01 (Fig 15), with an overall length of 188 rings. Site chronology DSDPSQ01 was compared to an extensive range of reference chronologies for oak, this indicating a repeated and consistent cross-match with a series of these when the date of the first ring is AD 1393 and the date of its last ring is AD 1580 (Table 4).

The second group comprises nine samples from the hall which were combined to form site chronology DSDPSQ02 (Fig 15), with an overall length of 234 rings. Site chronology DSDPSQ02 was compared to an extensive range of reference chronologies for oak, this indicating a repeated and consistent cross-match with a series of these when the date of the first ring is AD 1122 and the date of its last ring is AD 1355 (Table 5).

This analysis can be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span
DSDPSQ01	11	188	AD 1393–1580
DSDPSQ02	9	234	AD 1122–1355

INTERPRETATION

For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings within this project is the Nottingham Tree-ring Dating Laboratory estimate of 15–40 (95% confidence range) rings.

Hall

The hall is represented by nine dated timbers in site chronology DSDPSQ02 (Fig 15). None of these samples has complete sapwood and it is thus not possible to calculate a precise felling date for the timbers represented. However, four of the samples did retain their heartwood/sapwood boundary ring, the average date for this being AD 1339. The overall variation of the heartwood/sapwood boundary date is 10 years and it seems likely that they represent a single programme of felling. Allowing for the outermost measured ring on sample DSD-P13, the estimated felling date is in the range AD 1356–79. The small amounts of sapwood lost from DSD-P12 and DSD-P16 do not affect this felling date range.

The remaining five dated samples have no trace of sapwood and thus it is not possible to calculate their likely felling date ranges. With the exception of DSD-P18 whose last measured ring dates to AD 1291, the dates of their last measured rings vary from AD 1341 to AD 1345. During sampling it was noted that the timber represented by DSD-P14 had heartwood/sapwood boundary present adjacent to the exit hole of the core, one other timber (DSD-P15), was recorded as having a possible heartwood/sapwood boundary although, again, not at the precise location of the core, on another timber, (DSD-P19), the potential identification of the heartwood/sapwood boundary was hampered by degradation of the surfaces of the timber, and the timber represented by DSD-P18, appeared to be, potentially, heavily trimmed. This, combined with the overall level of cross-matching within the entire group (Table 3), including a possible same-tree match, suggests that they are part of a coherent group and are hence all likely to have been felled during the period AD 1356–79. This interpretation is supported by the fact that these timbers appear integral to the roof structure with no evidence of insertion or reuse.

Cross-wing

The cross-wing is represented by eleven dated timbers in site sequence DSDPSQ01 (Fig 15). Sample DSD-P08 had retained complete sapwood. The final fully formed ring, and hence measured, dates to AD 1580 but the spring vessels for the following year are present, indicating that the timber represented was felled during the late spring/early summer of AD 1581. A second sample had retained complete sapwood but the outermost rings were very compressed and distorted so could not be measured or even counted accurately. However, with an outermost measured ring of AD 1565 it is clearly compatible with the AD 1581 felling date and it seems likely that this timber was felled at a similar time. Four other samples were taken at points on the timber represented where complete sapwood was present but, due to its very friable nature in this roof, the sapwood did not survive coring fully intact. Three of these had lost between 10–15mm of sapwood, whereas one had lost up to a maximum of 5mm. Due to the variable nature of the growth rates of these samples, the estimated number of lost sapwood rings was calculated using both the overall average growth rate and the average growth rate for the last ten measured rings. This suggests felling dates ranging from the very late AD 1570s to the early/mid AD 1580s and hence indicates that these timbers were felled at a similar time and a time compatible with the AD 1581 felling date identified.

One of the five remaining samples has the heartwood/sapwood boundary present and has a felling date range of AD 1569–94, again compatible with the AD 1581 felling date identified. The other four samples have no trace of sapwood and thus it is not possible to calculate their likely felling date ranges. However during sampling it was noted that the timbers represented appeared to be more heavily trimmed. Thus with the dates of their last measured rings varying from AD 1499 to AD 1539, combined with the overall level of cross-matching within the entire group, including several potential same-tree matches (Table 3), they appear likely to be part of a single felling programme in, or around, AD 1581. All of the dated timbers from the cross-wing roof appear integral, with no sign of insertion or reuse.

DISCUSSION AND CONCLUSION

Dendrochronological analysis has established that the original hall roof is constructed of timber felled in the period AD 1356–79. This therefore confirms the fourteenth-century date assigned to the hall on stylistic grounds. It also identifies that the builder of the house is likely to be Sir John Dauntsey who inherited the estate after AD 1349 and held it until his death in AD 1381. The cross-wing was probably constructed just over two centuries later using timber felled in a single felling programme, possibly in AD 1581, or spanning a few years in the very late AD 1570s and early/mid-AD 1580s, when the estate was in the ownership of Sir John Danvers.

The overall level of cross-matching between the dated samples from the cross-wing suggests that these timbers probably originated from a single woodland source.

Particularly high *t*-values in excess of 10.0 can be found between a number of samples suggesting the possibility that they could be derived from either the same-tree or trees located in very close proximity to each other (Table 2). The dated timbers from the hall also probably originate from a single woodland source (Table 3), and again at least one possible same-tree match is indicated. The two site chronologies generally produce the highest *t*-values, and thus show the greatest degree of similarity, with reference chronologies from Wiltshire and the surrounding counties (Tables 4 and 5). This suggests that it is likely that the timbers from both the hall and cross-wing were derived from relatively local woodland sources.

The timbers from the two roofs show slight differences in growth characteristics. Those from the later cross-wing are generally derived from slightly faster grown and slightly younger trees than those in the hall. However it is notable that all are from relatively mature trees.

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TABLES

Table 1: Details of tree-ring samples from Dauntsey House, Dauntsey, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
DSD-P01	Cross wing truss 4 north principal	130	13c 10–15mm lost	1.36	240x130	1444	1560	1573
DSD-P02	Cross wing truss 4 collar	116	no h/s	1.30	300x130	1415	---	1530
DSD-P03	Cross wing truss 4 south principal	133	no h/s	1.30	300x120	1393	---	1525
DSD-P04	Cross wing bay 3 south rafter 3	79	h/s	2.04	150x100	1476	1554	1554
DSD-P05	Cross wing bay 3 south rafter 2	113	12c[1]	1.17	170x90	1453	1553	1565
DSD-P06	Cross wing truss 3 south principal	158	20c 2–5mm lost	1.35	250x150	1422	1559	1579
DSD-P07	Cross wing truss 3 collar	80	14c 10–15mm lost	1.09	280x140	1493	1558	1572
DSD-P08	Cross wing truss 3 north principal	106	23C[2]	1.31	300x120	1475	1557	1580
DSD-P09	Cross wing truss 2 south principal	144	no h/s	1.32	250x130	1396	---	1539
DSD-P10	Cross wing truss 2 collar	129	7c 10–15mm lost	1.12	220x140	1446	1567	1574
DSD-P11	Cross wing truss 2 north principal	94	no h/s	1.30	270x130	1406	---	1499
DSD-P12	Hall truss C1 west cruck blade	90	h/s 5mm lost	1.32	350x130	1246	1335	1335
DSD-P13	Hall truss C1 west arch brace	80	16	1.33	400x130	1276	1339	1355
DSD-P14	Hall truss C1 tiebeam	191	no h/s	1.04	420x120	1155	---	1345
DSD-P15	Hall truss I1 collar	88	no h/s	0.91	310x140	1256	---	1343
DSD-P16	Hall truss C2 tiebeam	203	h/s 5–10mm lost	0.92	330x220	1143	1345	1345
DSD-P17	Hall truss I2 collar	165	17	0.93	250x130	1188	1335	1352
DSD-P18	Hall truss I2 west cruck blade	117	no h/s	0.86	300x140	1175	---	1291
DSD-P19	Hall truss C3 tiebeam	221	no h/s	0.85	340x190	1122	---	1342
DSD-P20	Hall truss C3 west cruck blade	70	no h/s	1.10	400x190	1272	---	1341

nm = not measured; h/s = the heartwood/sapwood ring is the last ring on the sample; c= complete sapwood was present on the timber sampled but was partially lost during coring; the estimated amount lost is indicated; C= complete sapwood is present on the sample; [1]= complete sapwood is present on the sample but compression of the outermost rings prevented accurate identification of the ring boundaries; [2]= complete sapwood is present on the sample but the outermost ring is only partially formed and hence not measured, this sample is therefore felled in late spring/early summer AD 1581

Table 2: Matrix showing the t-values obtained between the matching ring sequences in site chronology DSDPSQ01; - indicates t-values less than 3.00; \ indicates overlap of less than 30 years; grey shading indicates possible same-tree matches

Filenames	DSD-P02	DSD-P03	DSD-P04	DSD-P05	DSD-P06	DSD-P07	DSD-P08	DSD-P09	DSD-P10	DSD-P11
DSD-P01	6.65	8.58	5.04	8.31	7.95	3.53	7.08	6.73	7.35	4.62
DSD-P02		5.81	4.85	5.43	8.69	5.20	6.62	11.56	6.64	4.26
DSD-P03			-	5.36	7.48	-	5.13	9.15	6.39	5.28
DSD-P04				4.20	5.66	4.56	6.24	5.76	4.96	\
DSD-P05					7.94	-	8.34	5.82	6.95	6.07
DSD-P06						6.19	11.43	10.63	9.59	6.41
DSD-P07							5.39	3.63	5.64	\
DSD-P08								6.57	7.07	\
DSD-P09									6.71	5.09
DSD-P10										-

Table 3: Matrix showing the t-values obtained between the matching ring sequences in site chronology DSDPSQ02; - indicates t-values less than 3.00; \ indicates overlap of less than 30 years; grey shading indicates possible same-tree match

Filenames	DSD-P13	DSD-P14	DSD-P15	DSD-P16	DSD-P17	DSD-P18	DSD-P19	DSD-P20
DSD-P12	-	3.53	-	4.16	4.29	5.50	-	3.77
DSD-P13		3.39	5.34	3.89	4.62	\	5.76	-
DSD-P14			7.64	8.11	6.41	8.96	6.75	4.19
DSD-P15				3.50	4.16	3.58	4.27	3.14
DSD-P16					9.35	5.34	14.95	3.70
DSD-P17						5.55	6.45	3.99
DSD-P18							4.07	\
DSD-P19								-

Table 4: Results of the cross-matching of site sequence DSDPSQ01 and relevant reference chronologies when the first-ring date is AD 1393 and the last-ring date is AD 1580

Reference chronology	*t*-value	Span of chronology	Reference
Newnham Hall Farm, Newnham Murren, Oxfordshire	10.1	AD 1414–1551	(Arnold and Howard 2006 unpubl)
May Tree Cottage, Hambledon, Surrey	9.2	AD 1413–1559	(Miles and Worthington 2000a)
Old Manor House, West Lavington,Wiltshire	8.9	AD 1264–1497	(Tyers and Hurford 2014)
Upper House Farmhouse, Nuffield, Oxfordshire	8.7	AD 1404–1627	(Haddon-Reece *et al* 1989)
Queen Manor Farm Granary, Clarendon, Willtshire	8.4	AD 1337–1602	(Tyers 1999a)
Black Ladies, near Brewood, Staffordshire	8.3	AD 1372–1671	(Tyers 1999b)
White House, Vowchurch, Herefordshire	7.9	AD 1364–1602	(Nayling 1999)
The Old Mansion, Clarendon, Wiltshire	7.9	AD 1315–1625	(Tyers 1999a)

Table 5: Results of the cross-matching of site sequence DSDPSQ02 and relevant reference chronologies when the first-ring date is AD 1122 and the last-ring date is AD 1355

Reference chronology	*t*-value	Span of chronology	Reference
Bremhill Court, Bremhill, Wiltshire	16.2	AD 1111–1323	(Hurford *et al* 2010)
Court Farm Barn, Winterbourne, Gloucestershire	13.7	AD 1177–1341	(Miles and Worthington 2000b)
Wick Farm Cottage, Heddington Wick, Wiltshire	11.6	AD 1158–1335	(Tyers *et al* 2014)
Chapter House, Christ Church, Oxford	11.4	AD 1142–1260	(Worthington and Miles 2003)
Abbey Barn, Glastonbury, Somerset	9.8	AD 1095–1334	(Bridge 2001)
The Manor Barn, Avebury, Wiltshire	9.7	AD 1072–1278	(Tyers 1999c)
Tithe Barn, Englishcombe, near Bath	9.7	AD 1157–1304	(Groves and Hillam 1994)

FIGURES

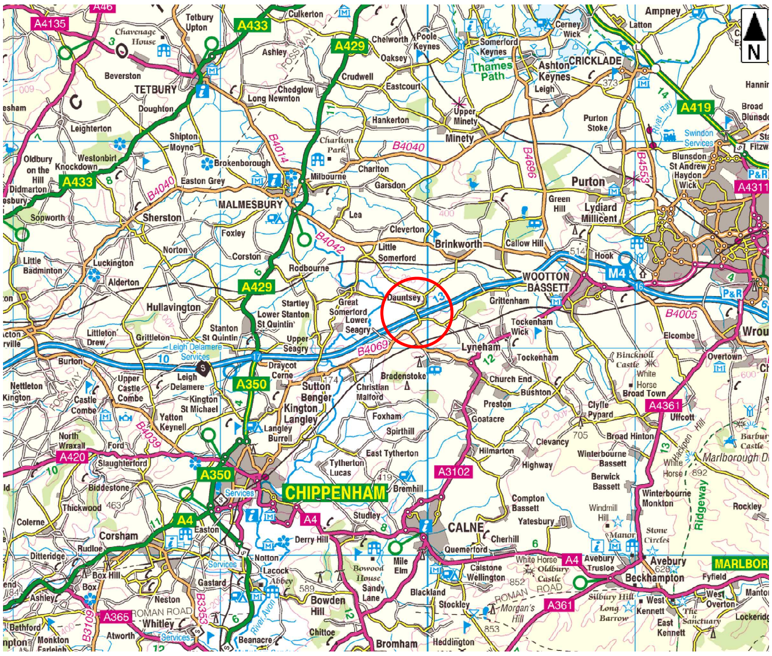

Figure 1: Map to show the location of the village of Dauntsey in Wiltshire. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

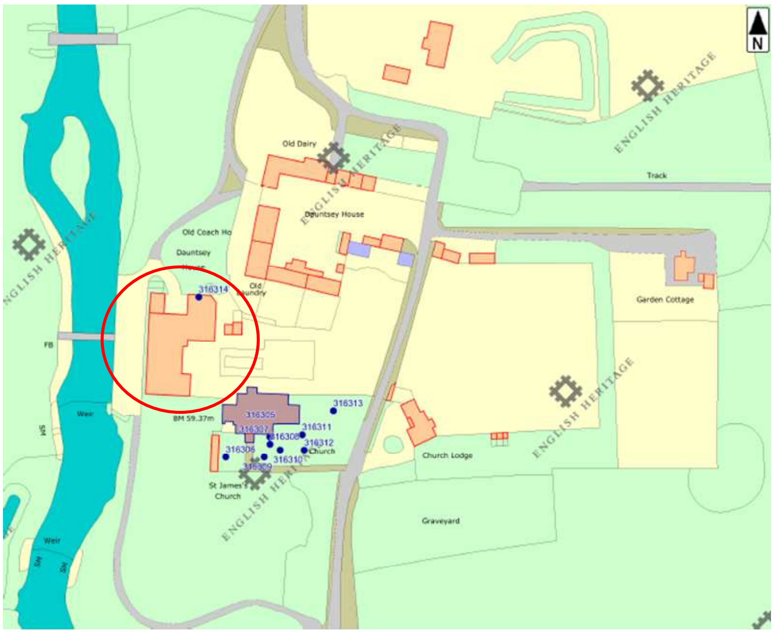

Figure 2: Map to show the location Dauntsey House, Dauntsey. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: The west (principal) front (Avis Lloyd)

Figure 4: Hall, truss C1 viewed looking south-east (Matt Hurford)

Figure 5: Cross-wing, truss 4 viewed looking east (Matt Hurford)

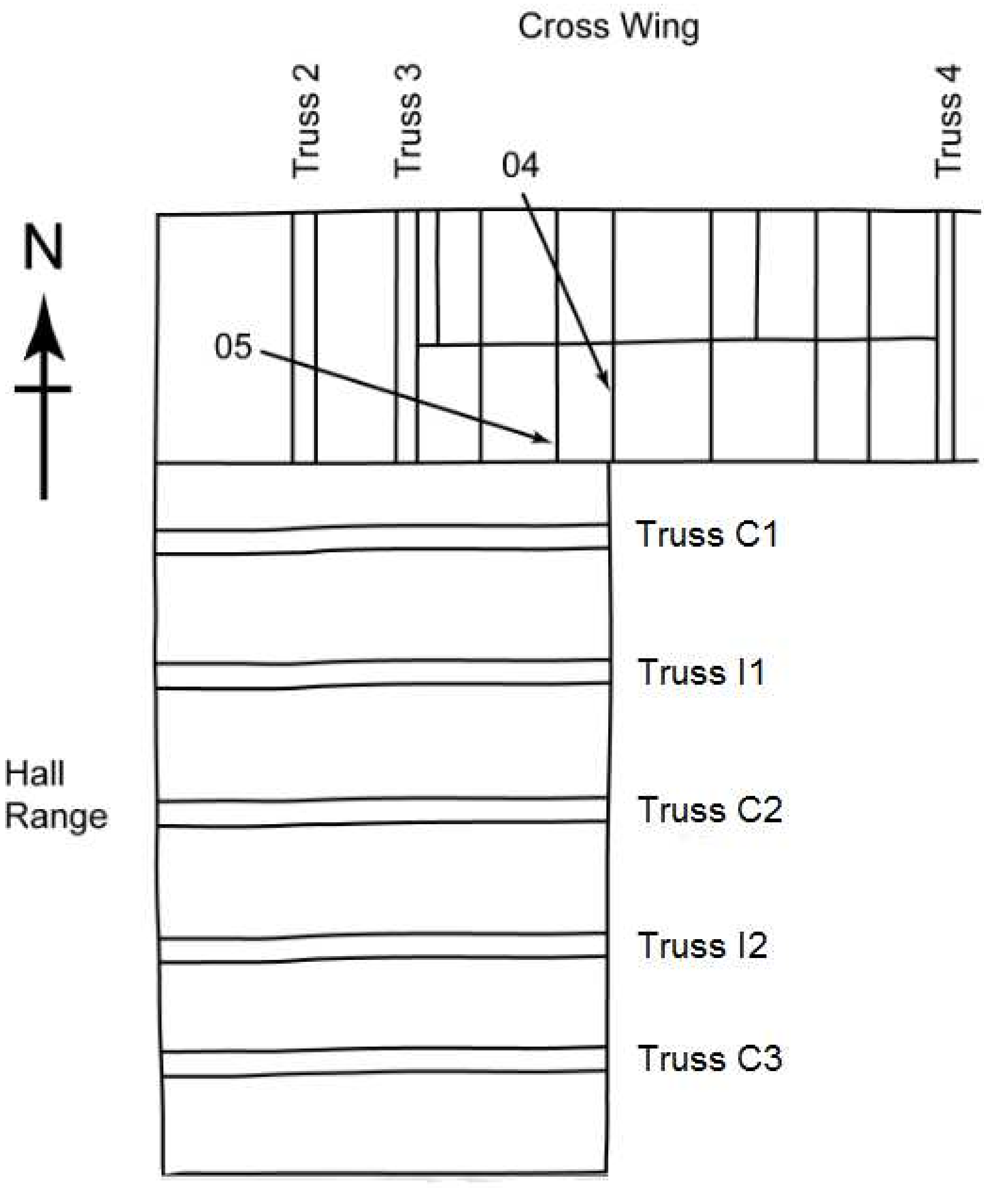

Figure 6: Plan of hall and cross-wing, showing truss position and location of samples 04 and 05

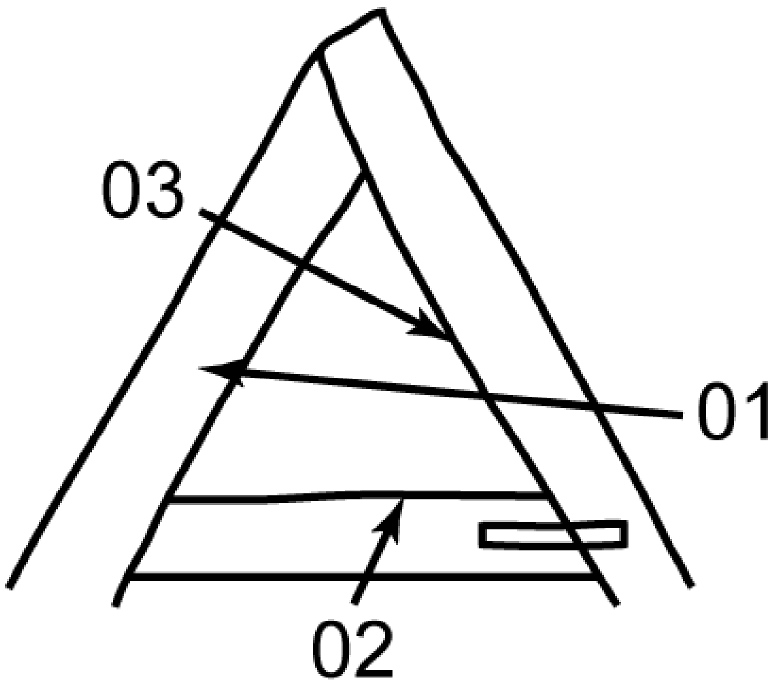

Figure 7: Cross-wing, truss 4, west face, showing the location of samples 01–03

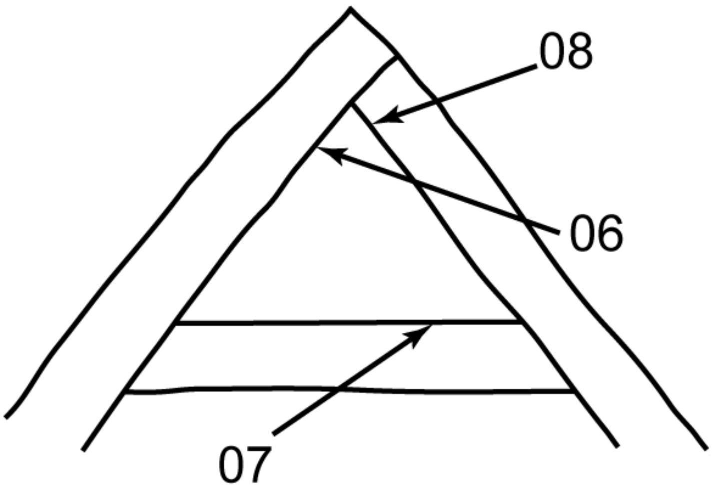

Figure 8: Cross-wing, truss 3, east face, showing the location of samples 06–08

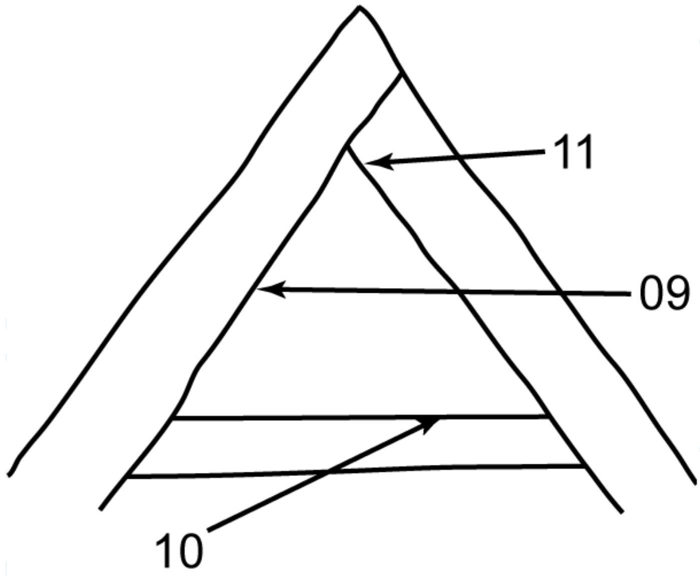

Figure 9: Cross-wing, truss 2, east face, showing the location of samples 09–11

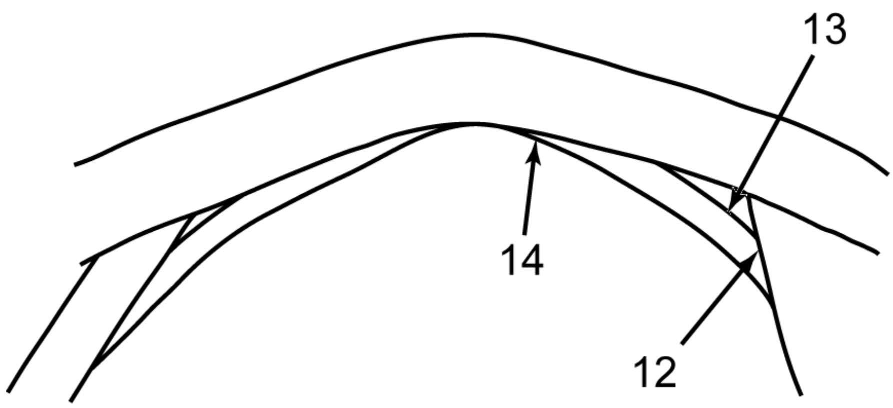

Figure 10: Hall, truss C1, north face, showing the location of samples 12–14

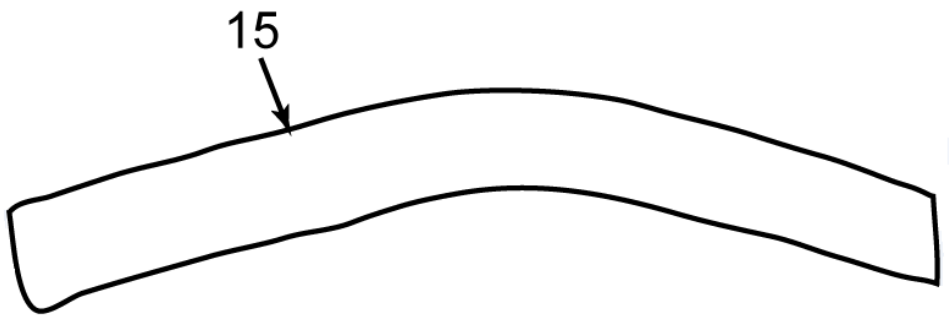

Figure 11: Hall, truss I1, north face, showing the location of sample 15

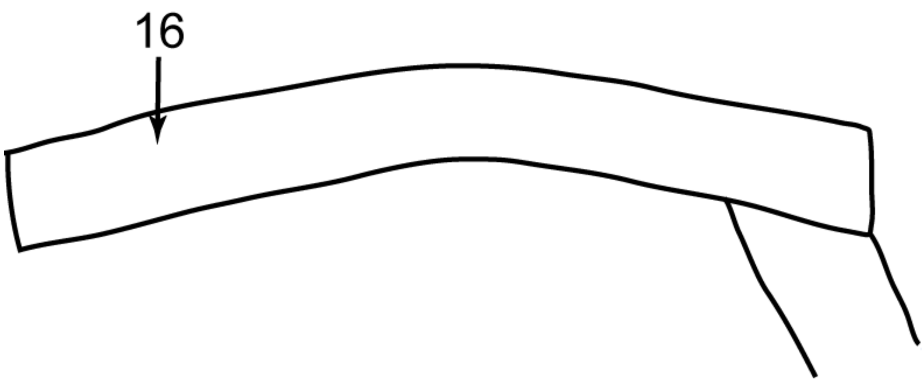

Figure 12: Hall, truss C2, north face, showing the location of sample 16

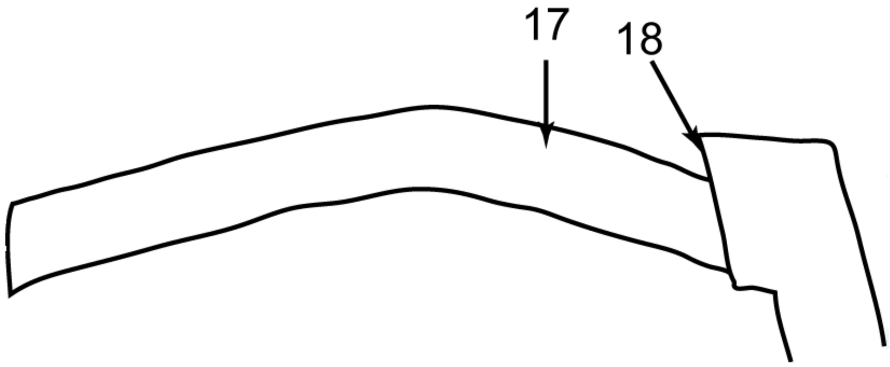

Figure 13: Hall, truss I1, north face, showing the location of samples 17 and 18

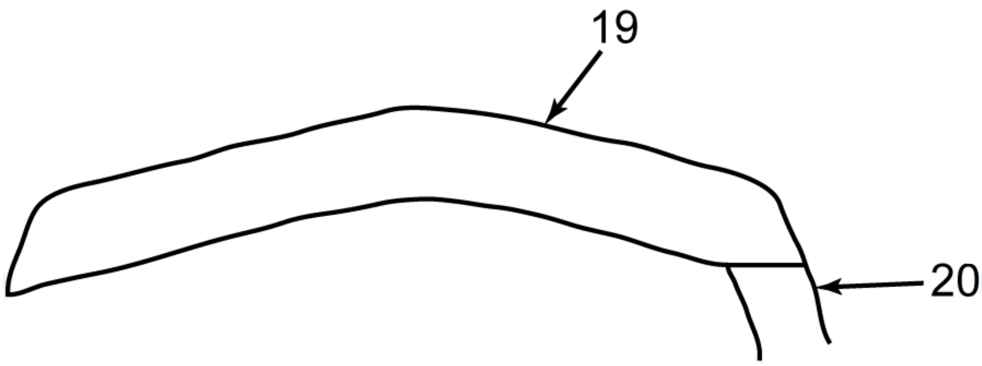

Figure 14: Hall, truss C3, north face, showing the location of samples 19 and 20

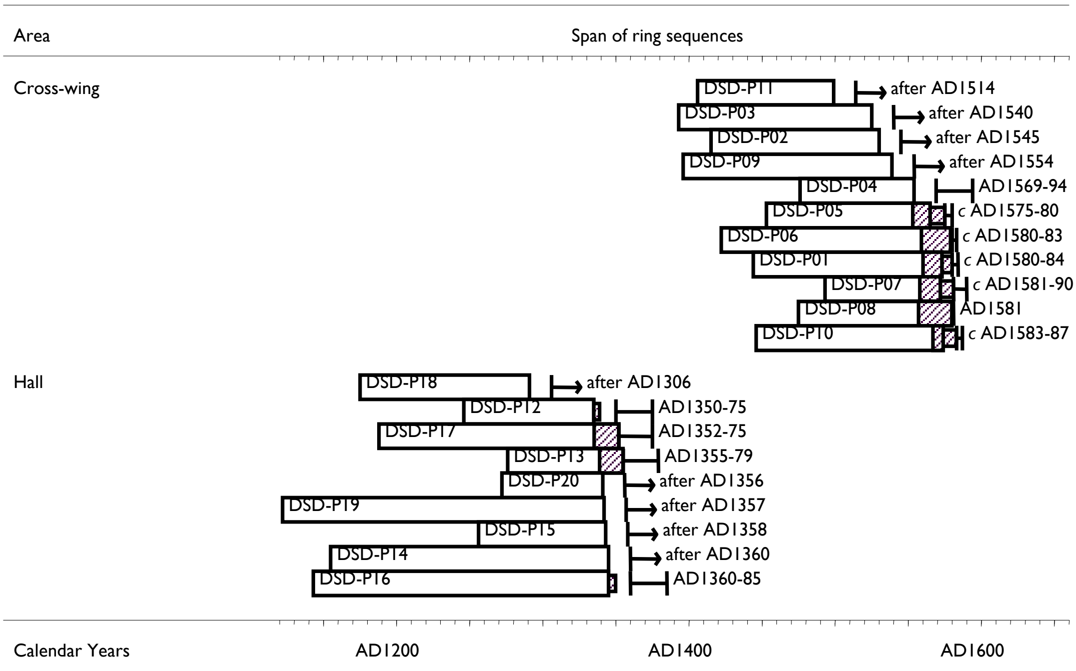

Figure 15: Bar diagram of the samples in site chronologies DSDPSQ01 (cross-wing) and DSDPSQ02 (hall) with the individual felling date ranges. White bar = heartwood rings; hatched bar = sapwood rings; narrow bar = estimated unmeasured rings or rings lost during coring

DATA OF MEASURED SAMPLES

Measurements in 0.01 mm units

DSD-P01A 130
117 108 107 163 154 166 138 158 106 96 117 176 164 148 121 92 99 72 81 147
97 109 135 85 118 124 123 128 121 107 122 98 93 92 86 76 90 151 153 126
143 102 133 162 145 165 153 135 119 145 117 131 173 130 93 109 121 103 75 90
119 114 124 92 76 108 111 142 188 131 152 118 113 152 156 165 113 141 205 157
151 150 171 178 188 161 136 189 119 179 179 189 95 129 151 188 136 145 83 141
86 130 129 141 131 149 178 160 136 154 140 160 136 78 92 165 176 173 145 206
177 261 212 146 146 183 178 163 132 132
DSD-P01B 130
114 103 113 169 155 169 135 138 109 81 108 177 158 156 115 77 109 70 88 154
106 90 142 86 100 119 143 136 106 107 121 97 92 90 89 68 90 161 150 126
133 101 126 159 155 162 154 131 129 144 120 129 170 132 95 113 117 108 95 90
113 113 127 93 81 100 113 140 186 127 155 123 114 149 157 155 119 143 203 159
159 155 187 169 196 159 130 179 113 164 182 187 160 138 140 187 136 151 90 140
101 127 117 161 124 143 174 157 134 158 142 164 137 84 100 161 173 168 147 209
166 272 218 144 137 188 184 159 127 133
DSD-P02A 116
278 312 351 250 172 308 323 140 263 486 271 158 269 283 160 140 176 245 163 119
190 198 127 109 136 114 197 122 103 124 110 123 167 173 177 190 188 114 89 112
167 134 154 105 85 91 98 131 162 107 119 138 108 114 93 123 108 111 140 80
150 116 122 101 117 117 149 121 92 83 76 107 117 84 115 103 118 98 84 72
88 98 110 68 60 65 60 58 54 63 70 68 64 58 59 45 67 79 83 92
63 68 104 119 82 47 67 109 106 79 80 79 124 135 97 101
DSD-P02B 116
282 305 354 256 166 317 332 135 258 496 266 158 270 280 150 157 171 255 156 116
184 213 130 111 135 127 187 122 102 129 117 118 168 172 182 184 190 100 105 108
162 129 156 103 78 96 104 134 164 114 102 144 107 111 94 125 109 111 137 85
150 111 122 107 123 107 149 123 78 93 79 102 114 84 116 100 122 97 84 69
99 94 101 64 64 71 64 64 41 65 71 65 65 56 57 45 70 80 83 89
76 56 123 103 92 57 51 115 97 89 67 85 115 133 102 102
DSD-P03A 133
66 66 71 112 110 141 159 116 172 143 119 92 108 221 130 159 99 92 119 151
157 187 205 176 225 195 171 212 194 153 204 117 81 66 91 125 139 113 136 160
111 93 85 82 87 94 98 115 184 148 138 182 155 140 154 169 199 168 178 115
130 122 167 150 155 143 106 109 67 79 90 77 100 95 63 61 65 61 66 75
77 76 67 64 57 65 54 69 126 99 100 135 118 156 210 161 140 131 166 135
172 113 134 209 203 136 188 144 125 101 122 124 115 94 139 118 177 166 206 186
196 176 153 130 138 155 177 83 130 218 166 120 122
DSD-P03B 133
70 58 74 107 116 151 152 96 161 130 126 83 117 212 140 161 93 98 121 142
152 187 210 175 225 193 171 207 200 150 201 115 85 67 89 126 136 108 136 159
116 92 97 74 86 87 94 111 185 137 139 178 160 130 163 170 196 166 175 122
126 124 165 156 151 151 102 108 72 68 97 91 85 97 57 58 68 52 74 69
72 80 68 64 57 63 50 74 124 98 103 139 112 153 216 159 142 132 171 130
169 115 132 213 198 135 186 148 131 91 128 123 113 98 136 119 173 165 204 194
186 191 142 133 144 141 175 93 130 217 166 117 122

DSD-P04A 79
329 249 219 309 428 335 269 212 205 168 303 295 325 260 279 170 219 169 173 246
330 244 143 139 190 207 122 188 182 349 321 177 194 153 183 227 272 183 216 192
168 169 199 208 107 130 251 222 197 131 186 209 212 194 117 195 186 169 162 334
221 199 173 246 190 176 105 155 129 196 129 118 158 141 163 135 111 143 144
DSD-P04B 79
332 267 213 310 426 337 266 217 214 162 298 297 325 257 281 167 219 166 172 257
331 250 144 139 187 207 122 187 199 333 316 183 194 150 185 222 260 178 220 189
174 179 196 207 117 138 258 215 199 129 191 198 206 201 109 196 197 169 157 320
220 217 165 251 188 176 114 148 128 201 121 126 159 141 155 135 107 144 137
DSD-P05A 113
95 135 159 151 155 130 123 173 115 155 219 109 138 185 104 135 180 180 184 122
166 109 134 124 148 152 149 156 221 169 118 118 101 112 193 180 162 195 106 107
117 103 113 231 154 98 106 130 102 89 110 76 136 149 98 121 136 125 88 145
129 135 133 82 135 134 150 79 118 157 125 114 112 114 119 152 110 127 183 115
93 85 89 80 76 115 64 66 91 63 82 56 58 63 58 66 69 65 80 72
88 68 93 68 58 68 76 92 62 77 57 54 51
DSD-P05B 113
88 139 162 152 158 122 132 175 112 153 213 105 132 186 106 129 194 182 190 124
166 115 125 120 145 149 154 152 207 173 127 115 101 117 197 179 166 196 113 103
120 103 120 221 151 93 106 132 104 103 93 76 126 145 97 121 138 106 106 141
140 132 133 89 131 139 141 80 128 152 133 115 113 119 120 149 111 130 181 114
71 89 90 77 78 117 57 65 82 69 86 50 60 65 58 68 50 82 79 74
89 73 89 71 54 70 76 94 61 77 53 57 51
DSD-P06A 158
150 289 180 194 179 283 378 216 172 241 260 154 180 264 222 165 108 172 149 226
135 146 113 91 72 84 77 103 61 92 62 67 65 101 118 125 106 87 125 89
153 211 128 167 177 123 97 114 233 163 179 143 150 200 150 164 162 228 258 283
257 169 141 111 143 230 183 210 154 132 85 95 94 105 168 136 93 98 90 79
67 85 76 75 74 77 84 117 100 116 160 149 146 114 112 128 188 184 81 102
182 146 116 100 91 112 159 190 160 201 105 114 130 190 196 127 150 172 132 133
117 109 64 115 92 120 111 156 109 125 70 101 95 139 93 70 64 103 116 104
112 62 127 99 92 96 110 177 135 111 89 95 86 75 65 88 69 107
DSD-P06B 158
151 289 185 193 189 289 378 213 170 248 246 163 181 267 219 188 102 168 149 218
126 147 124 81 84 75 78 90 76 85 63 70 56 107 113 125 106 77 131 91
152 219 115 171 172 124 103 115 232 165 175 143 157 187 155 169 149 235 260 327
251 175 152 113 137 239 177 211 156 126 83 101 90 106 168 133 94 92 93 74
76 76 82 72 84 74 82 115 96 111 150 151 147 116 103 134 190 181 90 95
176 160 116 99 97 101 162 181 161 206 103 115 130 185 188 124 143 171 141 132
112 109 71 105 101 112 123 157 121 108 77 103 95 150 86 73 65 93 121 91
127 70 122 105 90 97 114 179 138 111 92 93 88 73 72 82 79 121
DSD-P07A 80
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106 118 104 96 121 113 123 58 85 157 110 115 97 108 130 130 133 128 165 118
123 146 165 132 97 114 174 151 150 113 144 90 123 99 83 129 128 120 115 87
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95 92 85 66 77 86 124 96 90 148 97 121 97 85 86 81 135 114 103 111

DSD-P08A 106
217 149 184 150 218 211 242 252 143 145 128 152 218 153 160 169 155 124 112 104
100 205 147 121 100 102 89 60 68 95 82 109 68 101 123 96 103 127 89 88
83 63 110 131 127 61 95 148 131 122 130 161 184 192 146 134 175 106 131 129
182 157 153 163 189 148 166 108 136 96 99 105 96 123 148 106 105 92 108 100
127 98 105 89 137 146 112 121 91 118 111 88 87 125 195 167 172 97 105 119
146 136 133 122 136 241
DSD-P08B 106
241 142 190 152 220 198 224 241 137 142 133 154 209 165 153 176 153 122 114 107
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80 64 91 131 128 58 99 143 136 118 132 148 180 188 148 138 176 118 128 131
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128 109 106 89 138 148 113 124 89 144 101 91 86 139 207 163 177 95 102 132
157 141 126 114 141 227
DSD-P09A 144
233 161 188 160 137 231 193 225 182 197 328 227 165 85 79 129 102 112 148 170
129 115 78 88 166 185 118 141 137 114 72 139 205 154 143 167 183 106 92 134
128 105 131 151 154 239 175 136 146 138 121 148 152 177 171 152 90 95 64 101
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173 200 159 233
DSD-P09B 144
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126 123 112 142 186 221 155 111 110 85 110 175 114 178 143 139 108 112 87 105
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49 40 49 69 53 50 83 54 67 30 44 46 53 67 47 56 149 96 72 93
83 112 106 117 104 151 85 92 86 109 116 114 118 169 108 123 79 96 49 142
120 148 165 165 132 138 138 191 130 258 151 115 203 251 257 184 383 175 236 186
217 217 209 357 223 188 191 206 218

DSD-P11A 94
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85 88 156 145 146 213 219 123 126 148 103 120 96 93 109 152 147 125 96 115
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133 93 124 122 159 152 150 133 119 160 121 145 112 92 144 137 142 92 114 75
137 164 148 144 163 157 140 108 132 148 219 217 134 209
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72 76 64 64 43 44 62 57 65 72
DSD-P12B 90
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162 149 203 179 152 246 174 187 246 167 136 214 194 227 265 197 286 183 130 132
180 140 121 137 129 111 220 225 214 164 165 172 168 135 171 144 193 172 172 166
188 150 138 106 64 45 39 63 65 44 54 67 57 64 66 85 70 66 55 67
63 85 57 61 52 50 54 61 66 76
DSD-P13A 80
253 338 289 285 274 208 210 230 292 235 230 168 119 168 207 156 226 197 127 119
94 89 107 102 164 155 147 118 137 107 134 120 130 121 125 99 87 121 131 146
210 141 93 121 97 111 93 101 66 94 80 116 101 120 73 88 112 79 109 129
92 113 104 153 130 139 97 69 49 49 69 54 77 53 92 82 68 88 74 77
DSD-P13B 80
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95 111 103 157 129 136 99 67 48 50 63 67 67 55 91 80 70 93 77 73
DSD-P14A 191
469 604 519 401 424 425 328 396 268 232 282 256 224 399 536 355 236 185 133 250
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35 43 46 41 39 43 40 41 45 45 39 49 41 48 49 78 44 33 39 52
44 35 49 33 50 35 58 44 38 41 40 54 40 41 48 35 28 33 42 45
40 32 46 47 44 45 39 48 74 39 52 67 75 40 61 70 62 80 117 82
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90 80 103 101 131 97 88 103 123 91 70 124 83 93 94 112 82 112 139 109
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103 120 98 72 87 99 84 99 70 72 62 71 63 77 78 99 62 77 77 91
109 85 85 97 88 96 130 117 81 64 78

DSD-P14B 191
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201 156 82 88 95 53 64 88 56 48 47 54 82 34 80 82 45 42 39 34
40 47 54 38 41 37 46 40 37 36 50 45 40 48 47 73 51 39 45 41
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DSD-P15A 88
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74 51 73 66 69 57 68 60 57 65 79 88 97 61 71 54 56 48 48 69
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64 62 64 80 77 91 76 80
DSD-P16A 203
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62 81 79 96 83 102 81 94 86 113 144 192 155 137 117 74 113 103 85 99
95 77 79 107 68 63 72 74 60 59 65 65 95 85 83 95 183 115 116 94
107 72 69
DSD-P16B 203
224 313 307 214 163 129 143 119 158 126 164 121 94 97 138 101 116 125 147 138
100 146 175 158 126 132 130 126 134 113 139 166 123 111 89 110 109 74 110 167
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91 77 83 99 78 72 61 73 62 60 69 69 89 81 84 88 187 115 112 91
112 64 55

DSD-P17A 165
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DSD-P17B 165
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92 136 141 116 180 165 151 91 108 93 114 105 123 131 125 115 86 95 109 103
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60 69 65 50 54 56 75 89 80 84 62 95 102 94 80 92 68 73 59 70
43 55 83 89 92
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51 53 56 41 64 54 64 41 41 62 56 117 79 80 108 81 58 46 50 44
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156 146 135 94 108 132 168 205 153 161 178 137 75 112 72 78 89 94 104 116
105 82 112 104 130 124 104 162 138 121 130 148 145 153 184 216 129
DSD-P18B 117
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67 62 54 43 50 76 88 65 46 48 41 47 54 64 59 84 50 50 46 39
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63 56 80 87 82 100 55 70 106 76 111 93 86 56 65 72 82 88 143 73
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DSD-P19A 221
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77 70 63 63 65 84 81 82 72 66 77 73 96 101 69 72 85 135 102 105
94

DSD-P19B 221
178 142 182 162 133 142 167 124 225 272 250 258 251 276 362 192 349 264 332 339
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94
DSD-P20A 70
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77 99 80 97 84 98 112 156 111 127
DSD-P20B 70
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148 176 120 80 79 89 98 111 142 101 106 131 121 132 123 168 124 137 91 111
106 119 141 175 150 206 101 90 92 119 121 95 108 103 96 103 122 96 76 68
81 95 78 99 92 94 110 151 115 128

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer

rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. Measuring Ring Widths. Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. Cross-Matching and Dating the Samples. Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. **Estimating the Felling Date.** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, before any new growth had started, but this is not too important a consideration in most cases). The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. Master Chronological Sequences. Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

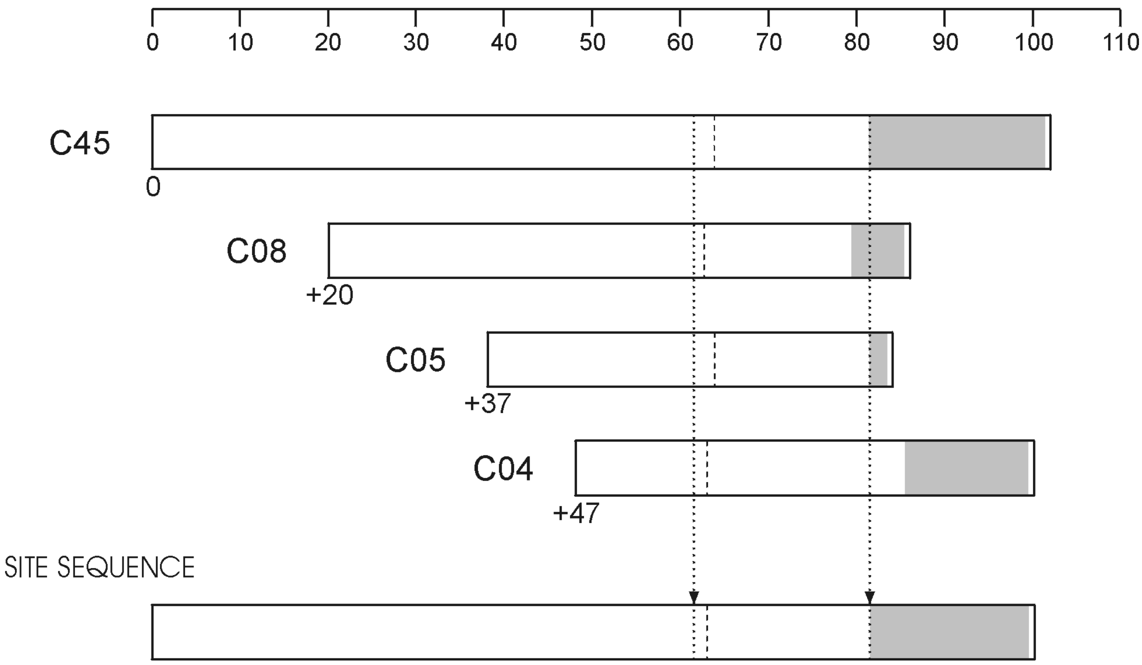


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

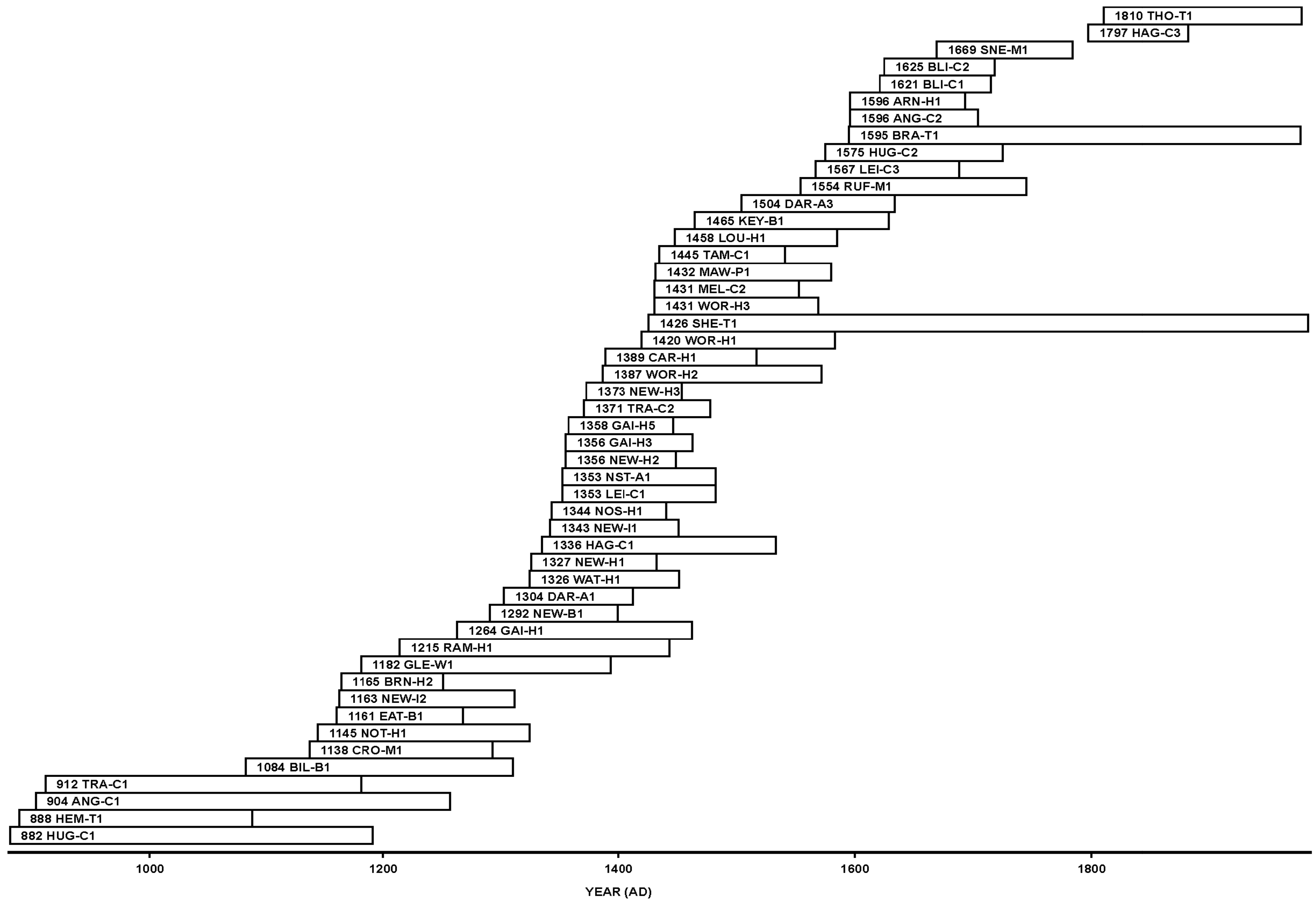
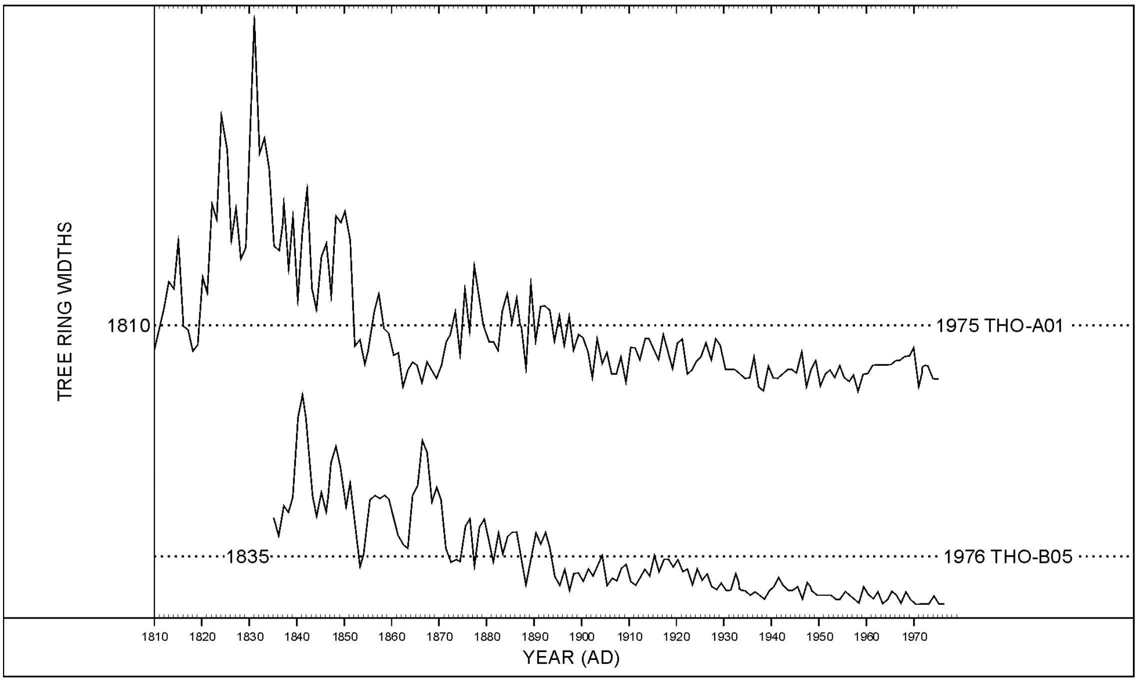


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

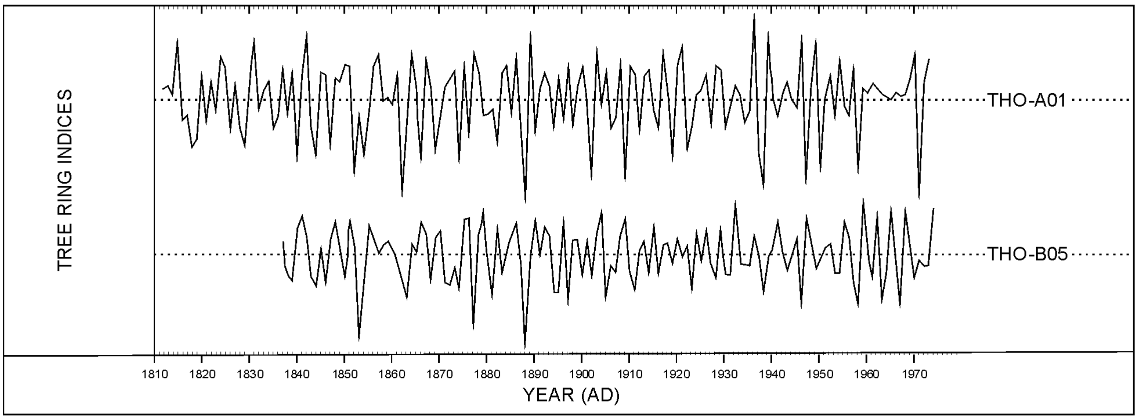


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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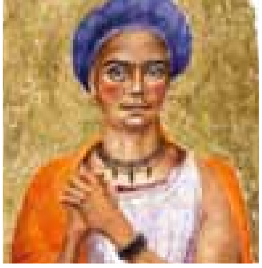


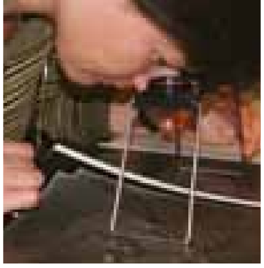


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