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ST MARY'S, FELTWELL, NORFOLK
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY

Analysis was undertaken on samples taken from the timbers of the nave roof, resulting in the construction of two site sequences.

Site sequence FTWASQ01 contains 17 samples and spans the period AD 1303–1494. One of these samples was felled in AD 1494. Interpretation of the sapwood on the rest of the dated timbers makes it likely these were also felled at this time.

These results suggest construction of the nave roof occurred in the last years of the fifteenth century.

The second site sequence, FTWASQ02, contains only three samples and is undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank the contractors for facilitating access. Freeland Rees Roberts Architects kindly provided the drawings used to locate the samples (Figs 6–16). Thanks are also given to the Scientific Dating Section at English Heritage and Cathy Tyers of the Sheffield University Dendrochronology Laboratory for their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

Norfolk Historic Environment Record
Norfolk Landscape Archaeology
Union House
Gressenhall
Dereham NR20 4DR

DATE OF INVESTIGATION

2009

CONTACT DETAILS

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CONTENTS

INTRODUCTION

The parish church of St Mary's is located in Feltwell in Norfolk (TL 715 907; Figs 1–3). Although there may have been a church on this site earlier, the oldest surviving parts today are thought to be the fourteenth-century chancel and south arcade. The south aisle and west tower are believed to be fifteenth-century and the north aisle dates to AD 1861–3, as does the north arcade. Also dating to the nineteenth century are the roofs of the chancel and the south aisle. In addition to the nineteenth-century restorations, the church has also undergone more ancient restoration. It is known that in AD 1494 a Papal indulgence was offered for money to repair the tower and bells following a fire (Pevsner 1962).

Nave roof

This is of 11 trusses; major and intermediary ones with roll-moulded tiebeams on arched braces and wall posts to corbels. The corbels to the north are thought to be nineteenth-century, and those to the south, fifteenth-century angel figures. The major trusses have pierced spandrels and queen-post struts to moulded principals (Fig 4). The tiebeams of the intermedate trusses are supported on shorter arched braces with the figure of an angel on each side (Fig 5). There is one set of moulded butt purlins to each side and a ridge piece. This roof was thought to date to the fifteenth century (www.imagesofengland.org.uk).

SAMPLING

Sampling was requested by Ian Harper at English Heritage's Cambridge Office to inform grant-aided repairs to the nave roof. It was hoped that successful dating of the timber of this roof would determine the date of the structure and in turn assist in the understanding of the church as a whole.

Once on site, an initial examination of the timbers was undertaken. At this stage there appeared to be a marked difference in the growth pattern of the timbers used within the construction of the roof, with the timbers falling into two distinct groups. After discussion with the Scientific Dating Section at English Heritage, it was decided to sample each group of timbers as if they were a separate phase. It was hoped that this course of action would give a greater chance for success if there did prove to be a difference in date and/or origin.

A total of 24 timbers was sampled. Each sample was given the code FTW-A (for Feltwell) and numbered 01–24. The location of samples was noted at the time of sampling and has been marked on Figures 6–16. Further details relating to the samples can be found in Table 1. Trusses and bays followed the numbering on the architect's survey drawings from east to west.

ANALYSIS AND RESULTS

At this stage it was seen that sample FTW-A21 had too few rings to make secure dating a possibility and so this was rejected prior to measurement. The remaining 23 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in 20 samples grouping to form two site sequences.

Firstly, 17 samples matched each other and were combined at the relevant offset positions to form FTWASQ01, a site sequence of 192 rings (Fig 17). This site sequence was compared against a series of relevant reference chronologies for oak, where it was found to match consistently and securely at a first-ring date of AD 1303 and a last-measured ring date of AD 1494.

One of these samples, FTW-A16, has complete sapwood and the last-measured ring date of AD 1494, the felling date of the timber represented. A further 10 samples have the heartwood/sapwood boundary present. In the case of nine of these, this ring date is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date for these nine is AD 1460, which allows an estimated felling date to be calculated for the timbers represented to within the range AD 1475–1500, consistent with these timbers also having been felled in AD 1494. The heartwood/sapwood boundary ring date of the tenth sample (FTW-A12) is somewhat later, at AD 1474, giving an estimated felling date for the timber represented of AD 1489–1514. Given that this felling date range again encompasses AD 1494, and that statistically and structurally this timber shows no anomalies when compared to the other timbers, it is thought likely that it simply has fewer sapwood rings than the rest and belongs to the same programme of felling. The other six samples without the heartwood/sapwood boundary ring have last-measured ring dates which make it possible they were also felled in AD 1494.

Three further samples matched and were combined to form FTWASQ02, a site sequence of 83 rings (Fig 18). Despite attempts to match this against the reference chronologies, no conclusive results were obtained, so this site sequence remains undated.

Attempts to date the remaining three ungrouped samples by individually comparing them against the reference chronologies was unsuccessful and these also remain undated.

Felling date ranges have been calculated using the estimate that mature oak trees in this area have between 15 and 40 sapwood rings.

DISCUSSION

Prior to tree-ring dating being undertaken, the nave roof was believed to be fifteenth-century in date. This suggested date has now been supported by the dendrochronological results, which have shown the roof to be constructed with timber felled in AD 1494. This raises the possibility that the Papal indulgence of AD 1494 to repair the tower and bells following a fire, mentioned above, might also have provided the funds for this roof.

The potential differences in timber date and/or source suggested by the surface examination did not materialise upon analysis. Despite the superficial differences in growth patterns exhibited by the samples (Fig 19), the analysis points towards a coherent group of timbers being utilised in the construction of the roof. The intra-site matching of samples is good, with a number of samples grouping at values in excess of t=7 and the possibility of at least one same tree match at t=15.8 between two stud posts from truss 11 (FTW-A23 and FTW-A24). It would appear that the difference in appearance is simply a characteristic of these trees.

Tree-ring dating in the Norfolk area has proved problematic in the past (eg St Catherine's Church, Ludham, Arnold and Howard 2007), with the lack of successful dating often attributed to the deficit of suitable reference material from the region. The production of a long, well-replicated site master such as FTWASQ01 is, therefore, of great importance and should prove helpful in the subsequent dating of timbers in this part of the country.

BIBLIOGRAPHY:

Arnold, A J and Howard, R E, 2000 unpubl *Tree-ring dating of timbers from Chalgrove Manor, Oxon*, unpubl NTRDL rep

Arnold, A J and Howard, R E, 2004 unpubl combined chronologies from Cobham Hall, Cobham, Kent, unpubl site chronology *COBBCDHFSQ01*, NTRDL

Arnold, A J and Howard, R E, 2007 *The west tower roof, St Catherine's Church, Ludham, Norfolk, Tree-ring analysis of timbers*, EH Res Dep Rep Ser, 10/2007

Bridge, M C, 2004 *Tree-ring analysis of timbers from six buildings in Winchelsea, East Sussex*, Centre for Archaeol Rep, 15/2004

Howard, R E, Laxton, R R, and Litton, C D, 2000 *Tree-ring analysis of timbers from The Barn and Cottage, Abbey Farm, Thetford, Norfolk*, Anc Mon Lab Rep, 48/2000

Laxton, R R and Litton, C D, 1989 Construction of a Kent master chronological sequence for Oak, 1158–1540, *Medieval Archaeol*, 33, 90–8

Pevsner, N, 1962 *The Buildings of England Norfolk 2: South & East*

Tyers, I, 1991 *Dendrochronology report on building timbers and wooden panelling from Sutton House, Hackney*, MoL EAS Dendro Rep, 02/91

Tyers, I, 1998 *Tree-ring analysis of Cann Hall, Clacton, Essex*, Anc Mon Lab Rep, 25/98

Tyers, I, 2004 *Tree-ring analysis of oak boards and structural timbers from the Transepts, Presbytery, and Tower of Peterborough Cathedral, City of Peterborough*, Centre for Archaeol Rep, 77/2004

TABLES

Table 1: Details of tree-ring samples from the nave, St Mary's Church, Feltwell, Norfolk

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
FTW-A01	South archbrace, truss 1	73	--	1377	----	1449
FTW-A02	North angel, truss 2	91	01	1367	1456	1457
FTW-A03	South angel, truss 2	112	--	1318	----	1429
FTW-A04	South archbrace, truss 3	70	--	----	----	----
FTW-A05	Outer stud post, north side, truss 3	144	--	1303	----	1446
FTW-A06	Mid stud post, south side, truss 3	61	--	1357	----	1417
FTW-A07	South principal rafter, truss 4	90	h/s	1370	1459	1459
FTW-A08	North wallpost, truss 4	53	--	----	----	----
FTW-A09	South archbrace, truss 5	76	--	----	----	----
FTW-A10	North archbrace, truss 5	83	--	----	----	----
FTW-A11	Outer stud post, south side, truss 5	92	h/s	1363	1454	1454
FTW-A12	North principal rafter, truss 7	134	h/s	1341	1474	1474
FTW-A13	South principal rafter, truss 7	78	h/s	1379	1456	1456
FTW-A14	South mid stud post, truss 7	109	h/s	1357	1465	1465
FTW-A15	Outer stud post, north side, truss 7	80	01	1374	1452	1453
FTW-A16	North angel, truss 8	139	26C	1356	1468	1494
FTW-A17	South angel, truss 8	121	01	1346	1465	1466
FTW-A18	Tiebeam, truss 9	98	h/s	1369	1466	1466
FTW-A19	Mid stud post, south side, truss 9	94	--	----	----	----
FTW-A20	North archbrace, truss 10	121	--	----	----	----
FTW-A21	South common rafter 3, bay 10	NM	--	----	----	----
FTW-A22	North wall post, truss 11	95	h/s	1370	1464	1464
FTW-A23	Outer stud post, north side, truss 11	110	--	1327	----	1436
FTW-A24	Mid stud post, north side, truss 11	86	--	1355	----	1440

Table 2: Results of the cross-matching of site sequence FTWASQ01 and relevant reference chronologies when the first-ring date is AD 1303 and the last-ring date is AD 1494

Reference chronology	*t*-value	Span of chronology	Reference
Kent	5.9	AD 1158–1540	Laxton and Litton 1989
Cobham Hall, Gravesend, Kent (combined chronology)	8.1	AD 1318–1663	Arnold and Howard 2004 unpubl
Peterborough Cathedral Presbytery roof, Cambs	8.0	AD 1208–1500	Tyers 2004
Sutton House, Hackney, London	7.1	AD 1319–1534	Tyers 1991
2–3 Friars Road, Winchelsea, East Sussex	6.8	AD 1351–1475	Bridge 2004
Charlgrove Manor, Oxon	6.6	AD 1355–1503	Arnold and Howard 2000 unpubl
Abbey Farm Barns, Thetford, Norfolk	6.5	AD 1332–1536	Howard *et al* 2000
Cann Hall, Clacton, Essex	6.5	AD 1301–1511	Tyers 1998

FIGURES

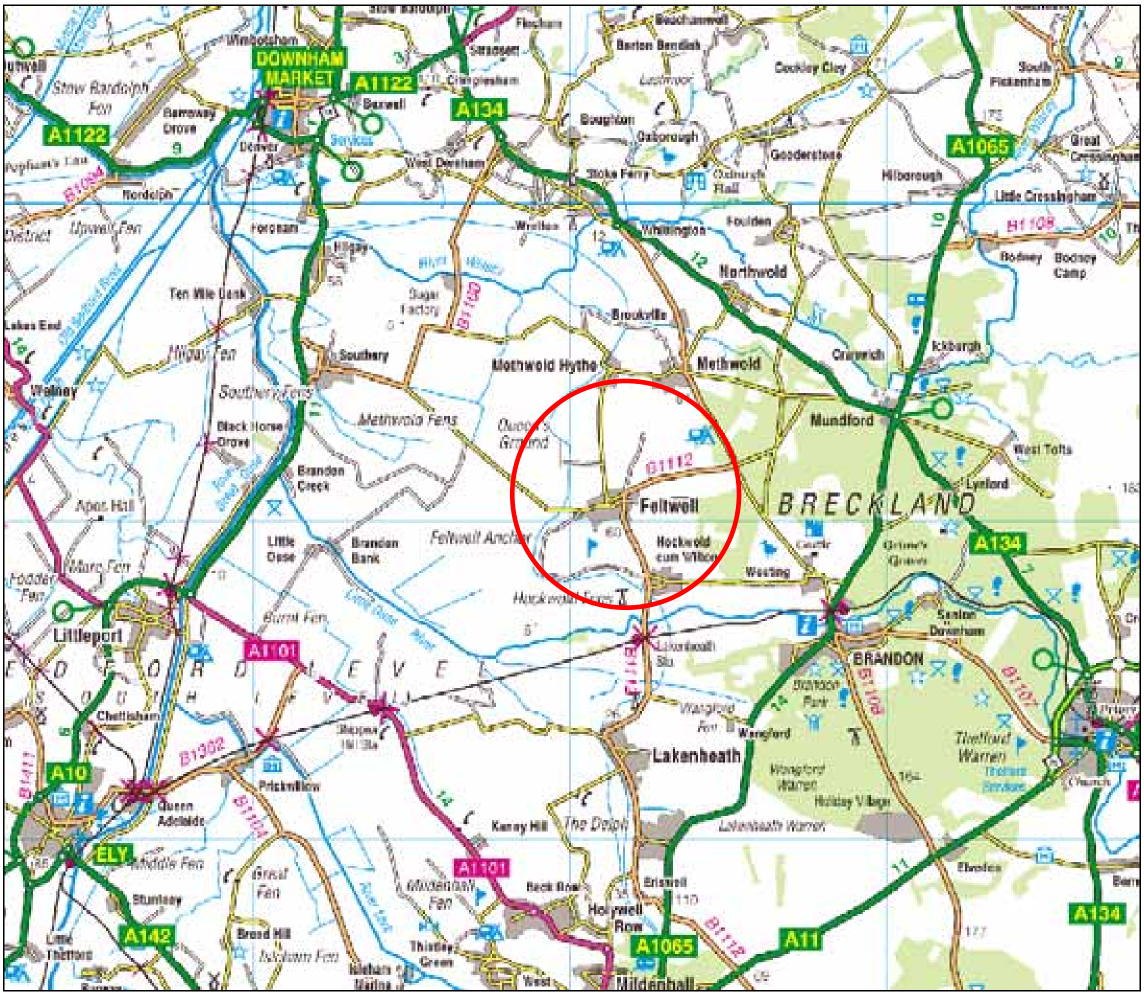

Figure 1: Map to show the general location of Feltwell (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

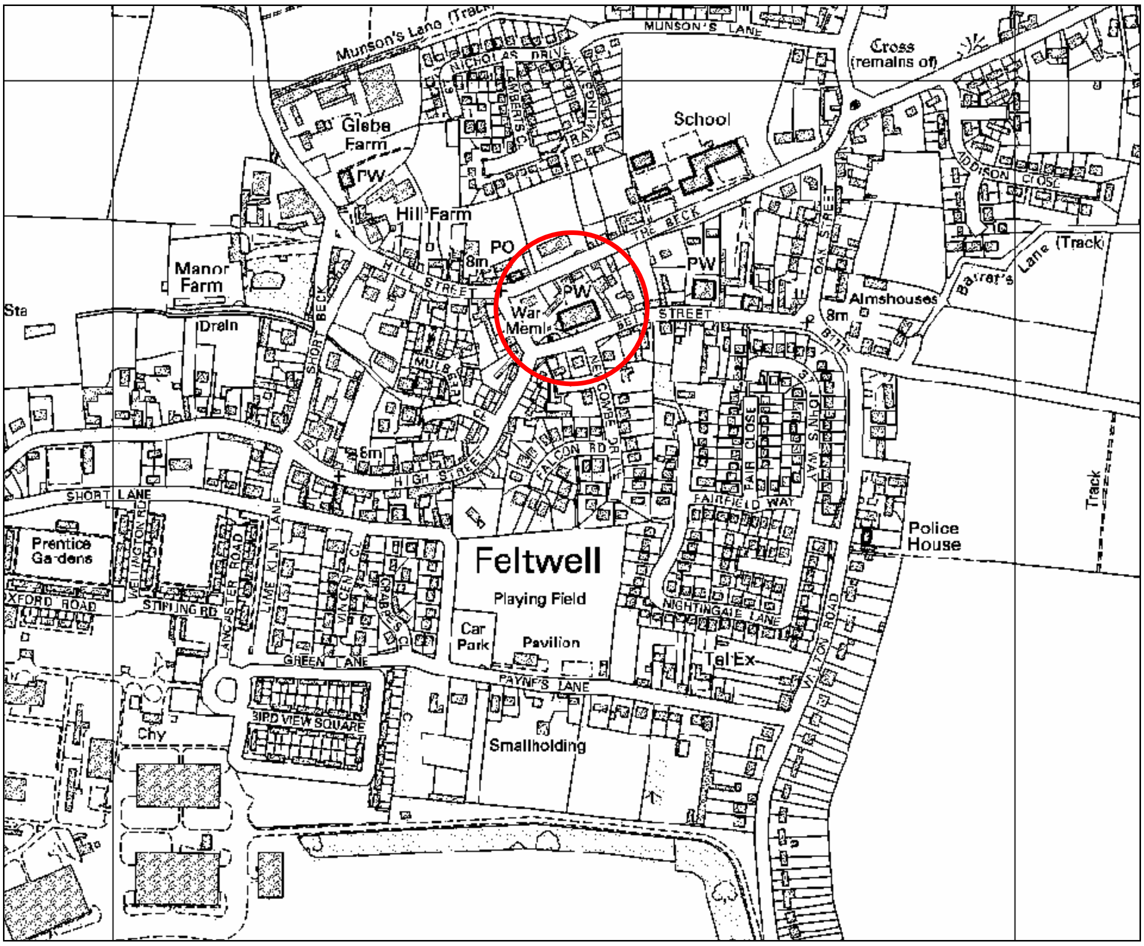

Figure 2: Map to show the general location of St Mary's Church (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

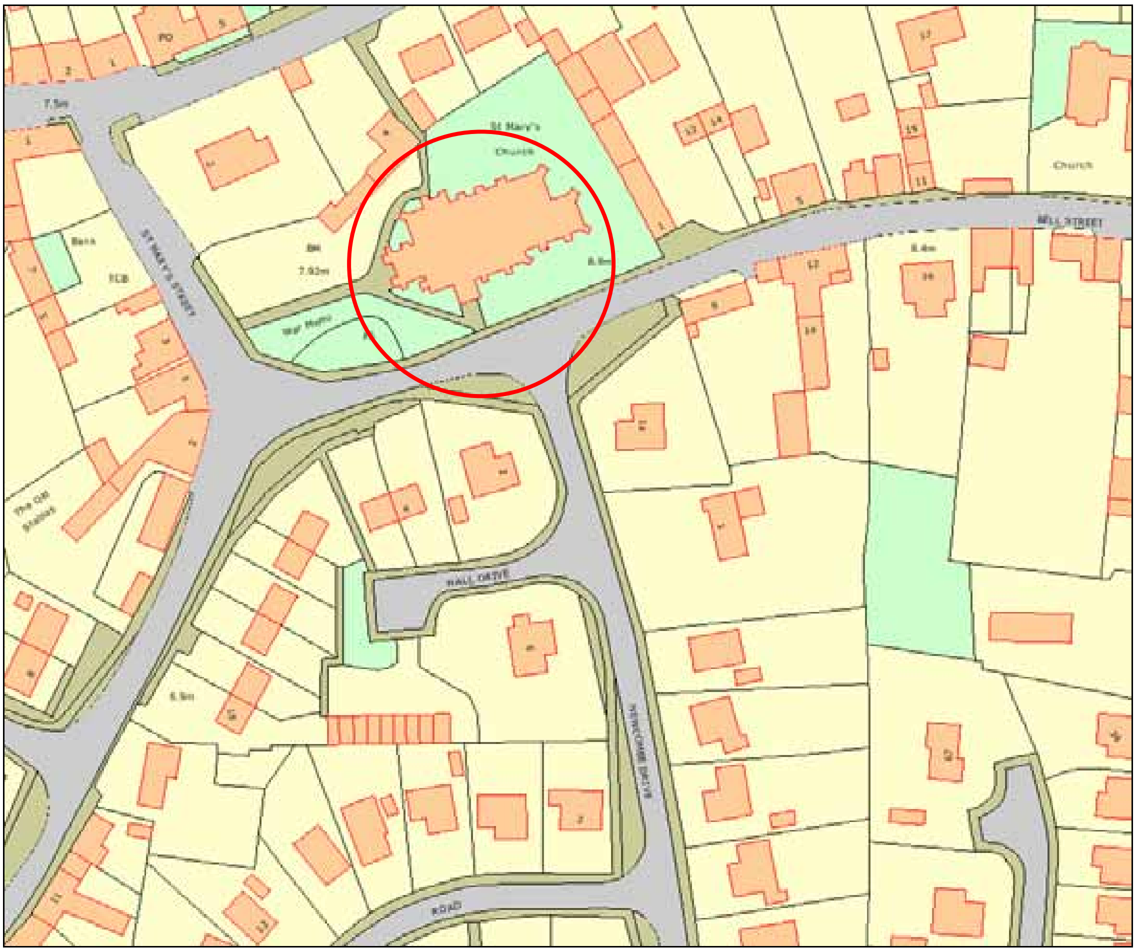

Figure 3: Map to show the location of St Mary's Church (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

Figure 4: Nave roof; principal truss 3 in the foreground

Figure 5: Nave roof; intermediary truss 6

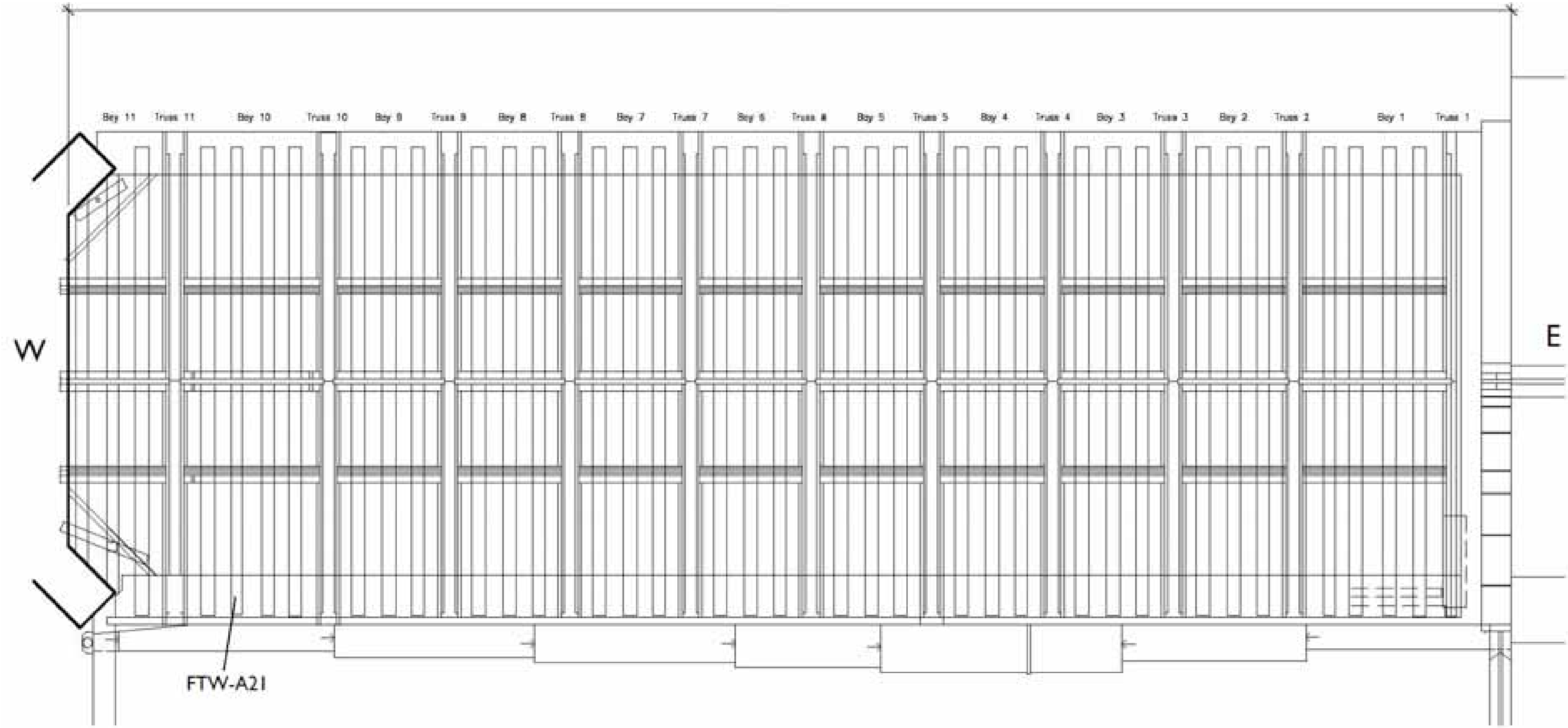

Figure 6: Plan of nave roof, showing the location of sample FTW-A21 (Freeland Rees Roberts Architects)

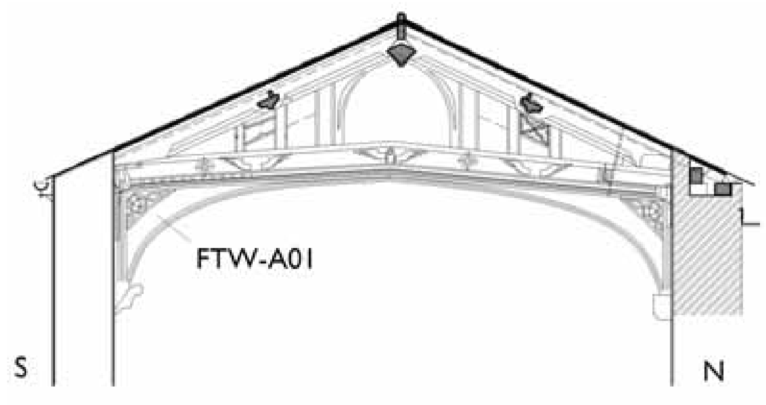

Figure 7: East elevation of principal truss 1 (based on truss 11), showing the location of sample FTW-A01 (Freeland Rees Roberts Architects)

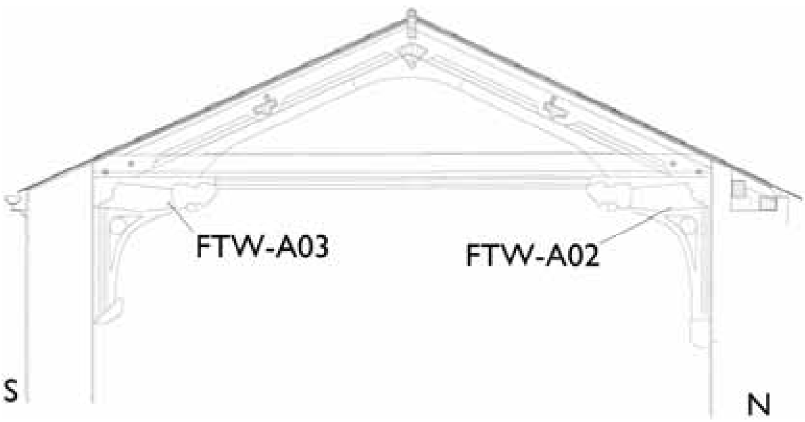

Figure 8: East elevation of truss 2, showing the location of samples FTW-A02 and FTW-A03 (Freeland Rees Roberts Architects)

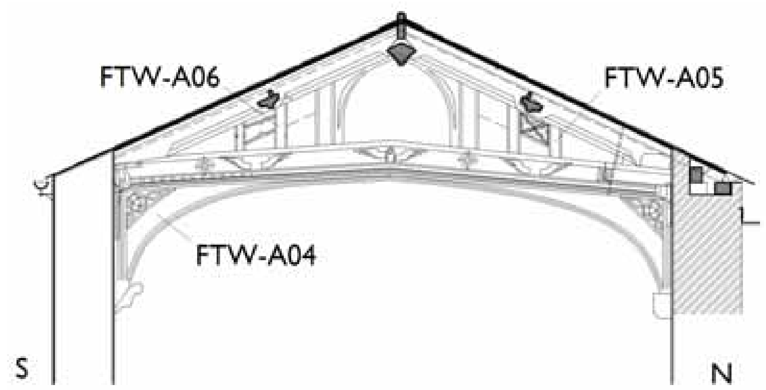

Figure 9: East elevation of principal truss 3 (based on truss 11), showing the location of samples FTW-A04–6 (Freeland Rees Roberts Architects)

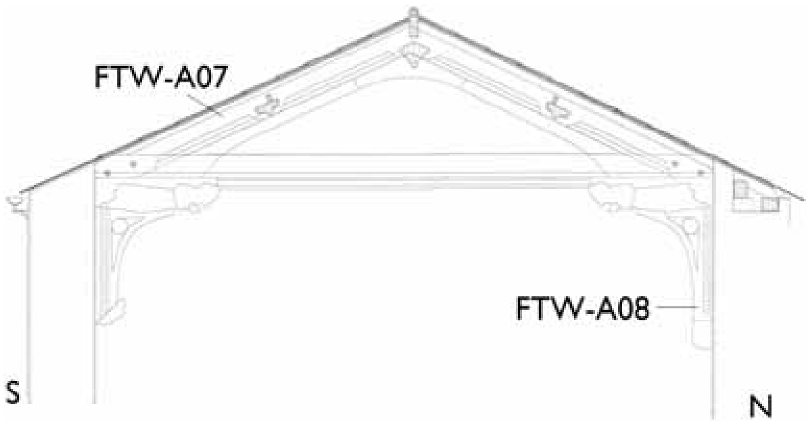

Figure 10: East elevation of truss 4 (based on truss 2), showing the location of samples FTW-A07 and FTW-A08 (Freeland Rees Roberts Architects)

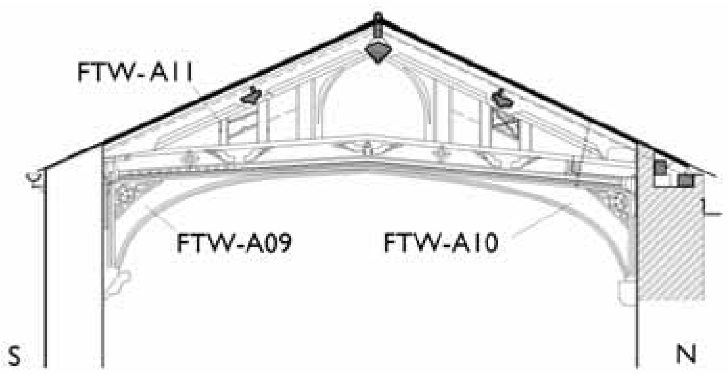

Figure 11: East elevation of principal truss 5 (based on truss 11), showing the location of samples FTW-A09–11 (Freeland Rees Roberts Architects)

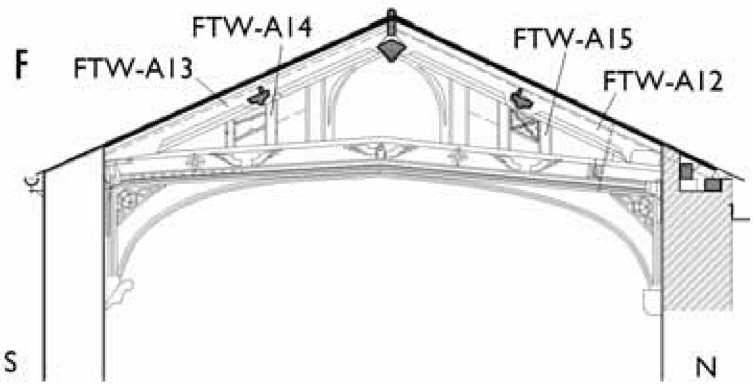

Figure 12: East elevation of principal truss 7 (based on truss 11), showing the location of samples FTW-A12–15 (Freeland Rees Roberts Architects)

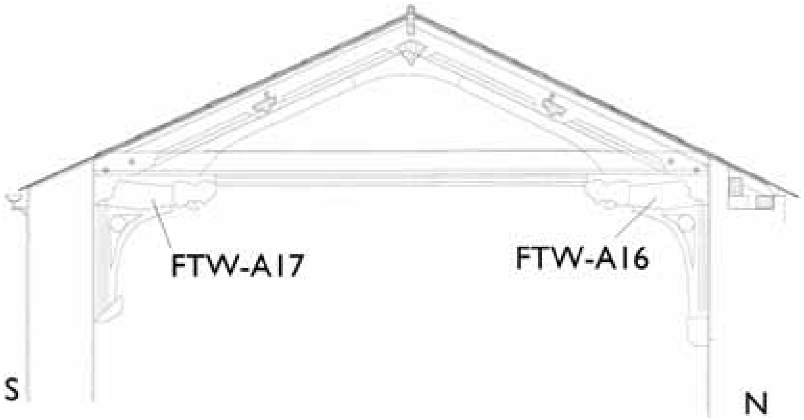

Figure 13: East elevation of truss 8 (based on truss 2), showing the location of samples FTW-A16 and FTW-A17 (Freeland Rees Roberts Architects)

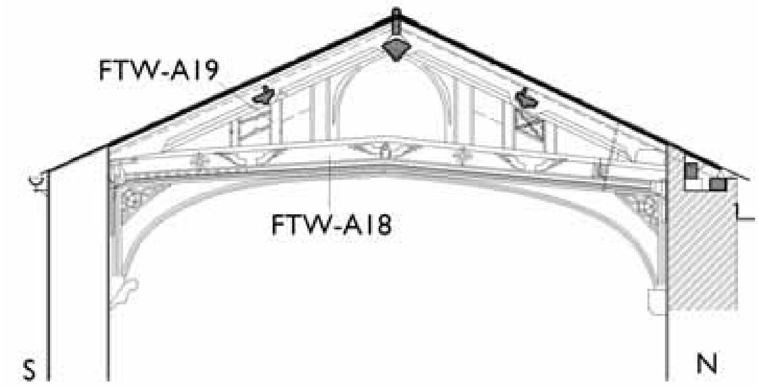

Figure 14: East elevation of principal truss 9 (based on truss 11), showing the location of samples FTW-A18 and FTW-A19 (Freeland Rees Roberts Architects)

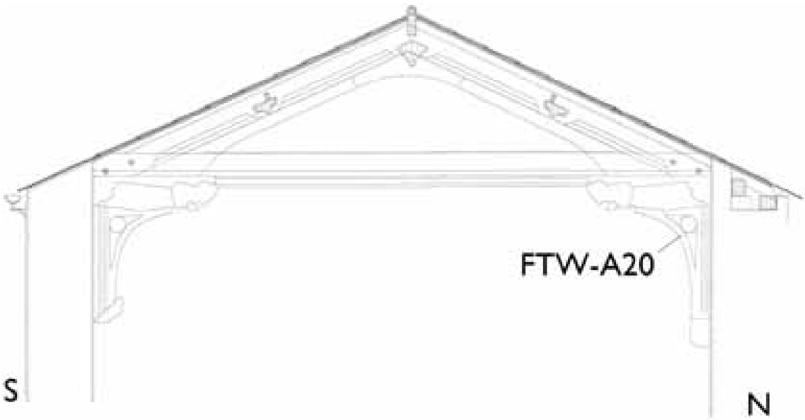

Figure 15: East elevation of truss 10 (based on truss 2), showing the location of sample FTW-A20 (Freeland Rees Roberts Architects)

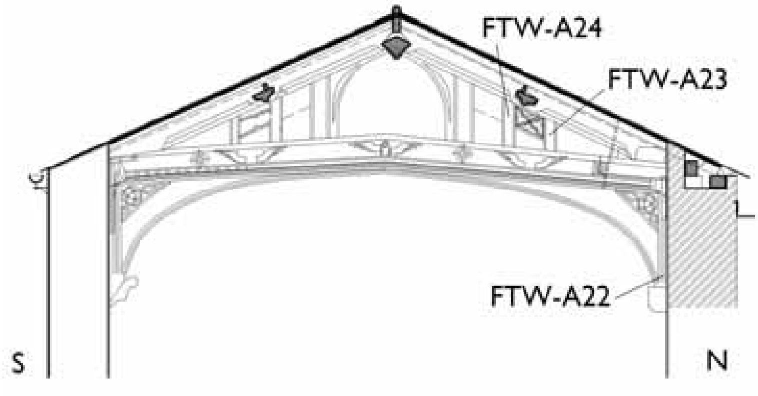

Figure 16: East elevation of principal truss 11, showing the location of samples FTW-A22–24 (Freeland Rees Roberts Architects)

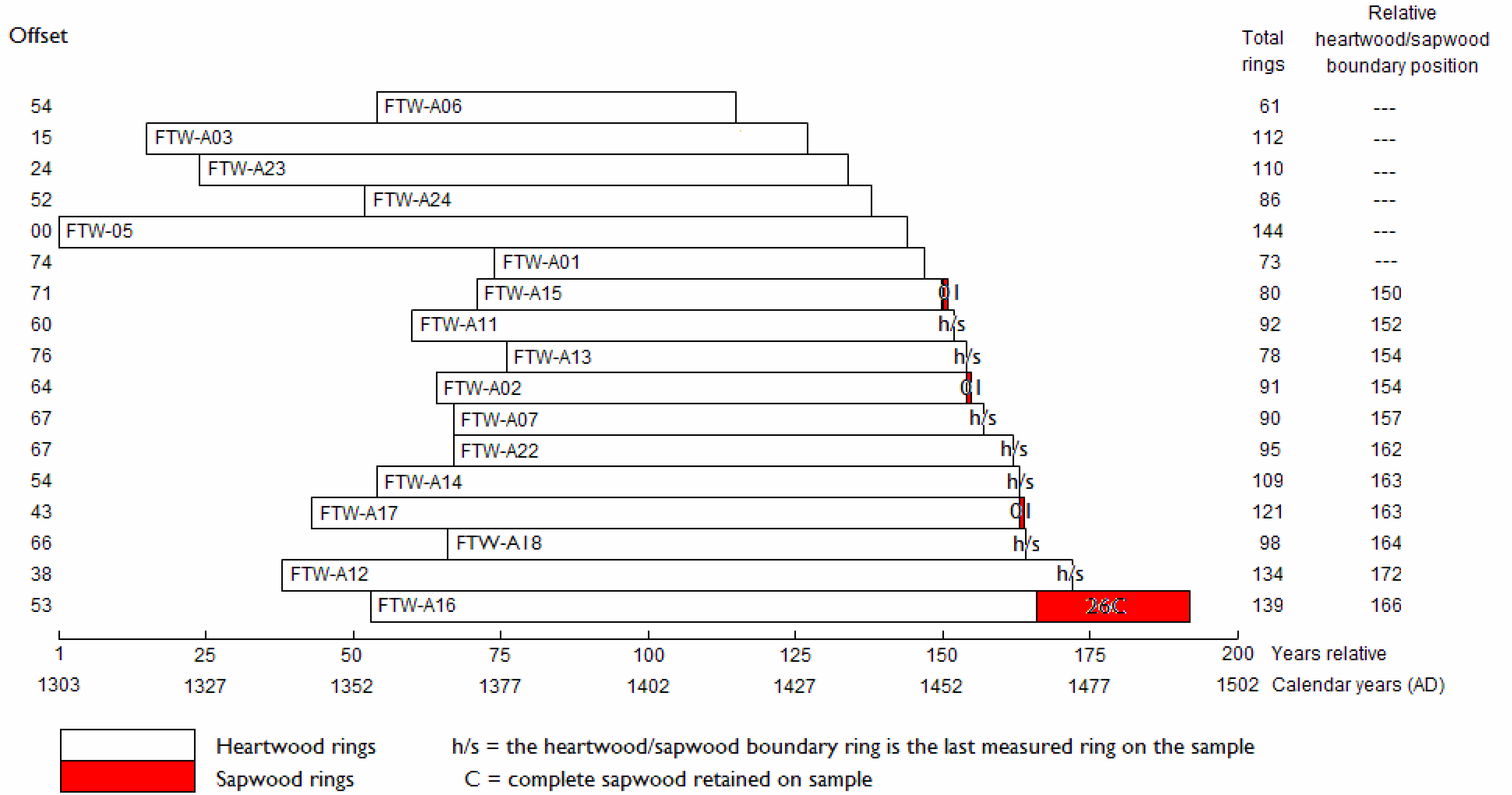

Figure 17: Bar diagram of samples in site sequence FTWASQ01

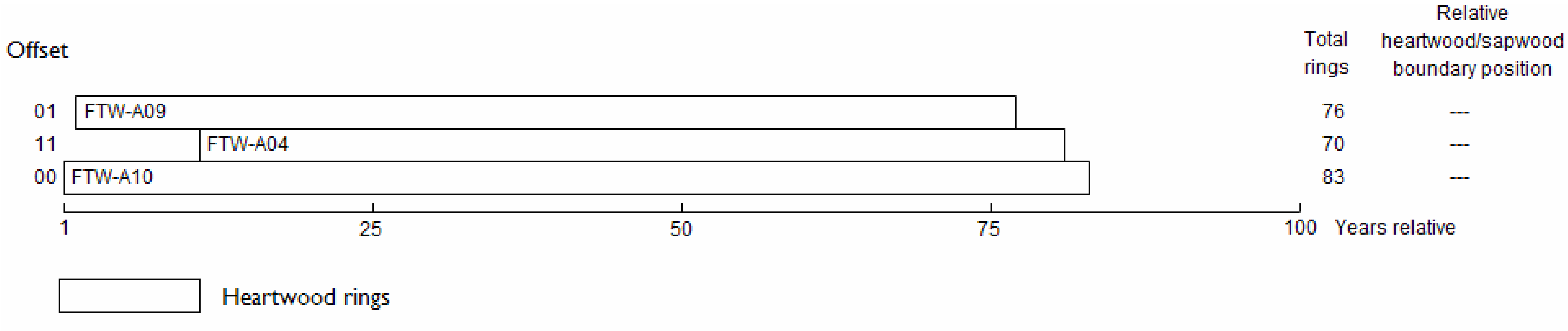

Figure 18: Bar diagram of samples in undated site sequence FTWASQ02

Figure 19: Superficially the samples fell into two groups, the first (upper sample) where the growth rings appeared to be more regular and generally evenly spaced and the second (lower sample) where they were more varied

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

FTW-A01A 73
 99 103 85 53 60 60 92 72 95 83 73 102 56 82 57 63 78 76 94 123
 129 111 81 88 108 118 123 123 149 112 115 86 66 83 117 102 165 142 131 84
 103 109 187 171 149 227 266 158 195 202 150 167 209 159 179 126 118 91 120 80
 117 114 98 122 89 141 97 62 67 99 81 66 139
FTW-A01B 73
 76 114 75 67 65 57 88 76 77 91 89 96 66 76 66 64 74 90 89 142
 131 111 83 91 111 117 125 138 148 113 123 88 72 93 122 109 168 158 127 89
 96 123 197 174 147 221 287 147 191 203 146 171 194 149 156 136 121 104 124 92
 114 106 88 106 86 144 96 64 70 94 78 65 145
FTW-A02A 91
 161 152 172 178 160 158 169 153 139 126 109 128 187 154 187 176 182 177 230 273
 298 305 215 207 183 183 188 199 202 211 211 230 223 199 154 159 151 180 147 132
 134 136 122 116 139 141 163 180 163 145 152 144 145 176 158 166 201 177 129 130
 157 176 184 168 149 137 153 115 129 145 160 153 125 135 97 104 103 108 82 86
 95 92 89 104 103 106 104 93 86 88 103
FTW-A02B 91
 158 157 169 178 157 165 166 160 139 125 115 132 209 149 183 187 170 181 230 277
 304 309 227 209 178 184 190 207 198 222 220 224 222 197 155 159 155 183 142 132
 131 137 125 123 131 131 161 184 156 153 148 145 143 175 162 161 199 184 149 124
 154 166 173 166 149 130 138 121 140 139 168 153 129 131 97 108 102 104 91 81
 98 91 88 103 107 106 96 100 93 90 105
FTW-A03A 112
 193 178 242 176 222 181 144 130 91 193 199 207 274 106 121 172 180 187 155 139
 186 171 165 166 163 204 259 254 220 149 149 95 64 39 60 66 65 82 48 72
 53 83 59 62 83 98 100 104 119 68 100 137 229 182 232 196 116 147 117 141
 154 132 94 91 83 101 56 88 96 119 125 101 108 78 93 81 80 79 131 119
 156 92 51 49 45 44 63 38 48 47 58 55 47 55 50 70 72 84 78 82
 66 64 63 86 77 127 99 69 95 97 124 106
FTW-A03B 112
 189 182 233 180 217 171 131 139 92 184 197 225 271 108 127 164 167 186 163 129
 179 165 155 167 150 182 257 256 201 150 154 103 66 67 57 74 75 72 65 72
 64 87 58 67 75 106 102 112 113 83 88 138 194 169 237 194 125 134 134 136
 157 130 93 91 84 109 49 87 95 125 134 92 95 84 85 72 88 76 117 135
 146 93 57 56 46 48 59 45 53 46 63 55 48 63 54 71 69 77 81 73
 67 60 66 86 74 130 92 78 85 96 133 117
FTW-A04A 70
 225 218 212 293 230 271 220 223 209 219 209 221 179 151 173 191 174 180 197 153
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 186 140 162 217 156 195 237 192 145 142
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178 147 172 216 165 199 235 197 150 136
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75 74 83 78
FTW-A05B 144
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278 279 380 312 343 297 314 284 310 301 368 388 297 314 385 306 311 300 376 342
338 296 299
FTW-A11A 92
246 307 140 139 178 230 259 221 186 231 210 153 155 241 223 321 212 119 109 81
92 109 179 163 143 178 119 112 85 79 107 162 183 195 150 125 117 86 134 153
176 254 264 163 151 183 83 107 101 89 148 193 131 85 90 155 171 222 168 225
291 154 125 128 126 116 147 159 161 137 117 93 102 85 109 117 121 122 119 170
147 110 89 119 140 145 133 140 109 99 96 134
FTW-A11B 92
218 308 143 144 183 225 263 221 187 234 211 153 158 237 220 318 200 119 106 90
91 120 165 178 144 180 119 118 83 91 105 153 183 194 155 122 113 101 137 154
178 255 259 176 178 200 98 102 121 107 161 197 132 89 99 148 165 214 178 216
289 148 130 126 130 113 158 152 142 157 101 93 106 81 100 129 116 129 121 171
145 110 85 114 136 134 140 130 110 100 93 146
FTW-A12A 134
215 242 109 134 92 85 139 171 179 154 225 199 221 207 209 189 218 223 253 245
222 206 221 201 183 217 188 165 229 166 151 196 209 188 216 210 204 251 188 200
198 149 239 179 191 219 208 284 187 216 228 178 181 231 174 209 225 242 134 124
132 114 115 175 214 178 180 206 189 178 178 181 202 140 171 155 186 192 181 199
138 76 164 161 155 121 127 112 101 95 104 139 114 146 189 93 131 118 103 105
132 197 212 119 116 97 115 120 146 128 89 133 153 155 115 166 154 184 163 149
141 190 165 148 202 157 133 91 113 126 109 113 91 109
FTW-A12B 134
213 258 102 141 93 86 138 177 180 153 216 203 225 208 207 182 221 219 244 247
234 189 211 208 178 214 185 175 229 165 144 194 212 195 210 214 186 249 189 199
208 140 236 184 199 220 216 282 180 208 224 171 186 250 173 228 233 241 142 113
126 103 131 166 217 172 193 196 195 184 173 174 195 140 175 176 178 196 167 200
139 70 172 162 145 112 132 108 105 104 98 128 120 150 191 94 135 123 106 95
134 199 219 116 112 101 114 118 156 126 95 113 158 156 128 162 149 171 172 142
132 192 167 151 192 156 127 101 103 132 104 117 82 97
FTW-A13A 78
99 97 105 98 117 100 100 108 168 146 115 166 110 113 119 100 125 120 164 146
130 114 112 134 134 153 119 145 95 122 161 96 98 100 135 112 115 109 86 59
69 68 75 69 75 82 50 52 62 63 68 60 74 103 67 58 57 64 68 77
73 74 77 151 125 79 77 66 84 72 129 94 97 80 72 120 105 143
FTW-A13B 78
103 101 97 103 110 99 104 106 173 141 138 164 115 115 122 94 123 122 134 148

134 121 108 135 134 151 121 141 105 124 152 97 95 93 140 109 104 104 86 67
63 64 79 66 75 85 46 43 68 63 72 68 64 102 66 63 64 62 69 69
71 70 80 134 121 81 84 64 76 74 128 95 91 78 69 112 102 161
FTW-A14A 109
162 90 136 171 171 155 200 187 154 109 86 112 141 114 88 110 94 84 97 98
116 139 119 80 95 72 68 75 91 142 158 162 107 91 54 58 81 100 82 118
128 84 61 97 134 113 139 146 124 117 97 79 82 70 100 105 131 111 108 64
66 98 113 135 150 142 182 138 99 110 119 112 105 118 82 104 85 76 110 57
107 88 74 77 90 113 121 99 74 97 110 98 110 106 103 101 96 101 89 117
96 118 100 94 86 104 104 95 100
FTW-A14B 109
161 75 140 173 171 160 202 183 159 106 89 119 132 110 97 110 91 80 101 106
110 136 123 77 112 50 74 81 84 132 155 149 122 82 60 48 73 106 77 129
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65 96 112 122 151 137 171 145 104 112 115 106 119 102 88 101 87 73 114 60
106 85 76 75 84 114 118 88 85 92 102 97 112 111 98 98 99 101 88 109
94 124 94 93 81 105 103 95 118
FTW-A15A 80
109 114 91 103 91 121 93 109 79 81 60 68 78 107 138 89 96 89 85 72
102 82 103 111 117 116 111 101 119 103 113 127 122 104 96 85 88 100 111 138
107 129 111 110 119 117 127 126 159 151 154 146 118 179 159 181 207 154 138 160
131 119 149 154 166 114 106 86 107 103 101 94 90 89 87 81 98 96 88 93
FTW-A15B 80
108 113 99 98 97 104 102 110 82 84 64 66 83 106 132 90 101 81 87 70
96 89 93 113 138 115 114 92 114 108 113 115 121 108 100 87 88 100 111 136
113 128 113 111 120 120 121 128 157 149 154 146 118 178 164 183 201 164 141 158
131 119 148 150 159 116 104 84 110 101 98 97 88 90 88 82 97 96 88 85
FTW-A16A 139
130 130 97 115 97 81 71 88 79 86 78 73 75 94 86 71 63 78 81 91
93 95 90 89 98 100 95 112 64 117 120 137 131 102 83 86 110 85 82 80
114 128 152 127 101 85 96 106 158 110 171 133 125 145 115 145 116 185 133 165
184 183 146 163 122 191 195 235 189 141 132 154 170 154 133 139 174 138 138 155
88 119 96 87 105 97 111 138 113 105 111 90 82 115 112 93 90 101 123 111
166 167 114 87 102 106 116 86 96 121 146 130 136 157 137 129 106 106 89 120
87 75 98 117 133 122 124 118 79 82 81 102 121 110 90 81 78 77 61
FTW-A16B 139
115 127 91 111 106 87 68 88 92 94 85 69 77 98 77 75 59 78 76 99
89 96 101 88 95 90 110 107 63 103 120 140 134 92 80 86 103 80 83 78
117 129 139 141 93 88 90 120 157 102 163 138 126 142 116 140 118 189 137 170
195 176 142 159 138 175 200 227 192 135 130 145 170 164 138 126 190 128 126 168
89 120 107 75 125 87 116 141 113 103 118 84 90 115 108 95 96 99 126 115
164 167 107 81 114 105 113 91 88 121 142 134 138 152 176 120 123 108 119 125
81 76 99 112 130 116 126 98 89 88 93 101 107 105 93 84 67 78 58
FTW-A17A 121
100 137 154 151 112 217 136 165 161 144 146 195 156 130 157 121 146 215 192 133
89 110 153 192 152 123 141 115 128 140 141 107 107 78 78 139 135 135 129 170
208 180 178 134 132 138 102 124 100 121 122 137 144 172 182 210 142 145 177 146
182 172 177 130 140 91 111 107 98 106 124 158 130 117 129 153 115 166 130 110
93 127 186 182 130 121 183 149 114 132 116 157 125 107 123 109 104 128 100 110
111 102 113 90 96 99 97 82 98 103 115 122 129 120 100 128 88 72 84 114
80
FTW-A17B 121
141 131 160 139 100 219 138 162 151 148 148 195 162 131 164 119 145 203 181 141

114 98 149 196 153 115 143 97 148 149 151 104 115 83 83 126 127 129 120 164
212 182 169 140 126 141 108 116 103 118 129 120 134 165 178 205 151 159 168 137
188 167 177 137 122 101 107 108 101 101 137 154 123 121 129 152 123 154 128 113
93 127 180 189 126 132 189 151 114 132 117 148 128 111 117 107 120 126 96 97
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FTW-A18A 98
184 160 132 179 237 219 244 187 115 134 134 135 133 103 95 55 108 159 208
204 178 201 136 134 148 184 224 142 150 132 223 211 213 245 147 238 146 251 149
192 237 167 126 140 264 201 194 215 132 167 141 190 167 156 218 178 124 92 131
159 175 157 178 268 213 214 187 182 167 190 203 157 169 155 200 133 137 151 121
187 270 186 227 153 149 217 225 286 226 165 169 245 161 174 140 126 247 220
FTW-A18B 98
159 183 131 174 262 218 248 189 104 143 138 139 145 96 89 56 113 150 195 217
174 195 143 137 162 178 213 142 179 164 233 196 223 244 150 239 154 241 150 188
229 179 116 147 260 202 195 203 136 170 144 189 167 161 211 182 117 91 122 158
170 153 176 277 214 209 188 187 152 193 201 158 168 162 209 124 141 152 128 178
301 176 227 152 150 220 235 278 222 159 173 247 160 170 146 135 253 177
FTW-A19A 94
171 182 214 154 151 198 280 314 220 274 164 157 162 165 237 187 198 229 168 127
102 117 113 116 141 141 158 89 123 74 93 90 101 110 124 126 93 102 139 130
127 195 162 128 133 118 84 111 128 126 130 144 172 162 121 118 136 124 108 125
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FTW-A19B 94
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116 110 107 87 126 113 119 101 88 95 115 140 119 101 89 104 105 133 117 132
135 146 174 159 129 107 141 189 155 146 143 91 68 63
FTW-A20A 121
155 205 239 231 167 212 227 215 141 306 188 125 268 128 247 212 199 122 111 88
71 77 65 87 66 41 54 44 74 51 59 41 46 51 45 78 87 126 70 72
140 202 112 123 60 49 91 64 70 74 69 89 74 77 96 87 50 76 119 82
76 94 94 108 130 108 118 111 114 103 126 148 147 167 138 116 130 132 124 100
104 71 85 106 61 85 130 202 278 418 230 330 165 137 184 200 286 339 357 421
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FTW-A20B 121
118 210 221 227 157 214 221 207 143 291 186 118 248 126 246 192 207 126 109 96
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318 299 251 231 134 233 183 343 245 291 284 208 97 145 161 147 75 59 45 102
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FTW-A22A 95
226 307 361 284 283 350 301 301 340 352 209 226 151 159 154 219 246 198 181 144
146 134 102 135 173 158 293 180 164 134 145 203 145 136 175 155 196 126 135 117
122 106 97 104 112 107 71 87 118 123 106 149 127 168 110 60 64 82 89 106
95 75 84 69 78 78 71 88 80 76 64 64 90 82 79 75 78 87 84 98
91 136 152 134 159 133 125 113 133 120 106 89 100 104 131
FTW-A22B 95

227 287 378 320 312 340 300 294 350 333 238 220 154 167 146 229 249 205 189 122
148 130 94 143 175 161 284 184 167 127 151 196 149 144 169 150 210 130 130 118
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97 79 82 83 77 76 77 84 86 72 73 69 78 89 74 78 69 90 86 90
90 131 153 140 154 128 125 108 130 116 101 101 107 80 136
FTW-A23A 110
79 95 90 90 72 74 89 89 97 96 90 93 97 118 91 107 105 104 100 116
95 125 112 109 132 138 141 154 102 96 150 126 132 140 139 129 143 147 127 107
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FTW-A23B 110
76 96 93 90 72 71 92 78 102 99 84 91 95 112 84 108 96 109 102 109
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116 129 122 122 139 123 120 124 119 106 118 127 133 159 137 126 161 165 134 122
146 145 166 172 159 143 152 139 149 163
FTW-A24A 86
129 113 166 155 148 154 160 156 175 199 167 156 143 165 193 169 146 182 173 164
168 138 136 152 165 148 145 149 135 134 138 168 173 213 144 126 134 141 141 141
152 174 160 189 170 173 160 168 155 182 156 143 129 136 126 122 148 139 138 140
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198 174 204 205 140 140
FTW-A24B 86
129 123 163 156 142 150 166 158 177 196 170 155 147 163 202 171 144 188 171 167
163 138 132 155 166 141 153 145 139 134 144 169 175 202 158 140 145 149 149 150
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

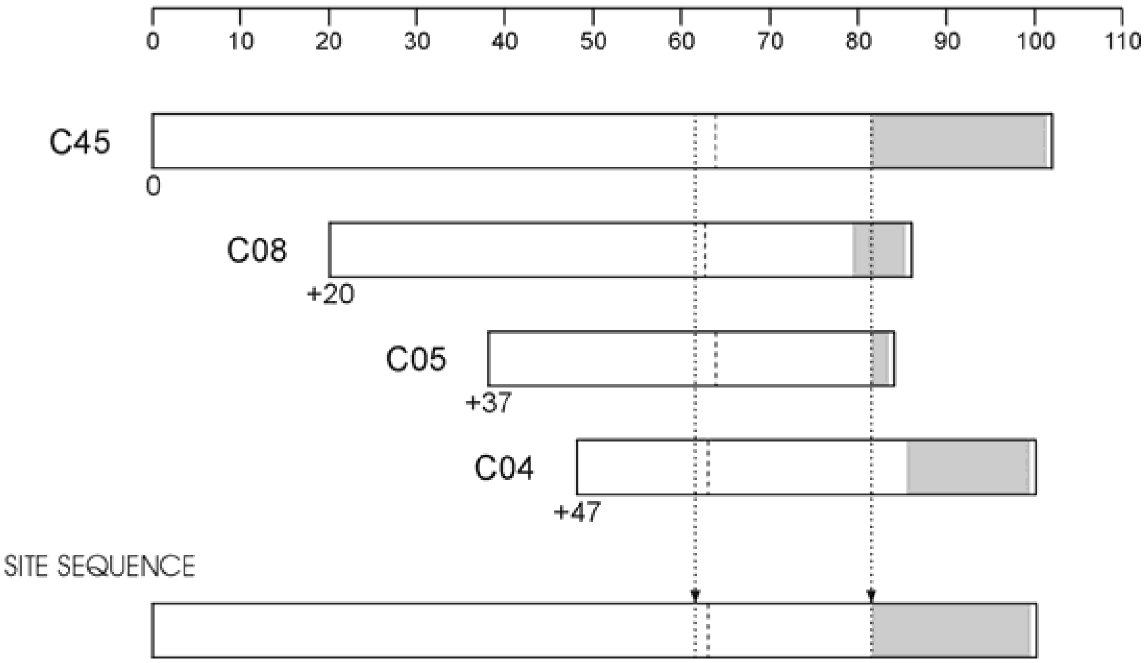


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

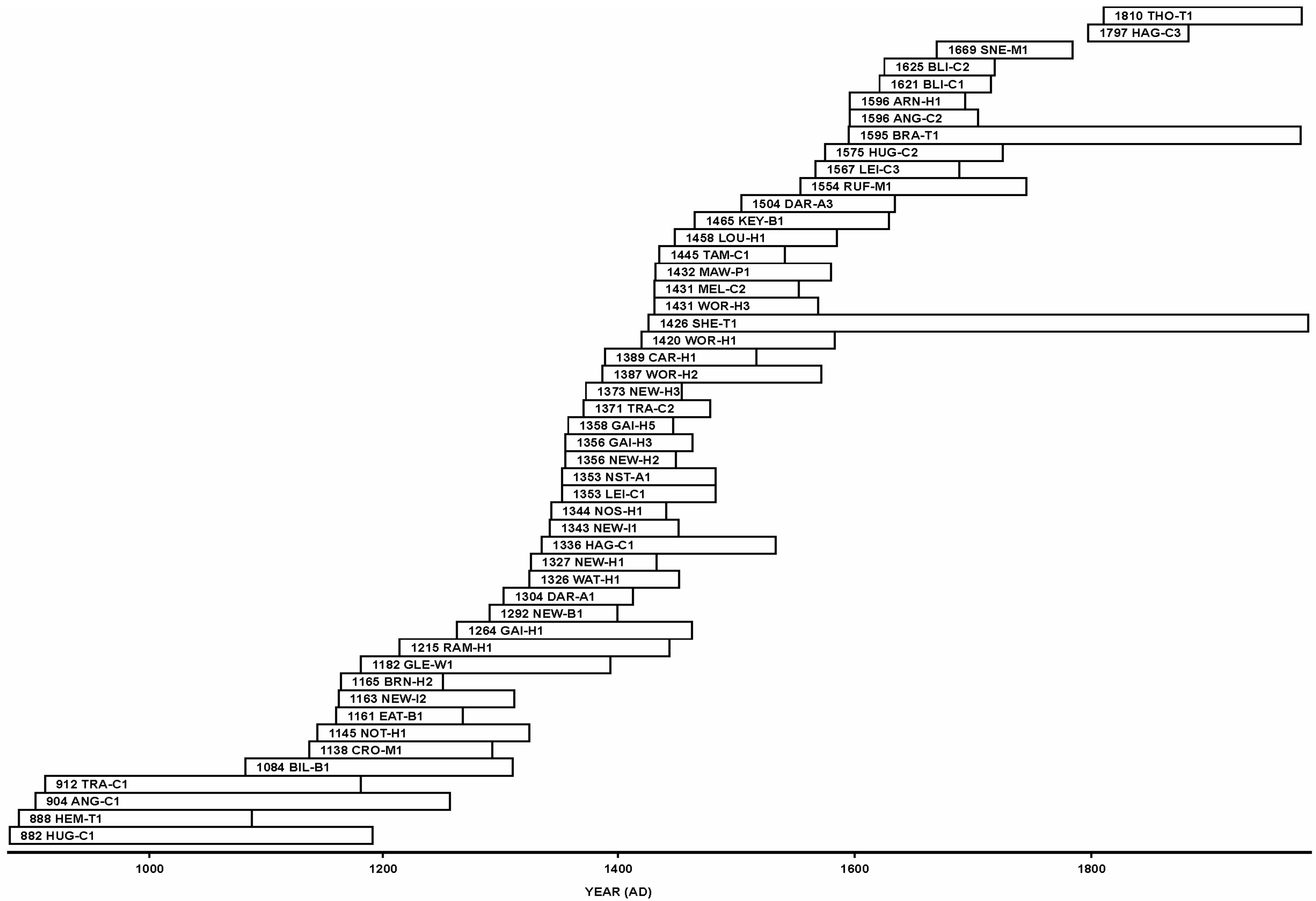
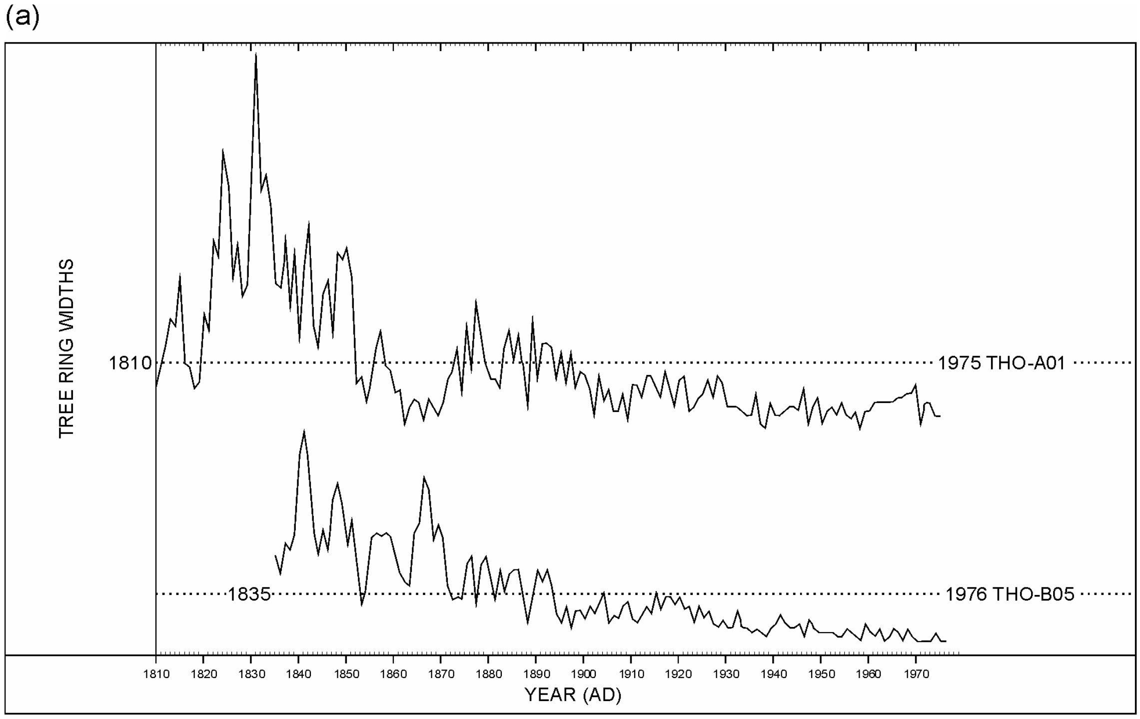


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



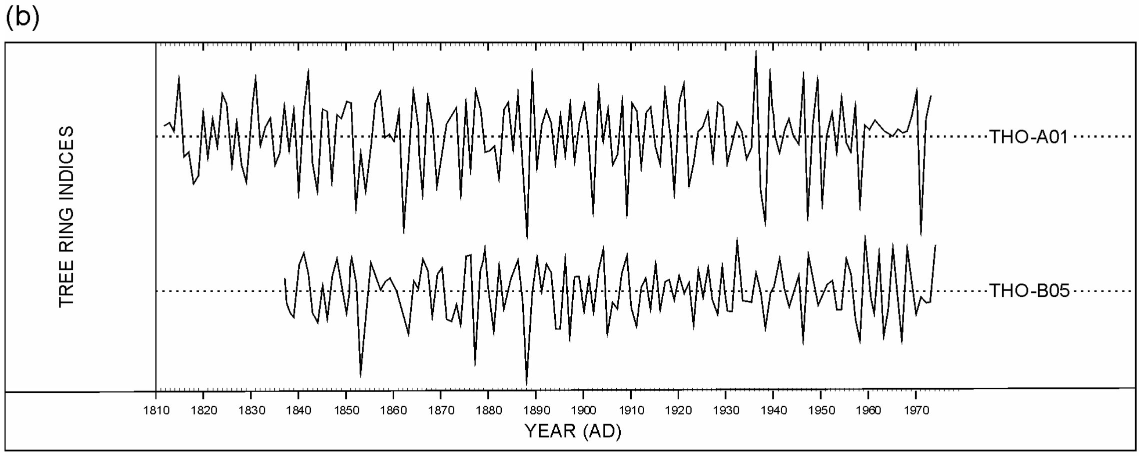


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, 33, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, 3, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, 15–26

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, 8, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, 22, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, 33, 90–8

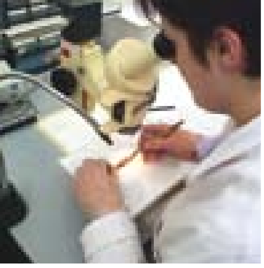
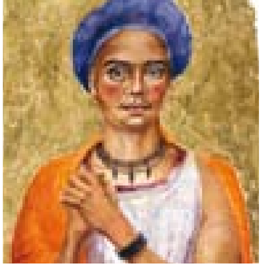
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*¸18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, 28, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



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