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6–8 Silver Street, Wakefield, West Yorkshire

Tree-ring Dating of Oak Timbers

Alison Arnold, Robert Howard and Cathy Tyers

Front cover image: The south front of 6–8 Silver Street, Wakefield. [© Mr John Turner. Source: Historic England Archive, IOE01/03859/32]

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Summary

Dendrochronological analysis undertaken on samples taken from timbers of this building resulting in the successful dating of eight of them. A wall plate is dated as being felled in the range of AD 1543–68, with a ceiling beam and a king post being a little later, dating to AD 1587–91 and AD 1584–1609, respectively. The other dated timbers have *terminus post quem* dates for felling at the very end of the fifteenth or in the sixteenth century and are also thought likely to date to the sixteenth century/early-seventeenth century.

Contributors

Alison Arnold, Robert Howard and Cathy Tyers

Acknowledgements

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Archive location

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

Historic Environment Record

West Yorkshire Historic Environment Record, c/o West Yorkshire Joint Services, Nepshaw Lane South, Morley, Leeds LS27 7JQ

Date of investigation

2022

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Contents

Introduction

Wakefield Upper Westgate High Street Heritage Action Zone

The West Yorkshire City of Wakefield lies between Leeds and Sheffield, approximately 13km south of Leeds (Fig 1). The Upper Westgate Conservation Area lies within the historic core of Wakefield and borders the Wood Street Conservation Area and the Cathedral Conservation Area. Westgate is one of the four principal streets radiating from the marketplace. It acts as a gateway to Wakefield town centre and has a wealth of eighteenth- and nineteenth-century buildings.

Wakefield Upper Westgate is one of more than 60 successful High Street Heritage Action Zone (HSHAZ) bids selected in 2019, a programme which is being delivered by Historic England, in partnership with local bodies, to unlock the potential of high streets across England, fuelling economic, social, and cultural recovery. Dendrochronology is one of the supporting elements to the HSHAZ programme to improve the understanding of the town centre area to inform and support future planning and improvement decisions.

6–8 Silver Street

Silver Street runs broadly north-east to south-west with this Grade II listed (List Entry Number: 1258693) timber-framed building being located on the north-west side of Silver Street, which extends from the top of Westgate (Fig 1). The oldest part, thought to be seventeenth century, is that fronting onto Silver Street which consists of four bays and being jettied at second, third and gable level. Behind this is a later addition containing a stair (Fig 2). The impressive frontage (to Silver Street) is close studded with some panels of herringbone framing (Fig 3) and the roof is of king-post type (Fig 4). Previously, listed as the former Black Swan Public House, the public house now only occupies the rear range with the front range being split between two businesses.

Sampling

Dendrochronological investigation was requested by Nicky Brown (Historic England Heritage at Risk Projects Officer) and Maria Carballeira Rodriguez (Historic England Architect), as one of the supporting elements to the HSHAZ programme, to deliver towards the overall objectives of the HSHAZ programme and to provide independent dating evidence to inform the programme of timber analysis, conservation, and repair towards the future care of this space.

Fourteen oak timbers (*Quercus* sp.) were taken from in situ timbers throughout the structure with each being given the code WKF-C and numbered 01–14. The location of sampled timbers has been marked on Figures 5–8 with further details relating to these samples given in Table 1. For the purposes of this report the Silver Street frontage of the building is deemed the south face. The main trusses and bays have been numbered from east to west.

Analysis and Results

At this stage it was seen that three of these samples were found to have too few growth rings (<30) to make secure dating a possibility and so were rejected prior to measurement. The remaining 11 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. All measurements were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in six samples grouping at a minimum value of *t* = 3.8.

These six samples were combined at the relevant offset positions to form WKFCSQ01, a site sequence of 163 rings (Fig 9). This site sequence was then compared against a series of relevant oak reference chronologies at which point it was found to match consistently and securely at a first-ring date of AD 1409 and a last-measured ring date of AD 1571. The evidence for this dating is given by the *t* – values in Table 2.

Attempts were then made to date the remaining five ungrouped samples by comparing them individually against the reference chronologies at which point samples WKF-C01 and WKF-C07 were found to span the periods AD 1450–1586 and AD 1426–88, respectively. The evidence for this dating is given by the *t* – values in Tables 3 and 4. The remaining samples could not be matched and are undated.

Interpretation

Tree-ring analysis has resulted in the successful dating of eight samples from the roof and structure of this building (Fig 10). Felling date ranges have been calculated using the estimate that 95% of mature oak trees in the area have between 15 and 40 sapwood rings.

Only three of the dated samples have the heartwood/sapwood boundary ring, the dates of which vary to such an extent that at least two separate felling phases are indicated. The earliest heartwood/sapwood boundary is for sample WKF-C11 (AD 1528), allowing an estimated felling date to be calculated for the timber represented to within the range AD 1543–68. Somewhat later are samples WKF-C01 (from a ceiling beam) and WKF-C13 (south gable king post). The heartwood/sapwood boundary ring dates of these samples are AD 1551 and AD 1569, allowing estimated felling dates to be calculated of AD 1587–91 and AD 1584–1609, respectively. In the case of sample WKF-C01 this felling date range allows for the sample to have the last-measured ring date of AD 1586, with incomplete sapwood.

The other dated samples have a series of *terminus post quem* dates for felling, ranging from AD 1492 (WKF-C08) to AD 1576 (WKF-C04). With the exception of sample WKF-C04, these samples could have been felled in the mid-sixteenth century with WKF-C11, or the late-sixteenth century/very early-seventeenth century with WKF-C01 and WKF-C13, or could alternatively represent a separate felling phase.

Discussion

The dendrochronology has identified timbers from the mid and late-sixteenth/early-seventeenth century with those timbers with *terminus post quem* dates for felling also thought likely to belong to the sixteenth/early-seventeenth century.

The site sequences against which WKFCSQ01 can be seen to match most highly against (Table 2), are from buildings in the East Midlands and Yorkshire which, given the location of Wakefield, is unsurprising and points towards a relatively local woodland source being utilised for the timber, as would be expected in this period. Interestingly, the references against which the individually dated samples are matched (Tables 3 and 4) are much more widespread despite being from the same general period in time. This might suggest that timber from more than one woodland source was utilised within the building.

It is unfortunate that so many of the samples do not have the heartwood/sapwood boundary giving a degree of uncertainty for the felling of a number of the timbers. Access to many of the timbers was restricted due to them being deeply embedded in the wall and with only one face being visible. A number of the timbers were also in a rather poor condition which had also impacted the survival of sapwood.

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Tables

Table 1: Details of tree-ring series from 6–8 Silver Street, Wakefield

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
First-floor level						
WKF-C01	Ceiling beam @ truss 2	137	35	1450	1551	1586
WKF-C02	Ceiling beam @ truss 3	NM (29)	--	----	----	----
WKF-C03	North wall post, truss 2	NM (28)	--	----	----	----
WKF-C04	South wall post, truss 2	88	--	1474	----	1561
WKF-C05	South wall post, truss 3	71	--	1425	----	1495
WKF-C06	North wall beam, truss 1–2	120	--	----	----	----
WKF-C07	Stud, bay 3	63	--	1426	----	1488
WKF-C08	South bressummer, bay 2	69	--	1409	----	1477
WKF-C09	South bressummer, bay 4	103	--	1409	----	1511
Second-floor						
WKF-C10	Ceiling beam, truss 2	163	h/s	----	----	----
WKF-C11	South wall plate, bay 1	100	h/s	1429	1528	1528
WKF-C12	West principal rafter, south gable truss	116	--	----	----	----
WKF-C13	King post, south gable truss	100	02	1472	1569	1571
WKF-C14	Ridge, middle to south gable truss	NM (29)	--	----	----	----

NM = not measured; h/s = the heartwood/sapwood boundary is the last ring on the sample

Table 2: Results of the cross-matching of site sequence WKFCSQ01 and example reference chronologies when the first ring date is AD 1409 and the last-measured ring date is AD 1571

Site reference	*t* – value	Span of chronology AD	Reference
Hardwick Old Hall, Derbyshire	9.4	1375–1590	Howard et al. 2002
Howley Hall, West Yorkshire	9.4	1415–1632	Arnold and Howard 2014
Bishops’ House, Sheffield, Yorkshire	9.4	1399–1579	Arnold and Howard 2021
Codnor Castle, Derbyshire	*8.6*	1381–1559	Arnold and Howard 2015
All Hallow’s Church, Kirkburton, Yorkshire	8.6	1306–1633	Arnold and Howard 2007
Dronfield Woodhouse Hall, Derbyshire	8.3	1342–1533	Arnold and Howard 2014
Oughtibridge Hall, Sheffield, Yorkshire	8.3	1424–1581	Arnold et al. forthcoming
Headlands Hall, Liversdege, Yorkshire	8.2	1388–1487	Tyers 2001a
Black Ladies, near Brewood, Staffordshire	8.2	1372–1671	Tyers 1999
Head Farm, Barnsley, Yorkshire	7.9	1385–1627	Tyers 2006

Table 3: Results of the cross-matching of sample series WKF-C01 and example reference chronologies when the first ring date is AD 1450 and the last-measured ring date is AD 1586

Site reference	*t* – value	Span of chronology AD	Reference
2 High Street, Kelvedon Bridge, Essex	6.8	1522–1598	Bridge and Miles 2022
St Peter’s Church, Pirton, Worcestershire	6.3	1485–1585	Arnold and Howard 2014
Peterhouse College Chapel, Cambridge, Cambridgeshire	5.7	1489–1637	Bridge et al. 2021
Ravenstone Church, Buckinghamshire	5.4	1523–1643	Arnold and Howard 2010
Cressing Temple Farmhouse, Essex	5.4	1514–1608	Tyers 1995
Woburn Abbey, Bedfordshire	5.4	1515–1625	Miles 2023 unpubl
Rochford Hall, Essex	5.3	1523–1572	Morgan 1988
Prebendal Manor, Nassington, Northamptonshire	5.3	1514–1565	Arnold and Howard 2018 unpubl
Mill House, Alpheton, Suffolk	5.2	1501–1616	Bridge 2002
Rose Farm, Mapledurham, Berkshire	5.2	1543–1613	Haddon-Reece et al. 1990

Table 4: Results of the cross-matching of sample series WKF-C07 and example reference chronologies when the first ring date is AD 1426 and the last-measured ring date is AD 1488

Site reference	*t* – value	Span of chronology AD	Reference
Magdalen College, Oxford, Oxfordshire	6.6	1277–1480	Miles et al. 2018
New Hall Farm barn, Ardsley, Yorkshire	6.3	1412–1532	Tyers 2010
ole, Sevenoaks, Kent	6.0	1323–1541	Arnold et al. 2008
15/19 Station Street, Mansfield Woodhouse, Nottinghamshire	5.8	1431–1538	Howard et al. 1997
Old Palace, Croydon, London	5.6	1320–1538	Arnold and Howard 2021
Great Watching Chamber, Hampton Court, London	5.5	1407–1534	Bridge and Miles 2015
The Golden Cross, Cawthorn, Yorkshire	5.2	1436–1516	Hillam 1983
Westenhanger Manor Barn, Stanford, Kent	5.2	1323–1489	Arnold and Howard 2009
Acton Court staircase, Iron Acton, Gloucestershire	5.2	1376–1575	Haddon-Reece and Miles 1994
New House Grange Tithe Barn, Sheepy Magna, Leicester-shire	5.1	1373–1506	Tyers 2001b

Figures

Figure 1: Map to show the location of 6–8 Silver Street, Wakefield. Marked in red: top left on map of England; top right scale: 1:6000; bottom scale 1:1250. [© Crown Copyright and database right 2023. All rights reserved. Ordnance Survey Licence number 100024900]

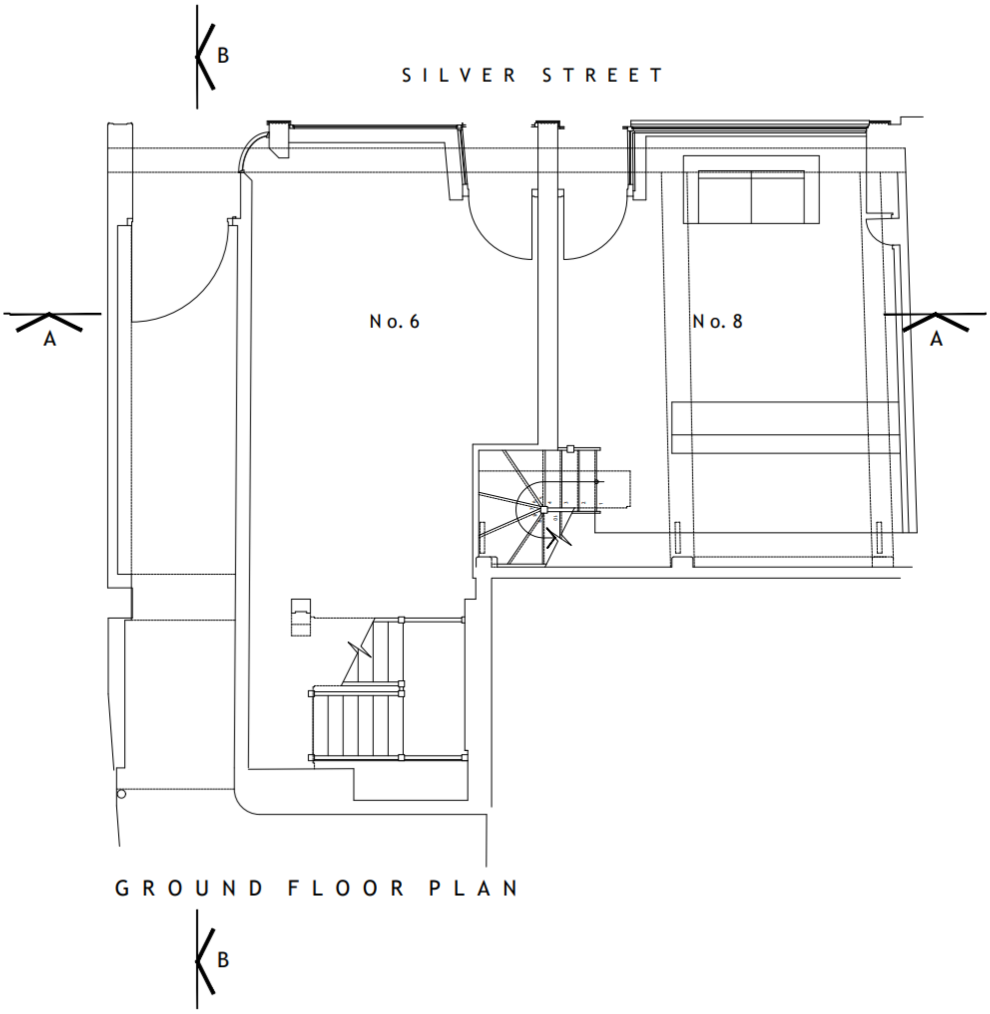

Figure 2: Ground-floor plan. [inc. architecture limited]

Figure 3: South wall at first-floor level, showing the timber framing of bays 3 and 4, photograph taken from the south-east. [Photograph: Robert Howard]

Figure 4: King-post roof, photograph taken from the south-west. [Photograph: Alison Arnold]

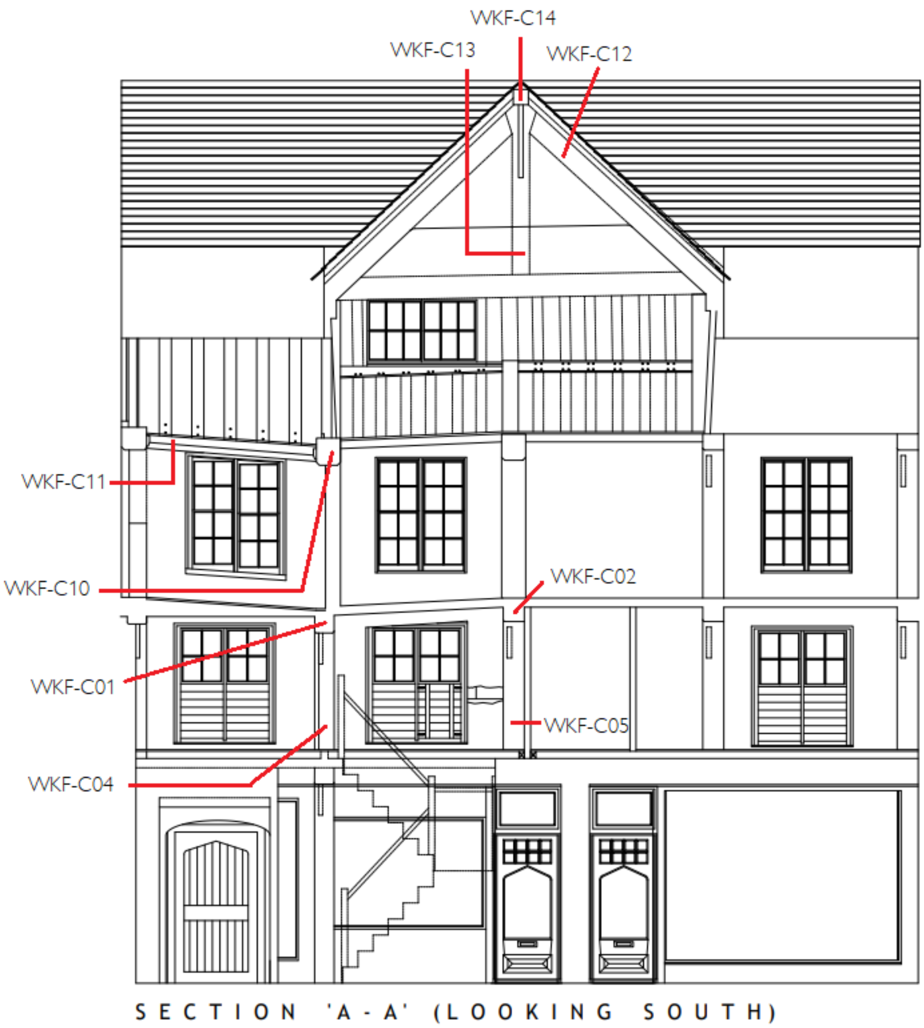

Figure 5: Section, showing sampled timbers. [inc. architecture limited]

Figure 6: Location of sampled timbers, photograph taken from the south. [Photograph: Alison Arnold]

Figure 7: Sampled timbers at first-floor level, photograph taken from the south-west. [Photograph: Robert Howard]

Figure 8: Sampled timber, photograph taken from the south-west. [Robert Howard]

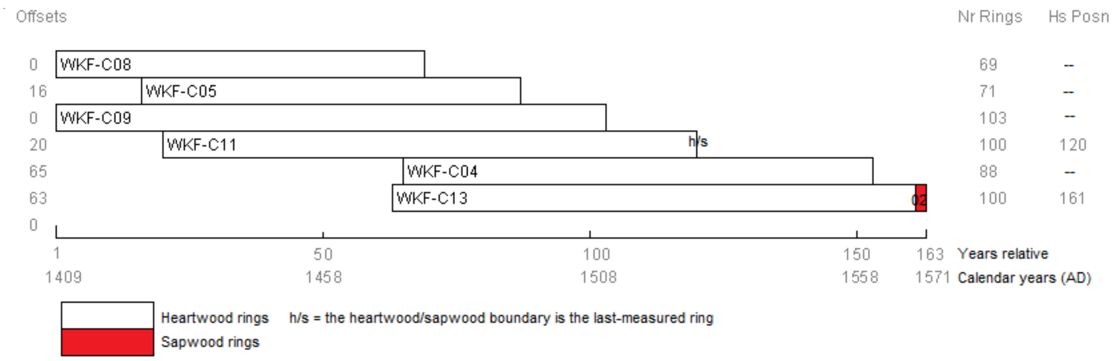

Figure 9: Bar diagram of samples in site sequence WKFCSQ01.

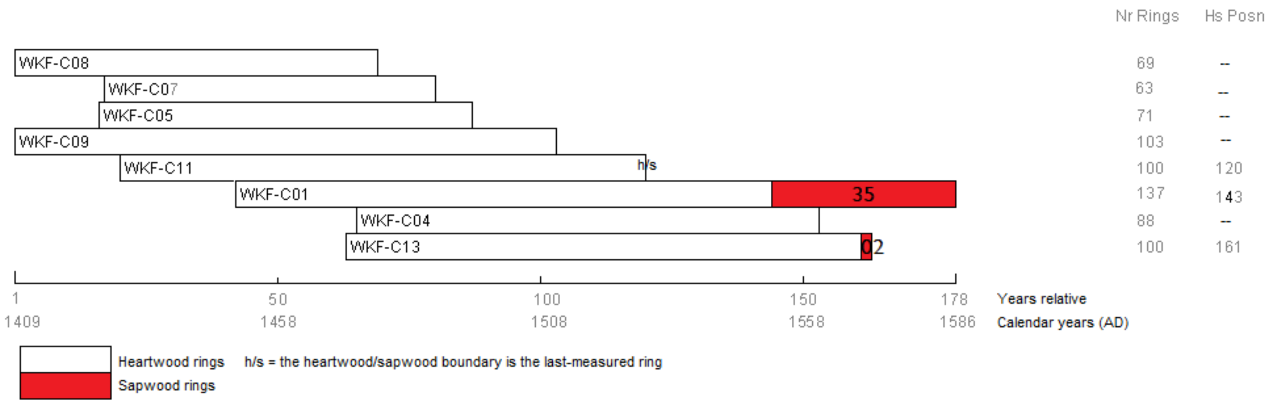

Figure 10: Bar diagram of all dated samples, sorted by last-heartwood ring date.

Data of Measured Samples

Measurements in 0.01mm units

WKF-C01A 137
291 423 347 190 147 83 212 281 232 372 339 192 186 158 115 99 87 110 123 128
121 190 245 202 172 157 153 167 192 234 218 179 230 237 216 256 234 203 171 162
181 191 195 173 193 238 180 147 173 194 183 193 192 153 160 158 153 180 204 158
138 186 252 298 332 333 287 250 216 231 127 119 118 120 110 82 89 162 112 101
79 103 96 65 76 93 83 80 80 76 82 81 68 61 74 88 60 56 69 81
53 31 35 32 30 37 29 28 35 33 35 36 45 41 38 47 44 51 38 60
59 57 43 47 44 48 50 54 35 34 51 50 56 49 67 58 72
WKF-C01B 137
322 421 288 196 149 99 182 276 242 376 336 189 185 159 122 99 89 113 116 119
104 185 241 203 171 165 142 156 203 218 214 187 240 248 216 264 231 199 166 164
171 189 189 179 204 225 178 150 173 183 187 193 191 154 164 163 153 195 197 159
150 178 269 289 326 318 284 248 213 229 127 117 122 128 101 88 89 154 111 114
76 94 93 63 83 81 71 71 79 64 82 81 71 69 76 73 58 55 81 85
48 41 27 34 29 38 32 33 29 35 30 43 43 47 37 42 46 41 42 59
49 55 41 41 48 48 52 43 36 43 55 50 59 45 71 50 68
WKF-C04A 85
145 148 163 176 192 184 192 165 169 178 196 137 109 87 142 122 136 176 182 200
199 173 204 217 179 214 185 192 208 139 128 109 143 134 155 131 154 133 132 126
181 189 196 130 164 170 149 159 122 166 139 158 143 147 140 113 154 129 157 141
166 184 164 169 184 125 159 159 166 154 135 173 144 135 120 120 132 116 131 111
106 86 124 105 121
WKF-C04B 47
210 200 204 208 147 174 190 211 176 199 147 181 197 204 139 113 102 147 139 149
194 208 205 200 177 223 230 209 223 193 196 223 137 139 124 172 169 185 140 170
149 142 146 190 209 207 131
WKF-C05A 71
503 600 615 601 565 442 451 581 297 380 447 503 325 296 271 334 268 217 259 348
304 310 322 365 288 298 339 385 363 424 351 325 314 286 280 377 361 317 265 215
227 260 355 490 428 523 363 270 303 329 311 249 315 260 249 248 237 240 227 254
230 283 362 247 195 190 212 261 226 364 341
WKF-C05B 71
482 594 613 599 508 480 449 597 279 377 444 509 325 295 271 342 242 229 298 357
299 310 313 357 296 308 321 376 342 439 345 345 308 282 286 372 362 302 274 221
229 257 361 476 413 507 370 277 307 318 297 259 315 252 251 240 235 237 233 256
209 281 340 247 192 178 211 254 225 322 358
WKF-C06A 120
319 230 248 219 296 228 284 205 207 214 189 213 205 154 209 178 173 275 220 197
131 125 146 119 111 123 149 128 109 120 143 141 154 128 111 125 105 157 147 101
123 123 101 103 116 135 129 123 97 96 105 79 81 60 80 50 54 55 56 93
77 75 78 80 84 64 53 79 43 44 68 55 50 57 53 58 75 48 51 53
54 64 40 47 37 44 34 36 38 33 49 41 37 34 45 28 30 31 32 32
28 25 69 47 40 39 45 33 42 47 42 42 39 37 50 34 46 37 39 27
WKF-C06B 120
307 236 239 223 298 252 276 213 208 206 187 212 209 151 223 184 177 264 210 185
152 131 149 132 115 133 174 119 115 117 144 141 147 127 115 127 111 151 141 103

110 99 110 106 112 123 119 128 97 99 102 81 79 65 68 51 52 49 61 89
84 75 78 84 82 69 53 78 44 42 65 58 50 54 57 53 74 53 48 59
52 60 42 46 42 40 41 32 41 34 48 40 38 40 36 31 30 27 25 32
30 31 70 40 44 37 49 33 40 49 44 53 32 32 49 39 39 38 37 33
WKF-C07A 63
161 143 172 209 149 154 183 167 164 167 159 175 177 189 224 166 182 187 187 170
173 190 183 144 168 198 169 144 156 146 145 134 101 113 121 144 171 147 140 120
140 134 143 194 199 140 159 129 108 144 158 43 38 31 31 41 35 48 49 39
50 53 60
WKF-C07B 63
165 140 175 207 150 154 172 164 170 161 157 180 180 166 195 163 167 187 185 171
166 194 193 138 174 210 165 156 142 161 143 128 101 113 128 139 167 143 140 128
131 135 155 187 204 134 155 134 113 151 153 40 34 35 39 35 35 37 46 45
47 56 67
WKF-C08A 69
168 136 117 152 149 129 137 143 138 160 95 167 243 184 228 164 139 95 82 105
97 86 101 156 102 110 107 130 123 124 91 135 127 96 149 150 137 116 131 146
127 118 166 134 124 117 120 128 102 108 105 95 82 97 79 79 101 113 107 122
78 117 134 126 132 180 146 153 169
WKF-C08B 69
160 138 121 150 149 135 133 153 139 157 91 171 248 184 224 161 144 91 66 98
91 91 100 148 89 111 111 119 135 119 92 126 138 97 148 161 125 118 129 145
129 121 165 138 125 120 115 125 109 100 108 95 85 94 81 78 106 107 112 131
84 119 124 126 135 198 147 148 171
WKF-C09A 103
353 277 249 293 257 337 359 418 358 234 234 475 379 277 358 265 245 209 237 235
285 262 269 296 267 215 231 187 154 117 159 207 252 164 345 324 252 165 187 200
240 176 195 244 232 218 167 221 156 138 187 170 151 186 182 225 118 76 85 70
64 78 90 80 117 112 138 162 141 112 133 180 100 64 70 102 95 80 118 79
46 47 74 75 76 70 118 194 137 123 203 168 124 173 211 288 285 174 215 156
159 108 198
WKF-C09B 103
343 267 254 300 251 341 366 418 365 214 233 474 385 276 358 274 237 203 232 250
305 303 266 302 277 208 204 176 154 114 154 203 240 163 333 331 248 168 188 201
233 178 187 245 233 222 175 226 165 138 180 172 153 180 180 219 112 86 70 74
51 76 88 75 121 109 138 160 145 107 137 167 106 55 78 102 90 81 119 87
50 47 77 79 62 79 117 181 118 136 213 166 120 146 229 282 281 173 218 165
158 122 207
WKF-C10A 163
140 128 152 172 150 148 108 104 155 116 129 165 160 135 69 41 43 40 50 52
62 65 67 78 45 81 79 126 112 108 135 118 150 89 76 115 81 85 85 83
74 90 104 85 105 75 110 124 107 102 106 109 161 107 108 76 116 175 134 145
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81 80 96 83 88 104 105 127 87 60 45 47 57 69 81 78 70 115 81 88
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72 76 73 75 80 75 93 93 92 68 71 73 54 42 55 43 42 46 53 40
36 40 48 50 56 59 72 57 63 47 49 28 31 34 42 52 45 45 39 35
49 56 43
WKF-C10B 163
143 133 171 200 167 158 133 140 195 107 115 173 171 142 77 44 44 39 54 46
62 75 63 80 46 83 78 121 114 111 139 119 152 82 76 113 71 82 93 80

78 105 99 83 116 77 106 140 98 113 105 121 151 101 115 79 112 177 137 140
109 99 103 102 63 64 44 88 83 73 63 83 103 76 84 70 83 49 68 55
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92 93 83 39 45 42 37 49 63 57 55 61 63 68 77 85 63 61 49 48
77 72 75 79 80 73 89 100 81 81 70 69 55 39 51 51 38 46 53 45
39 37 48 50 51 63 72 50 59 46 50 33 33 30 44 48 53 32 44 40
44 56 53
WKF-C11A 100
148 189 187 295 200 148 199 157 161 119 147 215 164 168 175 209 179 134 134 116
122 131 104 121 171 136 143 141 124 138 132 174 155 194 184 148 177 156 154 156
117 118 104 101 83 85 109 120 98 74 73 72 86 62 62 67 73 59 87 68
54 61 80 76 74 92 75 92 76 78 81 79 74 73 85 82 71 87 86 79
84 73 75 69 70 80 58 62 69 58 58 42 48 29 47 66 44 49 44 52
WKF-C11B 100
147 186 192 308 197 150 205 163 157 124 148 214 162 168 180 211 179 130 133 126
125 128 110 131 158 135 126 140 119 134 132 168 154 201 185 148 177 158 158 149
119 124 112 94 98 79 117 131 96 71 74 76 72 65 64 66 68 66 81 67
54 56 79 79 77 84 77 99 71 75 76 82 70 75 79 81 78 76 86 85
81 75 78 66 60 77 61 71 63 59 56 40 53 35 48 54 52 46 34 51
WKF-C12A 116
287 269 245 187 199 197 211 210 211 175 168 207 161 149 172 183 170 169 75 129
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116 110 102 110 111 89 128 124 160 79 130 133 96 127 119 194
WKF-C13A 100
124 124 116 188 175 186 133 109 144 143 83 129 202 358 394 479 233 159 148 215
206 225 216 230 241 248 194 180 145 109 121 187 191 178 196 183 198 254 211 262
180 122 204 158 200 209 274 264 169 217 242 210 170 147 159 185 219 224 186 243
176 144 230 263 165 317 276 268 253 223 91 110 100 90 103 77 81 91 119 155
119 127 107 149 207 113 82 90 89 76 102 80 97 91 77 62 87 102 151 141
WKF-C13B 100
123 129 106 197 172 183 147 118 131 138 97 119 208 365 412 477 224 160 159 208
200 236 224 217 259 237 189 180 139 112 129 182 202 169 206 190 201 254 208 268
181 113 211 163 209 221 272 271 172 213 242 200 175 144 165 188 223 225 189 241
169 170 225 259 164 325 260 277 248 213 79 118 98 83 104 80 86 87 118 155
119 128 108 151 201 114 82 91 83 85 99 78 108 82 74 69 85 91 152 120

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

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

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 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

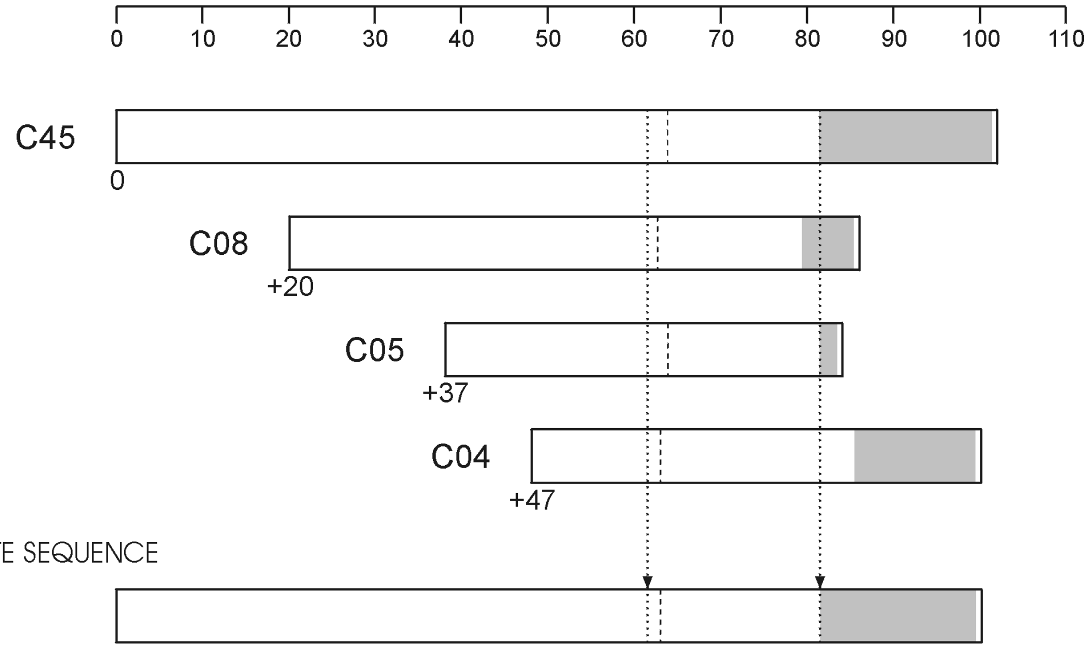


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are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

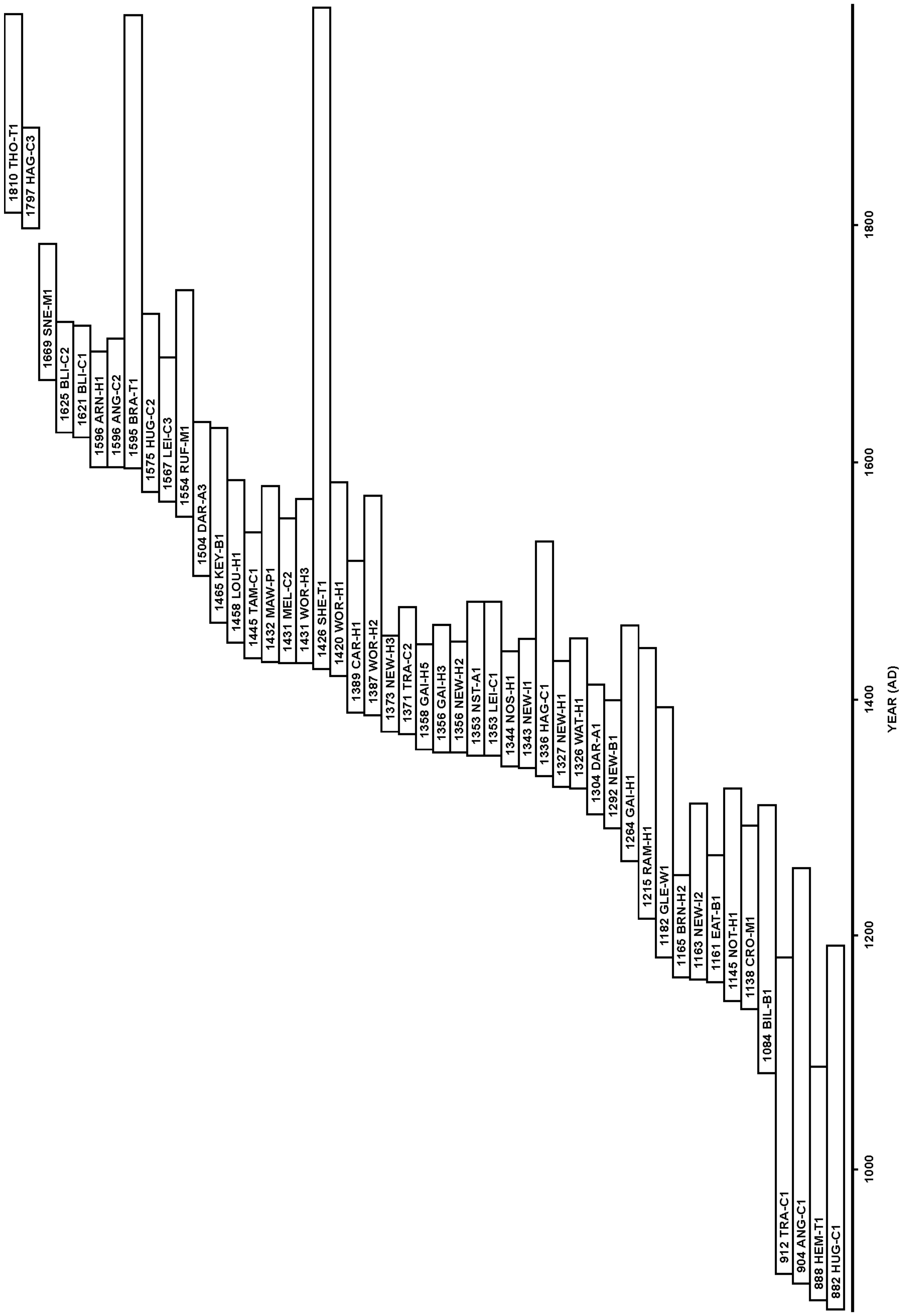
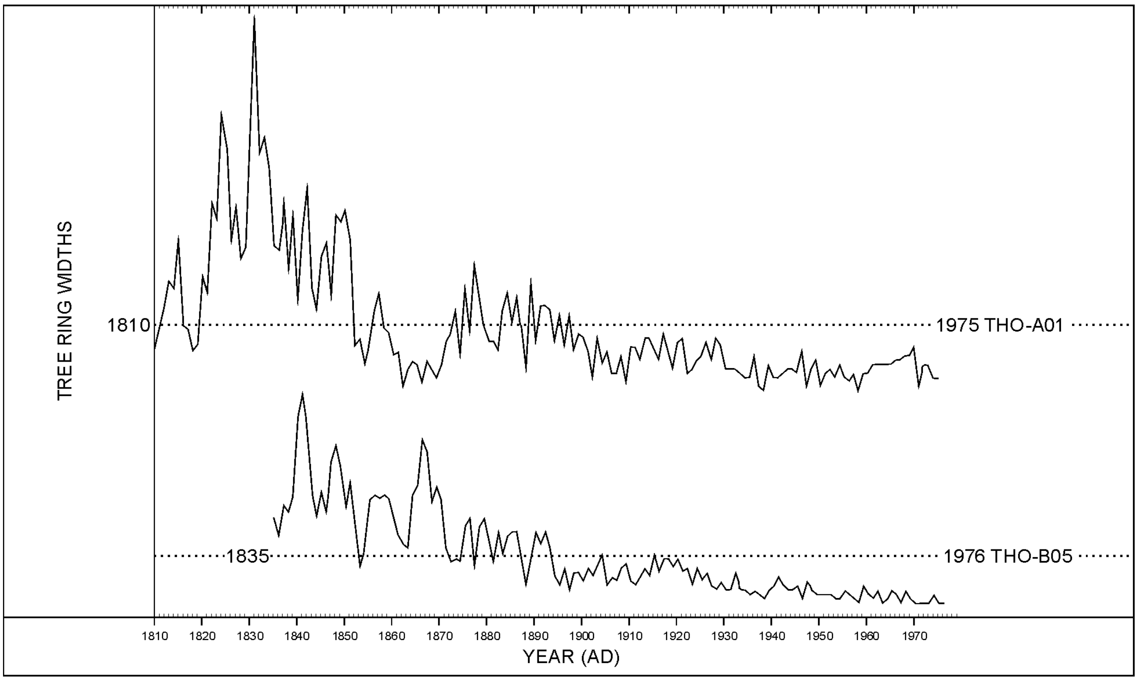


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

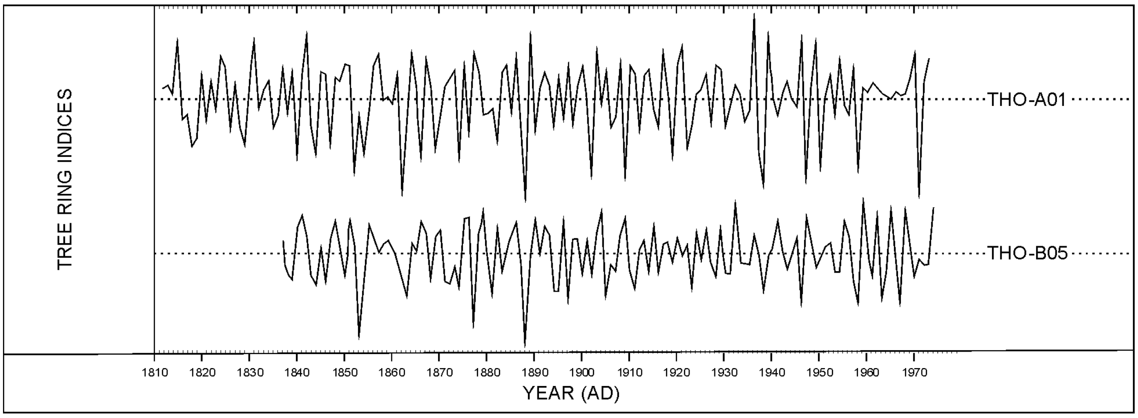


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known
Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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