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THE OLD COACH HOUSE AND DOVECOTE, EASTCOTE HOUSE GARDENS, HIGH ROAD, EASTCOTE, HILLINGDON, LONDON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION AND ANALYSIS

ENGLISH HERITAGE

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TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

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SUMMARY

Analysis by dendrochronology of 16 of the 20 samples from timbers in The Old Coach House has produced four site chronologies comprising six, four, two, and two samples each, of 88, 129, 101, and 107 rings respectively. The first three of these site chronologies can be dated, their rings spanning AD 1504–1591, AD 1569–1697, and AD 1720–1820, respectively.

Interpretation of the sapwood and the heartwood/sapwood boundary on the dated samples indicates that timbers representing several different felling dates are to be found here. Six timbers from the roof have an estimated felling date in the period AD 1592–1614. At least three timbers from the gallery floor frame have an estimated felling date in the range AD 1703–28, with a fourth joist also possibly felled at this time. A further floor joist from the gallery is unlikely to have been felled before AD 1827, and may be coeval with a stud from the west wall which has an estimated felling date in the range AD 1833–58.

The adjacent Dovecote was also assessed for potential tree-ring analysis but was deemed unsuitable for dating and no samples were taken.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to thank all those who assisted with this programme of tree-ring analysis. In particular thanks are due to Sarah Harper, Conservation Officer for Hillingdon Borough Council, who assisted in gaining access to the Coach House. We would also like to thank the members of Eastcote Billiards Club for their cooperation during sampling. Finally, we would like to thank Dr Peter Marshall, English Heritage Scientific Dating Team, for commissioning this programme of tree-ring analysis and Cathy Tyers, Sheffield University Dendrochronology Laboratory, for advice and assistance throughout the production of this report

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CONTENTS

INTRODUCTION

Eastcote House and and a number of associated outbuildings, in Hillingdon, West London, dating at least in part to the early sixteenth century, were demolished in 1964. The Old Coach House and adjacent Dovecote (TQ 107 888, Figs 1 and 2) remain and now stand within the former gardens, these, and the garden walls, being grade II listed and on English Heritage's Heritage At Risk register (www.english-heritage.org.uk/publications/har-2011-registers/).

The listing for the Coach House describes it as being timber-framed and of early-seventeenth century date with later alterations. It is of two storeys beneath a tiled roof, with framing, in rectangular panels, to the upper levels only. Externally it would appear that original *in-situ* timber is only visible to the north gable wall, the framing to the west wall apparently having been extensively, though perhaps not entirely, replaced during later restoration; it is possible that a few original timbers remain or have been reused. It is also likely that the later timbers have been inserted in the same position as the timbers they have replaced, and in many cases an attempt at authenticity has been made by morticing and pegging some of them together. It would appear very likely, however, that several episodes of repair are to be found here. The timber-framed panels to both north and west walls are filled by brickwork, some of that to the west wall set herring-bone fashion, some with bricks on end, some in smaller rectangular sets being of particularly varied and decorative form. Externally there appear to be no timbers to the east wall or to the south gable wall, these now being entirely of brick.

Internally the building is divided into four bays by three principal rafter trusses and the two, lighter timber-framed, gable end walls (Fig 3). In addition to principal rafters and tiebeams, the trusses, which support two rows of purlins to each pitch of the roof, also have collars and queen struts (Fig 4a-c). There are braces from short wall posts to the tiebeams, and from the upper parts of the principal rafters to the upper purlins. The majority of these timbers appear to be integral with each other, being fully jointed and pegged, and to represent the primary phase of construction, there being no clear evidence for the reuse of older timber or for the insertion of later repair pieces. This is in contrast to the walls which appear to have had thick oak boards either applied to the inner faces of the timber frame, or inserted into the walls, in almost 'mock' timber-frame style not necessarily related to the original form.

The southern third of the building contains a first floor gallery supported on a close-set series of north/south joists of oak, these themselves being supported on two east-west softwood cross-beams (Fig 4d). Some of these oak joists show evidence of possible reuse in the form of redundant mortices. It is possible, however, that these mortices relate to some now removed internal fittings or structure. A short, narrow, brick-built, outshot projects to the east beneath a cat-slide roof, from what is now taken to be the rear of the building. This outshot contains timbers only to its roof.

The detached, brick-built, rectangular dovecote to the south of the Coach House is of two storeys beneath a roof hipped to all four sides. The roof comprises small, modern, probably late-twentieth century, softwood common rafters supported by purlins to each pitch. Internally there is a central vertical spindle post with a single arm off, the spindle fitting into a structure at its top made up of cross-beams

SAMPLING

Tree-ring analysis of timbers to both the Old Coach Hose and the Dovecote was requested by Kim Stabler and Will Reading, English Heritage London region. It was hoped that this would provide independent dating evidence for what appeared likely to be the primary timbers of the roof and wall-framing of the Old Coach House, if suitable, and for the timbers of the first floor gallery at its southern end, and of the roof timbers to the Dovecote. It was hoped that this would determine the original construction date of both buildings, and hence establish how much of the fabric might be original. In addition it was hoped to date the insertion of the gallery in the Old Coach House.

An initial assessment of the suitability of the timbers within both the Old Coach House and the Dovecote was made prior to sampling. It was clearly seen at this time that the timbers of the Dovecote, being of small scantling softwood, and having very few rings, were totally unsuitable to tree-ring analysis. It was also seen that the roof timbers of the brick-built outshot to the Coach House, although of oak, were again of small scantling and also derived from fast-grown trees. As such it was felt that they were unlikely to provide suitable samples for analysis. In addition many of the wall-frame timbers of the Coach House, although again of oak, appeared to be either relatively modern repair pieces, or to be reused timbers of uncertain origin. Finally, it was seen that the two cross-beams of the Coach House gallery floor were of softwood but, although they were large timbers, contained insufficient rings for dating. In view of this assessment, sampling was, therefore, restricted to the roof, the oak beams of the gallery floor, and a small number of potentially original wall timbers, of the Old Coach House.

Thus, from the material available, a total of 20 samples was obtained by coring. Each sample was given the code ECT-A (for Eastcote, site “A”), and numbered 01-20. A selection of joists to the first floor gallery was cored as samples ECT-A01-08. Samples ECT-A09-18 are from the roof, an attempt being made to obtain samples from as wide a range of locations within the roof as possible. The remaining two samples, ECT-A19 and A20, are from the west wall, the sampling of this being somewhat limited by the possible presence of multi-phase repair timbers.

The location of all samples was noted at the time of coring and marked on survey drawings made and provided by MRDA Ltd, Architects and Conservation Consultants, London. These are reproduced here as Figures 5a-e. Further details relating to the samples can be found in Table 1.

ANALYSIS

Each of the 20 samples obtained was prepared by sanding and polishing. It was seen at this time that four samples had fewer than the minimum of 50 rings here deemed necessary for reliable dating, and these were rejected from this programme of analysis. The annual growth-ring widths of the remaining 16 samples were, however, measured, the data of these measurements being given at the end of this report.

The data of the 16 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing four separate groups of cross-matching samples to be formed at a minimum value of t=4.5. These four groups account for 14 of the measured samples, the samples of each group cross-match with each other as shown in the bar diagrams, Figures 6a-d. The cross-matching samples of each group were combined at their indicated offset positions to form site chronologies ECTASQ01-SQ04.

Each of these four site chronologies was then compared to an extensive corpus of reference material for oak, this process resulting in the dating of three of them. The evidence for this dating is given in Tables 2–4. Each of the four site chronologies was then compared with the two remaining measured but ungrouped samples, but there was no further satisfactory matching. These two remaining ungrouped samples were then compared individually with the full range of reference chronologies for the oak, but there was no satisfactory cross-matching, and these samples must remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
ECTASQ01	6	88	1504–1591
ECTASQ02	4	129	1569–1697
ECTASQ03	2	101	1720–1820
ECTASQ04	2	107	undated
Ungrouped	2	---	undated
Unmeasured	4	---	---

INTERPRETATION AND DISCUSSION

Site chronology ECTASQ01

None of the six dated samples in site chronology ECTASQ01, all of them from the roof of the Old Coach House, retains complete sapwood and it is thus not possible to give a precise felling date for any of the timbers represented. All six samples, however, do retain some sapwood or at least the heartwood/sapwood boundary, that is, only the sapwood rings are missing. It is thus possible to give an estimated likely felling date range for these timbers.

As may be seen from Table 1 and Figure 6a, the overall position of the heartwood/sapwood boundary varies by only 12 years. The earliest heartwood/sapwood boundary is at relative position 65 (AD 1568), on sample ECT-A11, with the latest heartwood/sapwood boundary being at relative position 77 (AD 1580) on sample ECT-A16. Such a limited variation is consistent with the timbers represented all probably cut in a single episode of felling. The average date of the boundary on the six samples in this site chronology is AD 1574. Using a 95% confidence limit of 15–40 rings for the amount of sapwood these trees had, and given that the latest sapwood ring of any sample (ECT-A11) is dated to AD 1591, would give the timbers represented an estimated felling date in the range AD 1592–1614.

Site chronology ECTASQ02

Likewise, none of the four dated samples in site chronology ECTASQ02, all of them from the gallery floor joists, retains complete sapwood, and hence it is again not possible to give a precise felling date for any of the timbers represented. Three of these samples do, though, retain either some sapwood or the heartwood/sapwood boundary.

As may be seen from Table 1 and Figure 6b, the overall position of the heartwood/sapwood boundary on the three samples in the group where it exists varies by only eight years, indicating that the timbers represented were all probably cut in a single episode of felling. In this case, the earliest heartwood/sapwood boundary is at relative position 117 (AD 1685), on sample ECT-A02, with the latest heartwood/sapwood boundary being at relative position 125 (AD 1693) on sample ECT-A07. The average date of the boundary on the three samples in this site chronology is AD 1688. Using a 95% confidence limit of 15–40 rings for the amount of sapwood these trees had would give the timbers represented an estimated felling date in the range AD 1703–28.

Allowing that the last extant heartwood ring on the fourth sample is dated to AD 1659, and allowing for a minimum of 15 sapwood rings, this timber is unlikely to have been felled before AD 1674. It is possible that the tree represented by this sample was felled at the same time as the three timbers discussed above. However, because this sample is without its heartwood/sapwood boundary it is also missing an unknown number of heartwood rings, and thus this cannot be proven.

Site chronology ECTASQ03

The two samples of the third site chronology, from a gallery floor joist and a stud post, are also without complete sapwood, but one of them, ECT-A20, retains its heartwood/sapwood boundary, this being dated to AD 1818. Using the same sapwood estimate as above, 15–40 rings, would give the timber an estimated felling date in the range AD 1833–58.

It is possible that the tree represented by the other sample in this site chronology, ECT-A06, was felled at the same time as that represented by sample ECT-A20, but again the sample is without its heartwood/sapwood boundary and is missing an unknown number of heartwood rings. All that may be reliably said is that, allowing that its last extant heartwood ring is dated to AD 1812, and allowing for a minimum of 15 sapwood rings, the timber is unlikely to have been felled before AD 1827.

Site chronology ECTASQ04

The fourth and final site sequence is represented by two samples, both of them from gallery floor joists. Although the site sequence cannot be dated it is likely, given that the position of the heartwood/sapwood boundary on the two samples varies by only eight years, that the timbers represented were probably cut in a single episode of felling.

CONCLUSION

Analysis by dendrochronology of 16 of the samples taken only from timbers in The Old Coach House (the timbers of the Dovecote all being unsuitable) has produced four site chronologies, three of which can be dated. Interpretation of the sapwood and the heartwood/sapwood boundary on the dated samples indicates that timbers with different felling dates are to be found here.

The earliest material is represented by six timbers from the roof, these estimated to have been felled in the period AD 1592–1614. There is no obvious evidence that these timbers have been reused, and it is thus possible that these represent the primary construction phase of The Old Coach House.

An early-eighteenth century phase of felling is represented by a small group of joists from the gallery floor. It is unclear if the estimated felling date for these timbers, AD 1703–28, represents the construction of this feature or, given that one other gallery floor joist is unlikely to have been felled before AD 1827, the gallery is of nineteenth century date. There is, however, no physical, framed, connection between the two sets of timbers, and in theory it would be possible to insert the nineteenth century timber as a repair or alteration into an already existing eighteenth century gallery.

An early- to mid-nineteenth century phase of felling is represented by at least one other timber, this estimated to have been felled in the period AD 1833–58. This would appear to represent a repair phase to the front wall.

Two other samples, ECT-A08 and A09, a joist and a tiebeam respectively, remain ungrouped and undated, despite both of them having sufficient rings for reliable dating. Given that the building appears to have undergone periodic repair and alteration, it is possible that each of the unmatched timbers is of a different date, and from a different woodland source. This would, in effect, make them 'singletons'. While such samples can occasionally be dated it is often much more difficult than with groups of well replicated data. It is also possible that the timbers are from time periods and woodland sources not yet sufficiently well represented by the corpus of reference material to produce positive cross-matches, although this seems relatively unlikely given the location and period.

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TABLES

Table 1: Details of samples from the Old Coach House, Eastcote Manor, Eastcote, Hillingdon, West London

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
	Gallery floor joists					
ECT-A01	Joist 1 (from east)	91	no h/s	1569	------	1659
ECT-A02	Joist 4	87	h/s	1599	1685	1685
ECT-A03	Joist 5	100	10	------	------	------
ECT-A04	Joist 7	102	10	1596	1687	1697
ECT-A05	Joist 8	92	3	------	------	------
ECT-A06	Joist 13	93	no h/s	1720	------	1812
ECT-A07	Joist 14	101	h/s	1593	1693	1693
ECT-A08	Joist 15	87	h/s	------	------	------
	Roof and wall timbers					
ECT-A09	Tiebeam, truss 1 (from north)	66	14	------	------	------
ECT-A10	East principal rafter, truss 1	69	h/s	1504	1572	1572
ECT-A11	West principal rafter, truss 1	86	23	1506	1568	1591
ECT-A12	West principal rafter, truss 2	63	10	1526	1578	1588
ECT-A13	West queen strut, truss 2	79	15	1511	1574	1589
ECT-A14	West principal rafter, truss 3	nm	---	------	------	------
ECT-A15	Tiebeam truss 3	nm	---	------	------	------
ECT-A16	East principal rafter, truss 3	56	8	1533	1580	1588
ECT-A17	East queen strut, truss 3	55	16	1536	1574	1590
ECT-A18	West queen strut, truss 3	nm	---	------	------	------
ECT-A19	West wall post, truss 1	nm	---	------	------	------
ECT-A20	West stud post bay 4	90	2	1731	1818	1820

*nm = not measured; **h/s = the heartwood/sapwood ring is the last ring on the sample

Table 2: Results of the cross-matching of site chronology ECTASQ01 and relevant reference chronologies when first ring date is AD 1504 and last ring date is AD 1591

Reference chronology	Span of chronology	*t*-value	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	7.3	(Arnold and Howard forthcoming)
Dovebridge, Derbyshire	AD 1502–1617	7.3	(Howard *et al* 1998a unpubl)
Powcher's Hall, Ely Cathedral, Cambridgeshire	AD 1457–1609	7.1	(Arnold *et al* 2004)
Moyns Park, Birdbrook, Essex	AD 1431–1606	7.0	(Tyers 1999)
Cressing Temple Farmhouse, Essex	AD 1514–1608	6.8	(Tyers 1995)
Cobham Hall, Cobham, Kent	AD 1317–1662	6.7	(Arnold *et al* 2003)
Church of St Michael & St Mary, Melbourne, Derbyshire	AD 1509–1652	6.4	(Arnold and Howard 2009)
De Grey Mausoleum, Flitton, Bedfordshire	AD 1510–1726	6.2	(Arnold *et al* 2003a)

Table 3: Results of the cross-matching of site chronology ECTASQ02 and relevant reference chronologies when first ring date is AD 1569 and last ring date is AD 1697

Reference chronology	Span of chronology	*t-value*	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	7.9	(Arnold and Howard forthcoming)
Kibworth Harcourt post mill, Leicestershire	AD 1582–1773	6.8	(Arnold *et al* 2004)
Hill Hall, Theydon Mount, Essex	AD 1525–1681	6.4	(Bridge 1999)
Old Clarendon Building, Oxford	AD 1539–1711	6.4	(Worthington and Miles 2006)
De Grey Mausoleum, Flitton, Bedfordshire	AD 1510–1726	6.2	(Arnold *et al* 2003a)
Worcester Cathedral, Worcester	AD 1484–1772	5.9	(Arnold *et al* 2003b)
Church of St Peter and St Mary, Stowmarket, Suffolk	AD 1542–1671	5.9	(Howard *et al* 1994)
Castle House, Melbourne, Derbyshire	AD 1583–1720	5.7	(Arnold and Howard 2009 unpubl)

Table 4: Results of the cross-matching of site chronology ECTASQ03 and relevant reference chronologies when first ring date is AD 1720 and last ring date is AD 1820

Reference chronology	Span of chronology	*t-value*	Reference
Chicksands Priory, Chicksands, Bedfordshire	AD 1670–1814	8.7	(Howard *et al* 1998b)
Ely Cathedral, Cambridgeshire	AD 1678–1828	6.3	(Esling *et al* 1989)
Tilbury Fort, Essex	AD 1678–1777	5.5	(Groves 1993)
Jessops Riverside, Sheffield, South Yorkshire	AD 1709–1842	5.5	(Tyers pers comm 2001)
Kibworth Harcourt post mill, Leicestershire	AD 1582–1773	5.1	(Arnold *et al* 2004)
Wortley Forge, Stocksbridge, South Yorkshire	AD 1750–1823	5.1	(Hillam and Groves 1992)
Thaxted Church, Essex	AD 1644–1813	5.0	(Tyers 1990)
Church Farm, Bringhurst, Leicestershire	AD 1664–1781	4.8	(Groves *et al* 2004)

FIGURES

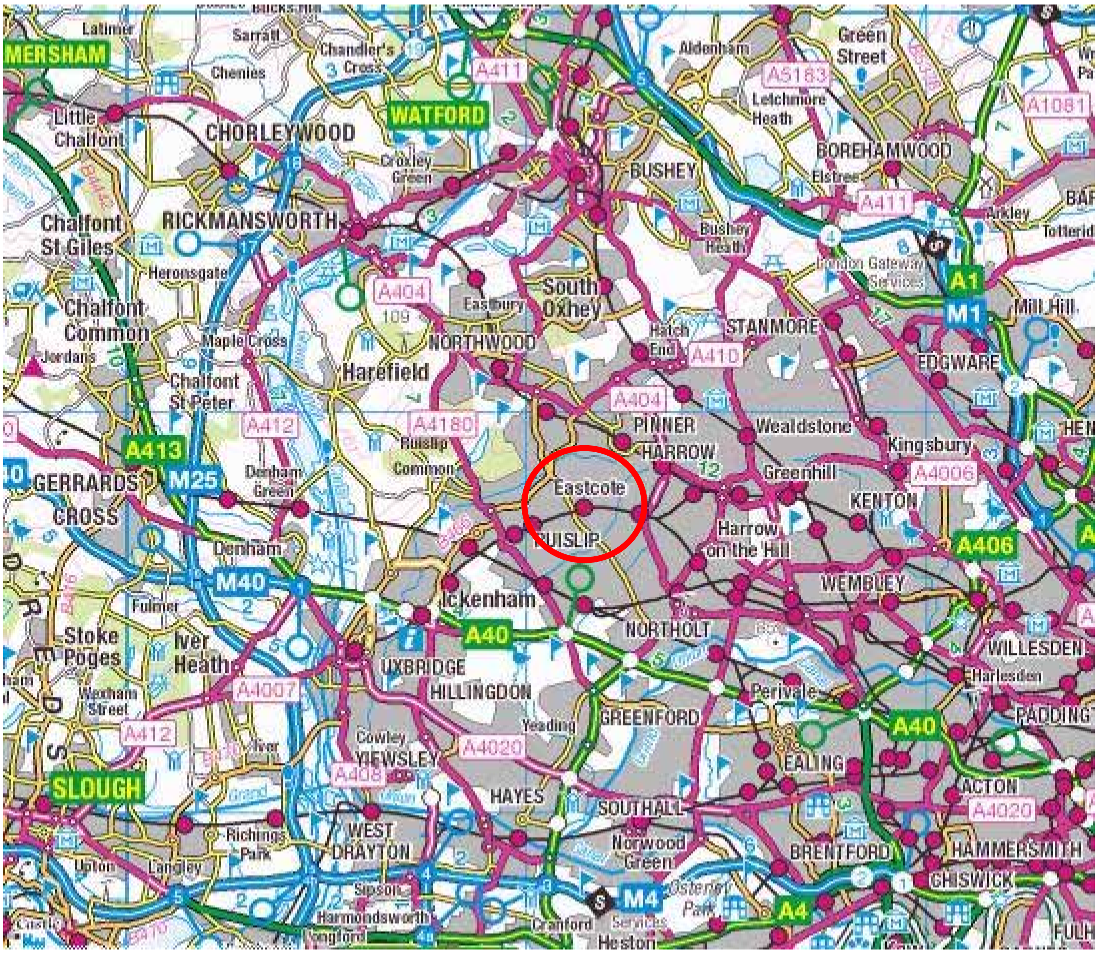


Figure 1: Map to show the general location of Eastcote Manor. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 2: Map to show the location of Eastcote Manor. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

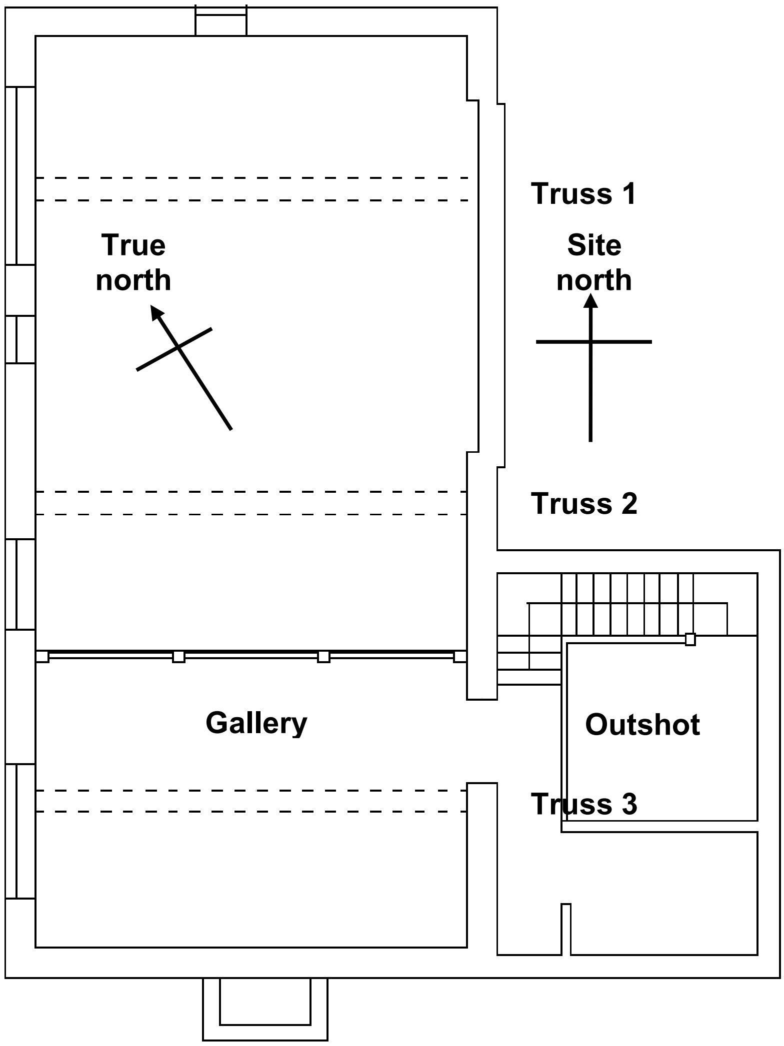


Figure 3: General plan of the Old Coach House

Figure 4a/b: General internal views of the Old Coach House, looking site north to south (top), and south to north (bottom)

Figure 4c/d: Views of the roof (top) and the beams of the gallery (bottom)

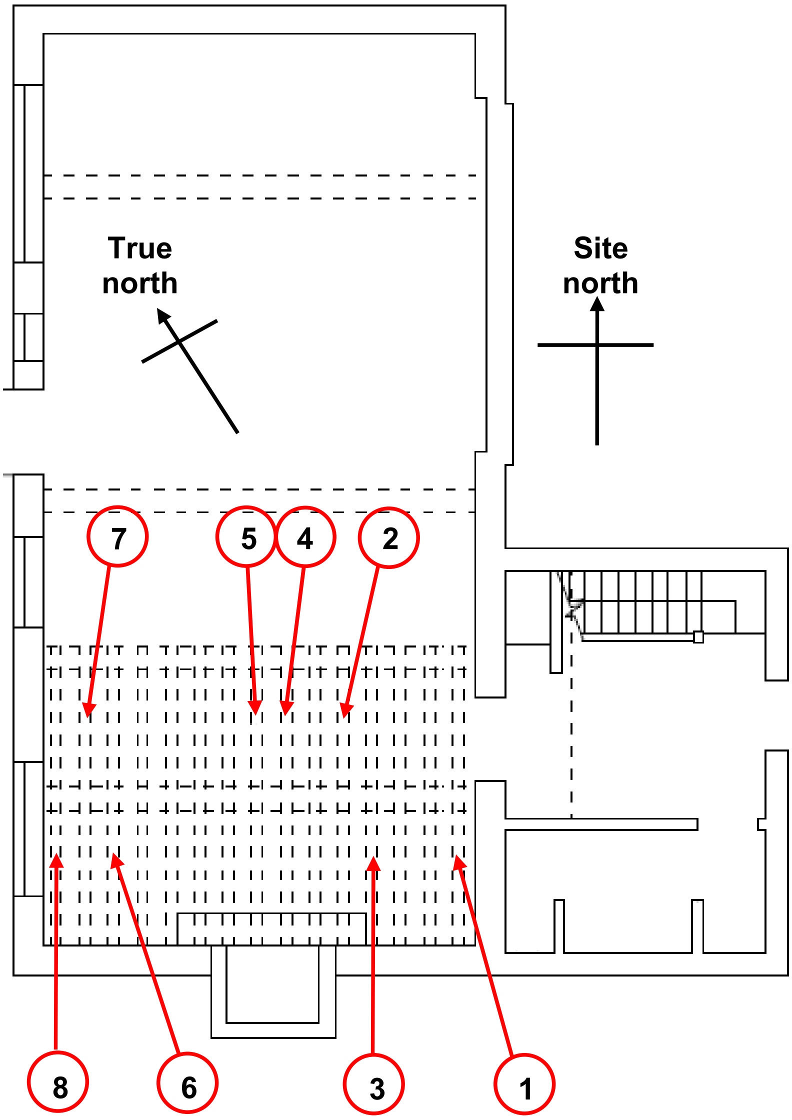


Figure 5a: Plan at ground floor level to show position of sampled timbers

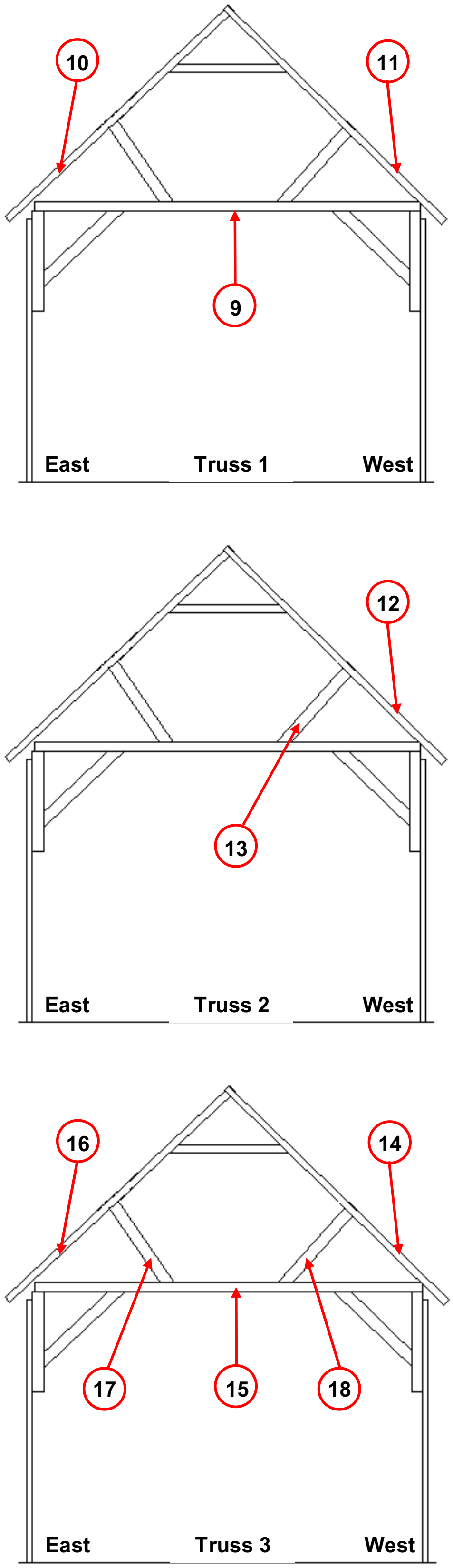


Figure 5b–d: Drawings of the trusses to show sampled timbers

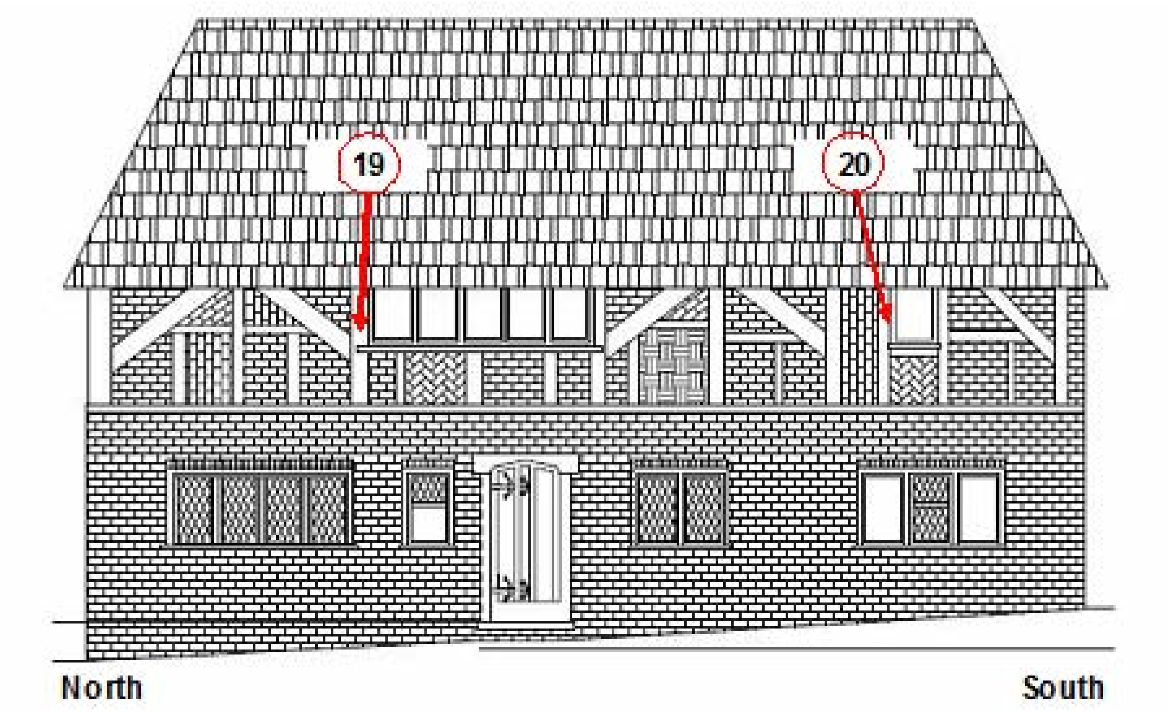
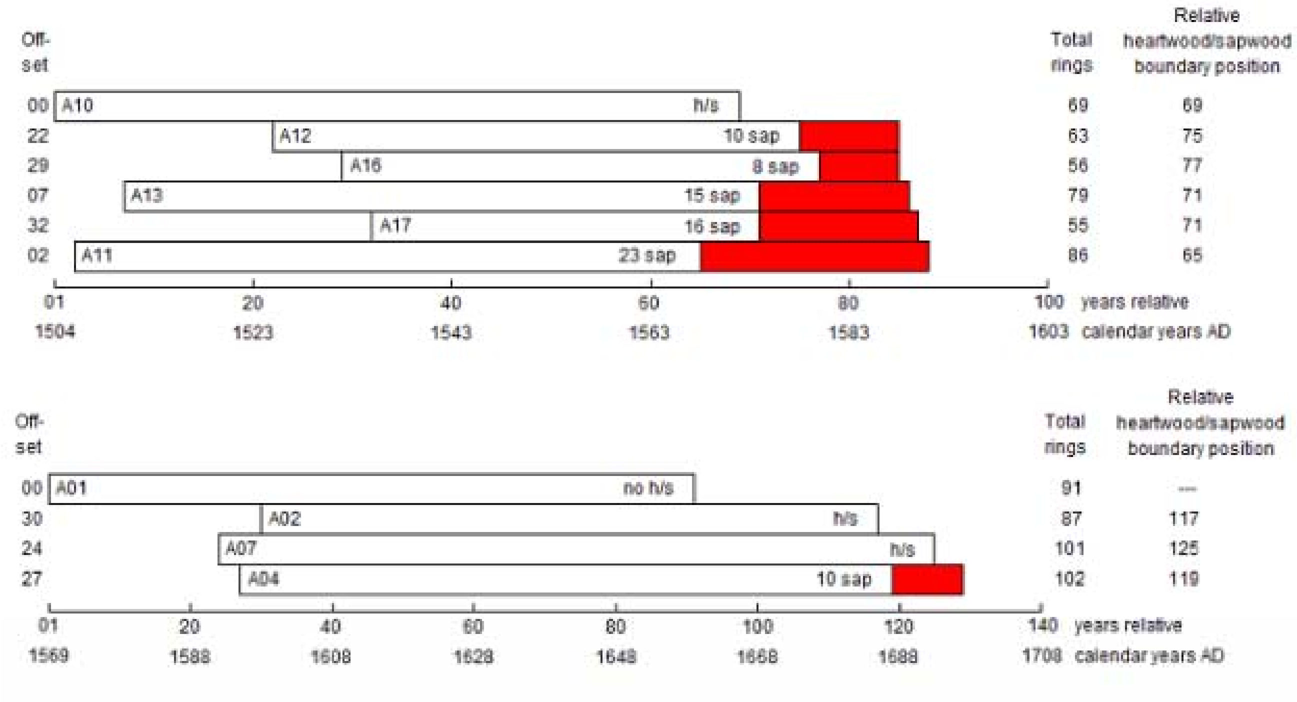
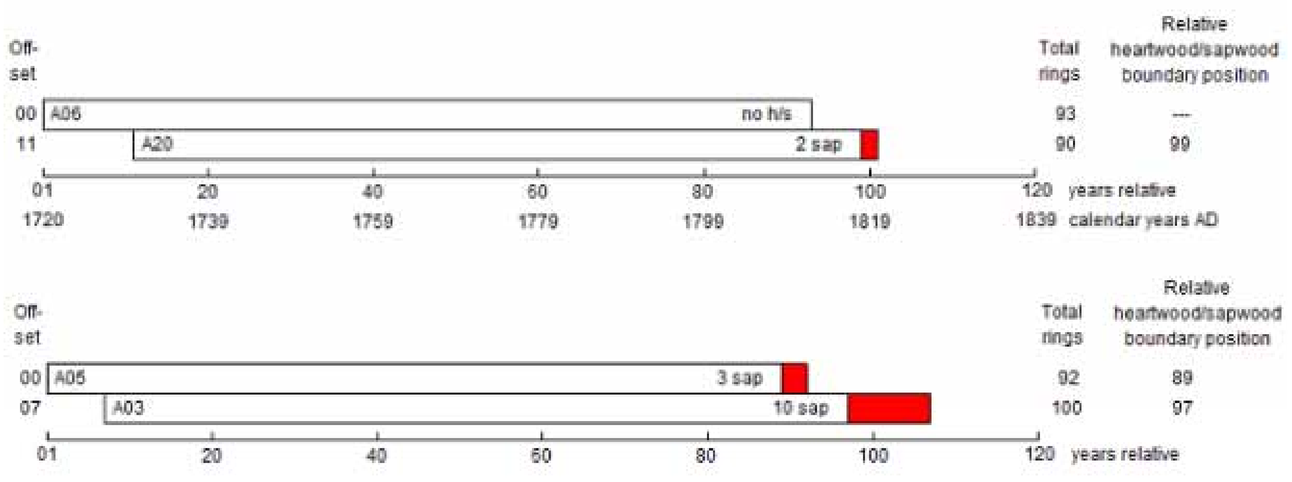


Figure 5e: Drawing to show sampled timbers



White bars =heartwood rings; Red bars = sapwood rings
h/s = the heartwood/sapwood ring is the last ring on the sample

Figure 6a/b: Bar diagram of the samples in site chronologies ECTASQ01 (top) and ECTASQ03 (bottom)



White bars =heartwood rings; Red bars = sapwood rings
h/s = the heartwood/sapwood ring is the last ring on the sample

Figure 6c/d: Bar diagram of the samples in site chronologies ECTASQ03 (top) and ECTASQ04 (bottom)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

ECT-A01A 91
282 508 341 283 311 238 357 315 341 281 301 341 201 174 177 222 250 249 220 333
265 204 200 193 208 284 291 337 234 280 238 216 168 155 178 190 160 277 239 194
180 180 113 173 180 105 73 79 115 163 138 166 83 122 90 89 121 157 156 165
149 130 140 163 123 101 113 68 61 114 79 47 54 55 63 90 80 123 117 90
59 66 72 98 92 81 144 127 90 145 186
ECT-A01B 91
283 508 331 271 301 250 330 319 337 282 299 337 219 171 173 218 249 256 220 323
263 208 209 187 210 280 301 341 238 278 231 216 172 157 187 199 154 271 238 191
186 190 101 167 177 111 73 74 129 177 147 162 84 121 93 83 120 156 153 170
150 129 142 162 123 100 102 72 64 108 79 48 51 56 60 88 83 119 118 93
58 71 72 89 98 80 148 125 100 132 179
ECT-A02A 87
295 210 303 200 224 189 141 283 234 222 160 187 147 104 44 51 75 120 106 121
163 183 198 156 201 167 171 183 143 94 103 106 157 190 171 91 127 61 64 85
155 144 131 125 116 106 120 161 170 202 155 228 172 150 87 138 175 118 106 165
90 199 158 167 121 29 36 51 60 86 64 70 94 89 110 94 84 58 133 107
94 152 125 263 198 129 116
ECT-A02B 87
287 217 311 211 220 182 142 291 230 226 158 189 128 106 45 51 90 108 108 119
166 179 197 181 183 164 169 181 140 100 100 109 156 186 166 103 123 62 60 88
159 142 129 138 114 102 124 162 154 200 156 222 175 142 86 139 183 136 110 163
110 196 150 167 123 26 31 55 68 85 53 70 94 90 110 110 83 61 121 118
102 155 125 248 196 136 119
ECT-A03A 100
299 270 269 272 270 241 248 241 250 227 191 221 203 149 231 212 217 213 214 212
101 126 155 188 95 105 97 80 108 105 122 45 41 68 95 101 121 143 104 88
104 84 108 130 75 78 81 73 85 142 76 117 55 56 77 61 94 114 102 115
49 55 69 80 74 110 164 175 193 167 156 161 126 150 179 93 39 62 79 95
109 162 189 110 185 194 264 219 243 182 240 231 247 141 189 167 260 252 189 266
ECT-A03B 100
289 269 253 286 270 239 237 251 235 211 187 212 196 139 241 213 229 214 229 211
111 112 145 167 102 104 99 69 113 101 122 52 51 58 102 101 126 144 85 103
93 95 102 121 75 78 84 64 89 142 75 119 58 50 78 69 86 115 105 114
50 57 63 77 73 120 164 173 190 166 160 150 122 146 177 92 48 56 81 90
111 161 207 110 168 183 273 226 242 183 242 235 251 139 189 169 252 260 184 261
ECT-A04A 102
356 297 314 281 271 232 258 245 297 204 311 269 214 186 178 137 162 239 169 241
293 395 335 248 227 189 221 276 253 261 201 195 171 220 165 153 209 161 129 139
54 43 78 78 105 100 145 131 127 98 180 144 173 141 172 152 108 84 71 213
137 109 190 121 188 176 122 71 34 45 55 38 53 59 65 90 100 133 111 112
61 129 86 89 123 110 177 201 165 193 354 206 268 203 141 255 142 193 218 208
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ECT-A04B 102
368 294 321 277 267 239 263 255 295 211 322 267 221 186 196 140 167 237 172 228
305 384 320 260 258 219 235 281 246 261 201 170 179 195 156 157 208 172 121 136
58 43 68 84 100 107 138 126 120 99 184 142 173 133 166 151 122 96 91 207
142 109 191 128 175 172 116 90 29 44 42 53 50 56 71 92 107 123 111 110

70 137 90 92 101 113 181 197 156 189 342 221 279 203 131 273 157 183 209 220
273 220
ECT-A05A 92
405 422 383 373 367 219 324 375 337 455 439 378 339 285 288 250 228 222 131 111
55 68 78 99 115 163 179 79 53 69 58 78 76 125 96 142 135 184 63 55
36 45 32 61 85 74 89 97 59 52 96 53 41 39 29 64 88 66 90 51
47 44 36 50 55 39 63 36 29 42 50 51 39 54 55 86 51 59 65 56
58 115 41 56 38 38 65 50 73 46 56 73
ECT-A05B 92
405 442 376 340 375 229 315 376 340 475 412 368 334 288 303 243 217 241 130 109
63 72 80 99 116 160 181 77 58 65 63 80 82 119 101 136 139 193 55 58
33 47 34 61 86 75 94 97 59 51 97 46 38 45 28 59 94 69 86 33
46 44 34 50 53 41 62 39 28 46 43 54 41 53 56 84 56 61 62 59
53 118 38 56 38 43 65 46 77 44 57 71
ECT-A06A 93
263 201 195 106 64 78 50 94 102 101 167 160 192 137 166 278 205 129 167 189
144 105 97 84 97 136 160 132 122 86 120 143 181 153 182 110 120 125 130 164
126 145 123 173 181 146 168 156 179 193 179 144 120 153 179 200 193 156 154 133
137 128 175 160 130 97 86 129 156 223 138 127 121 86 100 151 114 135 147 104
105 97 94 111 111 137 132 119 114 91 107 106 146
ECT-A06B 93
228 209 193 104 76 65 51 92 98 96 173 158 185 146 168 263 205 132 166 194
145 105 83 95 91 143 158 135 121 76 113 148 171 162 181 116 116 123 139 173
125 137 122 174 172 137 153 172 188 205 183 146 127 150 182 199 191 164 158 133
130 136 157 171 125 106 99 135 163 234 134 116 125 87 101 147 107 128 144 117
96 100 90 120 111 125 134 123 118 98 114 104 131
ECT-A07A 101
212 388 290 399 321 299 232 193 209 188 240 223 157 246 216 172 186 172 129 117
179 124 277 188 252 255 228 216 183 281 267 194 235 216 192 186 201 155 177 236
193 148 162 78 75 67 56 63 61 86 83 85 78 102 73 106 88 133 128 117
92 96 238 142 93 147 158 216 156 116 100 37 60 74 78 96 83 77 97 89
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ECT-A07B 101
193 386 280 417 317 284 237 188 208 194 243 224 145 247 230 161 182 175 123 128
161 129 275 176 271 245 236 226 189 256 267 202 252 224 204 180 207 162 167 220
187 156 171 86 72 78 69 79 80 94 103 93 88 97 80 121 105 134 132 114
84 82 232 152 89 150 149 223 153 117 100 37 40 62 64 102 74 87 92 93
143 120 102 63 129 106 63 72 59 164 175 159 201 422 294 285 228 153 319 281
385
ECT-A08A 87
192 217 212 140 182 210 190 175 162 148 144 136 172 174 195 176 242 272 242 253
246 215 163 192 176 132 178 189 203 184 240 97 59 63 62 69 108 149 172 256
190 196 246 191 135 66 51 56 94 141 185 408 294 259 355 172 76 77 128 195
219 276 218 83 105 120 156 303 333 247 258 296 172 112 62 74 90 114 194 369
275 218 249 248 102 69 49
ECT-A08B 87
201 212 214 135 183 208 195 176 164 145 148 138 168 165 203 171 232 274 237 252
241 210 177 186 191 131 177 203 217 185 240 94 64 55 55 76 115 161 173 243
189 185 229 194 137 66 58 57 100 134 190 423 315 230 385 161 83 82 124 201
210 291 219 101 99 125 148 321 332 257 240 305 161 101 73 79 89 106 216 380
319 239 284 273 95 64 46
ECT-A09A 66

290 370 418 342 346 395 247 325 291 298 244 333 243 213 214 221 163 158 150 170
126 124 105 146 180 184 153 117 160 190 168 164 186 122 74 140 136 107 112 109
85 101 77 115 182 138 224 245 123 144 95 87 85 124 130 92 140 158 84 154
153 196 183 146 102 160
ECT-A09B 66
304 373 406 337 343 391 260 338 295 307 257 333 260 217 216 221 129 137 146 163
128 127 108 153 172 172 159 117 151 190 165 161 183 114 94 139 140 111 104 108
79 103 90 98 195 148 218 252 114 149 106 88 81 121 133 89 141 163 85 152
147 189 185 147 102 180
ECT-A10A 69
224 281 194 205 146 155 135 176 148 223 184 153 123 40 126 159 103 147 134 113
99 111 101 119 113 123 118 185 142 145 152 201 211 167 149 177 166 190 127 237
229 243 155 135 140 275 264 228 301 331 284 334 204 181 229 252 322 266 304 235
126 238 262 126 241 416 564 593 451
ECT-A10B 69
246 278 190 203 176 160 125 176 150 211 182 149 128 44 117 145 100 146 114 104
97 103 115 111 119 121 111 197 154 120 144 198 210 160 139 185 156 198 124 246
228 234 159 151 162 274 275 243 234 328 319 332 213 180 240 248 334 258 302 231
131 226 260 134 243 434 490 600 454
ECT-A11A 86
601 352 215 101 113 182 122 117 88 82 77 51 87 100 94 99 117 97 96 82
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93 109 175 312 252 281 159 183 122 76 70 89 81 89 157 62 90 129 226 196
207 145 126 125 121 165
ECT-A12A 63
158 218 346 397 372 271 296 243 313 393 336 224 305 330 376 348 175 216 203 206
164 174 211 234 186 198 163 175 168 199 144 121 95 156 149 201 171 217 272 180
104 153 230 241 285 202 148 93 56 41 58 69 121 182 214 163 115 266 241 226
331 140 127
ECT-A12B 63
167 194 343 393 381 279 297 245 311 391 324 225 315 316 370 341 166 217 210 201
163 178 201 227 186 200 168 183 172 195 150 105 97 153 148 190 170 230 296 181
103 162 224 241 289 201 155 92 62 41 52 62 101 151 249 171 157 236 250 219
337 134 128
ECT-A13A 79
58 86 78 90 66 103 36 78 64 52 57 50 36 39 31 49 44 38 50 73
123 145 163 100 116 100 106 68 137 243 280 247 287 296 250 164 237 227 210 186
220 169 226 234 223 153 169 145 159 134 155 172 218 212 181 130 138 182 200 212
238 201 174 125 93 66 79 123 145 154 154 142 175 199 246 235 196 153 187
ECT-A13B 79
63 87 77 87 72 96 44 66 68 56 54 46 38 41 31 54 41 37 53 73
133 139 144 107 100 98 112 106 150 239 275 238 305 303 252 165 239 238 215 199
212 183 216 220 219 172 176 140 150 142 152 145 219 184 176 139 143 190 191 206
244 194 174 127 97 68 65 130 143 154 153 142 176 216 249 221 216 160 193
ECT-A16A 56
244 313 391 334 224 609 586 670 681 504 451 454 493 353 370 393 446 321 369 354

390 354 457 346 263 303 397 416 392 294 353 313 254 221 262 299 252 245 197 141
114 74 48 57 71 97 189 268 170 191 245 254 282 344 281 219
ECT-A16B 56
242 312 392 337 226 601 568 676 666 499 451 469 496 372 376 385 417 320 393 350
390 373 434 365 258 312 410 417 406 310 356 319 231 226 253 283 212 234 192 134
103 58 49 63 56 128 180 230 179 182 223 267 307 353 274 206
ECT-A17A 55
334 224 315 230 211 237 140 205 182 232 163 147 279 291 280 295 295 360 288 302
228 160 205 171 290 211 309 196 198 199 160 144 172 140 221 227 177 219 251 213
187 220 211 196 276 220 179 209 202 279 260 126 87 65 128
ECT-A17B 55
335 224 306 224 227 226 145 198 203 235 160 140 297 289 270 320 288 370 280 319
217 189 194 166 288 194 287 197 186 207 165 144 177 141 242 216 178 212 258 222
193 232 227 195 282 196 210 213 182 274 263 121 88 69 130
ECT-A20A 90
207 256 232 216 137 141 131 205 127 96 76 75 75 125 147 146 170 114 98 146
187 212 174 173 115 110 110 94 119 143 160 165 311 193 171 153 184 238 195 174
166 149 130 259 258 269 244 184 159 141 144 174 187 203 142 111 144 222 284 205
170 156 116 144 235 203 188 199 175 136 169 186 183 174 192 186 182 135 141 212
234 211 180 241 107 81 87 111 191 287
ECT-A20B 90
208 254 230 215 146 142 132 201 134 94 80 69 79 126 138 158 157 106 88 146
177 218 169 178 127 99 117 94 109 139 169 161 320 190 168 154 184 242 183 166
158 146 135 257 266 274 242 181 153 150 142 181 197 198 135 121 149 207 309 203
160 167 114 142 236 192 190 203 173 127 174 187 187 169 199 182 183 144 144 193
250 185 219 234 110 81 90 107 188 293

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 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 1988). 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

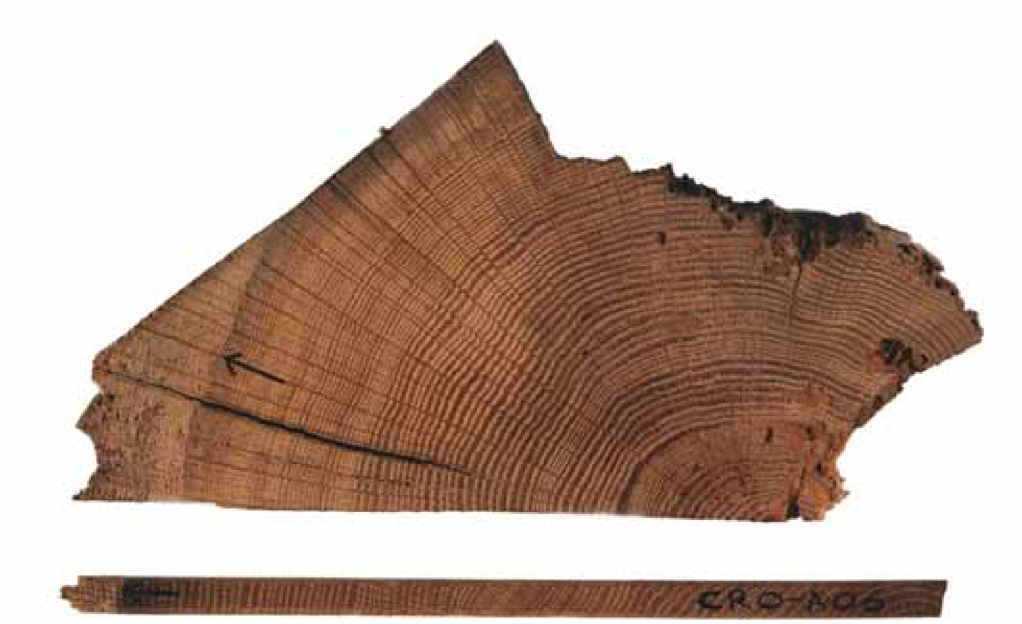


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

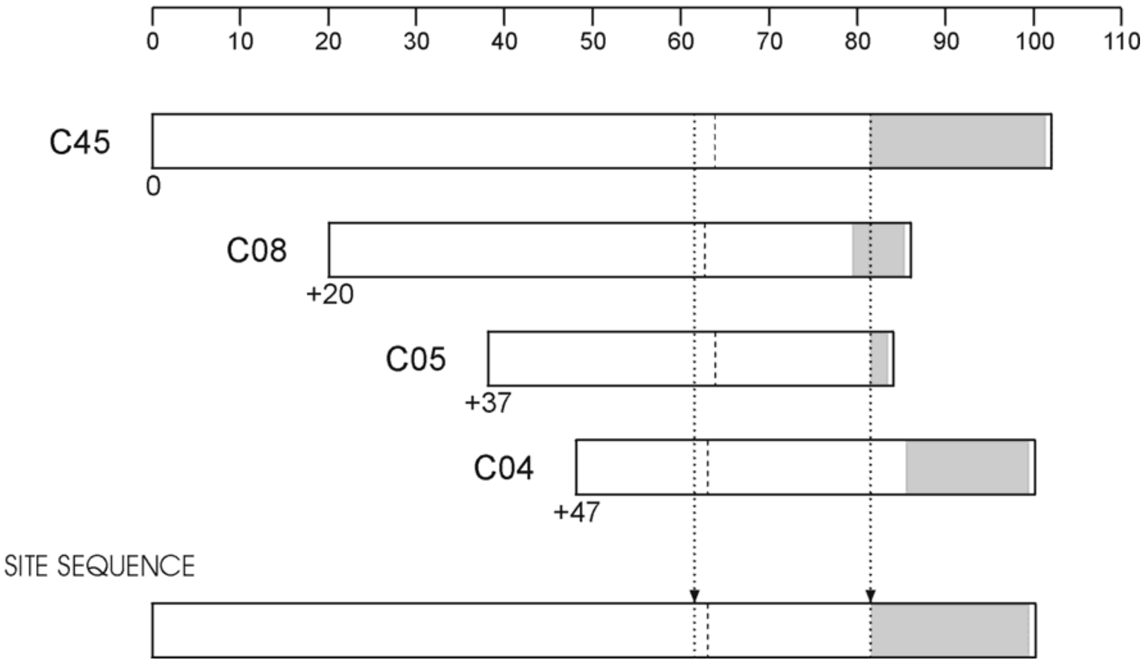


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

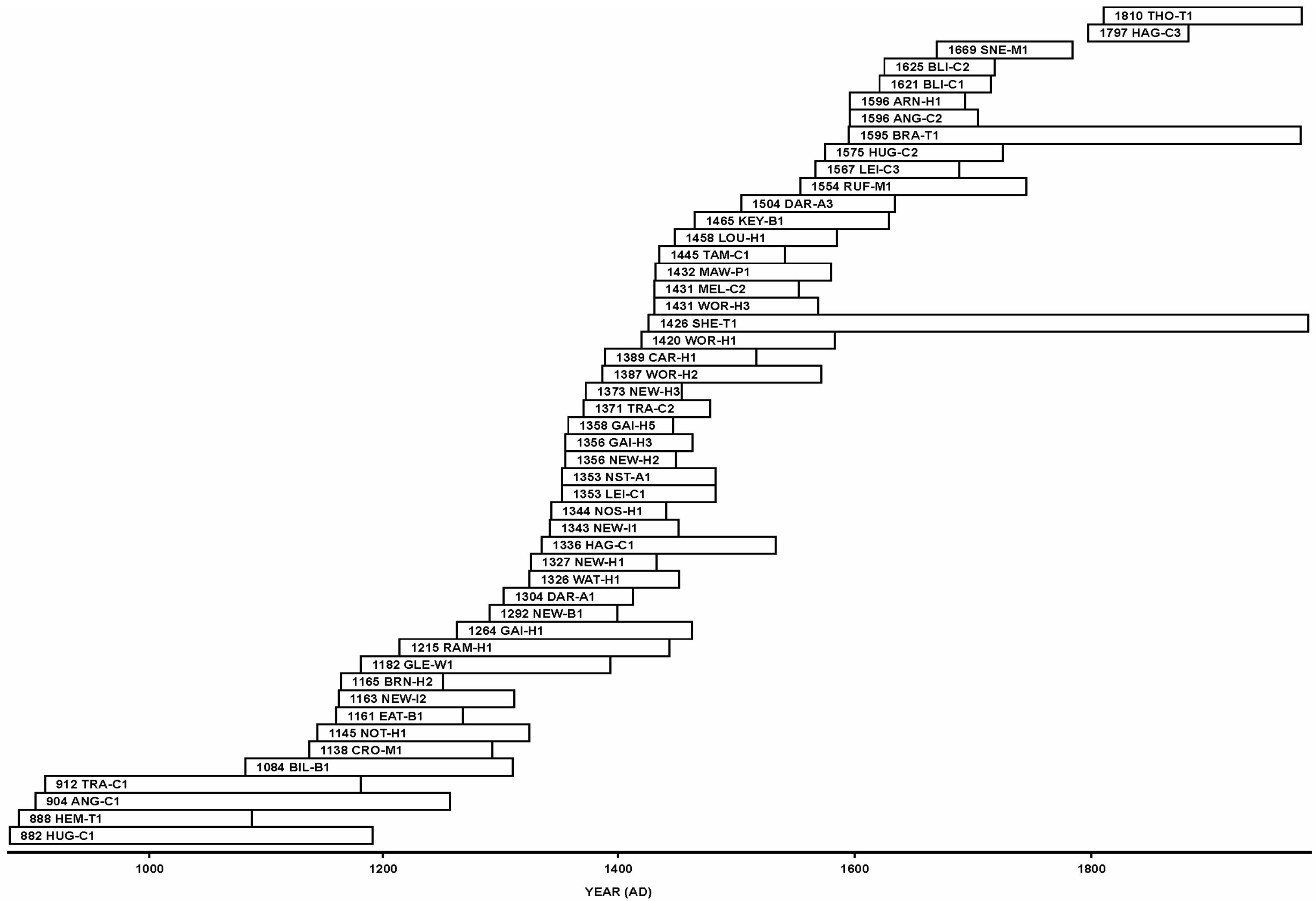
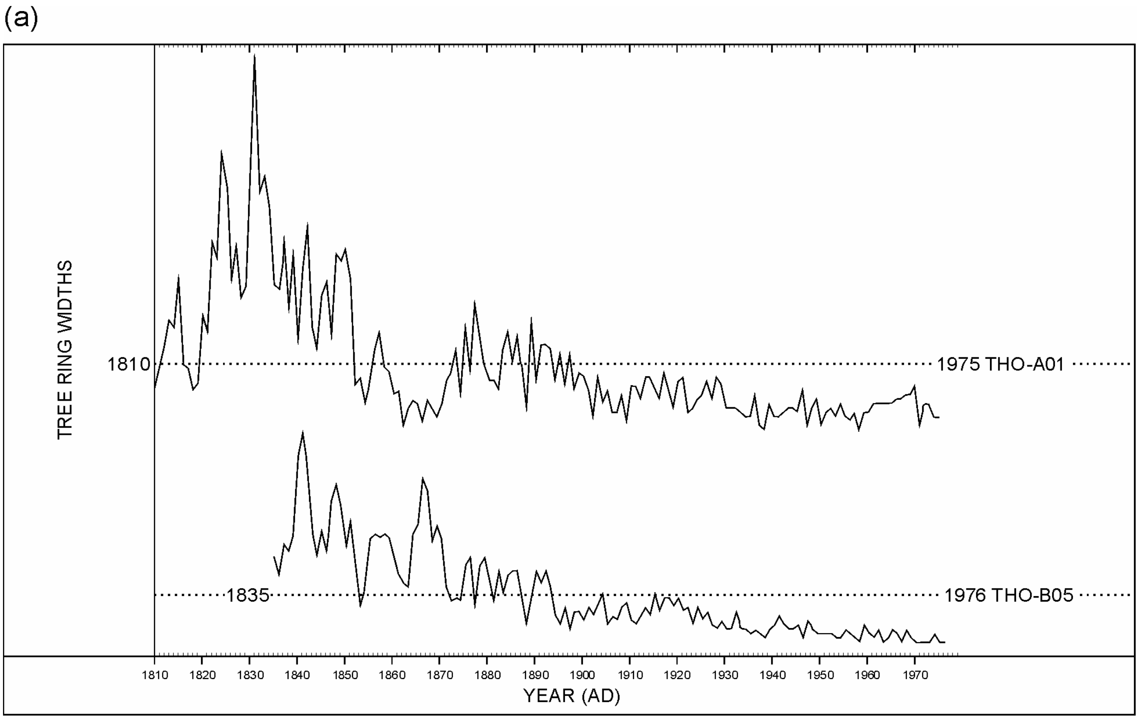


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

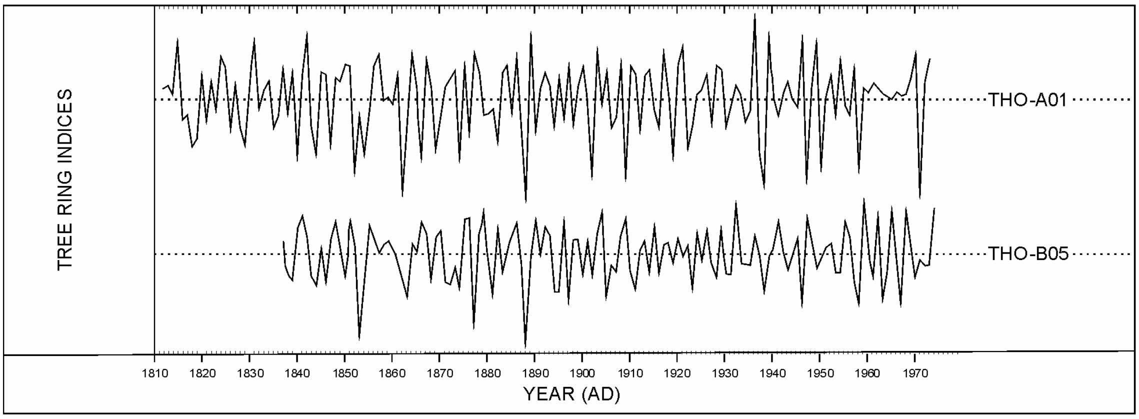


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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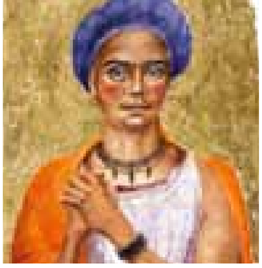


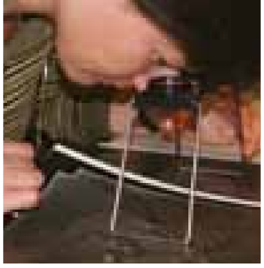


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