

RESEARCH REPORT SERIES no. 55-2014

7-12 CHURCH STREET, DRONFIELD, DERBYSHIRE TREE-RING ANALYSIS OF TIMBERS SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard



INTERVENTION
AND ANALYSIS


ENGLISH HERITAGE

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7-12 CHURCH STREET,
DRONFIELD,
DERBYSHIRE

TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: SK 35318 78377

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ISSN 1749-8775 (Print)

ISSN 2046-9802 (Online)

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SUMMARY

Dendrochronological analysis was undertaken on 13 of the 15 core samples obtained from the five cruck trusses of this barn. This analysis produced two site chronologies. The first site chronology, comprising nine samples from trusses A, B, C, and D, has an overall length of 214 rings, dated as spanning the years AD 1313–1526. Interpretation of the sapwood in these samples would suggest that some of the timbers of trusses A and B were felled in the late AD 1450s or early AD 1460s, while some of the timbers of trusses C and D have an estimated felling date range of AD 1537–62. The second site chronology, comprising two samples from truss A, has an overall length of 110 rings but cannot be dated. Two further measured samples remain ungrouped and undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to thank David Renwick, Project Manager of the Church Street development, and the many contractors on site at the time of sampling, for their considerable help and cooperation during assessment and coring. We would also like to thank Professor David Hey for the background information to the sites in the introduction and Edele Mynns and Co Ltd, Chartered Architects and Surveyors, for the use of their survey plans and drawings. Finally we would like to thank Shahina Farid and Cathy Tyers (English Heritage Scientific Dating Team) for commissioning this programme of tree-ring dating and their assistance during the production of this report.

ARCHIVE LOCATION

Derbyshire Historic Environment Record
Environmental Services Department
Shand House
Dale Road South
Matlock
Derbyshire DE4 3RY

DATE OF INVESTIGATION

2013

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INTRODUCTION

The grade II listed 12 Church Street is a range of former shop units near the centre of Dronfield (Fig 1), these being built of coursed rubble masonry sandstone with stone and Welsh slate roofing. The site was the subject of a programme of archaeological survey and recording by West Yorkshire Archaeological Services (2013) and Professor David Hey (unpublished) has undertaken a substantial amount of documentary research on the building and its surroundings which forms the basis of the background information below.

These units had been converted to commercial use from what are believed to be a series of early seventeenth-century outbuildings belonging to a now lost farmhouse, Buttermore Farm, which stood just to the west of the barn where there is now a small car park. These outbuildings contain five full-height cruck trusses (Figs 2 and 3), the trusses supporting a single purlin roof which also retains some windbrace. There is also a two-bay, three-storey unit at the east end of the range, but this appears to contain only relatively modern softwood timbers. There is no indication that these buildings were ever used as domestic accommodation, although all of them have been subject to alterations undertaken in the eighteenth, nineteenth, and twentieth centuries.

The ridge pieces, purlins, and wall plates of the barn extend beyond the extant five trusses suggesting the original building may have been longer, and it is possible that there were once further trusses at either end before the present gable walls replaced them. There is also a possibility that the front and rear stone-built outer walls themselves replace original timber-framing.

It is also believed, on the basis of structural and carpentry evidence that the barn may have been built in two stages, possibly to adapt to the slope of the ground, although the order of construction cannot be determined. The two trusses at the western end (here designated trusses A and B) are at a lower level than the three trusses, C, D, and E, to the east end. In addition, the tie beams of trusses A and B are halved into the eastern faces of the cruck blades, whereas the other tie beams are halved into the west faces. The distance between trusses B and C is shorter than in the other bays, suggesting there may have been a division or break here, and truss C is the only one to bear carpenters' marks, which are chiselled into the northern cruck blade and into the tie-beam and collar in the form of Roman numerals.

SAMPLING

Sampling and analysis by dendrochronology of the timbers to the main single-storey range of 7–12 Church Street was requested by Bob Hawkins, English Heritage Designation Adviser. This programme of analysis was undertaken to provide independent dating evidence for the original construction of the building and the date of any reused timbers, or any timbers subsequently inserted. It was hoped that this information would inform

repairs and conservation plans for the building which is currently undergoing conversion to domestic accommodation.

Thus, from the timbers available, a total of 15 samples was obtained by coring. Each sample was given the code DRN-C (for Branfield, site C) and numbered 01–15 (Table 1). These samples were distributed equally throughout the building, taking into account the suitability of timber for tree-ring analysis. In this respect it should perhaps be noted that the barn presented timbers with variable numbers of rings. The timbers of truss E, and the east end in general, were derived from slightly faster grown trees and thus had lower numbers of rings. Consequently many of the timbers in this area were unsuitable for tree-ring analysis.

The locations of these samples were recorded at the time of sampling on a drawing made by Eddon Mins and Co Ltd Chartered Architects and Surveyors, and provided by English Heritage. These drawings are reproduced here in Figure 2 and Figures 4a–e. Details of the samples are given in Table 1. In this Table, as in the drawings, the trusses have been identified A to E from west to east following the scheme of the Eddon Mins' plans, with individual timbers then being further identified on a north–south basis as appropriate.

ANALYSIS AND RESULTS

Each of the 15 samples obtained from the five trusses was prepared by sanding and polishing. It was seen at this time that two samples, from the collars of trusses C and D, had too few rings for reliable dating, and so they were rejected from this programme of analysis. The annual growth widths of the remaining 13 samples were, however, measured, the data of these measurements being given at the end of this report. The data of the 13 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing two groups of cross-matching samples to be formed.

The analysis initially resulted in the production of one sub-group of five samples from trusses A and B and a second sub-group of four samples from trusses C and D. Both sub-groups dated independently very well and in spite of the short period of overlap between them (Fig 5) they also cross-matched well. Because of the satisfactory independent dating of each sub-group, the nine constituent samples were combined at their indicated offset positions to form a single site chronology DRNCSQ 01, this having an overall length of 214 rings. Site chronology DRNCSQ 01 was then compared to an extensive corpus of reference material for oak. This indicated a consistent and repeated match with a number of reference chronologies when the date of its first ring AD 1313 and the date of its last measured ring is AD 1526. The evidence for this dating is given in Table 2.

The second group comprises two samples, these cross-matching with each other as shown in Figure 6. The two samples were combined at their indicated offset positions to form DRNCSQ 02, this site chronology having an overall length of 110 rings. Site chronology DRNCSQ 02 was also compared to an extensive corpus of reference material

for oak, but there was no conclusive cross-matching at any position and it must, at least for the moment, remain undated.

Sitechronologies DRNCSQ 01 and DRNCSQ 02 were then compared to the two remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. The two ungrouped samples were then compared individually to the full banks of reference data, but again there was no satisfactory cross-matching and these two must, therefore, also remain undated. This analysis is summarised in Table 3.

INTERPRETATION

Analysis by dendrochronology of the timbers of 7–12 Church Street has produced two sitechronologies. The first sitechronology comprises nine of the 13 samples measured, its 214 rings dated as spanning the years AD 1313–1526. However, although these nine samples have formed a single site chronology, interpretation of the sapwood on them indicates that, as may be seen from Table 1 and Figure 5, timbers of two distinct phases of felling may be found in the single-storey range, their being in the order of 80–100 years difference between them.

Earlier felling phase – trusses A and B

This phase of felling is represented by samples DRN-C 01, C 04, C 05, C 06, and C 07, all these samples being from the timbers associated with trusses A and B. Two of these samples, DRN-C 04 and C 05, have last measured ring dates of AD 1454 and AD 1451 respectively. Both these samples are derived from timbers which have complete sapwood on them, meaning that they both have the last ring produced by the source tree before it was felled. However, because of the soft and fragile nature of this part of the timber, small amounts of sapwood, between 5–10mm, were lost from the samples coring (denoted by lower case 'c' in Table 1 and Fig 5). In such circumstances it is possible, based on the growth characteristics, to estimate how many sapwood rings the lost portions might have contained. In both these cases the loss suggested that the two timbers represented were felled in the late AD 1450s or early AD 1460s.

The relative position of the heartwood/sapwood boundary on the other three samples of this earlier group DRN-C 01, C 06, and C 07 (Table 1; Fig 5), is such that it is highly likely that the timbers they represent were also felled at about the same time, and that all five timbers were cut as part of a single episode of felling in the late AD 1450s or early AD 1460s.

Later felling phase – trusses C and D

This phase of felling is represented by samples DRN-C 09, C 10, C 11, and C 12 representing all four crack blades of trusses C and D. None of these samples retain complete sapwood, or are from timbers with complete sapwood on them, and it is thus not possible to provide an exact felling date. The four samples do, however, retain some

sapwood or at least the heartwood/sapwood boundary, this being at a very similar relative position in all four samples (Table 1; Fig 5), and indicative of a single phase of felling.

The average date of the heartwood/sapwood boundary in these four samples is AD 1522. Adding to this the likely 95% probability interval the amount of sapwood these timbers might have had, 15–40 rings, would give them an estimated felling date range of AD 1537–62.

Undated site chronology DRN CSQ 02

The second site chronology DRN CSQ 02, comprises samples DRN -C 02 and DRN -C 03, and is 110 rings long. This site chronology cannot be conclusively dated. Both samples are from the timbers of truss A; the south blade and collar respectively. There is some disturbance to the growth rings of both samples, although it is not particularly pronounced which may have affected the dating of these two samples to date. It therefore remains a possibility that these two samples represent a different felling date to the other two identified, but clearly this cannot be proven dendrochronologically. Such supposition would rely solely on structural evidence.

Undated samples

Two final ungrouped samples, DRN -C 08 and C15, remain ungrouped and undated. As may be noted from Table 1, both these have few rings and hence were reconsidered borderline as to their suitability for successful dating.

DISCUSSION AND CONCLUSION

Two phases of felling have been identified from the dated timbers of the single-storey range near truss A, dating to the late AD 1450s or early AD 1460s, and a later phase having an estimated felling date range of AD 1537–62. Given that these phases also represent discreet groups of timbers, with the earlier date found only amongst the timbers associated with trusses A and B, and the later date only amongst the timbers of trusses C and D, it is likely that these represent the approximate construction dates for these portions of the building.

As such, the re-reading shows that although the building in its present stone-built form may date to the early seventeenth century, it actually has its origin nearer to the middle part of the fifteenth century, with a further phase of construction in the mid-sixteenth century. Thus this single-storey range appears to be of somewhat greater antiquity than is indicated in the list description. The results obtained in this analysis also support the structural interpretation that this single-storey range was built in two stages.

The overall loss-matches between the five samples from the earlier phase would suggest that although these timbers were probably derived from a single woodland

sources, although individuals were not growing particularly close to each other and are possibly from different stands of woodland. The overall cross-matching between the four samples from the later phase, however, would suggest that these timbers were probably derived from a single woodland, with these trees being closely adjacent to each other.

It is likely that the woodland sources for both earlier and later dated timbers was relatively local, although compared with reference data for all parts of England, the highest levels of similarity between the site chronology and the reference chronologies are found predominantly with sites in Derbyshire (with three other sites in Devonfield producing notably high t-values) and the surrounding counties.

The lack of timber suitable for analysis on truss E, and hence the difference in growth characteristics compared with those associated with the other trusses, could signify that they represent an additional phase but this cannot be proven.

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West Yorkshire Archaeological Services, 2013 7–12 Church Street Dronfield Report No 2654

TABLES

Table 1: Details of tree-ring samples from 7–12 Church Street, Dronfield, Derbyshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
DRN-C01	N orth blade, truss A	122	h/s	1313	1434	1434
DRN-C02	South blade, truss A	98	h/s	—	—	—
DRN-C03	Collar, truss A	90	h/s	—	—	—
DRN-C04	N orth pitch, truss A - B	100	15c	1355	1439	1454
DRN-C05	South pitch, truss A - B	70	11c	1382	1440	1451
DRN-C06	N orth blade, truss B	107	h/s	1315	1421	1421
DRN-C07	South blade, truss B	84	h/s	1347	1430	1430
DRN-C08	Collar, truss B	42	18C	—	—	—
DRN-C09	N orth blade, truss C	105	h/s	1416	1520	1520
DRN-C10	South blade, truss C	108	h/s	1417	1524	1524
DRN-C11	Collar, truss C	nm	—	—	—	—
DRN-C12	N orth blade, truss D	86	8	1441	1518	1526
DRN-C13	South blade, truss D	92	h/s	1434	1525	1525
DRN-C14	Collar, truss D	nm	—	—	—	—
DRN-C15	N orth blade, truss E	44	23c	—	—	—

h/s = the heartwood/sapwood ring is the last ring on the sample

C = complete sapwood is retained on the sample. Where dated, this is the felling date of the tree represented

c = complete sapwood is found on the timber but all or part has been lost from the sample in coring
nm = sample not measured

Table 2: Results of the cross-matching of site sequence DRNCSQ01 and relevant reference chronologies when the first-ring date is AD 1313 and the last-ring date is AD 1526

Reference chronology	Span of chronology	t-value	Reference
All Hallows Church, Kirkburton, West Yorkshire	AD 1306–1633	11.1	(Arnold and Howard 2007)
Dronfield Hall Barn, Dronfield, Derbyshire	AD 1313–1526	10.5	(Arnold and Howard 2014)
Primrose Hill Kings Norton, Birmingham	AD 1354–1593	10.5	(Arnold and Howard 2008)
Lea Road Foundry Site, Church Street, Dronfield, Derbyshire	AD 1344–1526	9.7	(Tyers 2003)
Elland Old Hall, Calderdale, West Yorkshire	AD 1372–1574	9.7	(Hillam 1984)
Ugthorpe Moor, Bradfield, South Yorkshire	AD 1349–1504	9.6	(Howard et al. 1994)
Dronfield Woodhouse Hall, Dronfield, Woodhouse, Derbyshire	AD 1342–1533	9.6	(Arnold and Howard unpubl.)

Table 3: Summary of tree-ring analysis from 7–12 Church Street, Dronfield

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
DRNCSQ 01	9	214	1313–1526
DRNCSQ 02	2	110	undated
Ungrouped	2	—	undated
Unmeasured	2	—	—

FIGURES



Figure 1: Map to show the location of Dronfield (top) and 7–12 Church Street (bottom) © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

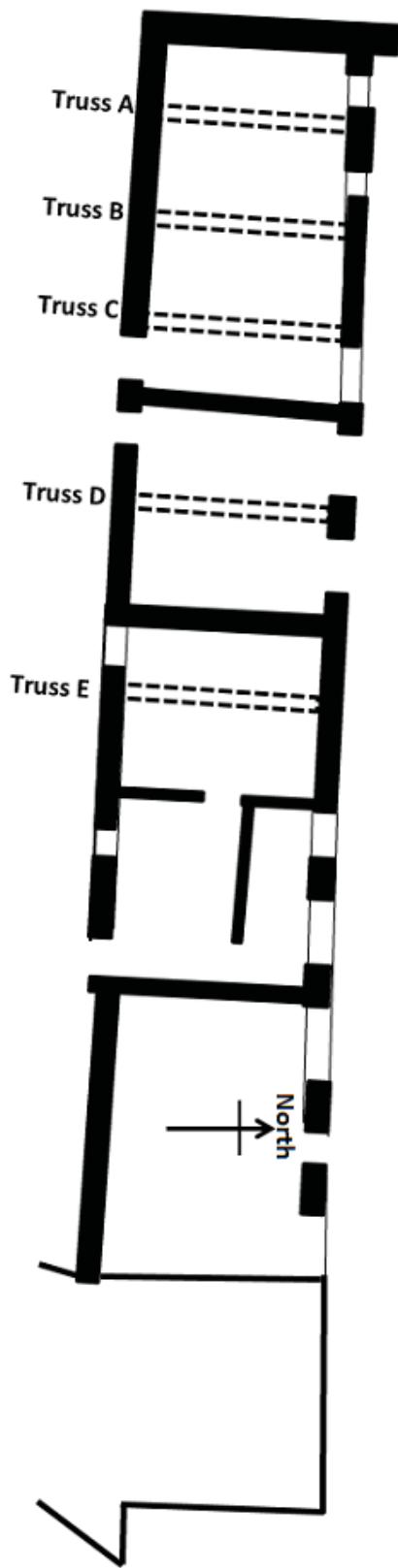


Figure 2: Simplified ground floor plan of 7-12 Church Street to show layout of the building and the position of the cruck truss (after Elden Minns & Co Ltd, Surveyors)



*Figure 3: Views of trusses A, B, and C (top), truss D (middle), and truss E (bottom)
(photographs Robert Howard)*

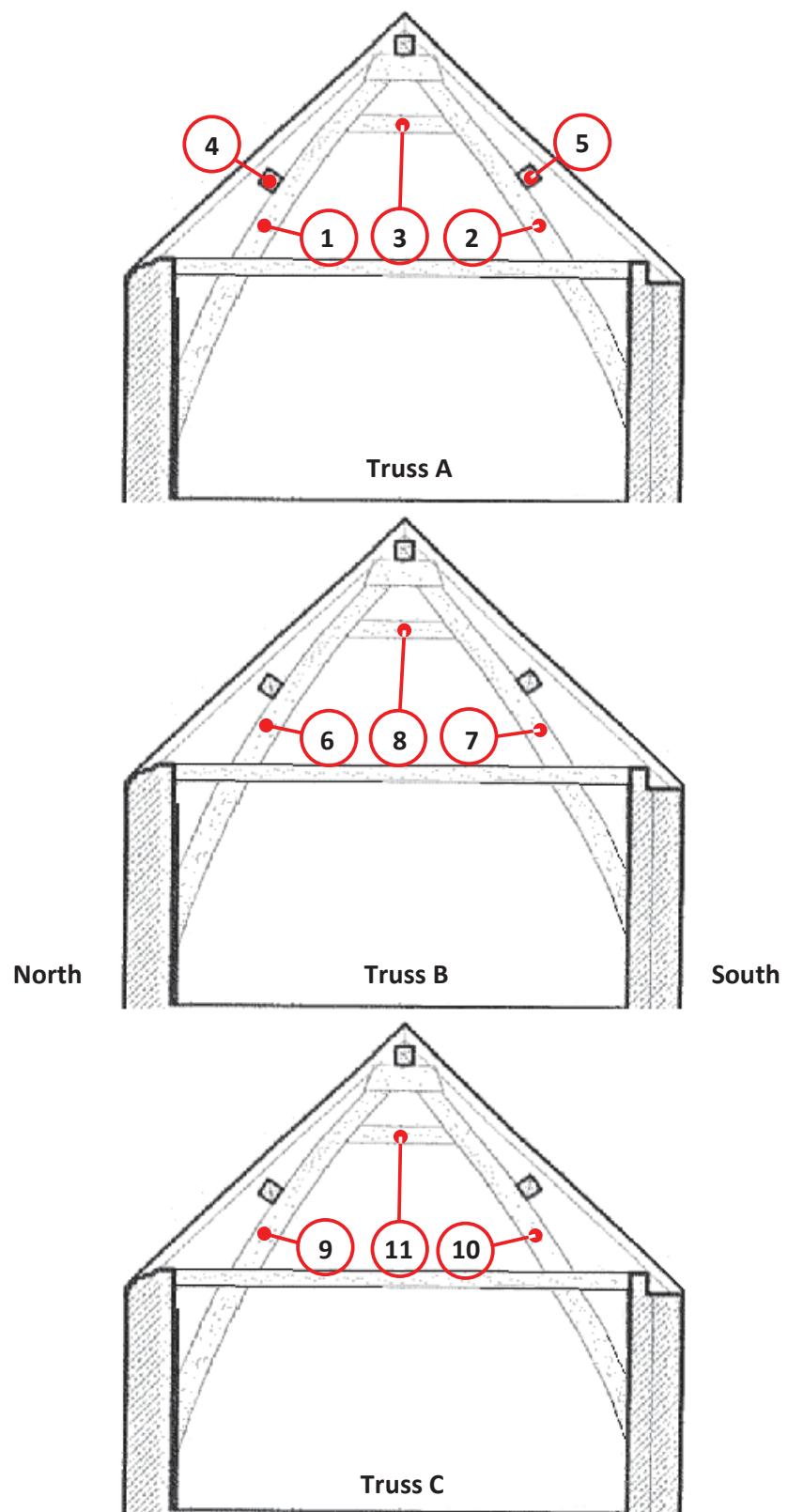


Figure 4a-c: Representative drawings of the trusses to locate the sampled timbers (after Elden Minns & Co Ltd, Surveyors)

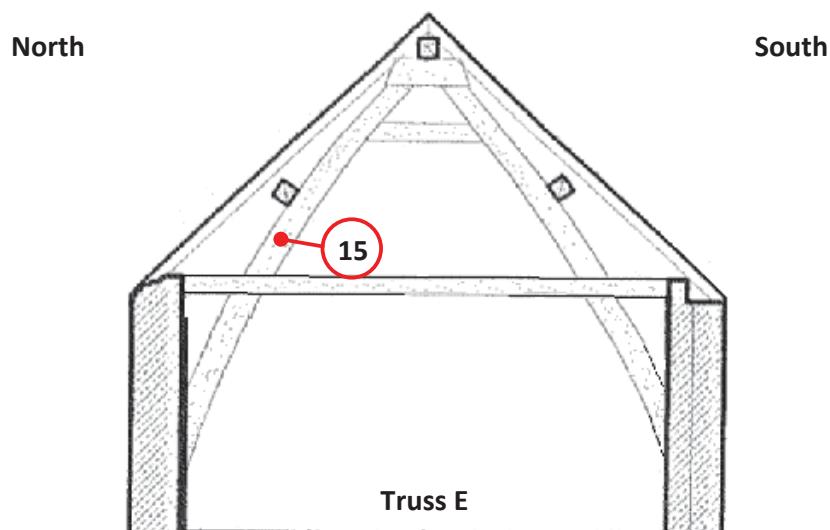
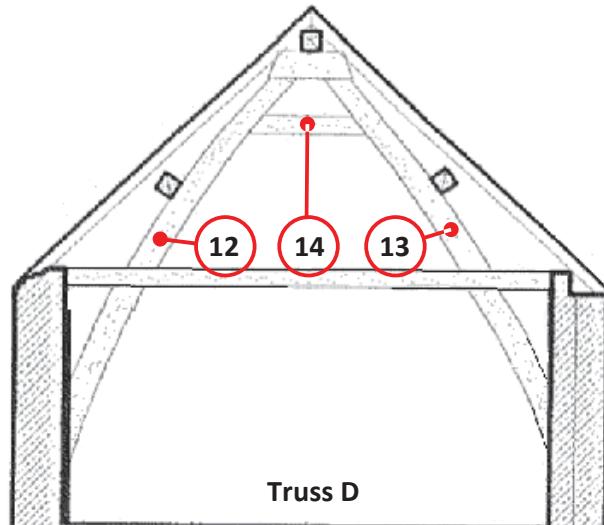
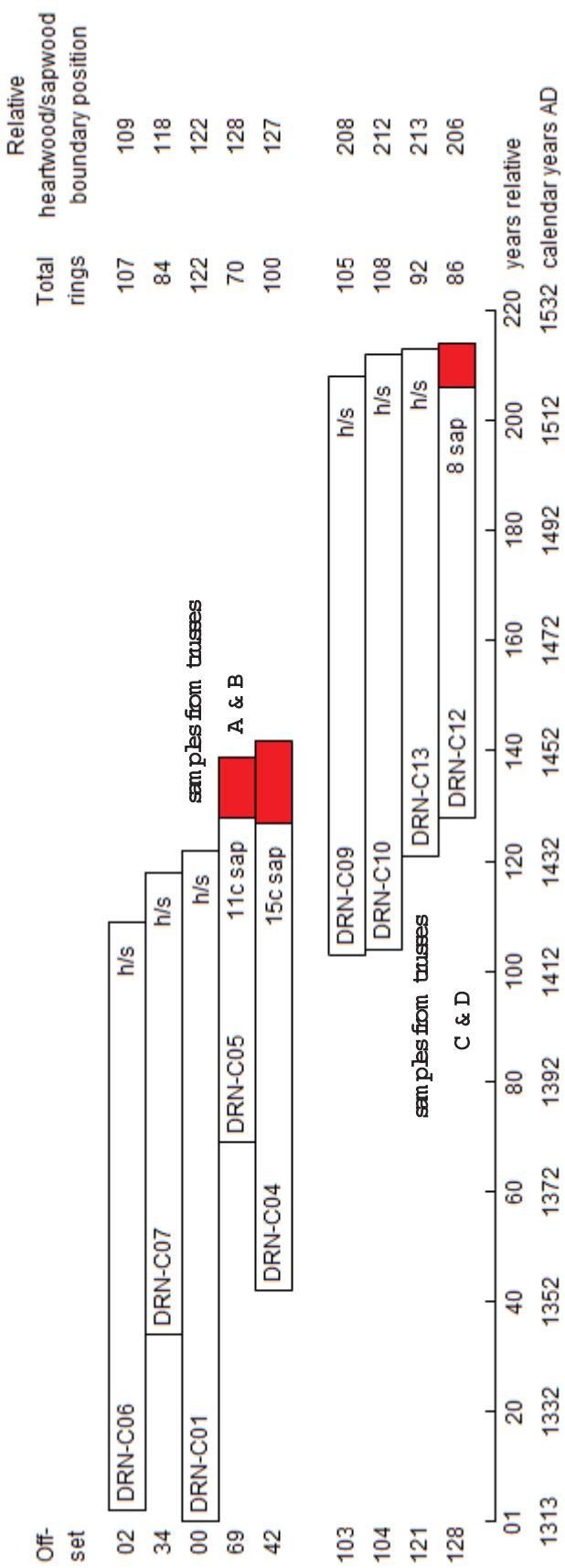


Figure 4d-e: Representative drawings of the trusses to locate the sampled timbers (after Elden Minns & Co Ltd, Surveyors)



W hite bars = sapwood rings, shaded bars = heartwood/sapwood boundary; h/s = complete sapwood is found on the timber but all or part has been lost from the sample in coring

Figure 5: Bar diagram of the samples in site chronology DRNCSQ01

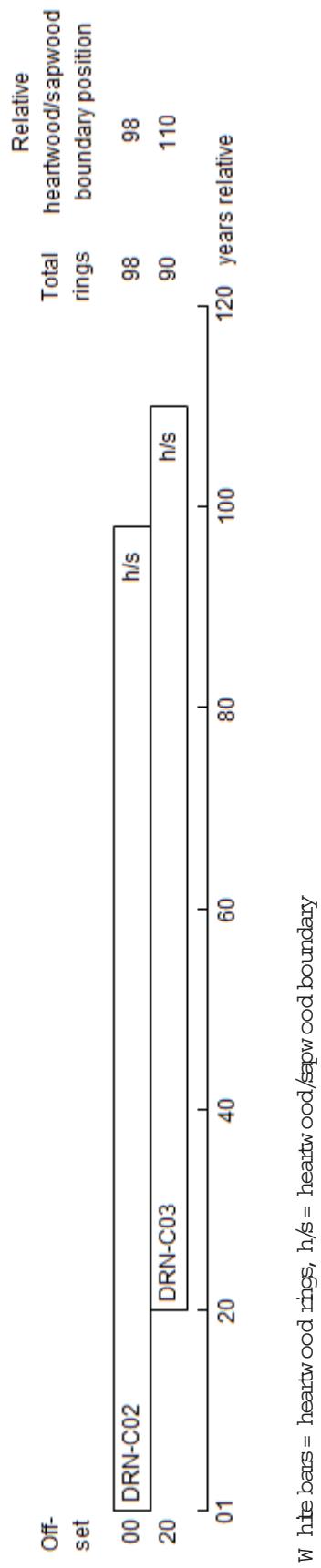


Figure 6: Bar diagram of the samples in situ chronology DRNCSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

D RN -C 01A 122

111 105 151 187 230 98 131 92 98 128 242 202 234 136 218 160 159 237 185 226
221 220 254 181 253 258 157 171 203 171 221 194 239 192 182 185 178 151 209 171
176 189 148 131 101 127 98 70 84 171 157 178 135 148 113 116 126 106 103 139
75 123 57 70 96 103 129 59 71 71 79 90 101 153 179 126 109 85 73 170
190 164 84 114 117 140 121 145 105 122 136 178 153 173 145 155 107 81 82 111
110 120 115 143 175 137 91 131 102 90 187 125 175 124 72 81 111 119 128 147
88 118

D RN -C 01B 122

113 128 179 200 221 91 134 87 105 123 245 203 239 132 225 179 145 248 189 207
221 231 239 182 246 239 157 177 189 178 221 207 242 202 154 189 190 145 195 189
156 192 143 127 103 108 110 73 81 179 150 153 114 143 110 109 129 108 106 148
73 127 75 68 95 102 135 73 79 89 70 93 93 149 145 121 117 85 76 162
204 156 89 129 132 128 128 134 101 118 114 163 146 166 143 150 105 84 82 95
125 117 106 134 175 159 75 146 101 103 191 134 171 100 60 78 92 112 121 159
88 123

D RN -C 02A 98

147 274 248 292 359 300 373 378 395 328 387 375 368 314 337 247 245 308 282 241
213 269 264 204 209 184 120 95 84 73 89 75 137 126 88 83 100 82 96 104
84 52 103 120 104 96 159 143 84 73 73 79 66 86 73 79 132 128 56 59
67 75 66 80 57 75 53 82 50 123 93 78 128 154 135 160 151 158 231 215
162 206 156 127 158 113 130 128 82 90 166 143 116 161 165 157 154 138

D RN -C 02B 98

141 276 242 289 363 299 356 380 387 328 396 371 333 312 332 248 259 342 266 225
213 276 262 227 233 214 136 90 75 78 85 78 125 132 89 80 97 93 95 95
85 56 104 115 107 95 150 148 90 69 72 71 67 95 76 71 128 120 57 67
71 68 65 81 64 64 67 76 108 92 67 137 155 138 153 154 145 253 212
165 197 157 123 158 106 128 135 80 84 174 143 125 159 157 159 150 144

D RN -C 03A 90

250 175 194 228 202 183 167 157 142 117 132 92 96 90 94 85 87 82 77 57
32 41 58 82 101 100 98 108 89 99 80 91 92 97 91 121 181 110 70 85
114 116 108 168 207 250 196 219 170 225 162 148 165 129 109 146 112 118 137 115
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D RN -C 03B 90

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118 114 91 116 104 92 127 114 93 134

D RN -C 04A 100

266 287 160 204 323 184 157 212 162 142 159 160 148 125 159 162 110 120 124 145
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154 153 132 131 106 148 175 121 159 176 161 104 141 145 135 154 170 140 148 166

D RN -C 04B 100

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103 118 151 128 132 73 110 98 91 129 100 123 133 114 113 102 100 92 83 87
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D RN -C 07B 84
77 68 59 102 182 212 294 376 322 313 193 362 323 205 208 494 287 319 298 379
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171 169 193 206
D RN -C 08A 42
369 395 424 383 485 468 378 282 295 243 200 210 187 167 185 178 164 103 162 135
153 350 482 463 335 292 185 360 282 331 195 248 270 338 178 145 145 299 330 267
250 410
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257 398
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226 170 209 150 220 207 168 190 246 222 187 242 213 245 223 200 209 185 181 235
255 212 141 171 243 221 200 184 206 209 205 200 262 203 215 174 170 193 171 306

230 190 175 191 203 284 204 256 240 187 168 248 184 146 162 150 154 139 149 156
264 150 178 177 114 115 134 128 122 141 160 117 151 168 246 238 181 98 129 141
128 141 138 150 127

D RN -C 09B 105

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233 200 142 181 206 231 177 204 209 199 209 201 273 203 195 178 190 189 211 278
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140 140 132 159 131

D RN -C 10A 108

513 387 293 383 434 327 460 362 363 332 415 486 450 285 323 335 245 226 253 307
237 304 122 203 126 160 214 214 233 175 207 198 328 292 298 198 189 189 240 351
256 257 248 276 300 234 237 252 212 221 260 289 265 309 254 246 264 176 321 218
257 221 180 179 259 259 284 243 261 203 287 271 192 229 175 178 169 222 265 290
241 231 284 202 202 184 171 148 203 223 225 259 325 261 250 284 228 185 137 238
179 212 233 180 268 255 181 310

D RN -C 10B 108

532 409 290 349 442 320 468 359 356 327 422 500 431 289 316 342 253 220 264 310
245 281 132 212 135 131 213 217 220 179 195 201 345 293 270 217 195 201 229 339
265 253 244 277 309 227 237 250 203 228 242 292 281 295 263 252 250 189 316 228
232 216 181 187 256 240 268 262 240 196 278 268 196 221 174 187 162 216 263 311
245 243 288 197 203 195 169 162 191 219 225 252 331 275 257 289 222 184 159 216
175 210 237 180 275 234 195 319

D RN -C 12A 86

279 230 318 310 305 213 188 164 346 260 294 245 196 210 236 262 316 217 303 314
405 316 253 267 229 278 318 340 348 410 278 317 240 235 332 254 365 306 234 243
210 203 317 309 270 191 334 375 228 321 196 302 296 300 281 325 206 186 292 211
209 212 192 176 267 276 168 192 256 281 200 181 178 148 170 240 187 184 174 160
240 167 137 201 190 252

D RN -C 12B 86

272 239 311 307 310 200 185 170 350 256 298 246 197 210 221 289 304 229 285 336
379 322 244 260 210 269 332 326 356 409 281 318 259 241 340 242 350 306 230 280
201 200 321 301 269 200 328 370 231 318 203 301 303 295 271 329 208 182 300 198
216 214 217 154 239 283 182 178 258 274 207 176 179 146 174 231 193 178 176 164
229 149 159 194 185 243

D RN -C 13A 92

501 497 432 374 316 186 295 300 181 228 314 217 171 196 275 323 295 307 271 239
232 339 368 365 273 207 289 267 237 264 226 207 251 229 275 260 290 304 231 228
176 370 332 257 248 240 215 331 255 342 300 230 256 374 225 209 245 254 225 266
204 228 317 237 280 347 265 187 190 168 175 200 230 190 238 276 250 153 184 218
262 258 260 221 190 209 209 206 184 142 158 226

D RN -C 13B 92

497 499 456 367 330 198 283 307 176 230 321 221 161 203 269 330 303 296 264 235
232 322 359 365 259 225 301 254 260 262 220 207 246 226 268 253 306 293 245 233
184 370 329 254 255 251 215 343 252 334 312 222 257 366 237 201 253 259 227 259
201 220 326 227 289 339 263 189 196 168 175 200 233 206 218 271 259 140 196 223
256 262 259 218 186 198 206 217 181 157 159 217

D RN -C 15A 44

432 378 321 352 349 314 242 235 284 284 265 242 207 242 278 235 114 63 42 68
107 96 78 122 117 86 107 103 132 103 110 110 107 126 146 94 92 103 149 114
151 109 267 225

D RN -C 15B 44

423 372 318 359 347 309 220 266 275 300 261 248 204 251 268 237 94 63 49 82
106 135 95 128 121 80 99 103 128 92 106 112 92 164 129 96 100 103 154 118
142 135 254 228

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 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 100 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

I. **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 a 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 take many more especially if construction is complicated. One reason for taking many samples is that generally it 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 omitting the outer rings towards 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 150 mm long and 10 mm 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 at 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 unwanted 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-grade paper and then finished by hand with four-grade 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 growing times 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 (i.e. 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 timber from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, JN-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; e.g. the sequence of ring widths 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 +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 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 0.8 mm for C45, 0.2 mm for C08, 0.7 mm for C05, and 0.3 mm 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 sequences 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 'maximum 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 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 precise reasons. Nevertheless, if at least some of the sapwood rings are left in 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 if a sapwood ring is not available elsewhere or 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 in other imbedded depths 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 is possible by adding on the full complement 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. As 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 dates broadly agree 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 Nottingham 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 greater region, 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 the buildings 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 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 sequences 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

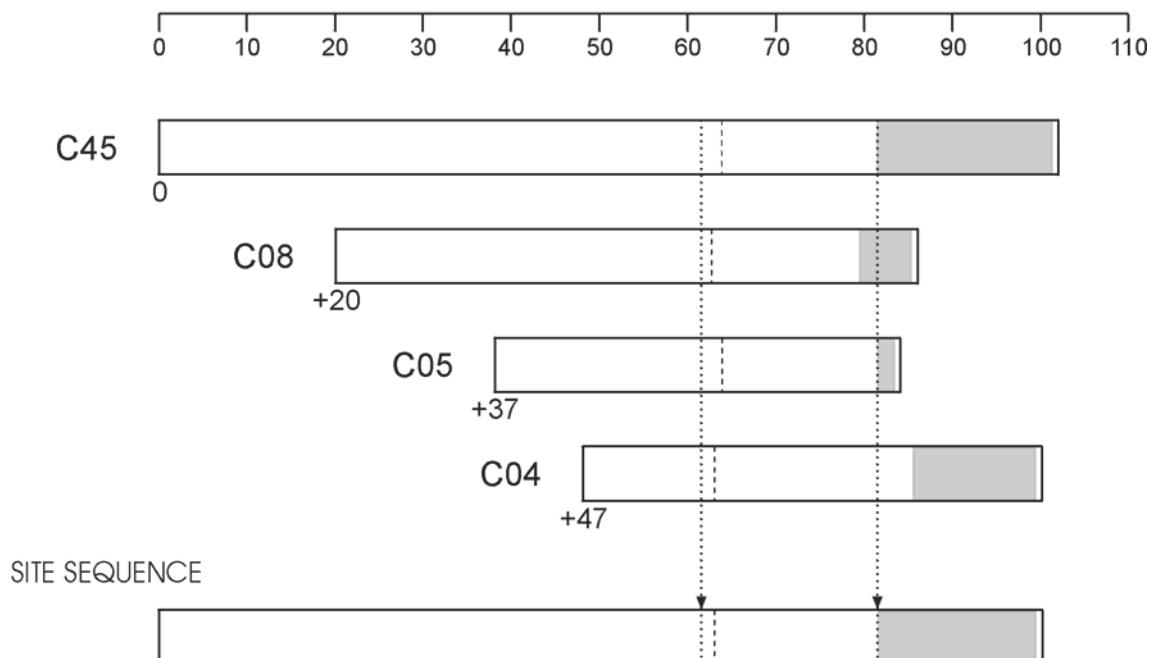


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

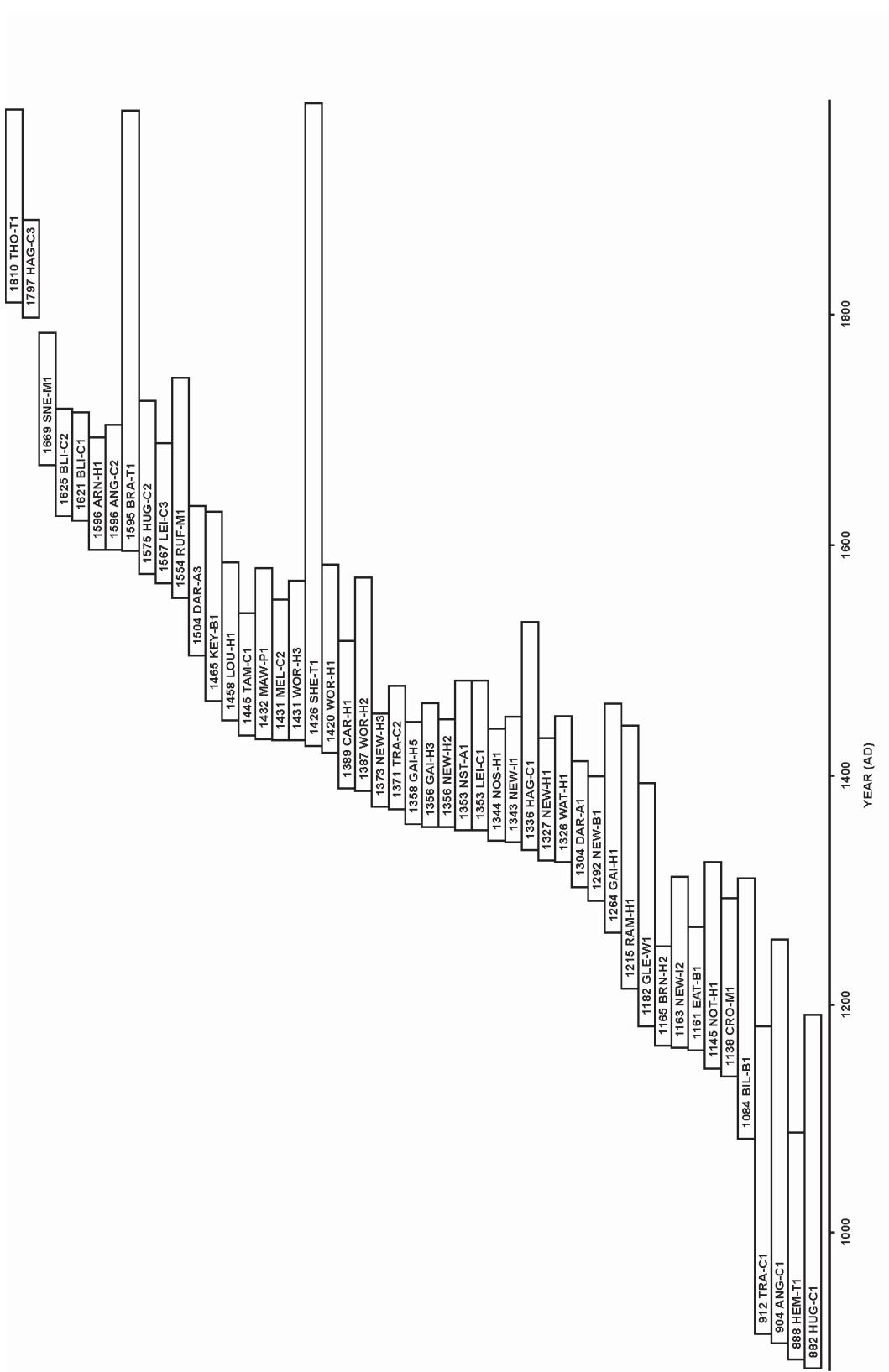
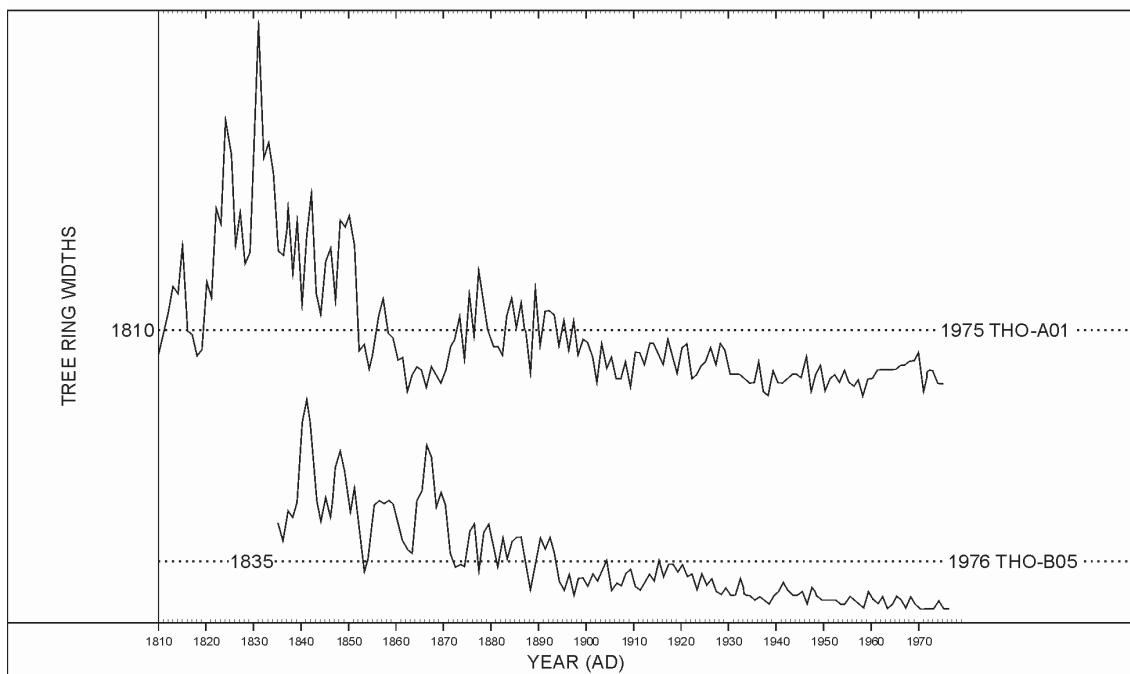


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

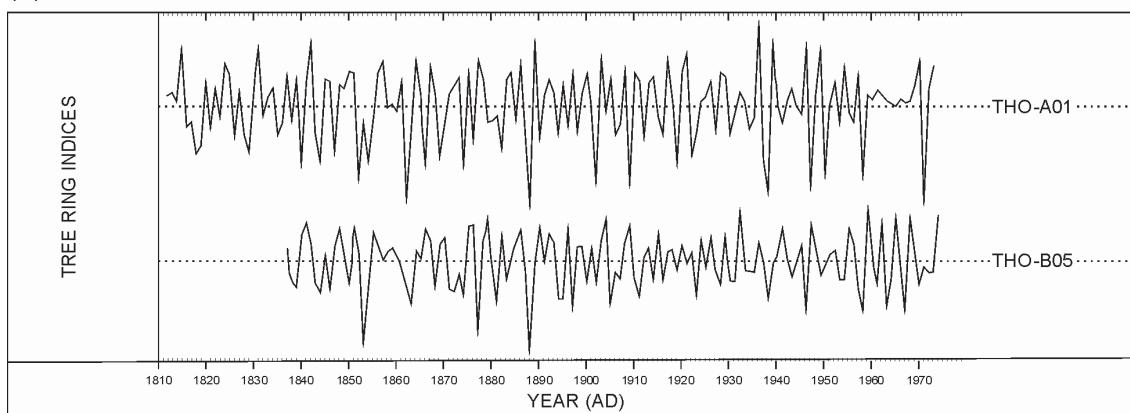


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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