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SHURLAND HALL GATEHOUSE, EASTCHURCH, ISLE OF SHEPPEY, KENT
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY

Dendrochronological analysis of 30 samples from the gatehouse of Shurland Hall has resulted in the production of three site chronologies. The first comprises eight samples of overall length of 122 rings, the second comprises 14 samples with an overall length of 192 rings, whilst the third comprises three samples of overall length 96 rings. Only the 122 rings of the first site chronology can be dated, these spanning the years AD 1405–1526. Interpretation of the sapwood on the dated samples indicates that they probably represent timbers cut as part of a single programme of felling sometime between AD 1536–61. As such they represent neither the early-sixteenth century rebuild of Shurland Hall by Sir Thomas Cheney in the period AD 1510–18, nor the enlargement of the site completed in time for the visit of Henry VIII in AD 1532. It is possible, however, that the dated timbers were cut at different times from as early as AD 1523 to as late as AD 1566.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to take this opportunity to thank Tim Whittaker and the Spitalfields Historic Building Trust, now owners of Shurland Hall, not only for their enthusiasm in restoring this building but also for their helpful cooperation with this programme of tree-ring analysis, particularly in identifying the original location of removed timbers. We would also like to thank Peter Kendall, Inspector of Ancient Monuments of English Heritage's Guildford Office for his help in arranging site access. The Nottingham Laboratory would also like to thank Keevill Heritage Consultancy for the use of sections of their report in the introduction below (Keevill 2006).

ARCHIVE LOCATION

SMR Officer
Kent County Council
Heritage Conservation
Invicta House
County Hall
Maidstone ME14 2LX

DATE OF INVESTIGATION

2006–8

CONTACT DETAILS

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INTRODUCTION

The remains of Shurland Hall stand on the Isle of Sheppey, in Eastchurch, Kent (TQ 992 715, Fig 1). It was once one of Kent's most important Tudor mansions, having been rebuilt by Sir Thomas Cheney (AD l482–l558), Lord Warden of the Cinque Ports and Treasurer of the Household, on the site of an earlier medieval castle. Sir Thomas Cheney is supposed to have demolished the original buildings and built a new mansion in AD 1510–18. However, it is thought more likely that he extended and revamped at least some of the earlier structures, eg, the hall, and the original gate tower. The house was later enlarged, this work being completed by the time Henry VIII visited in AD 1532.

The house of Sir Thomas Cheney consisted of a gatehouse, in front of which, to the west, was a walled courtyard. There was a single gate in the front wall of this courtyard, and two entrances in each side wall. The gatehouse had gable-ended buildings to either side which extended east, or rearwards, towards the main hall, and formed the side ranges of an inner courtyard (the probable guest ranges). Another series of courtyards, to the rear of the main hall, consisted of pentice-type cloister buildings linking the hall to the chapel in the south-east corner and a possible kitchen/brew house range at the back of the group of buildings. The stable courtyards and ancillary courtyards were to one side and exit to the park would have been possible through a large courtyard to the rear.

The house was supposed to have been enlarged before the royal visit, with wings added from the gateway, a banqueting hall built to the east side of the inner courtyard, and dormitories on either side. In its final form it is believed that there were not less than nine quadrangles enclosed within high stone walls, the complex spreading over several acres, and presumably presenting an impressive sight (Fig 2). Sir Thomas Cheney died in December AD 1558 and the estate passed to his son Henry. From that time on, Shurland Hall gradually went into decline.

The house remained in residential use into the twentieth century, but was used by the military during World Wars I and II. Subsequently it was abandoned, and gradually began to fall into ruination (Fig 3). This process has accelerated markedly over the last decade, despite local and national concern for the future of this exceptionally important building.

The present gatehouse at Shurland, to the west of where the main buildings once were, is the most intact surviving part of the buildings, all other elements of the site now being lost. The tower forms the central portion of the gatehouse, with the twin turrets on the west front flanking the entrance. The northern and southern rooms of the extended gatehouse clearly butt against the tower, with straight joints being visible internally and externally on both the east and west facades. It is unclear whether the tower was originally wholly free-standing, or whether it may have had attached flanking courtyard walls. The tower was extended, probably quite soon after its original construction, to become a continuous range as an integral element of a multiple-courtyard house.

The building is currently a Scheduled Ancient Monument and is on the English Heritage Buildings at Risk Register.

THE TIMBERS

The timbers found within the gatehouse comprise lintels to doors and windows, bridging beams of the first-floor frame, and common joists of the ground-floor frame to both the northern and southern parts of the gatehouse (there are none in the central gateway itself), these being set directly on the earth beneath, and almost certainly reused here. There are no roof, partition wall, or other structural timbers of any sort to be seen.

Given the extensive nature of the conservation and repair work being undertaken here, and particularly the decayed and unstable nature of the timbers (Fig 4a/b), the majority of these beams, particularly the bridging beams and common joists, had been removed from this structure and stored *ex-situ* before sampling was undertaken (Fig 5). In most instances, as with the bridging beams for example, the precise location of these timbers was recorded prior to removal. In some cases, however, as with the common joists, only the general original location was noted. Only door and window lintels remained undisturbed and *in-situ*. The other parts of Shurland Hall are now represented by partial wall remains and footing, and there are no timbers to these areas.

SAMPLING

Sampling and analysis by tree-ring dating of the timbers within the gatehouse of Shurland Hall (there being no other timbers elsewhere to this site) were commissioned by English Heritage. The purpose of this programme of analysis was to inform urgent repair work on this Building at Risk. It was hoped that tree-ring analysis of the timbers would not only establish the construction date of the gatehouse, confirming whether or not it is part of Sir Thomas' programme of works, but also identify possible later phases of alteration, and establish how much, if any, older material from the original gate tower might have been reused.

The usual procedure in tree-ring dating is to obtain samples by coring. In this instance, however, having been long exposed to the elements, the timbers were often of a delicate nature and the cores would simply have fragmented. This method was, therefore, rejected and, from those timbers which were deemed beyond conservation or reuse, a total of 31 samples was obtained by the removal of cross-sectional slices with a chainsaw. These slices then being reduced to smaller radial sections.

Each sample was given the code SRL-A (for Shurland site "A") and numbered 01–31. Where possible, the original location of these samples was recorded at the time of sampling on a simple plan, reproduced here as Figure 6. Where the exact original location is not known, the general location only is given. Details of the samples are also given in Table 1.

It will be seen from Table 1 that none of the timbers which remain *in-situ* have been sampled. Such timbers were not only few in number, but sometimes buried within the walls and not easily accessible; like their floor-frame counterparts, they too were often badly rotted at their outer edges. Under these circumstances, given that such timbers appeared to be derived from moderately fast-grown trees, it was felt that they were unlikely to provide satisfactory samples for tree-ring analysis.

ANALYSIS AND RESULTS

Each of the 31 samples obtained was prepared by sanding and polishing. It was seen at this point that one sample, SRL-A22, had less than 54 rings, the usual minimum required for reliable dating, and so it was rejected from this programme of analysis. The annual growth rings of the remaining 30 samples were, however, measured, the data of these measurements being given at the end of this report. The data of these 30 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing three site chronologies to be formed at a minimum *t*-value of *t*=4.5.

The first site chronology, SRLASQ01 (Fig 7), comprises eight samples with an overall length of 122 rings. Site chronology SRLASQ01 was compared to an extensive corpus of reference material for oak, this indicating consistent and repeated cross-matches with several of them when the first ring date of the site chronology is AD 1405 and the last measured ring date is AD 1526. The evidence for this dating is given in Table 2 where an indicative selection is listed.

The second site chronology, SRLASQ02 (Fig 8), comprises 14 samples with an overall length of 192 rings. Site chronology SRLASQ02 was also compared to an extensive range of reference material for oak, not only that held by the Nottingham Laboratory, but also with the reference material held by other dendrochronology laboratories. There was, however, no satisfactory cross-matching, and these 14 samples must remain undated.

The third and final site chronology, SRLASQ03 (Fig 9), comprises three samples with an overall length of 96 rings. Site chronology SRLASQ03 was likewise compared to an extensive range of reference material for oak by the Nottingham Laboratory and others, but again there was no satisfactory cross-matching, and these three samples must remain undated.

Each site chronology was then compared with the remaining five measured but ungrouped samples, but there was no further satisfactory cross-matching. Each of the remaining five ungrouped samples was then compared individually with the reference chronologies, but again, there was no satisfactory cross-matching and these samples must, therefore, also remain undated.

This analysis can be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span (where dated)
SRLASQ01	8	122	AD 1405–1526
SRLASQ02	14	192	undated
SRLASQ03	3	96	undated
individuals	5	---	undated
	1	---	unmeasured

It was noticeable during this analysis that a number of samples within each group cross-match very well with each other, suggesting the possibility that the trees represented by each group were all growing close to each other. There are, for example, values in excess of *t*=6.0 between the samples in site chronology SRLASQ03, and values in excess of *t*=8.0 between the samples of site chronology SRLASQ01. However, the most similar samples are those of site chronology SRLASQ02, where values in excess of *t*=13.0, *t*=14.0, and even *t*=15.0 are seen. Indeed, values as high as these would suggest that some timbers have been derived from the same tree, which, given that most of these are small common joists formed of quartered trees, is a distinct possibility.

DISCUSSION AND CONCLUSION

The tree-ring analysis undertaken here has produced three site chronologies, only one of which, SRLASQ01, can be dated, its 122 rings spanning the years AD 1405–1526. This site sequence includes main beams and common joists from the north and south ranges, as well as a bridging beam from the central range. None of the seven samples in this site chronology retains complete sapwood and it is thus not possible to determine their exact felling date with reliability. Several of them, however, do retain the heartwood/sapwood boundary.

The heartwood/sapwood boundary, where it exists, on the samples in site chronology SRLASQ01 varies from relative position/date 113/AD 1517 on sample SRL-A06 to relative position/date 122/AD1526 on sample SRL-A08, a variation of only nine years; the overall average date of the boundary is AD 1521. Such a limited variation could be taken as evidence that the dated timbers were cut as part of a single felling operation. If this were the case, using a 95% confidence limit of 15–40 rings for the amount of sapwood the trees might have had, they would have an estimated felling date in the range AD 1536–61.

The view that the timbers were all felled at the same, or at a very similar time, is further supported by the degree of cross-match between some of the samples. The high levels of '*t*' between some samples would certainly suggests that the timbers came from a single woodland source, a phenomenon more frequently seen amongst timbers of the same phase of felling than amongst timbers felled at different times.

This assumption, however, is not necessarily correct as the dated timbers are not part of a single, integral, framed structure, free of the evidence of reuse, but from loose timbers, many of which are clearly recycled in their present positions. It is thus quite possible that the dated timbers were felled at different times from possibly as early as 1523 to as late as 1566. The felling date range of each individual timber is given below, again using a 95% confidence limit of 15–40 rings for the amount of sapwood the trees might have had.

Sample	Felling date range
SRL-A01	AD 1533–58
SRL-A02	AD 1523–38
SRL-A03	AD 1534–59
SRL-A04	Unlikely to be before AD 1506
SRL-A05	Unlikely to be before AD 1526
SRL-A06	AD 1532–57
SRL-A08	AD 1541–66
SRL-A14	Unlikely to be before AD 1513

It is clear, therefore, that the timbers represented by the dated material do not belong with the supposed major rebuilding of Shurland Hall by Sir Thomas Cheney in the period AD 1510–18, and although there is a slight possibility that one or two timbers may have been felled for the enlargement of Shurland completed prior to the visit by Henry VIII in AD 1532, it is very unlikely that they all were. It would appear, therefore, that they represent a later phase of building works, despite there being no documented event in the period AD 1536–61 which would call for the further felling of timbers.

Although dendrochronology cannot be used to identify the precise source of timber (eg Bridge 2000), it would appear that the timbers in the gatehouse are likely to be from woodlands that were reasonably close to Shurland. As will be seen from Table 2, many of the highest *t*-values obtained during the dating of site sequence SRLASQ01, and thus the greatest degree of similarity, are with reference chronologies from sites elsewhere in Kent and south-east England.

In this respect, it is of interest to note the lack of cross-matching and dating of the other two site sequences, and the remaining single samples. Site chronology SRLASQ02, containing 14 samples, is certainly well replicated and , having in excess of 190 rings, is certainly long enough for reliable dating; site chronology SRLASQ03, comprising three samples and at less than 100 rings long, though still adequate, is perhaps less so. Neither site chronology, nor the single samples can be dated regardless of the fact they have been compared to an extensive corpus of reference material from Britain and elsewhere in Europe.

This lack of cross-matching might suggest two possibilities. Either there is some peculiarity with the annual growth rings of the undated samples, potentially reflecting highly localised growth conditions, which make cross-matching and dating difficult, though none is apparent in the samples, or, alternatively, although less likely, the timber is from a time and/or a place for which no reference material is currently available. In this respect the unmatched data from Shurland may in due course be of considerable use.

The phenomenon of undated site chronologies and individual samples has, to a certain extent, been encountered previously in Kent, during the survey of that county by the Royal Commission on the Historical Monuments of England (Pearson 1994). During tree-ring analysis undertaken as part of that survey it was noted that amongst a number of buildings believed, on stylistic and architectural evidence, to date to the early- to mid-fourteenth century, a number produced no dates, despite having suitable chronologies or samples. Such buildings were not, however, confined to any particular area, but strung out from Eastry in the east to Fawkham in the west, although, interestingly, always in the north of the county. This does not of course prove that the undated timbers from the gatehouse at Shurland Hall are also of an early date, but it is a possibility and it does show that Shurland is not an isolated case.

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TABLES

Table 1: Details of tree-ring samples from Shurland Gatehouse, Eastchurch, Kent

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
SRL-A01	Bridging beam, centre range	110	h/s	AD 1409	AD 1518	AD 1518
SRL-A02	Main beam 1, south range	105	h/s	AD 1419	AD 1523	AD 1523
SRL-A03	Main beam 2, south range	104	h/s	AD 1416	AD 1519	AD 1519
SRL-A04	Common joist, south range	80	no h/s	AD 1412	------	AD 1491
SRL-A05	Main beam 1, north range	80	no h/s	AD 1432	------	AD 1511
SRL-A06	Common joist, north range	107	h/s	AD 1411	AD 1517	AD 1517
SRL-A07	Common joist, north range	55	no h/s	------	------	------
SRL-A08	Common joist, north range	76	h/s	AD 1451	AD 1526	AD 1526
SRL-A09	Common joist, north range	87	no h/s	------	------	------
SRL-A10	Common joist, north range	65	no h/s	------	------	------
SRL-A11	Common joist, north range	124	no h/s	------	------	------
SRL-A12	Common joist, north range	94	no h/s	------	------	------
SRL-A13	Common joist, north range	140	no h/s	------	------	------
SRL-A14	Common joist, north range	94	no h/s	AD 1405	------	1498
SRL-A15	Common joist, north range	163	no h/s	------	------	------
SRL-A16	Common joist, north range	105	no h/s	------	------	------
SRL-A17	Common joist, north range	101	no h/s	------	------	------
SRL-A18	Common joist, north range	67	no h/s	------	------	------
SRL-A19	Common joist, north range	66	no h/s	------	------	------
SRL-A20	Common joist, north range	60	no h/s	------	------	------
SRL-A21	Common joist, north range	95	no h/s	------	------	------
SRL-A22	Common joist, north range	nm	no h/s	------	------	------
SRL-A23	Common joist, north range	98	h/s	------	------	------
SRL-A24	Common joist, north range	124	h/s	------	------	------
SRL-A25	Common joist, north range	89	no h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
SRL-A26	Common joist, north range	63	no h/s	------	------	------
SRL-A27	Common joist, north range	113	h/s	------	------	------
SRL-A28	Common joist, north range	85	no h/s	------	------	------
SRL-A29	Common joist, north range	160	no h/s	------	------	------
SRL-A30	Common joist, north range	95	no h/s	------	------	------
SRL-A31	Common joist, north range	76	no h/s	------	------	------

*NM = not measured
**h/s = the heartwood/sapwood ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site chronology SRLASQ01 and relevant reference chronologies when first ring date is AD 1405 and last ring date is AD 1526

Reference chronology	Span of chronology	*t*-value	
Kent-88	AD 1158-1540	8.4	(Laxton and Litton 1989)
Manor House, High Street, Fordwich, Kent	AD 1264-1556	7.8	(Arnold *et al* 2003)
China Court, Petham, Kent	AD 1375-1491	6.9	(Howard *et al* 1988)
Walmer Castle, Kent	AD 1396-1523	6.9	(Howard *et al* 1997)
Chilton Manor, Sittingbourne, Kent	AD 1368-1520	6.6	(Howard *et al* 1988)
Abbey Farm Barns, Faversham, Kent	AD 1344-1471	6.4	(Howard *et al* 1998)
England, London	AD 413-1728	6.2	(Tyers and Groves 1999 unpubl)
Ightham Mote (billiards room), Ivy Hatch, Kent	AD 1405-1521	6.2	(Howard *et al* 1996)

FIGURES

Figure 1: Map to show the location of Shurland Hall

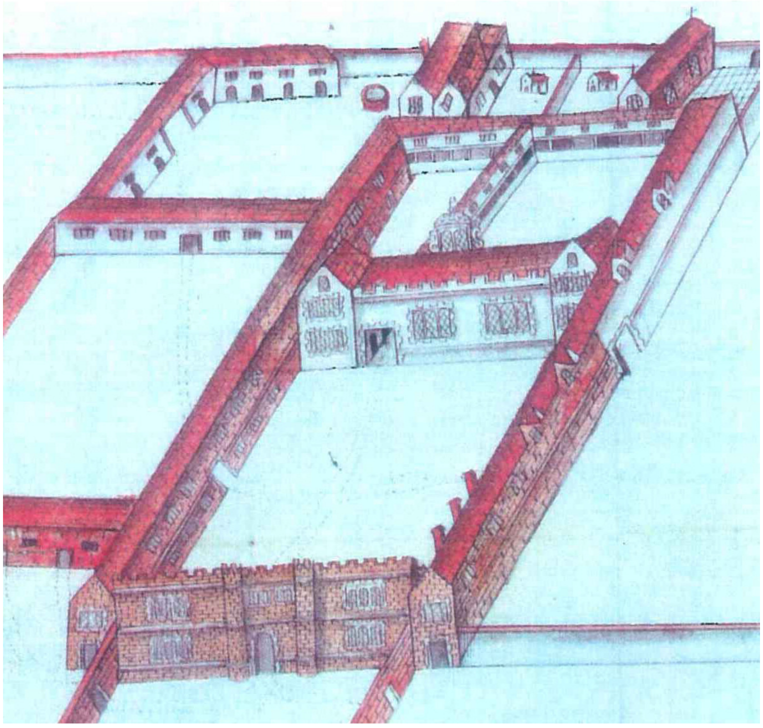


Figure 2: Shurland Hall in 1572 from the west, with the gatehouse in the foreground (detail from Map of the Isle of Sheppey…., *Elizabethan State Papers, SP12/87, The National Archives, © Crown Copyright)*

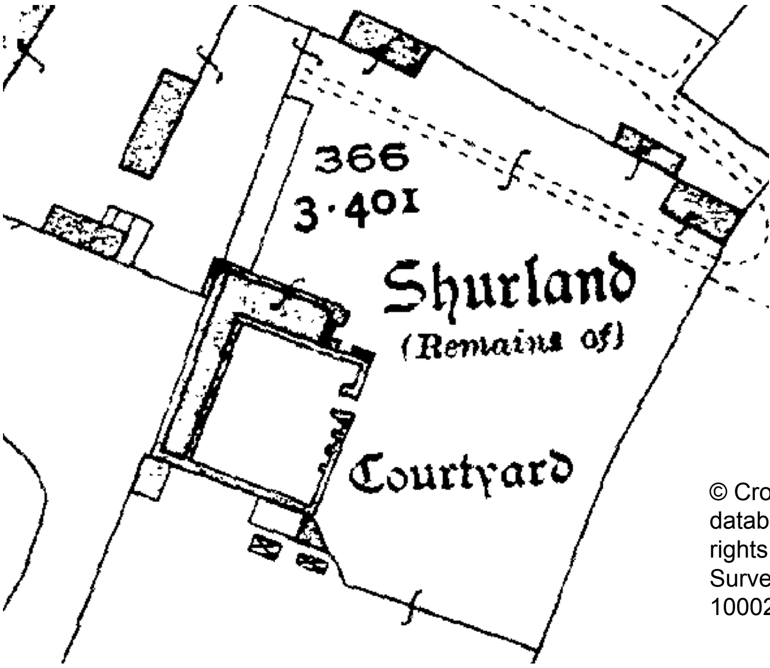


Figure 3: Map to show the surviving ruins of Shurland Hall in 1933

Figure 4a/b: Photographs to show derelict and dangerous nature of the building before room clearance and stabilisation (photos by Peter Rumley consulting archaeologist)

Figure 5: Photograph to show two of the removed bridging beams

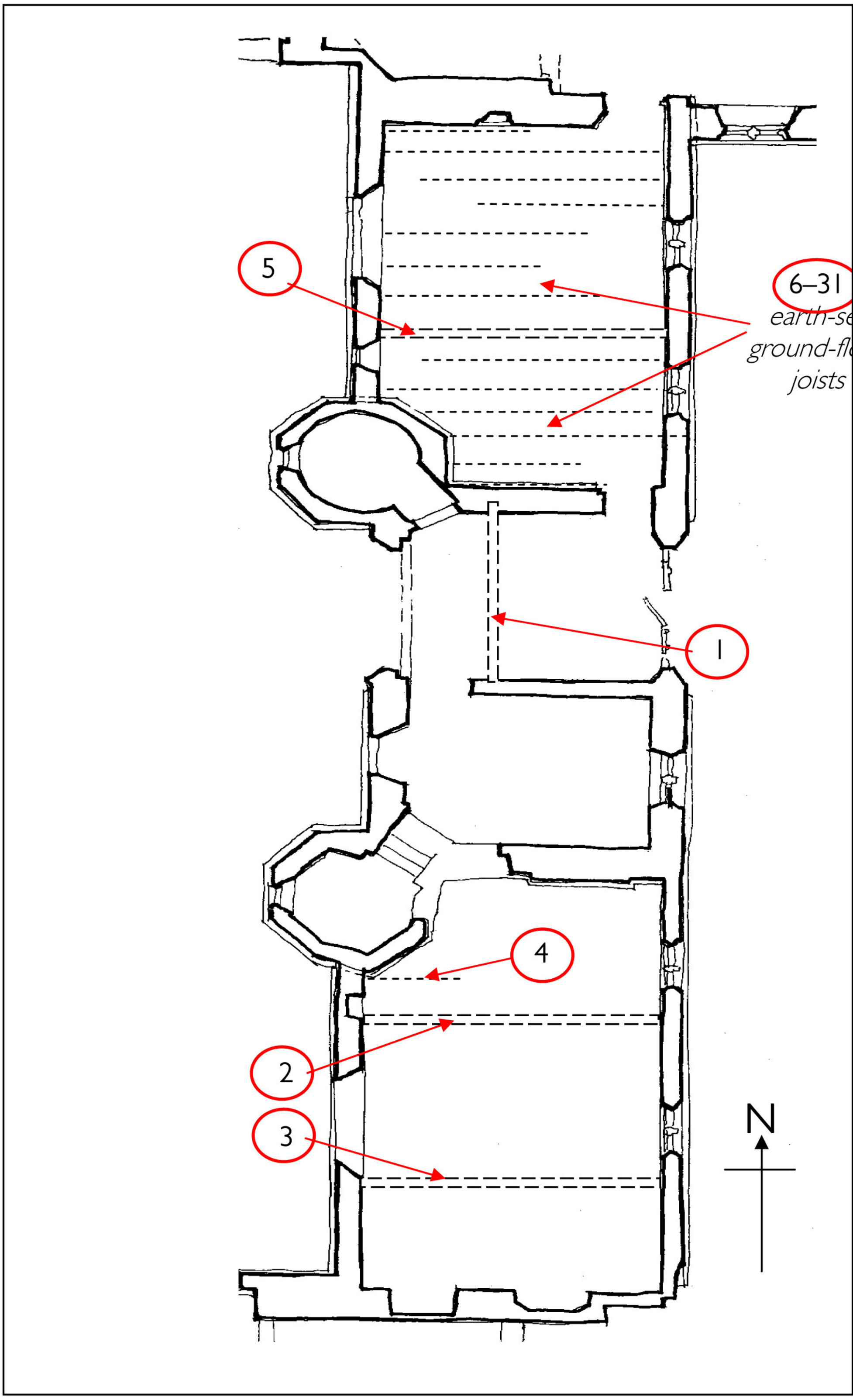
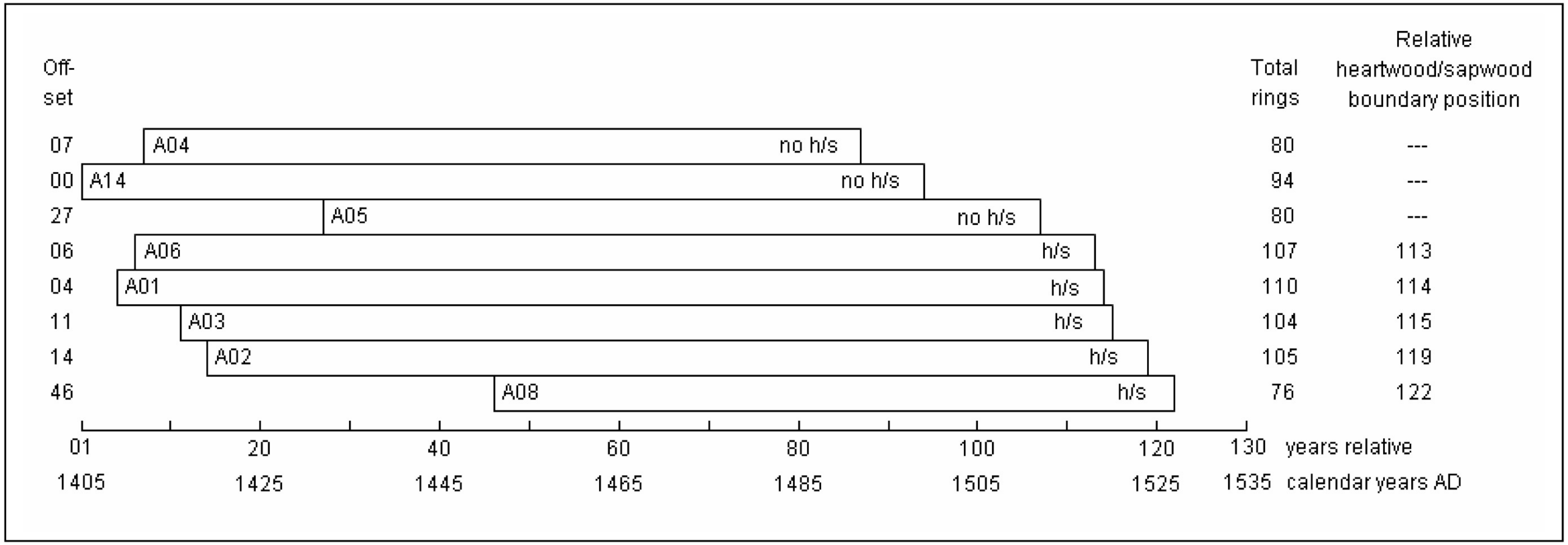
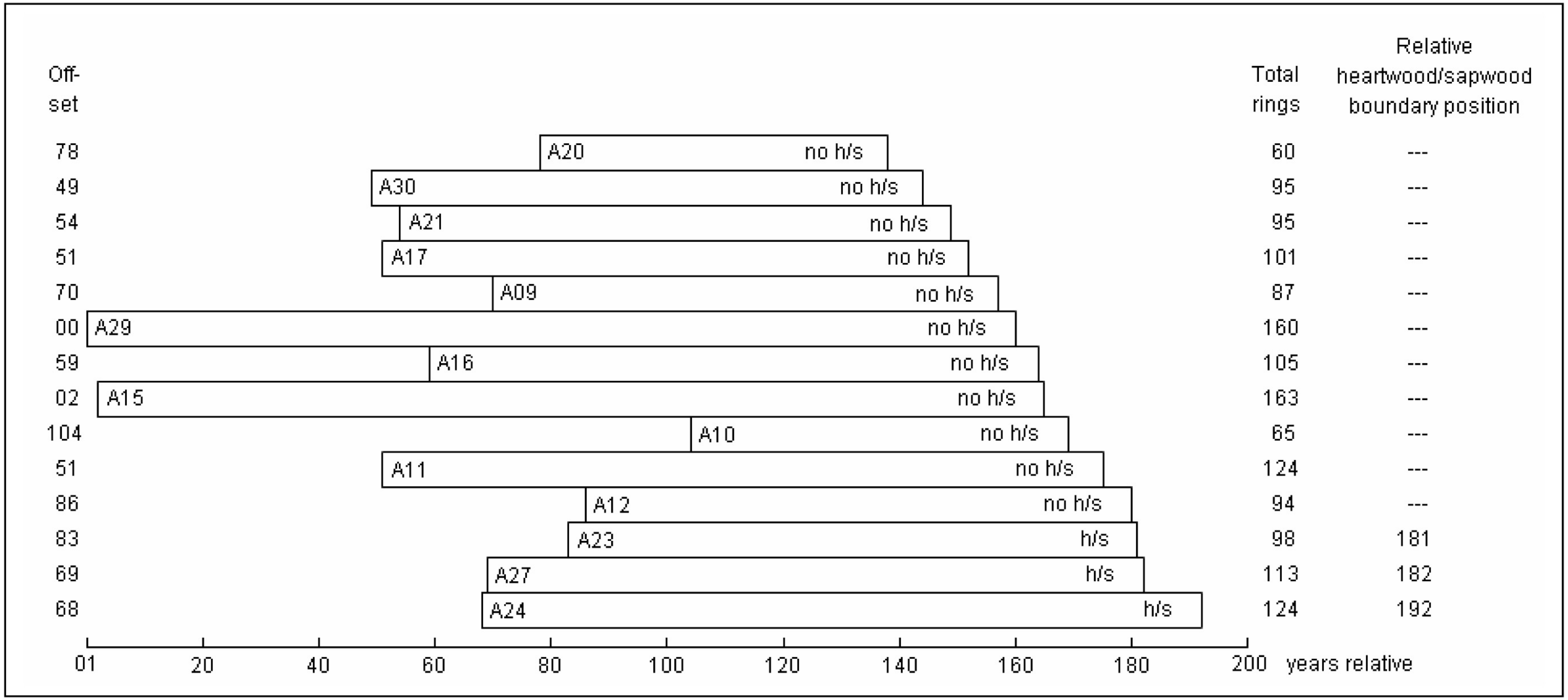


Figure 6: Plan of the gatehouse to show position of sampled timbers where known, or general location where not recorded before removal



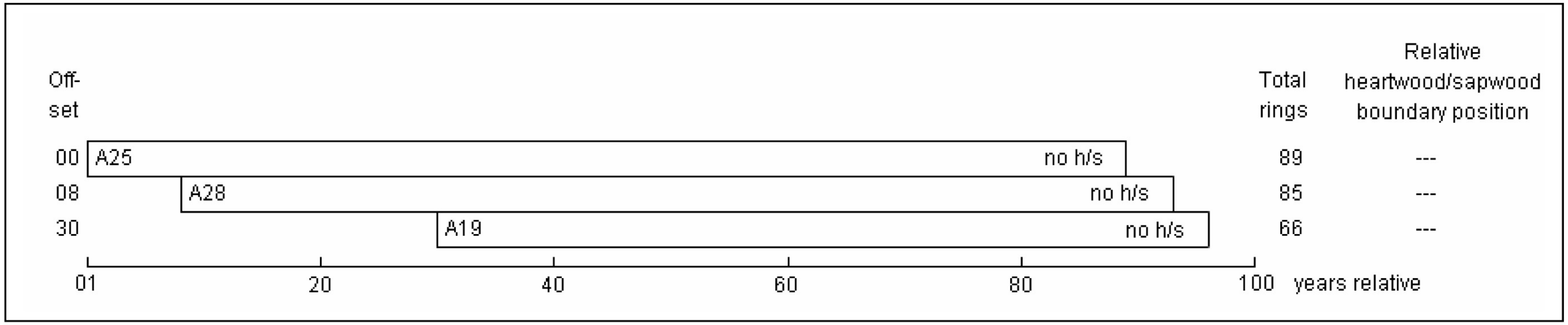
Empty bars ☐ = heartwood rings
h/s = the last ring on the sample is at the heartwood/sapwood boundary, only the sapwood rings are missing

Figure 7: Bar diagram of the samples in site chronology SRLASQ01



Empty bars = heartwood rings
h/s = the last ring on the sample is at the heartwood/sapwood boundary, only the sapwood rings are

Figure 8: Bar diagram of the samples in site chronology SRLASQ02



Empty bars = heartwood rings
h/s = the last ring on the sample is at the heartwood/sapwood boundary, only the sapwood rings are

Figure 9: Bar diagram of the samples in site chronology SRLASQ03

DATA OF MEASURED SAMPLES

Measurements in 0.01 mm units

SRL-A01A 110
179 138 229 200 169 191 275 198 183 270 251 410 346 328 466 352 360 375 280 355
409 417 342 421 314 257 370 312 285 270 230 251 288 245 276 272 249 250 243 195
291 160 219 198 203 225 278 262 236 252 194 214 214 159 207 131 144 155 138 205
173 184 166 121 162 149 153 140 93 102 100 99 239 151 140 157 183 168 145 142
157 148 141 102 121 128 135 212 167 162 126 119 139 107 91 125 151 228 178 140
184 150 123 111 84 91 98 128 103 116
SRL-A01B 110
172 121 224 177 166 182 276 213 200 275 240 409 370 385 515 324 381 367 275 372
379 412 394 415 331 264 359 324 302 235 213 247 296 252 258 276 274 275 278 239
274 152 231 199 195 240 285 285 235 248 188 251 196 194 199 149 154 165 178 188
175 183 165 111 133 124 192 159 101 118 100 115 237 146 155 159 175 196 155 123
174 153 138 102 139 132 146 254 145 141 141 141 120 121 96 126 134 228 171 141
182 132 137 98 108 107 112 129 105 113
SRL-A02A 105
129 144 145 143 229 162 151 153 133 128 137 174 256 204 150 157 212 204 169 193
116 173 155 193 139 105 120 127 140 156 203 103 130 114 88 106 127 172 148 117
116 152 159 157 149 123 146 104 104 141 140 94 93 107 101 131 156 137 130 91
114 146 208 188 128 210 216 166 181 141 140 209 126 114 129 152 131 214 184 143
160 96 94 118 61 57 88 86 90 92 108 100 45 57 73 90 112 70 90 103
116 101 77 100 175
SRL-A02B 80
102 139 126 108 117 126 150 167 111 125 131 92 109 109 145 157 140 154 129 169
167 148 106 122 108 97 144 120 96 110 104 141 163 169 114 106 113 158 180 233
136 153 154 160 138 153 130 135 129 98 75 106 150 122 195 119 98 112 82 116
97 61 88 93 104 95 92 97 84 61 60 69 89 90 88 81 109 93 110 107
SRL-A03A 97
113 182 380 176 200 209 252 243 225 167 130 150 188 223 134 124 194 142 105 134
110 135 104 141 102 113 108 156 142 124 149 101 135 122 95 102 130 148 128 117
117 123 156 181 171 128 156 145 163 230 177 104 156 216 150 150 247 155 145 146
193 232 281 224 221 255 227 185 186 159 162 228 155 131 153 163 169 228 221 146
144 112 95 103 57 60 80 117 93 107 103 89 58 72 126 92 136
SRL-A03B 104
156 177 162 163 230 201 184 230 192 290 257 191 128 158 177 192 209 148 150 257
195 186 167 151 199 171 189 193 177 145 146 168 179 205 125 145 126 122 115 186
184 134 159 144 172 155 198 153 96 118 127 102 132 137 103 103 103 111 108 134
90 106 74 157 142 207 141 120 149 127 165 134 118 122 125 96 75 106 102 115
152 146 106 106 85 102 107 65 69 113 126 119 86 107 116 68 81 80 77 93
120 122 72 124
SRL-A04A 80
188 231 174 208 174 201 230 288 229 193 244 218 200 211 173 119 114 114 127 123
89 81 72 83 83 79 99 75 82 106 88 82 73 58 63 71 69 92 72 80
52 40 51 81 101 66 67 80 75 93 106 85 98 87 78 73 80 113 106 120
113 85 79 70 52 46 54 64 74 59 48 39 59 51 66 56 41 41 68 60
SRL-A04B 80
281 196 227 213 177 180 226 299 227 199 214 225 212 199 173 120 109 110 152 116
103 93 65 91 89 73 99 78 101 103 88 92 69 62 75 66 80 91 63 74
56 44 54 79 106 64 79 76 78 92 111 85 97 84 90 61 89 114 111 124

110 92 81 80 51 47 60 61 72 64 50 41 71 50 66 53 45 53 67 57
SRL-A05A 80
478 364 310 456 260 252 293 239 319 412 324 411 383 314 266 259 257 320 203 325
200 157 223 195 244 239 210 159 151 231 233 254 170 153 177 273 327 252 205 171
1 207 177 217 181 327 286 138 139 137 168 135 99 98 151 176 180 129 140 146 235
SRL-A05B 80
479 350 296 474 273 241 297 258 330 384 311 411 387 314 286 282 287 297 214 295
17 188 135 185 236 117 110 186 259 340 315 243 190 306 321 245 192 205 239 275 199
204 178 189 166 316 278 133 145 146 162 219 124 157 166 168 131 112 107 122 204
SRL-A06A 107
65 277 402 176 154 360 389 600 341 341 409 454 375 457 369 365 329 229 280 233 219
233 139 119 134 179 201 148 192 138 141 121 113 124 93 125 110 90 103 100 72
82 55 63 78 140 108 125 115 116 149 129 99 101 125 66 84 74 70 80 101 88 64 81 73
77 73 88 81 93 73 108
SRL-A06B 107
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41 73 73 96 92 91 117
SRL-A07A 55
138 138 196 105 203 145 190 164 201 103 75 127 164 172 184 164 191 183 137 109
85 101 135 135 106 103 106 160 178 178 141 166 168 179 148 146 149 68 103 107 132 125 155 111
99 118 136 122
SRL-A07B 55
128 141 194 105 210 151 171 164 195 89 77 115 178 184 185 165 208 183 139 97
93 102 137 140 101 108 95 147 189 179 150 165 172 124 153 105 120 94 1 182 144 126 151 68 98
104 136 102 156 121 103 123 140 121
SRL-A08A 76
201 212 184 131 161 132 130 112 114 118 115 145 141 77 157 123 129 172 122 127
82 106 66 120 112 162 124 175 382 381 509 500 327 399 450 388 398 324 277 359
347 279 267 2 320 378 380 368 306 192 147 190 355 216 150 189 155 185 238 273
SRL-A08B 76
204 217 186 129 157 139 129 122 129 112 137 146 137 78 138 107 139 176 127 109
90 87 83 97 118 148 119 17 341 281 283 242 285 443 337 232 316 280 204 149 100 280 577 516
552 431 511 408
330 362 390 348 252 198 147 189 342 232 140 197 167 188 214 266
SRL-A09A 87
102 110 104 127 131 112 78 95 94 145 131 133 84 85 70 84 70 111 93 76 75 95 124 97 131
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94 119 106 143 88 135 95 133 112 130 116 125 108 97 114 114 165 133 123 129 121 178
SRL-A09B 87
70 89 114 97 115 93 93 94 88 136 124 121 94 99 108 86 118 111 75 81
83 72 75 68 77 85 116 54 83 86 131 89 123 125 97 106 88 117 117 86
104 68 102 114 129 104 136 120 91 110 99 137 91 139 85 122 128 122 129 97 133 87 115 128
107 154 115 138
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SRL-A10A 65
129 153 126 163 102 111 115 143 117 119 84 88 85 119 115 105 90 92 106 124
115 141 99 140 140 120 141 67 92 121 125 104 94 101 87 138 116 78 124 91 90
123 107 122 83 131

SRL-A10B 65
177 148 126 157 110 113 119 151 108 131 83 88 90 117 110 109 113 116 100 121 105 94 122 88
107 109 120 126 92 95 108 115 98 100 134 125
143 106 137 144 100 136 76 94 112 126 113 88 86 99 139 103 88 124 86 85
114 107 131 99 120
SRL-A11A 124
75 79 76 86 89 59 60 46 69 84 79 77 82 86 93 91 78 85 80 102 94 105 93 113 99 88
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SRL-A11B 124
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142 152 104 117
SRL-A12A 94
178 152 82 119 96 71 106 83 78 66 84 72 66 73 79 84 78 99 62 62 94 92 82 70 51 78
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207 98 59 87 68 81 79 88 116 75 96 92 90 125
SRL-A12B 94
166 127 90 131 111 78 92 94 75 119 149 88 91 119 124 97 109 120 104 74
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111 129 103 100 72 87 122 108 74 78 69 81 112 116 85 115 94 87 102 94
159 77 71 77 69 89 72 85 78 103 92 99 70 118
SRL-A13A 140
115 144 155 231 220 294 262 444 251 132 215 368 166 183 204 173 163 194 99 163
182 258 68 106 122 76 72 79 95 129 201 111 178 129 113 137 154 141 112 109
142 132 66 97 61 95 192 115 115 75 75 105 72 105 94 100 86 89 83 92
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SRL-A13B 140
124 153 162 200 237 299 270 470 271 129 190 375 187 179 193 175 141 179 82 173
168 261 73 127 113 63 53 92 70 107 196 97 173 132 125 129 166 122 117 115
129 144 71 94 66 93 182 127 127 66 74 106 69 107 91 95 95 90 83 95
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72 93 106 57 55 68 61 66 79 86 71 59 52 61 64 55 44 42 36 46
52 47 63 80 58 66 54 46 42 47 42 33 30 38 44 66 57 29 52 48
SRL-A14A 94
339 288 192 248 216 273 270 239 214 256 240 159 136 150 149 178 124 103 166 158
139 120 122 105 117 126 143 139 108 102 178 129 112 123 140 140 122 174 113 103
84 117 107 109 173 132 162 131 90 128 136 185 176 136 131 139 168 173 137 116

113 110 87 158 130 84 115 124 117 186 211 103 130 126 232 247 327 215 139 178
158 158 135 111 121 145 87 99 148 142 135 224 178 232
SRL-A14B 94
314 290 191 244 212 273 272 241 203 269 255 155 132 157 155 176 122 119 163 153
146 108 118 98 109 137 144 149 104 98 174 139 98 137 128 141 103 174 112 96
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114 111 93 143 130 89 116 114 124 188 196 118 131 129 243 239 333 200 145 179
178 165 132 113 117 147 77 99 142 160 145 238 203 132
SRL-A15A 163
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112 96 101 92 118 108 69 89 92 77 54 83 93 53 40 58 81 65 71 58
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172 166 161 158 124 173 110 109 103 129 95 109 87 68 75 72 76 82 96 128
107 106 93 77 86 91 91 90 87 105 86 84 89 90 54 63 57 64 44 49
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72 62 101
SRL-A15B 163
126 119 83 95 76 76 95 110 100 113 102 96 111 114 95 106 148 95 107 125
117 88 107 88 120 106 69 101 84 98 69 84 95 48 46 52 81 73 66 61
59 59 50 57 58 52 53 74 57 59 55 82 69 71 66 66 64 86 91 66
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179 180 164 154 126 173 109 106 114 127 83 117 88 73 64 83 75 95 91 135
111 107 103 56 82 104 92 93 86 106 71 90 90 94 42 72 64 54 47 54
61 61 53 52 79 57 73 68 53 64 79 77 70 108 101 91 96 76 61 75
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SRL-A16A 105
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SRL-A16B 105
93 92 104 64 101 99 88 80 74 90 82 99 94 80 96 88 102 65 82 76
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75 82 98 92 91
SRL-A17A 88
99 118 65 80 87 76 86 88 77 88 76 89 65 82 67 85 106 94 68 86
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90 95 83 98 99 88 91 75 94 132 107 83 118 130 136 138 118 152 132 135
113 143 103 139 119 98 86 94 100 112 89 109 77 105 86 94 80 73 89 68
67 78 84 105 96 91 84 88
SRL-A17B 97
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85 71 105 79 102 86 80 74 88 95 105 75 102 74 95 108 111 60 79 88
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76 92 113 112 83 90 116 117 125 101 113 112 128 97 112 115 127 102 107 84

90 95 114 110 130 89 113 87 97 109 95 80 65 79 84 77 113
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101 92 148 124 103 102 48 50 70 68 76 79 97 84 83 69 103 93 85 83
101 78 64 75 80 104 140 123 102 76 173 176 102 149 105 220 173 123 126 153
131 135 163 137 122 117 125 83 105 156 162 206 141 111 119 112 174 136 113 130
179 237 289 287 297 275 244
SRL-A18B 67
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138 121 159 156 120 136 99 100 104 150 171 194 167 99 124 103 168 142 114 120
178 233 274 275 302 276 243
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137 276 205 143 150 163
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123 124 160 190 169 157 135 121 112 77 121 169 166 209 225 264 238 168 178 167
146 273 212 133 146 162
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127 121 103 131 126 126 96 124 84 114 92 94 82 107 99 127 119 132 93 98
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SRL-A21B 95
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SRL-A23B 85
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SRL-A24A 124

131 185 169 147 108 143 193 202 119 97 139 174 172 190 117 157 144 183 180 184
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SRL-A24B 124
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SRL-A25A 85
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107 144 176 142 148 129 124 126 176 143 117 127 91 103 109 139 132 167 173 128
140 145 101 74 85 107 149 130 181 294 339 274 179 213
SRL-A26A 63
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120 116 143 185 138 136 156 115 117 118 108 138 129 144 130 151 133 99 110 127
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SRL-A26B 63
158 177 175 193 192 202 206 257 196 184 138 158 187 222 238 196 165 184 145 220
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153 121 149 197 170 132 163 110 113 109 90 132 124 151 129 151 143 104 115 144
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SRL-A27A 113
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145 168 86 136 90 94 110 164 87 85 113 166 146 136 117 138 144 138 129 114
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SRL-A27B 113
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SRL-A28B 85
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114 85 124 119 157 134 164 112 106 95 64 79 71 138 108 168 157 199 193 157
134 163 140 248 272
SRL-A29A 160
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85 57 70 64 52 51 61 48 45 86 46 66 62 60 81 68 62 62 55 75
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SRL-A29B 160
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183 220 161 181 157 159 109 162 96 108 113 124 96 89 81 71 65 59 81 90
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SRL-A30A 94
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90 83 93 94 119 96 124 78 96 97 116 103 103 91
SRL-A30B 95
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68 71 81 73 73 72 85 62 63 82 81 101 110 64 75 83 84 91 79 54
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SRL-A31B 76
122 108 117 99 106 112 144 121 99 133 98 132 111 91 140 123 133 95 118 88
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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

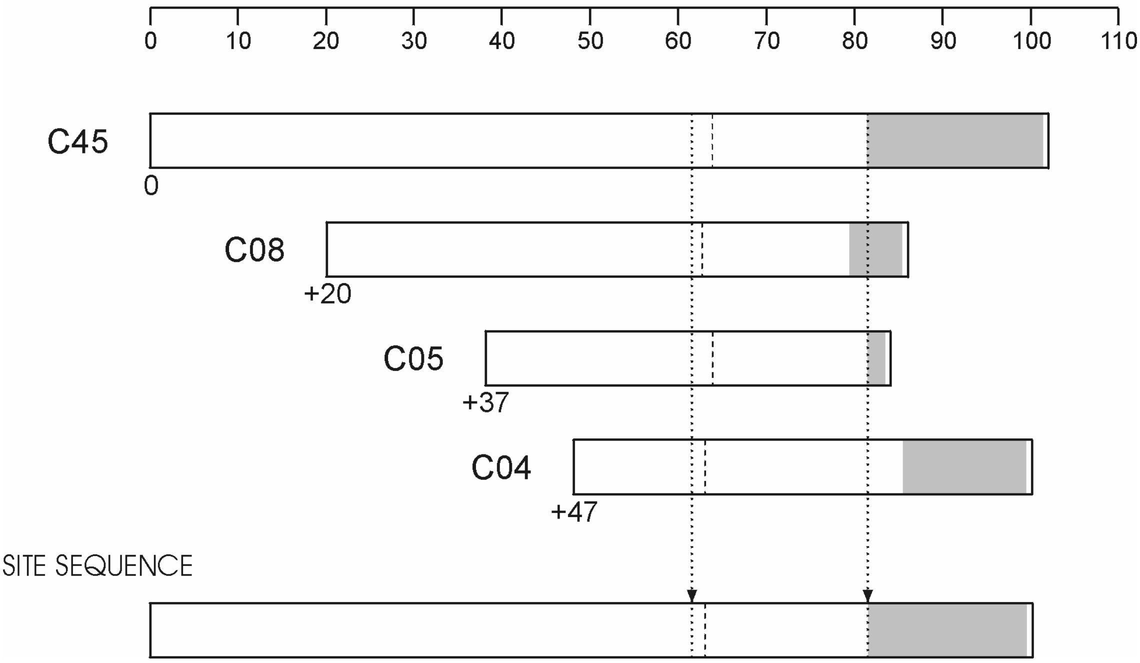


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

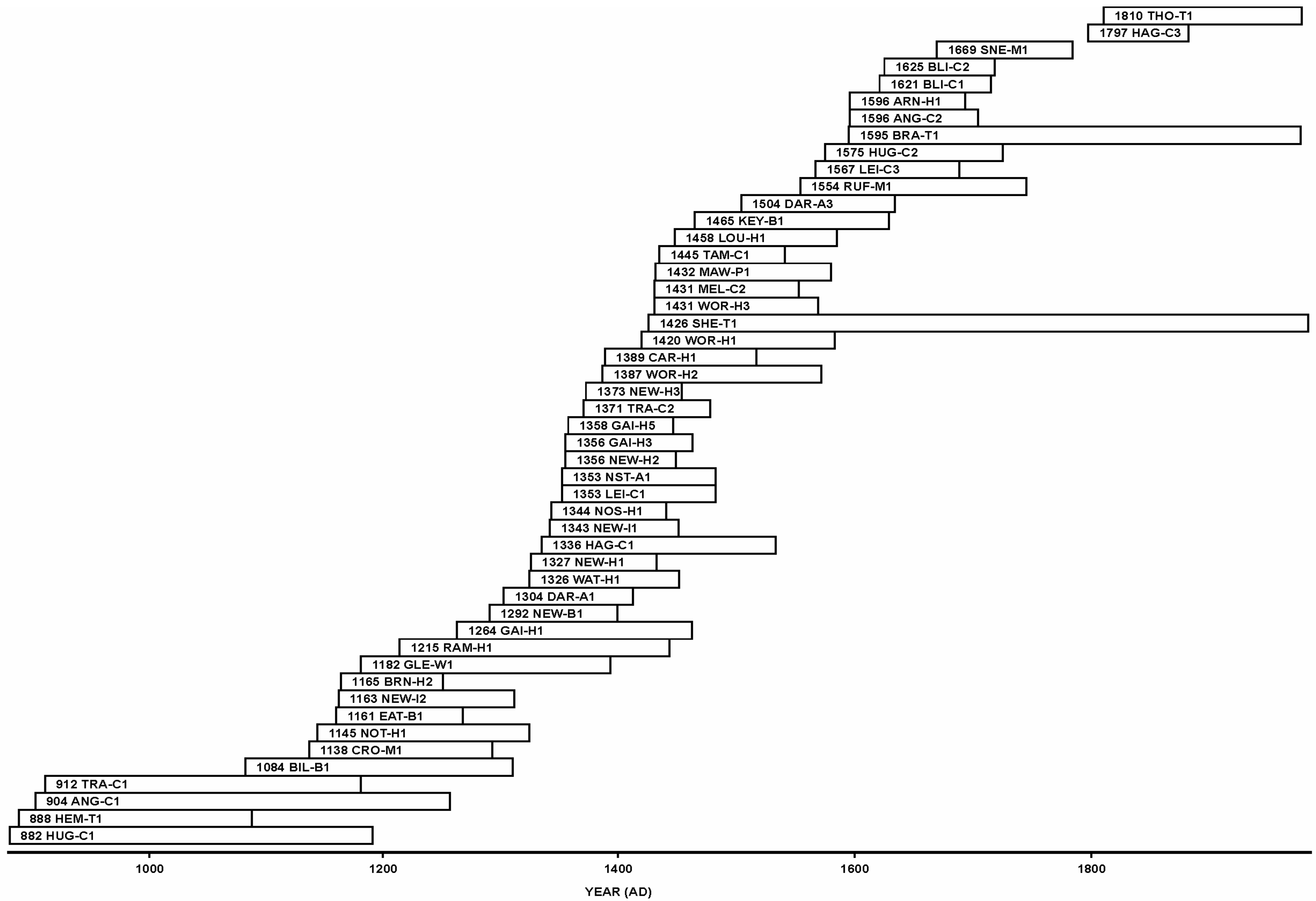
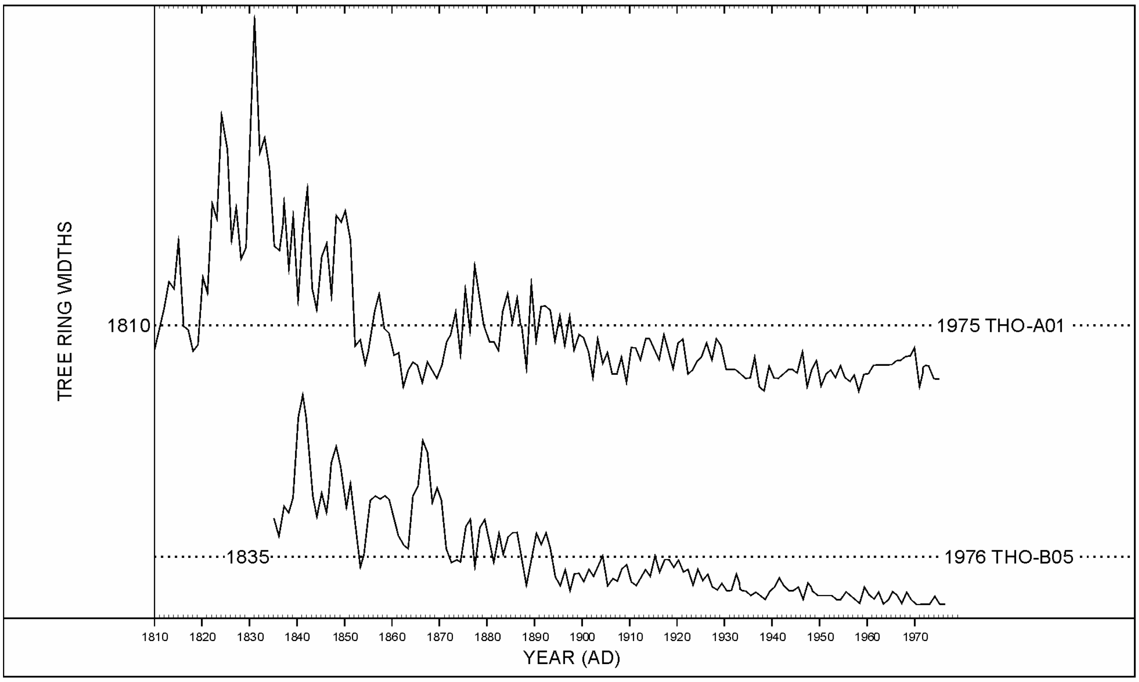


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

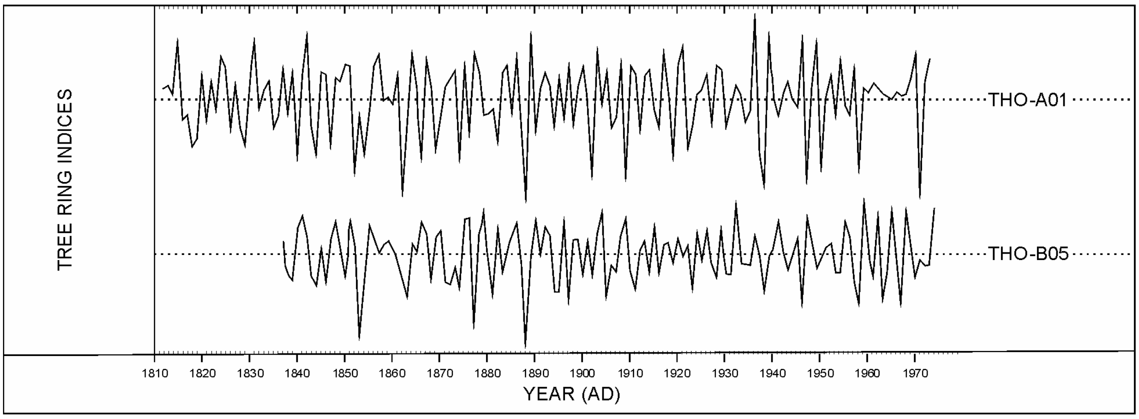


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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