Research Report Series 17/2025

Atherstone Place, 12 Eastgate, Lincoln

Tree-ring Analysis of Oak Timbers

Matt Hurford, Roderick Bale, Alison Arnold and Robert Howard

Scientific Dating

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Summary

Dendrochronological analysis was undertaken on 14 of 16 oak samples taken from Atherstone Place, 12 Eastgate, Lincoln. This resulted in the production of two site chronologies, TEGLSQ01 and TEGLSQ02. Site chronology TEGLSQ01, comprising 10 samples and with an overall length of 90 rings, can be dated as spanning the years AD 1629 to AD 1718. Site sequence TEGLSQ02, of 240 rings and comprising three samples, can be dated as spanning the years AD 1128 to AD 1367. This analysis has established that the clasped purlin roof over the Northern Addition is constructed of timbers felled in, or around, the spring of AD 1719, thus corroborating previous research that suggested an eighteenth-century remodelling of this part of the property. The ceiling frame of the cellar within the thirteenth-century open hall incorporated timbers felled during the late fourteenth or early fifteenth century.

Contributors

Matt Hurford, Roderick Bale, Alison Arnold, and Robert Howard.

Acknowledgements

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Front cover image

Atherstone Place, 12 Eastgate, Lincoln. [© Mr David Brown. Source: Historic England Archive IOE01_15245_26]

Archive location

The Historic England Archive, The Engine House, Fire Fly Avenue, Swindon SN2 2EH

Historic Environment Record

Lincolnshire Historic Environment Record, Lancaster House, 36 Orchard Street, Lincoln LN1 1XX

Date of investigation

2023–4

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Introduction

The dendrochronological investigation at Atherstone Place, 12 Eastgate, Lincoln is part of a wider study of the buildings in Lincoln Cathedral precincts, which includes the provision of a programme of advanced continued professional development, led by the Nottingham Tree-ring Dating Laboratory, this latter being commissioned and funded by Historic England (Project No: 7856).

Atherstone Place is Grade I listed (List Entry Number 1388519 https://historicengland.org.uk/listing/the-list/list-entry/1388519) and stands immediately north of Lincoln Cathedral (Fig 1–2). The ancient houses of Lincoln were subject to a detailed study (Jones et al. 1990) from which the background information in this report, is taken.

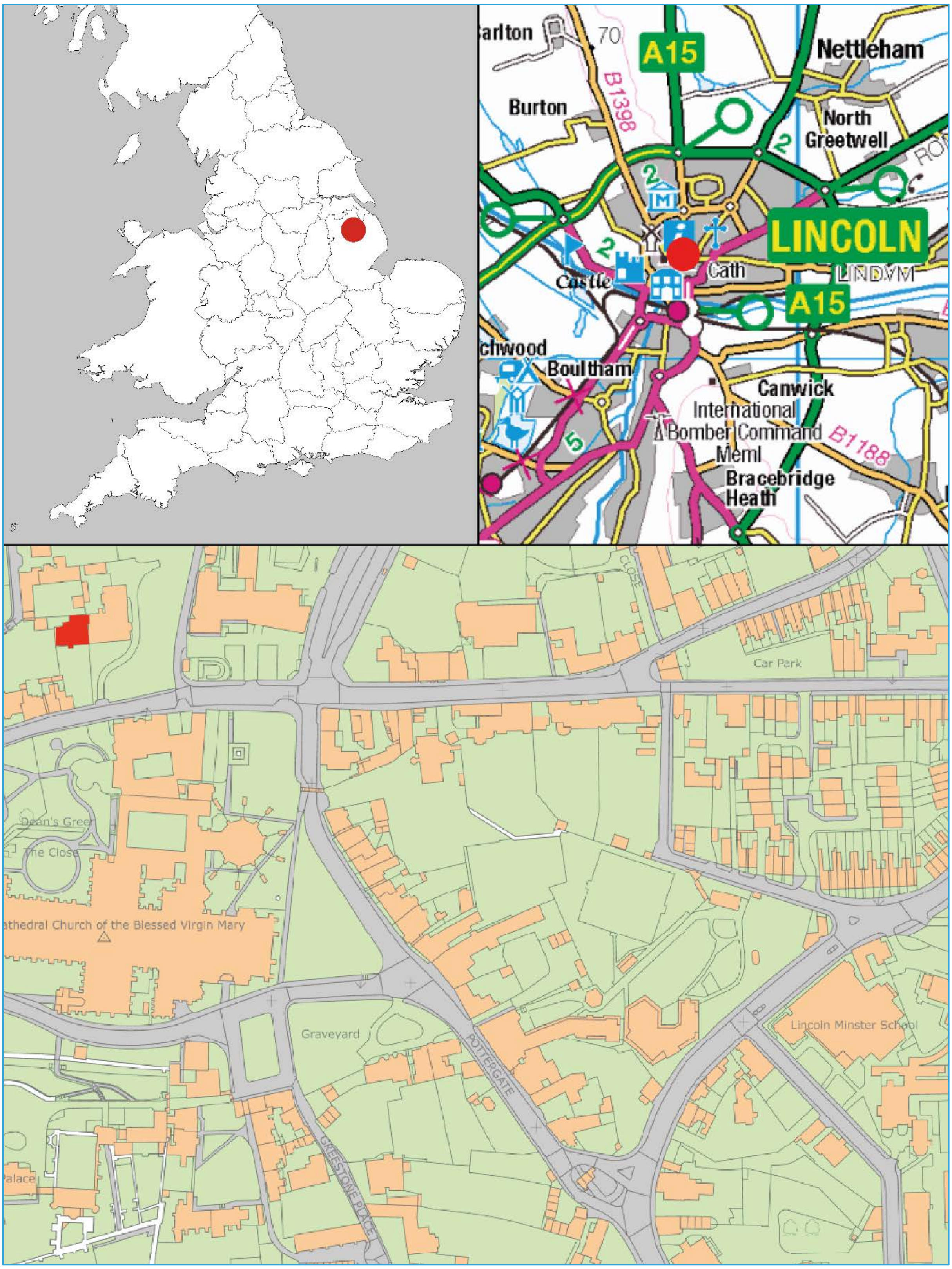

Figure 1: Map to show the location of 12 Eastgate in Lincoln. Top right: Scale: 1:105,000. Bottom: Scale 1:2,500. [© Crown Copyright and database right 2025. All rights reserved. Ordnance Survey Licence number 100024900]

Figure 2: General view of the north elevation and west gable of the Northern Addition that abuts the thirteenth-century open hall, viewed looking south-east. [Matt Hurford]

Atherstone Place is a pair of houses that were once part of a single mansion, a complex comprising several buildings. It has been known by its current name since at least AD 1582 and comprises numbers 12–13 Eastgate and 18 James Street. A former open hall of late thirteenth-century date, heightened and re-roofed in AD 1810, is represented by the greater part of 12 Eastgate with a seventeenth- and eighteenth-century addition abutting the north elevation (Fig. 3).

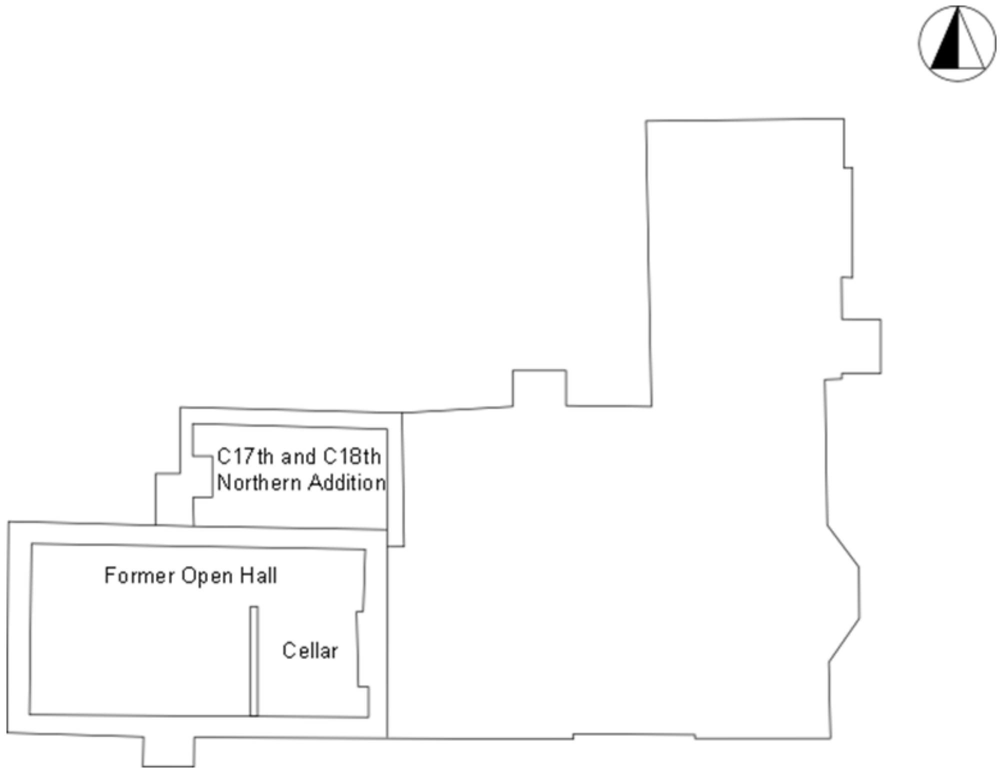

Figure 3: Sketch (not to regular scale) of the ground-floor plan of Atherstone Place with the Northern Addition and cellar within the former open hall at the south-west end of the property. [Matt Hurford]

The roof over the Northern Addition is of clasped purlin type. In total there are 19 pairs of common rafters, with a single set of purlins, which are clasped between five collars, extending between common rafter pairs 3, 6, 9, 13 and 16 (Fig. 4). There is no evidence of reused timbers but the southern purlin between common rafters 13 and 19 is softwood, and almost certainly a replacement.

Figure 4: The roof over the Northern Addition, viewed looking south-west. [Matt Hurford]

The timbers in the cellar, located within the thirteenth-century open hall, comprise three cambered beams with a straight chamfer and plain stop, which support the floor above. Empty mortices are present, indicating either a remodelling of the room or that the beams are reused (Fig. 5). It has been suggested (pers. comm. Jonathan Clark) that these timbers are from the original hall roof.

Figure 5: Ceiling beam 01 in the cellar, viewed looking south-east. [Roderick Bale]

Sampling

A total of 16 oak timbers (*Quercus* sp.) were sampled, with each being given the code TEG-L and numbered 01–16. Samples, TEG-L01–13, were taken from the roof over the Northern Addition abutting the former medieval hall. A number of these timbers had complete sapwood, but unfortunately, due to the very friable condition of the sapwood, all or part was lost during the sampling procedure in the majority of cases. Samples TEG-L14–16, were taken from beams within the cellar located in the former medieval hall. As noted above, the timbers of the extant roof over the hall are from the nineteenth-century re-roofing and were not sampled. Details of the samples are given in Table 1. The timbers have been located and numbered following the scheme on the drawings provided, and their positions are marked on them (Figs 6–7).

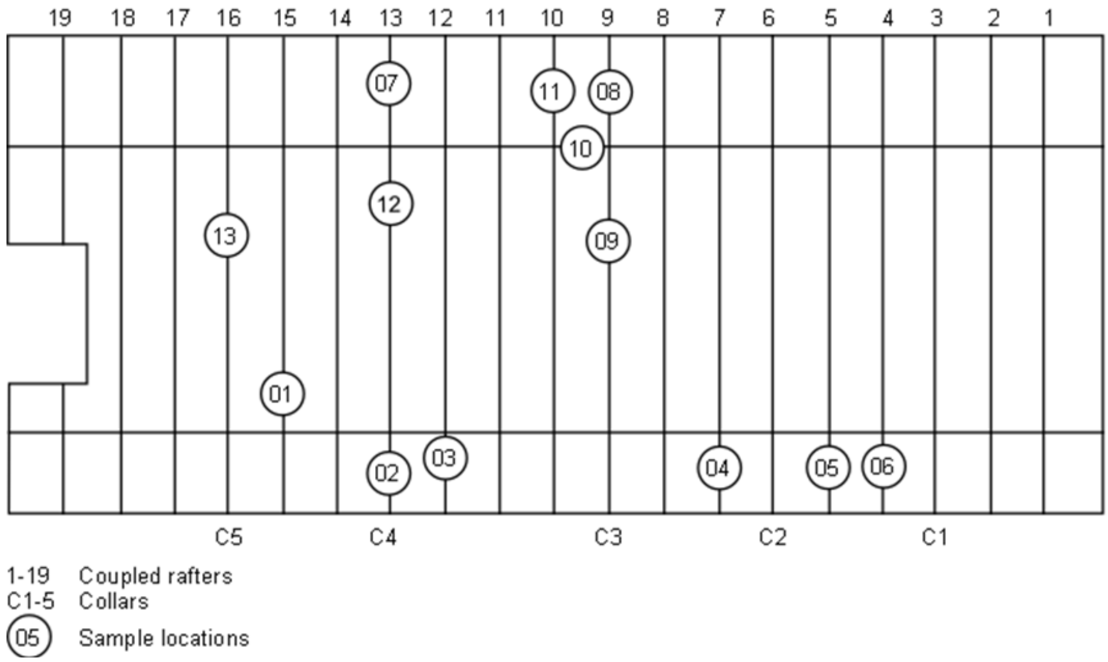

Figure 6: Sketch plan (not to scale) showing the location of samples TEG-L01–13 within the roof of the Northern Addition. [Matt Hurford]

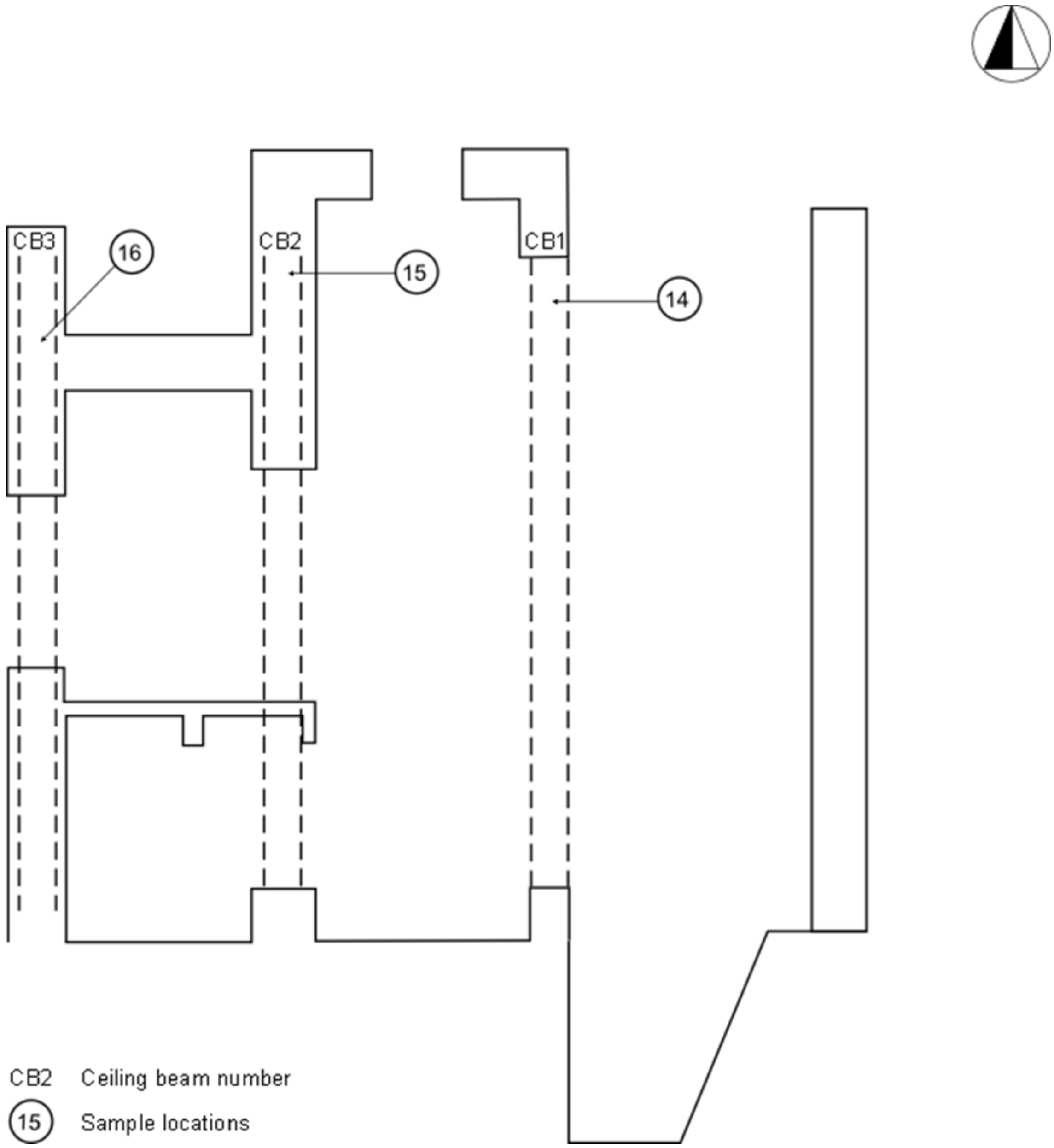

Figure 7: Sketch plan (not to scale) showing the location of samples TEG-L14–16 within the cellar. [Matt Hurford]

Table 1: Details of tree-ring series from Atherstone Place, 12 Eastgate, Lincoln.

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Northern Addition, roof						
TEG-L01	South common rafter 15	86	h/s c	----	----	----
TEG -L02	South common rafter 13	55	18 c	1654	1690	1708
TEG -L03	South common rafter 12	50	9	1658	1698	1707
TEG -L04	South common rafter 7	72	16	1636	1691	1707
TEG -L05	South common rafter 5	NM (29)	----	----	----	----
TEG -L06	South common rafter 4	71	29	1646	1687	1716
TEG -L07	North common rafter 13	71	29C	1648	1689	1718
TEG -L08	North common rafter 9	56	no h/s c	1641	----	1696
TEG -L09	Collar 3	57	28C	1662	1690	1718
TEG -L10	North purlin between common rafters 9 and 10	NM (23)	----	----	----	----
TEG -L11	North common rafter 10	84	26	1629	1686	1712
TEG -L12	Collar 4	42	9 c	1671	1703	1712
TEG -L13	Collar 5	70	19	1639	1689	1708
Former open hall, cellar ceiling						
TEG -L14	Ceiling beam	229	no h/s	1128	----	1356
TEG -L15	Ceiling beam	140	1	1228	1366	1367
TEG -L16	Ceiling beam	124	no h/s	1239	----	1362

Key: h/s = heartwood/sapwood boundary retained on sample; no h/s = heartwood only sample; C = complete sapwood retained on the sample, outermost partial ring not measured (spring felled), c = complete sapwood retained on the timber but all or part of the sapwood lost during sampling or preparation.

Analysis and results

All 16 samples were prepared by sanding and polishing, at which point samples TEG-05 and TEG-L10 were noted as having an insufficient number of rings (<30) for secure dating purposes and so were rejected from this programme of analysis. The remaining 14 samples had their growth-ring widths measured, the data of these measurements are given at the end of the report. All measurements were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 13 samples matching to form two groups.

Firstly, 10 samples grouped at a minimum *t* – value of *t* = 5.2 and were combined at the relevant offset position to form TEGLSQ01, a site sequence of 90 rings (Fig 8). Comparison of this site sequence against the reference chronologies resulted in a secure match at a first-ring date of AD 1629 and a last-measured ring date of AD 1718. The evidence for this dating is given in Table 2.

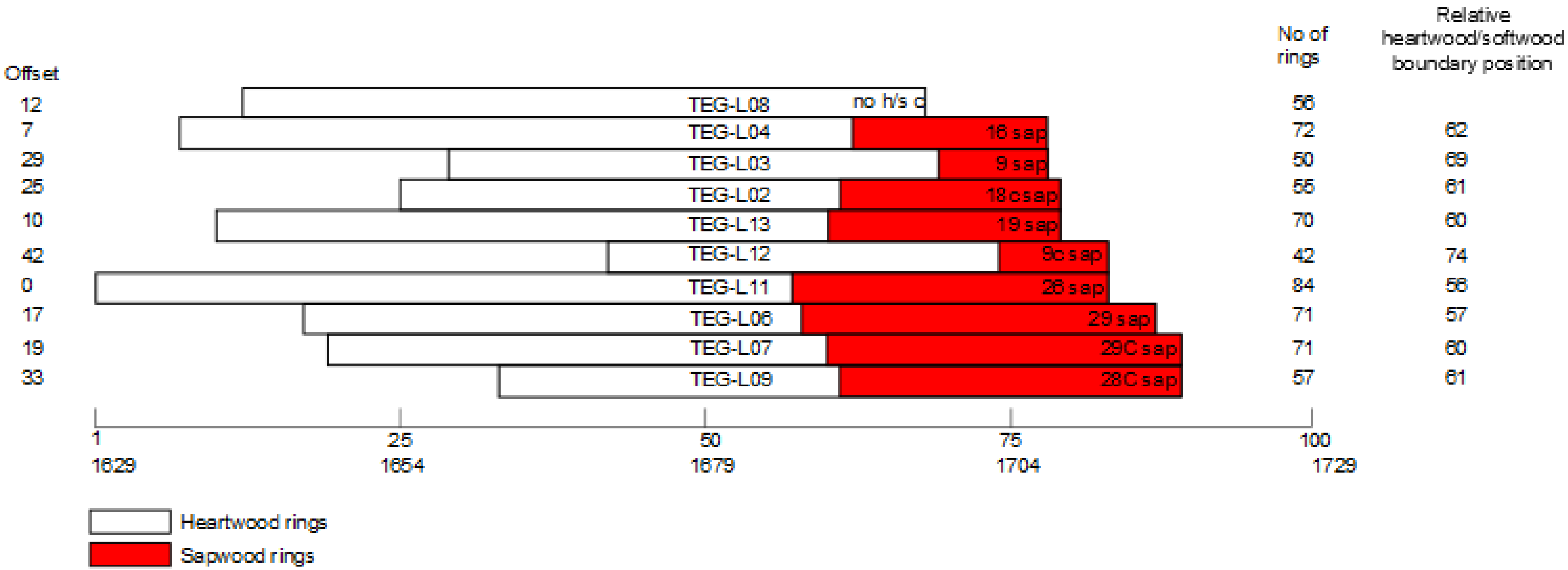

Figure 8: Bar diagram of samples in site sequence TEGLSQ01. no h/s = heartwood only sample; C = complete sapwood retained on the sample, outermost partial ring not measured (spring felled), c = complete sapwood retained on the timber but all, or part, of the sapwood lost during sampling or preparation

Table 2: Results of the cross-matching of site sequence TEGLSQ01 and example reference chronologies when the first ring date is AD 1629 and the last-measured ring date is AD 1718.

Reference chronology	*t* – value	Span of chronology (AD)	Reference
St Hugh's Choir, Lincoln Cathedral, Lincolnshire	10.9	1575–1724	Laxton et al. 1984
Kibworth Harcourt Mill, Leicestershire	8.9	1582–1786	Bridge et al. 2022
Church of St Peter, Barton on Humber, Lincolnshire	8.7	1606–1713	Tyers 2001
Claydon House, Buckinghamshire	8.6	1613–1756	Tyers 1995
Manor House, Thorpe by Water, Rutland	8.4	1622–1688	Arnold and Howard 2021
Southwell Minster, Nottinghamshire	8.3	1573–1716	Howard et al. 1996
Bay Hall, Bennington, Lincolnshire	7.9	1591–1717	Howard et al. 1998a
Lincoln Guildhall, Lincolnshire	7.8	1632–1739	Arnold and Howard 2021
Blidworth, Nottinghamshire	7.5	1625–1717	Laxton et al. 1982
Kirby Hall, Northamptonshire	7.4	1509–1795	Arnold et al. forthcoming

Three samples matched each other at a minimum value of t = 7.9 and were combined at the relevant offset position to form TEGLSQ02, a site sequence of 240 rings (Fig. 9). Comparison of this site sequence against the reference chronologies resulted in a secure match at a first-ring date of AD 1128 and a last-measured ring date of AD 1367. The evidence for this dating is given in Table 3.

Attempts were then made to date the remaining measured but ungrouped sample, TEG-L01, by comparing it individually against the reference chronologies. However, there was no satisfactory cross-matching and it, therefore, remains undated.

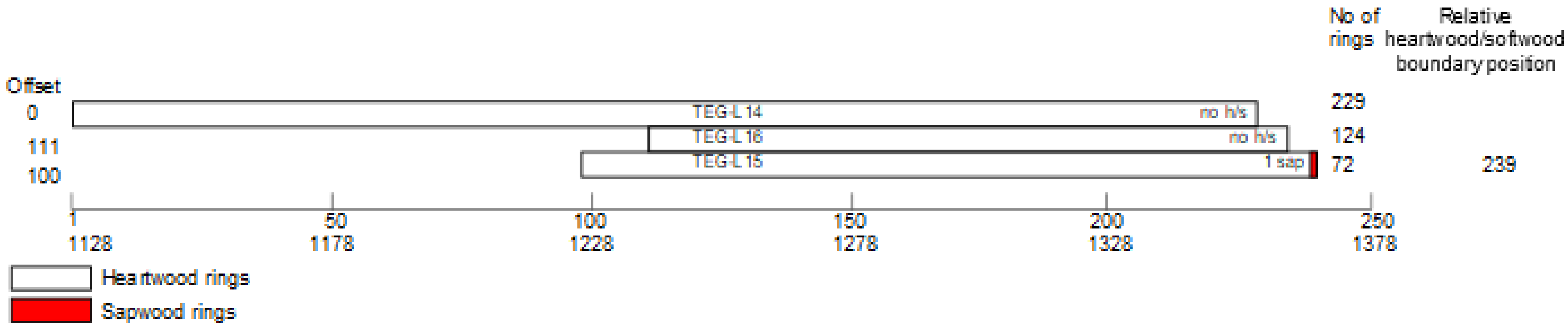

Figure 9: Bar diagram of samples in site sequence TEGLSQ02. no h/s = heartwood only sample.

Table 3: Results of the cross-matching of site sequence TEGLSQ02 and example reference chronologies when the first-ring date is AD 1128 and the last-measured ring date is AD 1367.

Reference chronology	*t*-value	Span of chronology (AD)	Reference
Ulverscroft Priory, Leicestershire	7.9	1219–1463	Arnold et al. 2008
51/2 High Street, Burton-on-Trent, Staffordshire	7.6	1156–1387	Howard et al. 1997
2 Coffee Yard, York, North Yorkshire	7.5	1198–1359	Howard et al. 1992
John Bunny House, Wakefield, West Yorkshire	7.3	11921411	Morgan 1988
Leigh Court Barn, Worcestershire	7.1	1230–1343	Tyers 2006
St Leonard’s Church, Cotheridge, Worcestershire	6.8	1264–1426	Arnold and Howard 2020
Chicksands Priory, Bedfordshire	6.8	1200–1541	Howard et al. 1998b
Black Hostelry, Ely Cathedral, Cambridgeshire	6.4	1233–1376	Arnold et al. 2004
St Nicholas Church, Fyfield, Essex	6.3	1226–1343	Bridge 2005
22/4 Kirkgate, Newark, Nottinghamshire	6.2	1209–1328	Arnold et al. 2002
Warren Farm, Charterhouse, Somerset	6.1	1303–1500	Arnold and Howard 2011

Interpretation

Tree-ring analysis has resulted in the successful dating of 13 samples from the property, principally associated with the roof over the Northern Addition but also three from the cellar in the former open hall. Where complete sapwood does not exist the 95% confidence limit of 15–40 sapwood rings appropriate for mature oaks in this part of England has been used.

Ten samples from the roof over the northern addition have been dated within site chronology TEGLSQ01. Two samples, TEG-L07 and TEG-L09, a common rafter and a collar, retain complete sapwood, and have a last measured ring date of AD 1718. Both samples were examined under the microscope and found to have the spring cells of the following year and thus can be said to have been felled in the spring of AD 1719. Another seven samples have the heartwood/sapwood boundary ring, the average date of which is AD 1692, giving an estimated felling date range of AD 1717–32 (allowing for sample TEG-L16 having a last-ring date of AD 1716 with incomplete sapwood), consistent with these timbers also having been felled in, or around, the spring of AD 1719. Additionally, sample TEG-L02 matches sample TEG-L07 at t = 10.9, a level high enough to suggest the possibility that both timbers were cut from the same tree and hence, felled at the same time (spring AD 1719). The final sample TEG-L08 does not have the heartwood/sapwood boundary but with a last measured ring date of AD 1696 this would be estimated to have a *terminus post quem* for felling of AD 1711, and so could have been part of the same felling programme as the other samples.

The cellar ceiling in the former open hall is represented by three dated samples in site chronology TEGLSQ02. One sample, TEG-L15, retains its heartwood/sapwood boundary, the date being AD 1366, giving a felling date in the range of AD 1381–1406. Although the remaining two samples do not retain their heartwood/sapwood boundary, and so likely felling date ranges cannot be calculated, the level of cross-matching between the three timbers suggest that they are a coherent group. Hence, it seems probable that they were part of the same felling programme in AD 1381–1406.

Discussion and conclusion

Tree-ring analysis on the clasped purlin roof has established that it is constructed of timbers felled in, or around, the spring of AD 1719, thus corroborating previous research that suggested an eighteenth-century remodelling of this part of the property (Jones et al. 1990, 108).

The ceiling in the cellar of the late thirteenth-century open hall incorporates timbers felled during the late fourteenth or early fifteenth century, which are almost certainly reused pieces, providing a *terminus post quem* for alterations to this part of the building. It has been suggested (pers. comm. Jonathan Clark) that they originated from the roof of the hall. If this is the case, then either the hall is later than previously thought or that it was remodelled in *c.*1400.

The dated site chronology TEGLSQ01 was compared to an extensive range of reference chronologies but in general the highest levels of similarity are found with those from the surrounding regions suggesting that the woodland source from which the timbers were derived is likely to be relatively local. In contrast, site chronology TEGLSQ02 matched with a disparate set of reference chronologies beyond the East Midlands, including Essex and Somerset. However, this does not necessarily mean that the timbers were not locally sourced, it may be that the climatic signal where the trees were growing was overshadowed by other tree-specific environmental factors.

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Data of measured samples

Measurements in 0.01mm units

TEG-L01A 86
248 148 181 314 250 179 173 128 76 80 76 90 82 47 67 44 47 37 34 26
19 29 20 45 98 178 64 33 62 51 66 68 57 47 55 53 56 63 73 58
63 70 91 78 48 62 83 71 118 114 103 130 65 107 112 130 135 80 99 67
59 67 58 82 77 116 100 76 67 58 53 33 33 49 57 70 42 82 87 74
71 66 73 61 27 54

TEG-L01B 86
207 191 183 228 253 181 173 119 82 69 73 87 64 40 52 35 46 40 36 26
19 24 22 41 97 166 66 41 53 43 72 59 60 53 46 52 54 65 78 60
58 72 86 77 53 53 86 71 117 113 113 129 60 117 106 132 139 74 100 64
62 64 59 87 77 120 103 73 69 67 50 31 40 59 59 63 55 71 89 73
68 70 68 66 30 57

TEG-L02A 55
350 434 343 311 273 274 339 179 129 167 123 124 123 150 146 160 168 213 198 199
139 104 158 172 225 219 259 165 271 240 158 93 199 194 127 102 128 198 126 171
230 302 458 465 292 190 116 138 108 124 104 95 58 71 165

TEG-L02B 55
355 445 341 313 281 272 331 182 134 158 121 125 137 140 134 169 158 216 200 191
149 100 164 167 227 218 262 157 270 233 164 90 203 192 142 92 140 174 140 175
217 286 416 475 300 182 124 141 108 125 109 87 57 70 160

TEG-L03A 50
192 122 131 91 57 66 53 44 52 70 126 105 101 162 124 111 70 53 54 80
96 78 81 81 111 83 72 71 110 101 82 50 45 68 65 77 62 70 113 106
137 117 108 133 101 106 127 84 124 133

TEG-L03B 50
194 120 139 83 57 70 49 39 58 70 117 104 118 155 123 113 62 60 51 86
107 76 73 82 110 95 66 80 102 107 76 52 42 63 59 85 60 73 107 116
134 121 109 127 98 88 119 91 118 132

TEG-L04A 72
299 188 345 316 297 321 328 289 323 289 274 173 189 157 100 88 87 114 143 226
195 162 177 171 157 91 70 93 77 48 63 100 114 107 85 97 109 117 70 54
43 79 101 77 105 76 128 96 80 64 74 65 48 32 38 44 41 59 33 39
52 77 73 58 54 64 46 55 45 62 56 72

TEG-L04B 72
296 194 336 307 306 321 329 280 318 294 271 181 191 164 89 89 85 116 144 226
202 165 179 168 159 85 64 95 69 55 63 97 104 116 90 85 107 126 64 55
47 81 97 77 104 78 118 95 73 78 70 72 46 33 37 51 42 50 36 38
55 77 65 56 59 65 51 49 45 45 61 59

TEG-L06A 71
224 246 298 216 139 166 139 146 237 309 249 187 261 209 241 133 106 136 135 114
91 111 114 109 94 119 127 138 75 40 41 80 82 49 81 49 91 67 48 66
119 98 53 27 27 48 78 93 77 70 126 114 125 110 90 94 64 68 90 48
43 90 103 97 55 36 59 23 27 35 89

TEG-L06B 71
240 227 322 231 146 193 122 143 214 284 280 229 258 198 236 125 103 126 129 111
84 112 105 119 103 122 131 136 67 42 41 74 84 58 78 54 99 66 56 65
109 99 58 26 28 57 64 85 68 68 140 108 122 120 83 91 60 76 97 55
53 62 119 87 50 40 56 26 24 39 86

TEG-L07A 71
415 236 278 223 206 217 168 280 191 189 197 177 273 139 153 130 91 140 166 142
189 209 172 267 201 209 160 104 161 184 187 252 215 100 283 218 138 64 165 158
117 91 109 148 104 143 141 154 296 280 192 91 105 121 120 91 79 68 49 65
71 87 40 50 90 74 65 75 50 44 54

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416 233 277 224 206 208 178 272 190 186 206 185 232 140 156 126 99 135 165 147
187 211 172 260 191 220 143 108 159 182 170 237 216 127 262 230 136 67 167 153
105 90 112 156 102 148 141 159 290 263 211 109 100 119 90 126 77 74 56 57
61 78 50 48 89 71 71 65 67 51 51

TEG-L08A 56
224 348 242 329 319 370 273 276 200 186 170 186 214 191 223 164 156 186 156 140
125 77 84 79 60 61 72 102 93 96 99 103 119 62 30 41 65 69 61 67
61 85 70 47 61 101 115 70 46 48 64 42 76 60 63 64

TEG-L08B 56
268 300 282 316 303 393 256 306 235 188 173 180 212 181 215 171 164 184 161 142
117 77 80 75 67 63 71 93 90 100 95 105 110 69 35 33 59 71 61 66
59 89 68 64 46 95 111 82 47 60 60 37 72 67 66 62

TEG-L09A 57
109 68 53 53 60 62 59 88 207 357 299 247 161 119 77 147 138 141 236 180
280 206 143 108 160 155 135 139 165 220 143 177 181 195 321 281 193 142 151 122
95 62 58 52 48 59 60 70 55 71 94 64 51 35 47 39 52

TEG-L09B 57
111 69 56 53 65 64 72 89 255 342 282 246 153 113 88 133 129 137 228 184
263 217 134 113 159 148 129 141 170 211 140 178 178 193 328 266 188 133 147 117
89 63 60 53 43 58 61 66 54 75 87 73 58 43 51 42 48

TEG-L11A 84
20 177 225 250 247 120 169 167 121 256 243 232 250 248 284 289 230 282 175 215
165 76 104 84 122 147 237 194 191 168 137 125 67 52 75 57 55 58 112 137
113 93 110 115 137 78 54 48 79 98 91 114 92 125 78 73 73 99 60 46
37 55 40 65 65 46 56 48 60 54 56 53 70 41 46 57 47 49 87 101
79 34 45 50

TEG-L11B 84
273 177 229 247 248 132 195 173 118 244 256 220 261 246 286 278 235 297 178 225
155 94 89 92 117 149 241 197 199 169 140 125 70 50 78 51 50 64 119 130
111 101 98 118 135 77 53 52 86 87 91 127 89 134 65 80 66 101 69 51
35 48 42 65 67 43 56 50 59 54 62 44 67 46 42 57 54 48 89 103
67 38 42 54

TEG-L12A 42
265 269 118 101 68 115 234 213 207 390 168 280 217 176 74 154 161 108 108 93
124 113 139 165 160 315 188 152 131 121 169 152 208 154 140 135 140 149 146 88
121 88

TEG-L12B 42
243 256 120 92 70 114 236 244 214 386 165 280 222 173 86 143 161 112 104 86
127 121 134 158 164 318 194 146 124 132 168 156 205 154 138 137 133 160 135 87
116 89

TEG-L13A 70
235 344 399 420 406 488 424 457 309 369 193 140 146 168 197 283 437 323 352 331
291 175 111 100 91 63 69 78 133 200 164 126 132 159 253 147 109 83 154 184
140 167 133 163 145 77 96 75 61 56 33 37 56 42 36 39 49 70 50 68
28 50 60 37 41 32 40 39 46 50

TEG-L13B 70
208 351 376 412 377 463 433 441 292 386 221 178 157 188 229 291 439 341 347 320
285 173 111 97 91 72 65 82 131 198 174 124 118 170 248 152 109 91 153 176
142 167 135 159 139 90 93 68 65 64 31 34 56 37 35 39 53 67 41 68
38 50 57 44 45 22 38 44 51 49

TEG-L14A 229
122 113 128 188 148 128 101 79 39 30 29 34 47 54 30 38 32 28 29 27
22 22 37 50 57 78 100 101 148 168 130 184 162 142 106 76 79 98 107 99
116 87 82 31 87 45 74 79 59 71 44 85 73 95 140 109 101 87 87 107
61 31 20 39 28 46 49 61 74 63 28 41 30 41 42 39 35 37 35 30
37 29 21 91 117 108 134 76 98 120 99 118 204 235 120 153 172 129 133 93
158 155 110 117 144 136 177 158 187 207 118 140 102 151 132 150 117 181 151 67
128 176 147 56 34 50 41 70 55 101 46 100 77 60 123 94 51 76 126 73
111 120 123 179 142 148 93 96 99 111 89 85 122 123 107 86 78 87 85 65
76 86 91 84 107 186 139 69 61 110 113 75 96 103 63 48 52 79 96 78
104 94 108 83 93 70 84 58 84 62 57 61 84 82 78 50 49 55 39 150
106 87 80 50 46 65 55 124 54 56 54 109 90 76 88 54 46 97 82 83
72 97 83 98 76 67 106 55 82

TEG-L14B 229
141 100 171 198 174 122 94 83 22 29 26 31 57 45 44 42 27 25 26 26
29 33 39 42 62 86 102 109 152 175 119 192 155 102 113 98 85 109 114 95
113 89 80 35 88 51 64 90 67 60 50 84 75 89 142 96 102 95 93 118
77 34 30 42 30 47 41 63 79 64 26 39 38 37 43 30 39 34 32 27
26 30 24 97 128 119 123 88 84 128 105 113 232 242 115 146 162 126 127 96
151 161 116 105 141 144 175 156 205 201 122 125 105 158 128 157 110 179 148 72
132 170 147 60 35 47 45 77 58 102 48 94 76 60 121 92 52 74 127 64

119 122 127 176 146 155 95 88 108 108 88 87 108 121 107 88 78 83 84 69
80 79 96 79 109 156 117 78 64 101 106 78 89 102 63 47 50 81 100 80
104 101 104 79 92 63 81 66 84 65 50 62 77 93 74 58 42 54 45 143
109 82 77 50 51 69 51 125 55 53 50 103 87 71 96 50 50 101 79 78
80 95 91 102 66 69 105 54 65

TEG-L15A 140
422 216 242 165 146 174 188 132 71 98 80 94 135 181 153 135 165 213 219 222
118 191 182 131 87 89 69 138 122 114 92 142 153 113 144 132 77 88 157 116
131 80 103 153 98 78 66 56 97 87 49 59 75 96 76 67 89 105 84 45
39 77 73 67 76 106 83 73 74 58 58 71 54 71 57 61 51 54 109 79
88 76 77 64 68 71 54 76 80 60 45 63 65 83 99 92 78 78 47 82
76 84 142 95 90 136 75 134 110 71 83 81 101 93 79 55 81 85 124 129
155 149 194 182 146 145 174 141 103 101 96 105 101 123 157 197 194 132 142 228

TEG-L15B 140
367 314 238 161 154 162 189 120 77 82 89 122 132 183 141 137 151 215 224 215
104 217 195 124 96 96 60 128 118 115 94 142 158 99 152 118 78 96 159 125
122 81 99 153 89 78 66 53 86 89 54 68 73 98 75 73 79 103 79 44
42 68 68 73 85 102 87 61 75 58 63 40 55 64 59 62 48 53 104 80
87 79 76 50 71 70 62 76 74 60 46 57 66 83 99 90 73 73 60 80
65 76 142 84 101 120 83 132 94 80 83 79 100 95 79 60 74 98 113 124
153 159 183 180 141 148 170 153 100 93 99 90 111 123 162 190 203 138 140 198

TEG-L16A 124
251 261 284 232 340 241 324 343 281 253 417 381 220 132 214 155 293 194 167 154
185 197 132 169 205 111 142 204 114 209 200 214 332 190 218 254 236 238 252 196
138 149 253 250 171 162 193 213 165 131 223 245 216 300 301 245 219 181 222 150
206 233 210 168 152 114 137 161 141 209 167 165 172 224 160 160 187 185 213 134
125 195 193 221 196 180 203 121 178 223 250 224 160 162 238 184 309 215 207 203
239 221 230 233 198 197 309 214 239 250 274 219 259 218 216 236 217 198 303 201
186 179 156 189

TEG-L16B 124
264 252 290 231 343 237 306 340 298 257 403 384 219 137 211 160 296 178 176 148
166 184 151 185 206 123 146 189 119 233 186 219 335 187 223 257 230 246 254 189
134 154 250 247 168 167 184 210 158 138 229 247 217 318 287 235 215 182 236 155
210 223 209 167 152 116 140 168 157 205 174 160 179 198 181 160 186 188 208 134
128 200 185 212 192 167 202 118 173 213 247 240 162 156 245 184 300 215 185 212
243 219 264 227 204 180 303 217 236 234 271 231 256 224 205 238 215 195 272 221
190 170 189 170

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 Nottingham Tree-ring Dating Laboratory's Monograph, An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings (Laxton and Litton 1988) and Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 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

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.

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.

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).

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 (i.e. statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the t-value (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton et al. 1988).

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; e.g. 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 Figure 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).

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, 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 complement of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/ sapwood boundary or transition ring and denoted H/S). Fortunately, it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a post quem date for felling is possible.

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 (e.g. Baltic boards), then some allowance has to be made for this.

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.

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 AD 1810 is very apparent as is the smaller later growth from about AD 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in AD 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

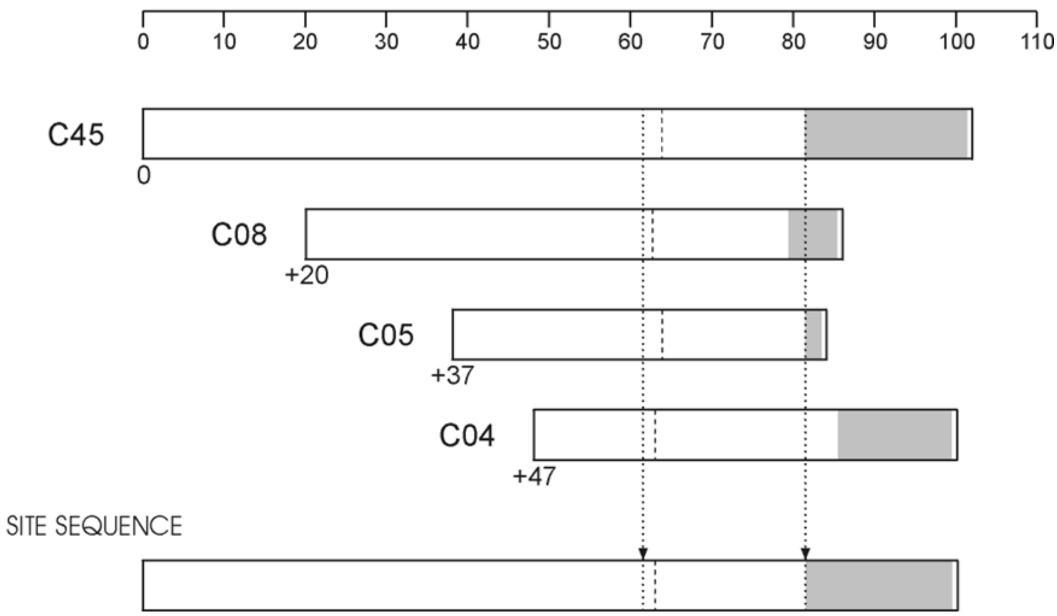


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them. The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are 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.

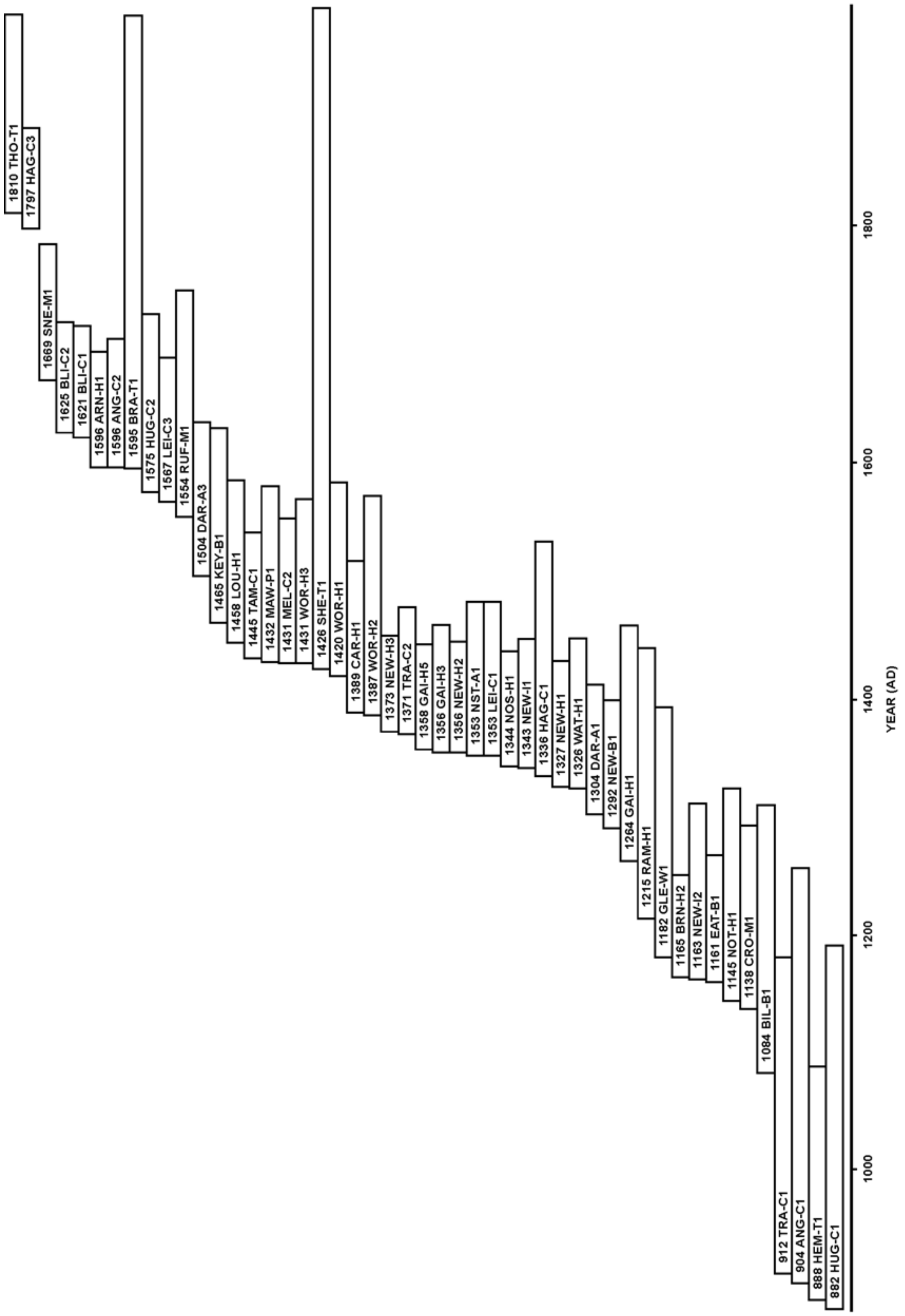
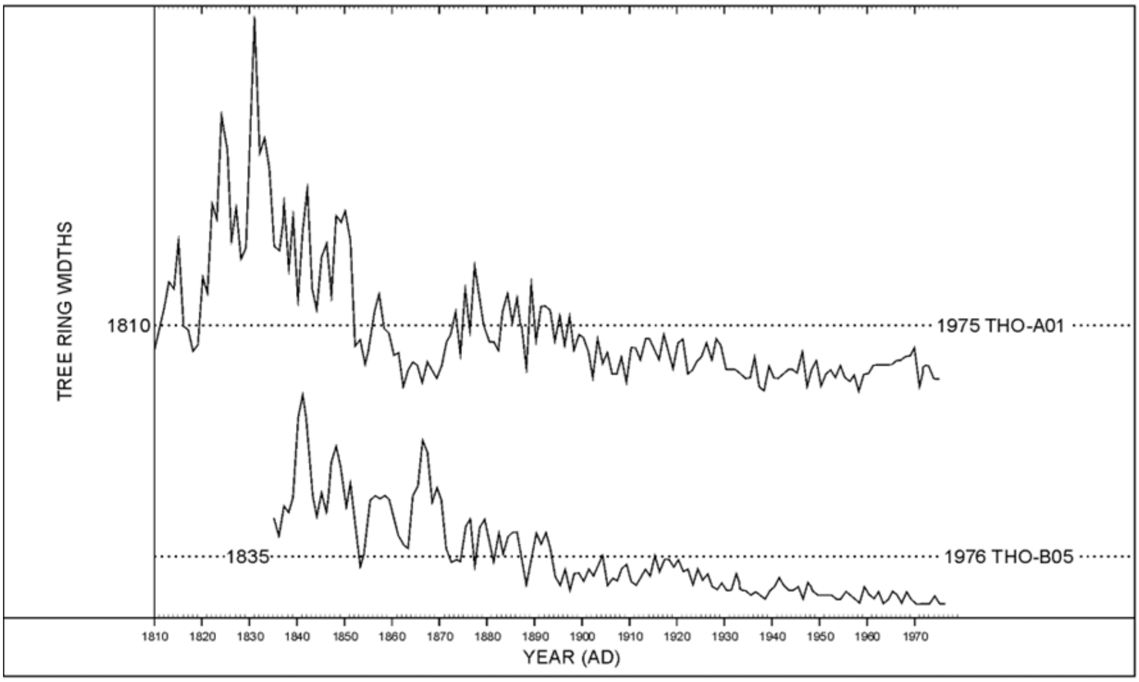


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)



(b)

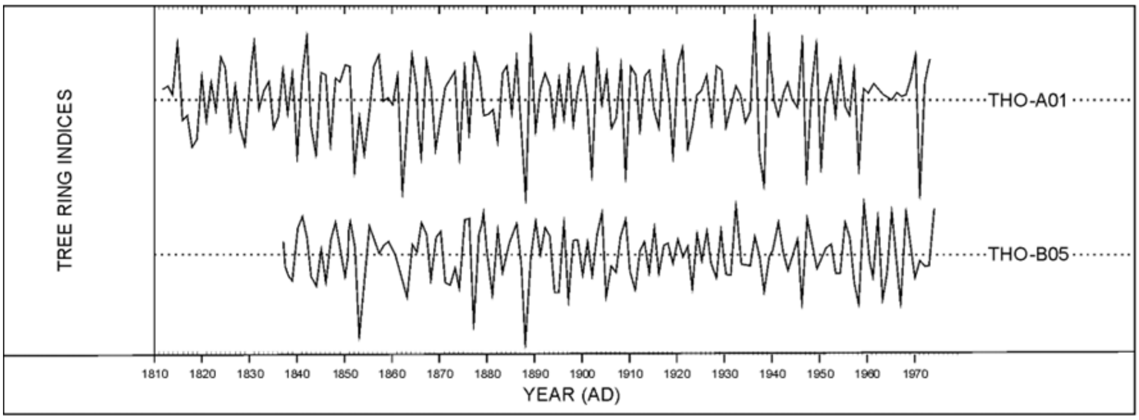


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young 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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