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AULD COTTAGE, MAIN STREET, NORWELL, NOTTINGHAMSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Matt Hurford, Robert Howard and Cathy Tyers

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SUMMARY
Analysis by dendrochronology was undertaken on 11 samples obtained from Auld Cottage, Main Street, Norwell, Nottinghamshire. This resulted in the production of a single site chronology, NRWESQ01, comprising all 11 samples, with an overall length of 178 rings, these rings dated as spanning the years AD 1335–1512.
Interpretation of the sapwood and the heartwood/sapwood boundaries on the dated samples indicate the timbers used in the construction of the cottage were probably all felled in AD 1512.

CONTRIBUTORS
Matt Hurford, Robert Howard and Cathy Tyers

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ARCHIVE LOCATION
Nottinghamshire Historic Environment Record
Trent Bridge House
Fox Road
West Bridgford
Nottingham NG2 6BJ

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CONTACT DETAILS
Matt Hurford and Cathy Tyers
Dendrochronology Laboratory
Archaeology Graduate School
University of Sheffield
West Court, 2 Mappin Street
Sheffield S1 4DT
Tel: 0114 2763146
Email: m.hurford@sheffield.ac.uk, c.m.tyers@sheffield.ac.uk

Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
Tel: 0115 9603833
Email: roberthoward@tree-ringdating.co.uk

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INTRODUCTION

Auld Cottage lies towards the centre of the village of Norwell (SK 7712561754, Figs 1–3). Much of the following information on the building is summarised from Jones (pers comm). Auld Cottage is shown on the 1832 Enclosure Map but is thought to have somewhat earlier origins, possibly in the early sixteenth century. It was originally believed to have been a single storey timber-framed building, probably of three bays, the westernmost subsequently demolished. The remains of three trusses and the associated wall plates survive. The eastern truss (truss 1) has been truncated above tie-beam level but the central truss (truss 2) illustrates the form of the trusses with two principal rafters and a tie-beam, resting on wall plates and jowled wall posts.

It probably initially served as an agricultural building, but was in residential usage, possibly as early as the seventeenth century, when it is thought the upper floor was inserted, providing two upper chambers. A stairwell and landing, probably originally served by a ladder, were also added. The central tie-beam (truss 2) has been cut through to allow for a doorway enabling access to the chamber at the west end (Fig 4). The stud partition for the upper eastern chamber (Fig 5) is supported by a horizontal timber which rests on the wallplates but not on the wall posts. The process of infilling the timber frame began in the seventeenth or early eighteenth century and continued into the twentieth century.

The building was extended eastwards, possibly in the eighteenth century, for the addition of a ground-floor fireplace with hood and chimney stack carried up to the first floor. The existing low pantile roof is perhaps of nineteenth-century date. A further nineteenth-century addition is the porch on the north side, giving access to the lower east chamber. During the twentieth century, the tie-beam of the easternmost truss (truss 1) was sawn through (Fig 6), and on the south side two brick-built gabled porch-like extensions were built to buttress the wall and a double doorway was inserted to allow vehicle access (Fig 7).

The tree-ring dating, funded by English Heritage as part of a dendrochronological training programme for the first author, forms part of a wider project being undertaken by Norwell Parish Heritage Group. This wider project is funded with a Heritage Lottery Fund grant awarded to Norwell Parish Heritage Group in AD 2006 to facilitate the production of a Village Trail, a Children's Trail and a number of booklets, one of which is devoted to the timber-framed buildings of the village (Jones 2009). The dendrochronological analysis of the timbers is intended to provide independent dating evidence which aids the understanding of the timber-framed buildings in Norwell and their historic development. Historical analysis on the crafts and trades within the village is providing a social dimension for the usage of a number of buildings, at least from the nineteenth century onwards. Tracing their earlier history is problematic, as they were almost entirely in the hands of Southwell Minster from the eleventh century to the AD 1950s and the surviving records relating to ownership and occupancy are often unhelpful for the location and identification of current buildings. It is hoped that evidence derived from the tree-ring dating project will assist in the identification of occupation, usage, and ownership, which at present is limited to the late nineteenth century onwards.

SAMPLING

A total of 11 samples was obtained, each being given the code NRW-E (for Norwell, site 'E') and numbered 01–11. The positions of these samples are marked on the drawings provided (Figs 8 and 9). Details of the samples are given in Table 1. In this Table the timbers have been located and numbered following the scheme on the drawings provided. The sampling strategy was constrained by access issues relating to unsafe flooring and coverings over various elements.

ANALYSIS AND RESULTS

Each of the 11 samples obtained was prepared by sanding and polishing and its annual growth rings were measured. These measured data (given at the end of this report) were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing all 11 samples to be formed into a single group, the samples cross-matching with each other as shown in the bar diagram, Figure 10.

The 11 samples were combined at the offset positions shown to form NRWESQ01, a site sequence of 178 rings (Fig 10). This site sequence was then compared to a full range of reference chronologies for oak, this indicating a consistent and repeated cross-match with a whole series of these when the date of its first ring is AD 1335 and the date of its end ring is AD 1512. The evidence for this dating is given in Table 2.

INTERPRETATION AND DISCUSSION

Two of the 11 dated samples, NRW-E04 and E05, which are both wall plates, retain complete sapwood (Fig 10 and Table 1). The last, complete, sapwood ring on both, and thus the felling of the trees, is dated to AD 1512.

A further five timbers, NRW-E01, E02, E03, E06, and E09, representing three wall posts, a tie-beam, and a brace, retain their heartwood/sapwood boundary. These timbers are likely to represent a single felling period, as their heartwood/sapwood boundaries are within eight years of each other, the average date of this boundary being AD 1488. Using the 95% confidence limit of 15–40 sapwood rings appropriate for mature oaks in this part of England would give the timbers represented an estimated felling date in the range of AD 1503–28, but, allowing for the outermost measured ring on NRW-E01, this can be truncated to AD 1511–28. This estimated range encompasses the precise felling date obtained from samples NRW-E04 and E05, and hence it is clearly feasible that these other timbers were also felled in AD 1512.

It is noticeable that the heartwood/sapwood boundary dates on these five samples are slightly later than on NRW-E04 and E05. Although this could be taken to imply that these timbers were felled slightly later than the two wall plates, this seems relatively unlikely, because three of these five samples, NRW-E01, E02, and E03, come from timbers which do have complete sapwood present, but from which small sections of the sapwood were lost due to its fragile nature from the sample during coring (Fig 10 and Table 1). Samples NRW-E01 and NRW-E03 both lost less than 5mm of sapwood, whilst NRW-E02 lost less than 10mm sapwood. Hence with end dates of AD 1510, AD 1509, and AD 1502 respectively with associated average ring widths for the outermost 10 rings of 1.40mm, 0.70mm, and 0.99mm, a felling date of *c.* AD 1512 appears likely.

The remaining four dated samples have no trace of sapwood and it is thus not possible to calculate their likely felling date ranges. The last measured, heartwood, ring dates on these four ranges from AD 1440 (NRW-E11) to AD 1470 (NRW-E07) indicating that they are clearly broadly coeveal, so it is feasible that they were also felled in AD 1512.

All the sampled timbers appear integral to the primary construction of the building, with the exception of sample NRW-E06, which is from a reused timber. The structural evidence combined with the overall level of cross-matching between the samples implies that all 11 dated timbers form a coherent group. This suggests that it is likely that NRW-E06 was part of the same felling programme as the other dated timbers, and in all likelihood was used in the earliest phase of the building and later removed from its original position and placed within the stud partition wall. Tree-ring analysis has therefore demonstrated that the timbers are all likely to have been used in the initial construction of the cottage shortly after felling in AD 1512, though one of the dated timbers, a brace, has been reused at a later date. The dendrochronological dating evidence clearly supports the proposed early sixteenth-century date.

The overall level of intra-site cross-matching suggests that the timbers used in the construction of Auld Cottage are a coherent group derived from a single woodland source. Although dendrochronology cannot be used to identify the precise location of this woodland, it would appear likely that it is relatively local. The highest *t*-values for the site sequence NRWESQ01, and thus the greatest degree of similarity, are with reference chronologies from sites in the surrounding region (Table 2).

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TABLES

Table 1: Details of tree-ring samples from Auld Cottage, Main Street, Norwell, Nottinghamshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
NRW-E01	Truss 1 north wall post	104	20c	AD 1407	AD 1490	AD 1510
NRW-E02	Truss 1 south wall post	112	16c	AD 1391	AD 1486	AD 1502
NRW-E03	Truss 1 tie-beam	132	19c	AD 1378	AD 1490	AD 1509
NRW-E04	Truss1–2 north wallplate	125	36C	AD 1388	AD 1476	AD 1512
NRW-E05	Truss 1–2 south wallplate	150	38C	AD 1363	AD 1474	AD 1512
NRW-E06	Brace in partition wall	70	h/s	AD 1413	AD 1482	AD 1482
NRW-E07	Truss 2 north wall post	132	no h/s	AD 1339	----	AD 1470
NRW-E08	Truss 2 brace from the tie-beam to the south wall post	49	no h/s	AD 1405	----	AD 1453
NRW-E09	Truss 2 south wall post	78	15	AD 1428	AD 1490	AD 1505
NRW-E10	Truss 2 tie-beam	133	no h/s	AD 1335	----	AD 1467
NRW-E11	Truss 3 tie-beam	82	no h/s	AD 1359	----	AD 1440

h/s = the heartwood/sapwood ring is the last ring on the sample
c=complete sapwood exists on the timber but part of the sapwood has been lost from the sample during coring
C=complete sapwood is retained on the sample

Table 2: Results of the cross-matching of site sequence NRWESQ01 and relevant reference chronologies when the first-ring date is AD 1335 and the last-ring date is AD 1512

Reference chronology	*t*-value	Span of chronology	Reference
All Saints Church, Knipton, Leicestershire	10.9	AD 1348–1488	(Arnold *et al* 2005)
East Midlands	9.7	AD 882–1981	(Laxton and Litton 1988)
Hagworthingham Church, Lincolnshire	9.2	AD 1336–1533	(Laxton *et al* 1984)
Lea Road Foundry site, Dronfield, Derbyshire	8.1	AD 1344–1526	(Tyers 2003)
Ightfield Hall Farm Barn, Whitchurch, Shropshire	8.1	AD 1341–1566	(Groves 1997)
Sinai Park, Staffordshire	8.0	AD 1227–1750	(Tyers 1997)
Primrose Hill, Kings Norton, Birmingham	8.0	AD 1354–1593	(Arnold *et al* 2008)
Combermere Abbey, Whitchurch, Cheshire	7.9	AD 1363–1564	(Howard *et al* 2003)

FIGURES

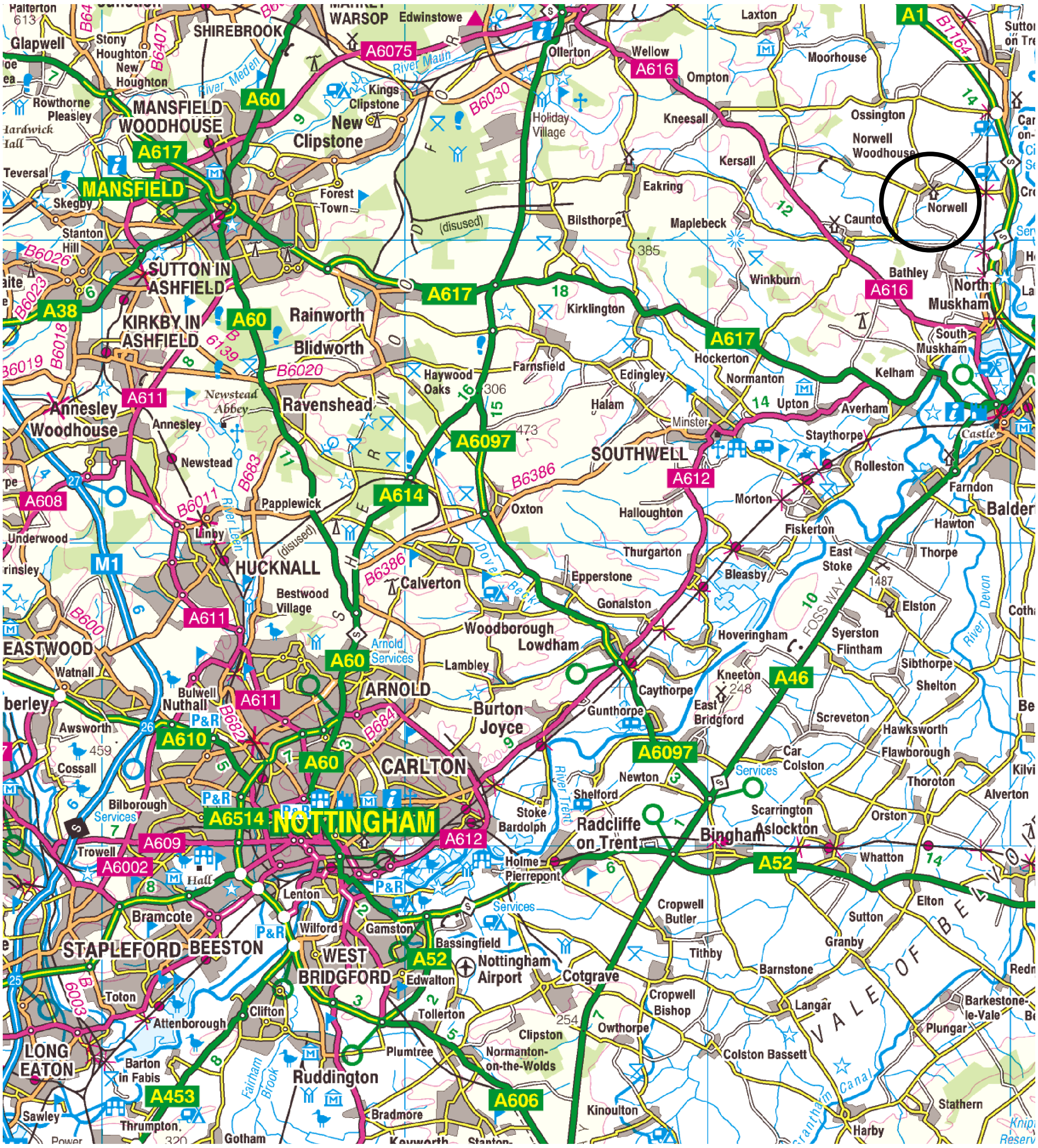


Figure 1: Map to show general location of Auld Cottage, Norwell, Nottinghamshire

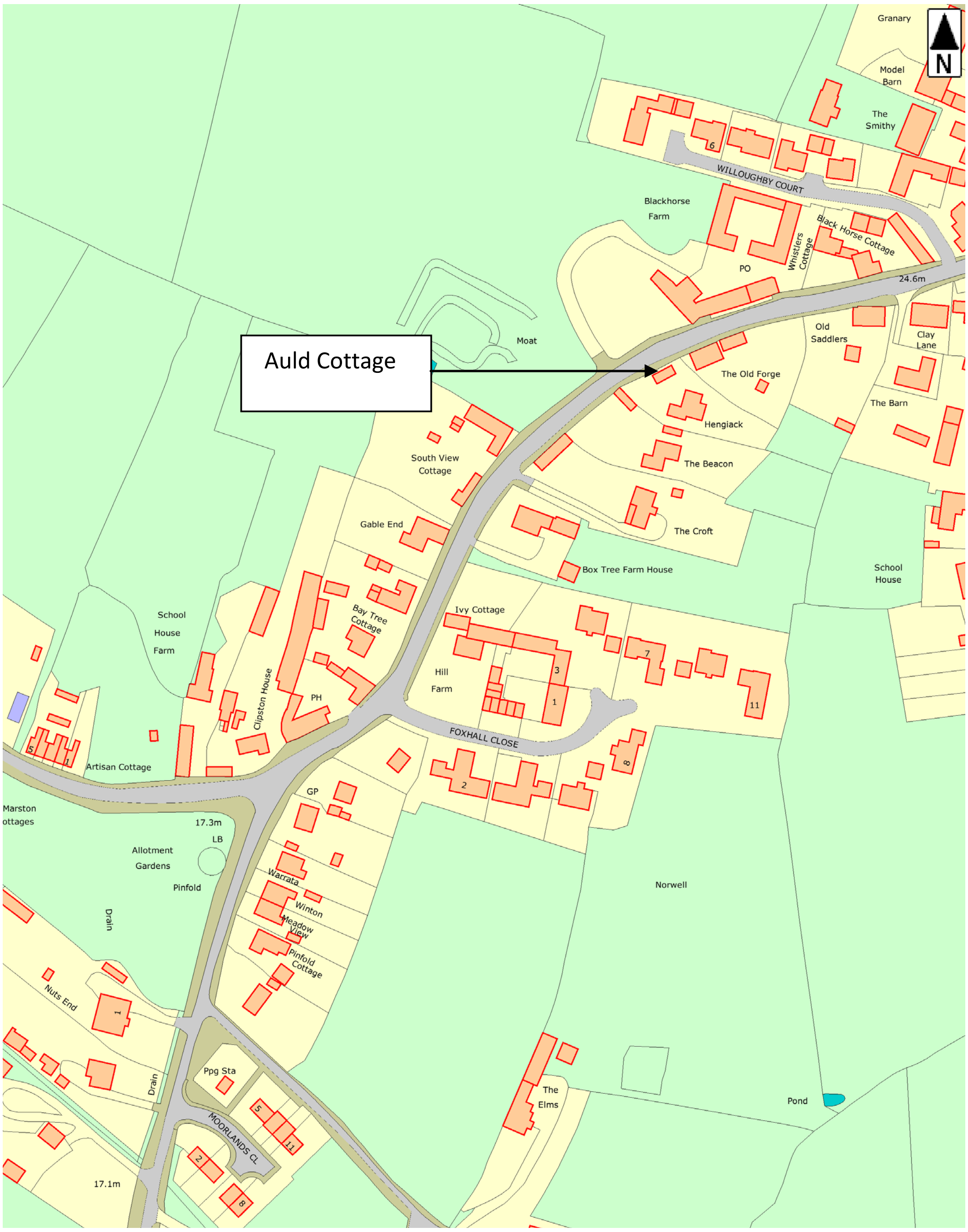


Figure 2: Map to show the location of Auld Cottage within the village of Norwell, Norwell, Nottinghamshire

Figure 3: General view of the front of Auld Cottage viewed looking south

Figure 4: Truss 2 stud wall viewed looking north-west

Figure 5: Stairway stud partition wall with sampled brace in the foreground viewed looking south east

Figure 6: Truss 1 south wall viewed looking south-east

Figure 7: General view of the rear of Auld Cottage viewed looking north

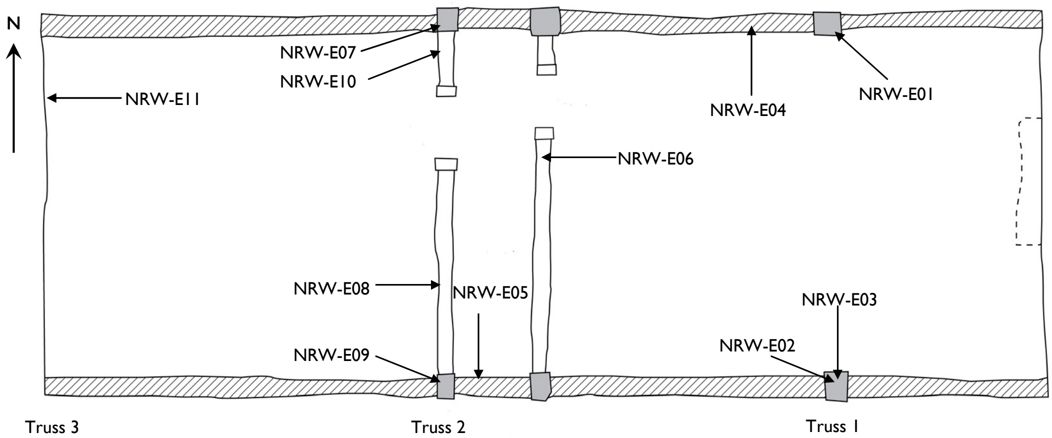


Figure 8: Sample location plan

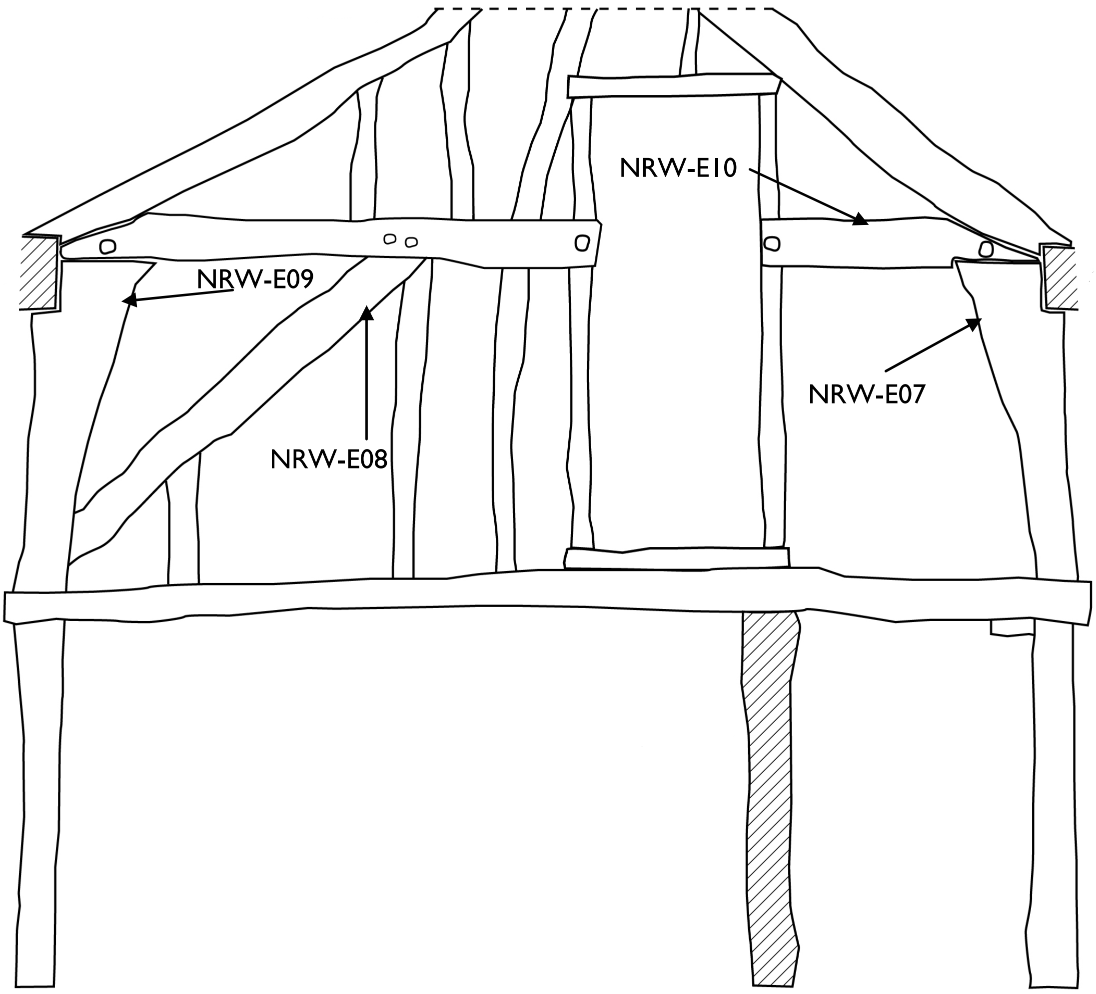
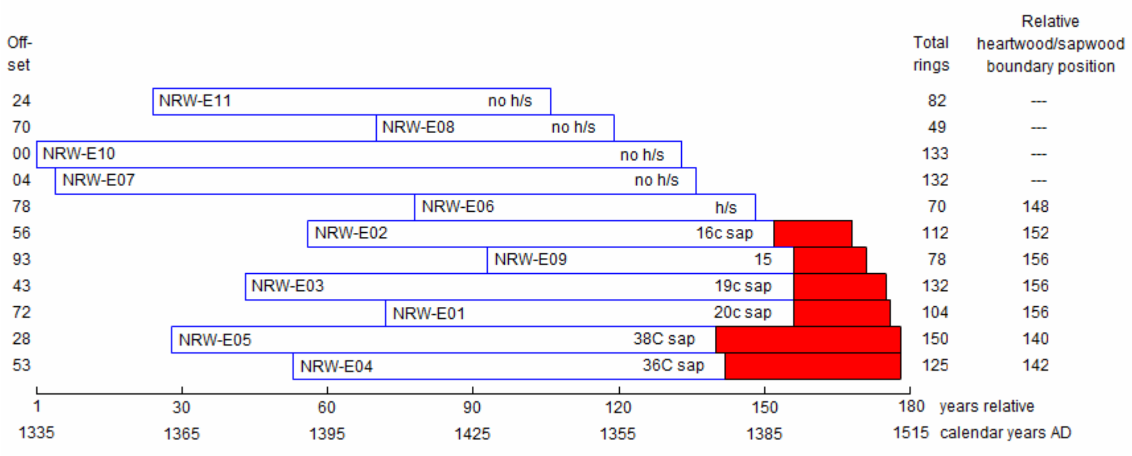


Figure 9: Truss 2 sample locations viewed looking west



white bars = heartwood rings;
filled bars = sapwood rings
h/s = the last ring of the sample is at the heartwood/sapwood boundary
c = complete sapwood exists on the timber but part of the sapwood has been lost from the sample during coring
C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the tree represented

Figure 10: Bar diagram of the samples in site chronology NRWESQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

NRW-E01A 103
119 191 154 137 162 139 122 109 97 86 103 110 120 213 207 152 196 171 169 98
118 150 144 210 278 267 159 114 117 104 121 75 91 112 113 96 180 121 125 99
121 155 131 148 156 133 122 146 225 268 172 169 298 315 224 209 186 186 150 122
135 125 136 253 209 199 228 153 183 99 181 124 142 194 213 223 243 258 257 150
327 222 194 197 136 176 185 161 183 255 182 106 141 151 114 99 174 185 133 170
122 81 137
NRW-E01B 104
145 207 147 142 152 133 141 120 108 98 94 126 112 191 199 135 182 163 173 103
116 143 148 209 276 264 158 124 107 112 115 74 93 114 109 103 169 135 120 103
112 148 134 140 156 137 122 136 223 274 173 171 295 305 230 208 180 194 147 116
137 127 131 270 206 197 229 154 170 101 158 133 139 170 209 223 238 260 253 152
331 229 204 208 140 179 184 171 183 253 184 102 155 150 112 104 176 180 137 187
107 88 124 191
NRW-E02A 112
261 132 108 148 215 152 105 93 94 83 141 121 169 286 218 253 295 307 217 214
287 193 186 166 169 173 140 254 168 290 289 183 258 258 195 125 133 151 131 178
178 426 309 210 191 217 197 158 220 165 324 169 308 186 155 115 123 211 151 146
195 160 176 161 216 228 126 123 193 236 163 138 134 126 139 103 112 80 84 109
141 121 172 90 113 71 86 107 132 165 164 118 153 137 157 136 176 104 120 113
88 91 103 96 110 145 99 67 93 101 92 73
NRW-E02B 112
246 140 108 132 192 174 97 100 95 79 114 115 144 256 218 247 276 322 215 214
220 198 182 160 172 165 149 251 171 294 288 180 258 263 197 116 150 134 143 185
174 413 298 218 189 226 189 148 219 160 303 168 294 181 151 116 123 189 147 141
189 168 167 176 215 246 129 119 199 239 153 150 142 125 133 115 109 84 90 122
130 124 162 105 105 78 84 105 120 169 164 120 144 152 150 137 170 117 118 115
85 82 112 103 102 135 103 72 108 91 101 73
NRW-E03A 132
128 293 127 106 134 90 58 62 100 98 68 36 56 76 68 42 35 58 64 61
61 62 54 132 148 127 202 139 110 78 99 85 91 83 76 69 76 81 86 83
128 79 119 141 78 98 83 81 48 58 69 57 47 63 56 41 50 104 199 187
153 118 123 127 90 123 141 107 72 87 91 80 83 141 74 75 75 99 102 78
86 92 120 102 80 83 79 88 83 75 69 79 107 106 77 83 79 103 85 98
109 95 86 107 85 89 78 73 81 85 81 74 68 52 53 57 61 49 59 55
44 59 64 48 57 71 62 79 83 84 68 69
NRW-E03B 132
138 291 120 111 128 84 68 56 98 112 65 38 51 69 76 37 40 61 64 52
65 54 57 123 154 124 223 131 98 89 82 85 76 87 80 71 70 87 81 64
110 81 119 141 77 89 88 74 55 63 59 57 44 58 51 40 50 102 189 186
161 115 141 141 87 119 158 94 82 71 105 78 79 138 77 77 76 96 104 79
92 89 129 109 67 84 74 94 83 78 59 74 109 106 72 79 86 104 86 111
105 94 79 108 75 97 76 79 74 93 79 72 61 58 57 57 57 54 54 54
51 59 59 52 53 72 67 75 84 82 74 101
NRW-E04A 125
213 195 209 259 166 124 136 138 136 89 134 110 143 197 132 143 257 164 143 172
174 135 113 116 112 109 113 94 95 93 76 68 73 89 69 94 114 86 54 75
77 65 92 60 71 63 58 68 53 60 56 84 58 65 65 83 58 58 47 53

64 50 59 57 37 46 47 46 42 38 47 39 67 39 54 64 58 75 59 45
46 43 62 71 64 60 54 52 51 49 32 51 45 57 48 60 56 48 53 75
37 38 55 42 41 56 42 50 60 51 30 43 51 46 38 43 51 45 50 47
34 50 43 42 50
NRW-E04B 125
212 200 216 250 167 126 134 132 140 94 134 111 150 200 140 160 235 168 146 172
169 142 107 127 106 113 107 97 90 70 86 60 81 96 75 96 105 82 61 83
72 74 80 52 65 63 56 70 64 55 55 83 51 61 71 75 71 53 50 48
60 55 56 56 38 51 45 42 42 41 40 46 55 48 56 61 45 79 62 45
43 44 64 67 68 58 56 55 43 47 39 48 47 66 42 59 50 51 53 65
52 38 54 42 36 56 43 53 59 50 30 44 49 44 37 41 49 46 49 48
34 49 43 42 51
NRW-E05A 150
326 288 163 200 182 132 201 168 131 136 136 110 103 103 140 131 135 148 108 99
68 78 78 111 141 119 87 84 78 71 59 65 99 104 63 73 80 83 97 88
91 97 84 88 76 97 108 95 91 84 64 66 71 71 54 77 53 53 71 58
59 66 54 30 44 45 47 50 50 76 45 45 49 51 49 66 33 41 49 47
53 44 39 37 58 46 40 48 44 50 57 43 47 48 47 55 42 49 45 53
44 44 69 41 42 39 37 48 42 61 54 56 68 53 49 37 51 56 72 43
57 49 76 47 46 41 38 42 39 33 42 37 35 38 30 29 36 37 27 38
35 34 60 38 33 32 55 50 47 45
NRW-E05B 150
326 299 175 193 181 137 198 166 130 136 134 111 104 100 135 131 135 151 114 98
67 79 87 102 137 119 88 82 83 75 63 64 103 107 62 75 79 80 97 86
89 100 83 88 76 100 104 96 93 79 66 68 73 68 54 74 55 51 71 53
66 65 53 34 41 47 50 49 55 69 54 42 51 39 57 59 42 44 53 45
58 43 43 49 41 45 39 49 46 46 70 39 48 48 47 52 46 48 51 50
49 45 65 45 40 44 35 53 43 57 52 52 76 57 47 39 56 53 80 51
60 54 64 51 57 43 44 41 38 38 41 36 33 48 29 26 28 36 27 38
38 41 52 36 34 31 53 52 49 40
NRW-E06A 70
79 70 68 60 62 108 67 67 71 79 109 106 79 77 114 126 135 126 114 129
125 111 91 77 108 127 96 101 107 89 93 94 77 76 96 101 103 80 81 76
87 85 72 101 54 64 78 117 87 108 113 76 92 72 59 51 45 98 96 84
79 86 128 62 57 66 86 89 110 113
NRW-E06B 70
98 66 73 57 60 105 69 70 72 69 109 105 83 77 109 128 140 127 117 129
126 110 100 78 102 107 70 98 105 92 86 105 74 81 90 110 111 76 75 73
89 80 72 95 59 62 70 111 89 97 112 83 87 65 65 52 54 86 86 74
80 89 129 59 54 70 88 89 113 118
NRW-E07A 132
369 339 292 201 134 103 59 59 78 108 161 126 95 62 86 80 43 56 71 60
77 25 59 374 431 444 137 112 178 167 277 249 87 81 135 63 87 63 140 142
225 385 114 65 91 71 94 189 314 178 66 54 23 45 54 44 38 63 27 39
35 49 41 52 165 437 472 567 342 220 208 108 102 70 61 33 65 33 41 75
60 42 72 67 61 64 38 25 50 99 87 116 111 287 147 113 90 92 147 119
64 83 72 66 43 62 62 55 62 67 51 41 73 46 55 65 77 85 45 45
29 109 100 50 63 50 59 48 33 40 37 36
NRW-E07B 130
353 305 284 181 137 108 59 48 80 113 148 126 109 61 90 87 45 58 76 60
84 30 46 384 433 424 121 111 175 185 267 257 75 87 137 63 80 68 135 144
223 382 120 68 78 78 87 189 309 186 78 54 30 34 59 39 40 57 24 28
38 46 38 57 157 382 484 558 343 225 200 105 109 64 64 31 60 38 42 81

55 49 70 57 64 70 38 28 42 104 96 105 117 272 152 130 93 98 148 122
58 90 91 70 48 61 54 58 66 61 52 39 73 53 55 61 74 85 47 51
41 96 87 56 62 55 53 49 37 78
NRW-E08A 49
410 384 308 294 183 198 180 143 121 125 141 145 144 298 191 513 332 273 271 259
196 145 216 245 233 281 309 275 199 193 209 235 211 97 140 209 191 140 260 193
149 101 134 172 148 120 122 126 119
NRW-E08B 49
398 402 295 291 186 214 190 140 121 117 140 133 153 311 200 495 327 266 266 266
185 146 224 256 214 274 305 284 193 197 219 223 205 94 137 221 188 126 216 189
145 103 132 170 154 123 130 109 183
NRW-E09A 78
400 294 282 387 318 254 268 231 284 281 237 324 199 267 193 320 229 209 183 169
233 203 196 273 187 165 157 184 177 153 118 142 245 142 142 130 91 129 122 85
61 74 116 131 102 102 129 150 109 123 130 137 117 179 139 155 111 107 120 135
95 103 121 103 91 133 107 121 126 112 78 88 74 111 85 83 86 90
NRW-E09B 78
399 297 295 385 300 268 280 231 287 280 239 333 201 270 189 320 228 208 186 178
224 201 193 276 176 165 152 189 189 152 108 131 235 139 134 115 85 113 115 88
66 58 114 120 109 105 131 153 129 107 126 141 117 188 140 161 110 112 123 123
98 102 122 101 92 139 107 121 126 112 79 85 75 111 86 85 86 89
NRW-E10A 133
215 363 398 608 235 109 108 44 40 45 126 87 53 61 89 63 50 39 34 31
42 55 81 114 153 110 126 212 187 123 108 84 61 123 578 533 304 408 268 286
183 144 278 233 288 330 286 264 212 144 165 249 295 287 282 203 265 223 151 138
181 151 99 182 167 166 267 259 212 346 251 258 198 210 190 169 155 111 94 90
90 59 96 118 64 86 108 90 89 115 82 59 96 105 73 76 68 94 76 79
62 56 61 67 45 35 35 45 43 53 61 27 41 45 42 43 40 33 39 39
37 40 28 32 21 35 40 33 41 38 44 42 39
NRW-E10B 133
201 247 490 379 233 117 97 48 38 37 136 109 51 69 89 57 55 56 28 36
35 59 70 128 155 109 126 212 181 126 115 69 60 128 593 496 300 358 241 292
183 157 269 230 297 339 283 255 198 139 166 227 297 275 281 195 255 211 146 131
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159 53 89 93 68 83 112 82 93 118 82 56 100 90 78 86 67 104 68 78
59 62 63 64 42 39 38 42 35 48 57 41 36 42 35 41 49 40 33 32
24 40 37 25 30 35 45 31 43 37 36 44 40
NRW-E11A 82
122 89 77 112 235 204 170 142 135 120 205 184 134 151 151 129 100 100 167 182
179 195 214 124 89 65 95 150 165 130 128 101 69 57 48 57 65 66 42 60
59 46 104 139 116 182 139 161 142 138 138 111 106 86 76 60 66 57 63 76
59 54 65 60 77 63 68 40 68 71 75 82 83 79 78 82 65 62 81 66
55 51
NRW-E11B 82
122 82 82 97 248 220 192 142 141 99 193 191 155 151 155 123 102 96 177 172
186 188 209 115 90 73 99 139 151 139 109 92 66 61 51 54 67 63 48 52
58 43 96 135 101 207 119 165 140 147 133 106 112 90 75 56 75 69 63 69
57 51 65 63 69 78 56 44 61 74 57 71 80 83 70 88 63 60 77 71 47 92

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

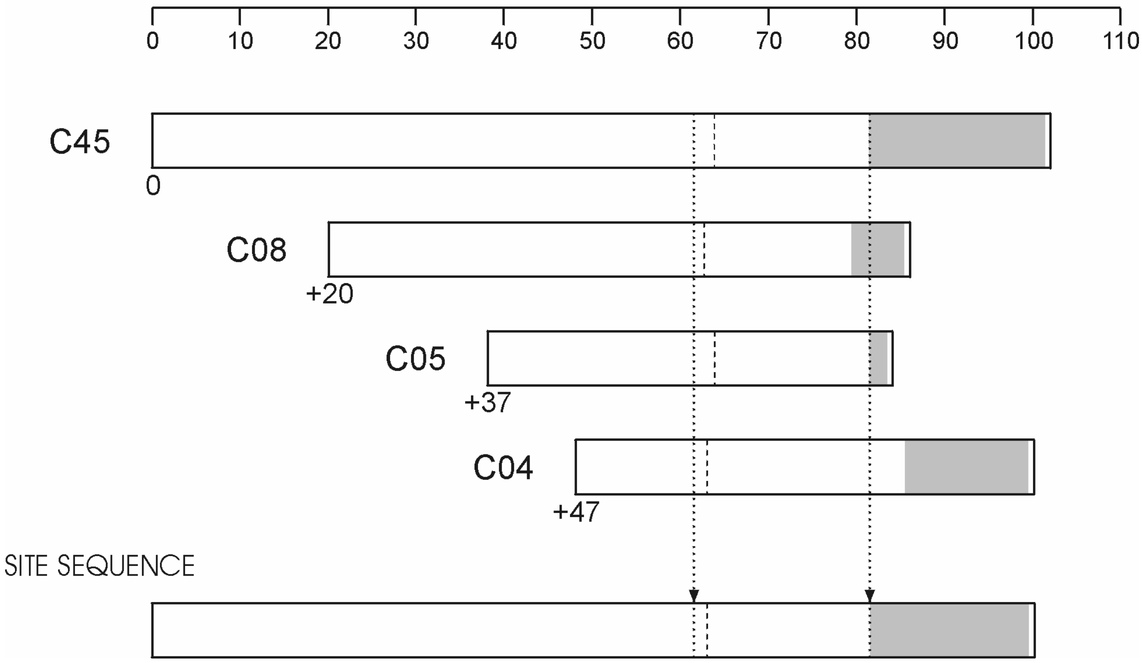


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

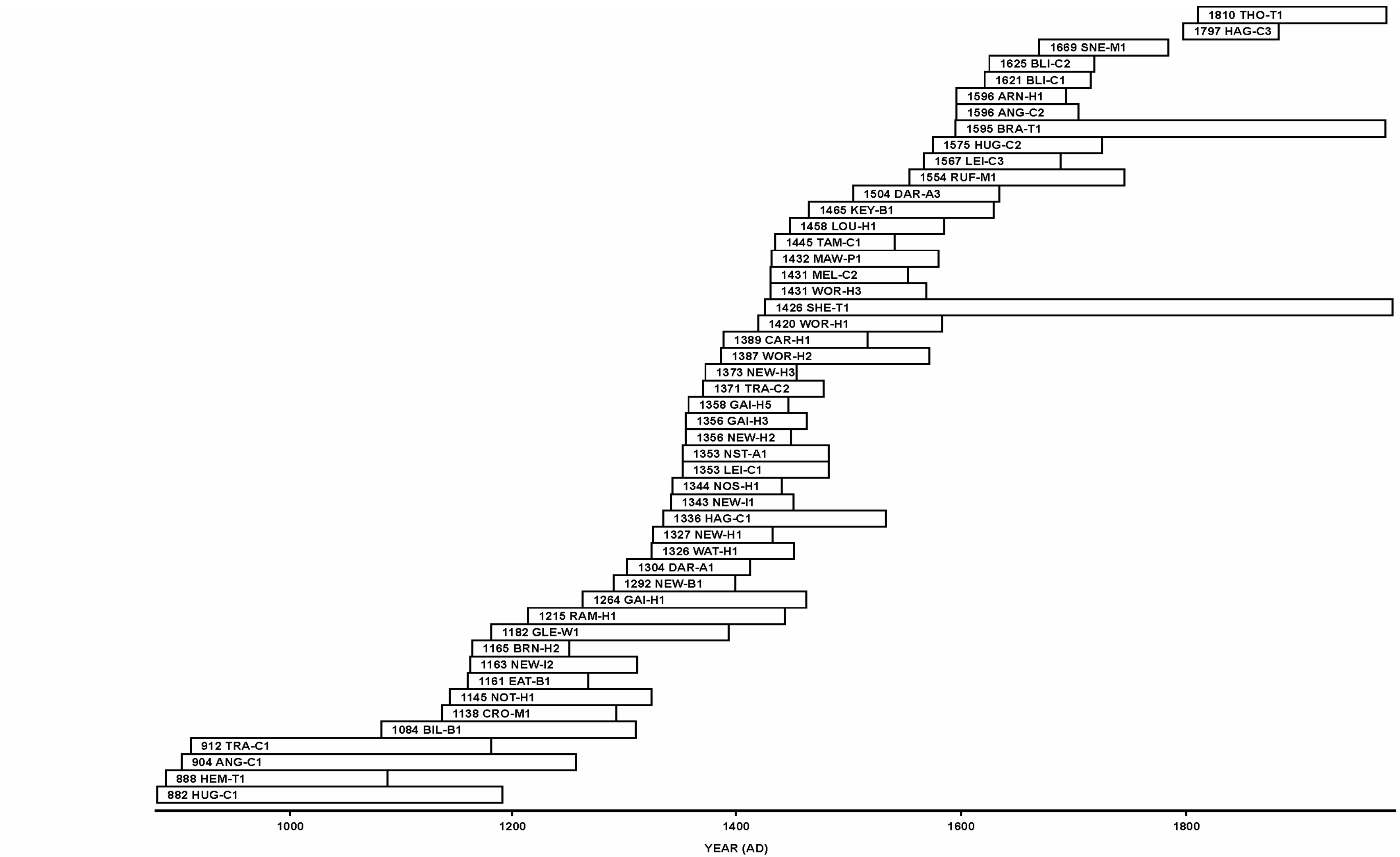
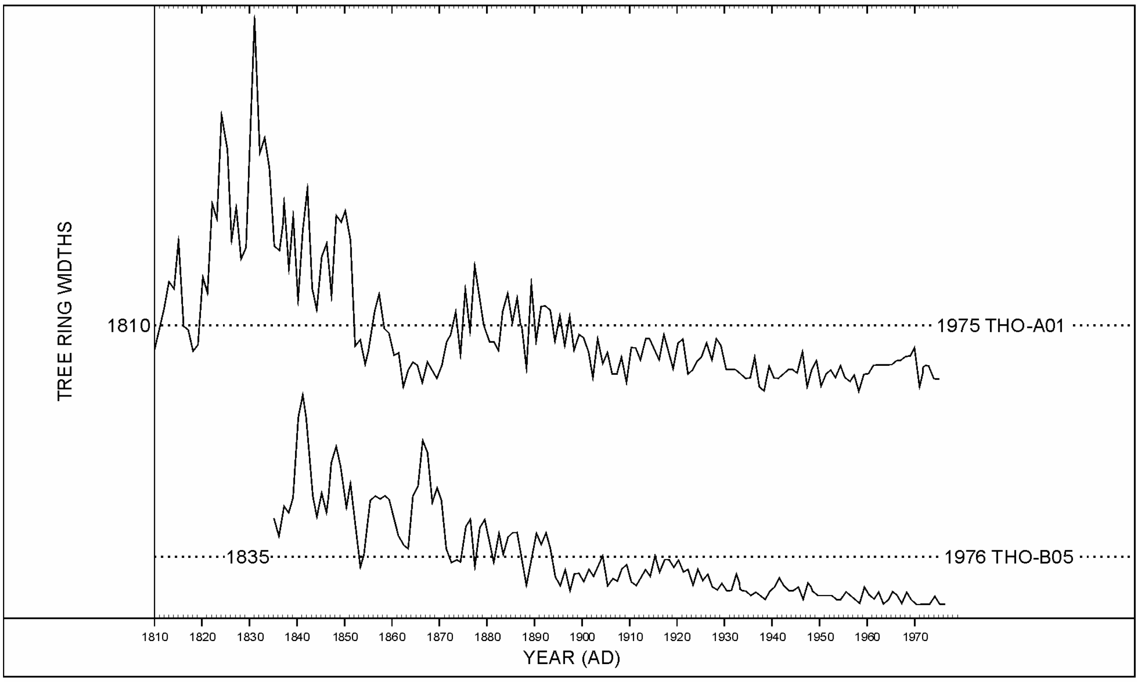


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

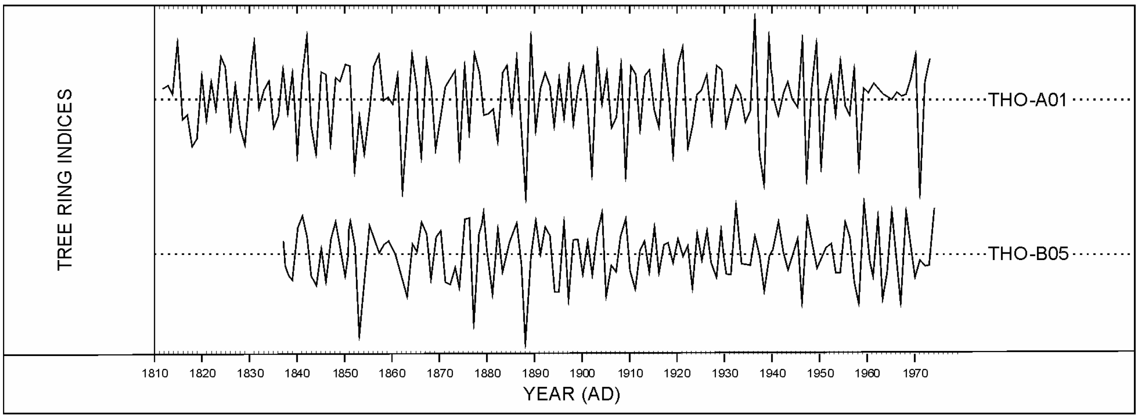


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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