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Gigi Bottega, Flying Horse Walk, The Poultry, Nottingham

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard and Cathy Tyers

Scientific Dating

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Summary

Dendrochronological analysis was undertaken on 19 of the 20 samples (one sample having too few rings for reliable analysis), obtained from different oak timbers throughout that part of the former Flying Horse Inn site now occupied by 'Gigi Bottega'. This analysis produced a single site chronology comprising 13 samples from timbers from both the first floor and the cellar. This site chronology is 89 rings long overall, these 89 rings being dated as spanning the years AD 1567–1655. Interpretation of the sapwood on the dated samples indicates that the timbers from both the cellar and first floor are largely coeval. The first floor contains at least three timbers, which were felled in AD 1647 and two others, which were probably felled at this date too, plus three timbers, which were felled in AD 1655. The cellar also contains one, and probably two timbers, certainly felled in AD 1655, plus three others, probably cut as part of either the AD 1647 felling or that of AD 1655.

Contributors

Alison Arnold, Robert Howard and Cathy Tyers

Acknowledgements

We would firstly like to thank the owner of Gigi Bottega, and all the staff there, for the help with this programme of tree-ring dating, and particularly for their forbearance during sampling. We would also like to thank Jonathan Kewley, Historic England Architectural Investigator, for not only helping in arranging access to this site and others, but also for providing plans, drawings, and photographs, and for providing much additional background information and other input into this report. Finally we would like to thank Shahina Farid, Scientific Dating Coordinator for Historic England for facilitating this site in particular and the overall project in general.

Front cover image

Flying Horse Hotel, Poultry, Nottingham [© Mr Alan Greaves. Source: Historic England Archive IOE01/07873/14]

Archive location

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

Historic environment record

Nottingham City Historic Environment Record, Brewhouse Yard Museum, Castle Boulevard, Nottingham NG7 1FB

Date of investigation

2021

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Introduction

The Fashion boutique and restaurant Gigi Bottega now occupies a portion of the Grade II former Flying Horse Inn and Hotel (List Entry Number: 1270519: https://historicengland.org.uk/listing/the-list/list-entry/1270519), itself now part of Flying Horse Walk shopping arcade situated between The Poultry and St Peter's Gate, just off the city's Old Market Square, in Nottingham city centre (Fig 1). It is traditionally believed that the Inn was established in AD 1483,with this date being visible on a carved plaque to the front of the building. Apart from probable earlier unrecorded alterations, the building is known to have been extensively restored in AD 1935, and again in AD 1989, when the Inn finally closed and the whole site was converted to retail and commercial use combined with some residential accommodation.

The Heart of Nottingham Heritage Action Zone (HAZ) is one of a number HAZ programmes, https://historicengland.org.uk/services-skills/heritage-action-zones/breathe-new-life-into-old-places-through-heritage-action-zones/, that aims to improve the city's attractiveness to investors and visitors, and to engage its residents. The objectives of the HAZ are to use the historic environment of Nottingham to reveal the city's history and in turn secure its future conservation. This will be achieved through various means from research and listing, through to innovative conservation and management. As part of this project, a number of potentially historic buildings in the city centre have been selected for survey, recording, and, where timbers are present, dating by dendrochronology (Kewley in prep.).

The premises of Gigi Bottega are one such candidate for dating, where a number of timbers are presently accessible. Although the building has undergone some further alteration and change, with some of the timbers within certainly known to have been moved and re-used, along with others showing evidence of possibly having been re-set, it is possible that some of these timbers are still in their original positions.

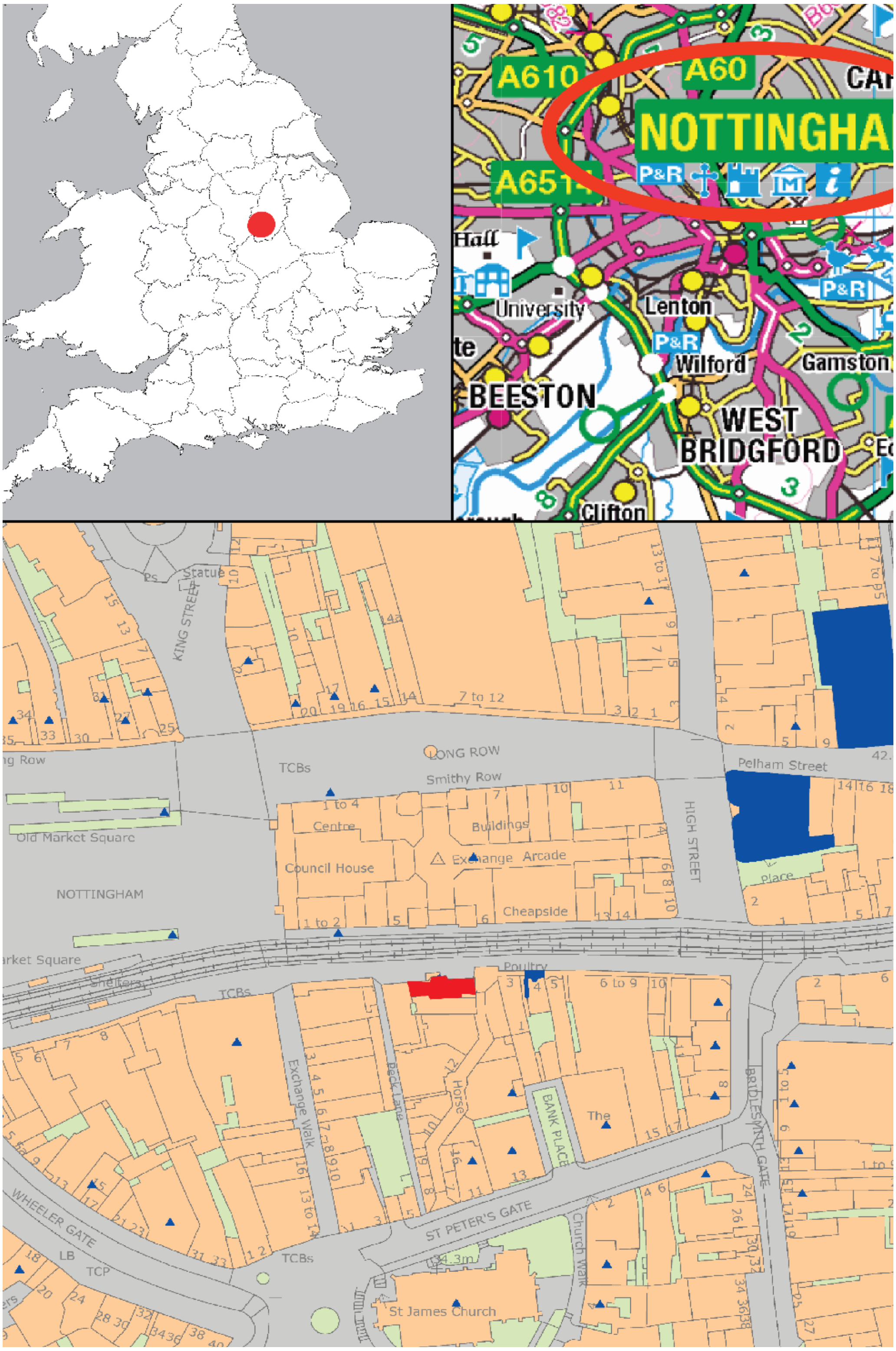


Figure 1: Maps to show the location of The Flying Horse in Nottingham, marked in red, with other listed buildings in the vicinity shown in blue. Scale: top right 1:105,000; bottom: 1:1,650. [© Crown Copyright and database right 2024. All rights reserved. Ordnance Survey Licence number 100024900].

Sampling

As part of the Heritage Action Zone project, a dendrochronological survey of the timbers within Gigi Bottega was requested by Jonathan Kewley. It was hoped that this might establish with greater precision and reliability the date of the timbers, possibly indicating the date at which any alterations might have been undertaken, and possibly establish if any original fabric, possibly of fifteenth-century date, remained, which would potentially confirm the long-held traditional date of the building.

Thus, from the oak (*Quercus* spp) timbers available, a total of 20 samples was obtained by coring. Each sample was given the code NGB-A (for Nottingham, Gigi Bottega, site ‘A’) and numbered 01–20. Samples were obtained from three distinct parts of the building, the majority of these coming from the ceilings, main beams, and available wall/partition timbers of the first floor, with a few timbers from the ground/shop floor also being sampled and, finally, samples were obtained from a small number of joists forming the ceiling of a cellar room below the shop floor area. Where possible, these sampled timbers have been located by reference to a set of plans drawn up for the 1935 renovation (Fig 2a/b), although in light of subsequent alterations, these do not now relate strictly to the present layout. The sampled timbers were, however, photographed at the time of sampling, these now being annotated with sample numbers as Figures 3a–i). Details of the samples are given in Table 1.

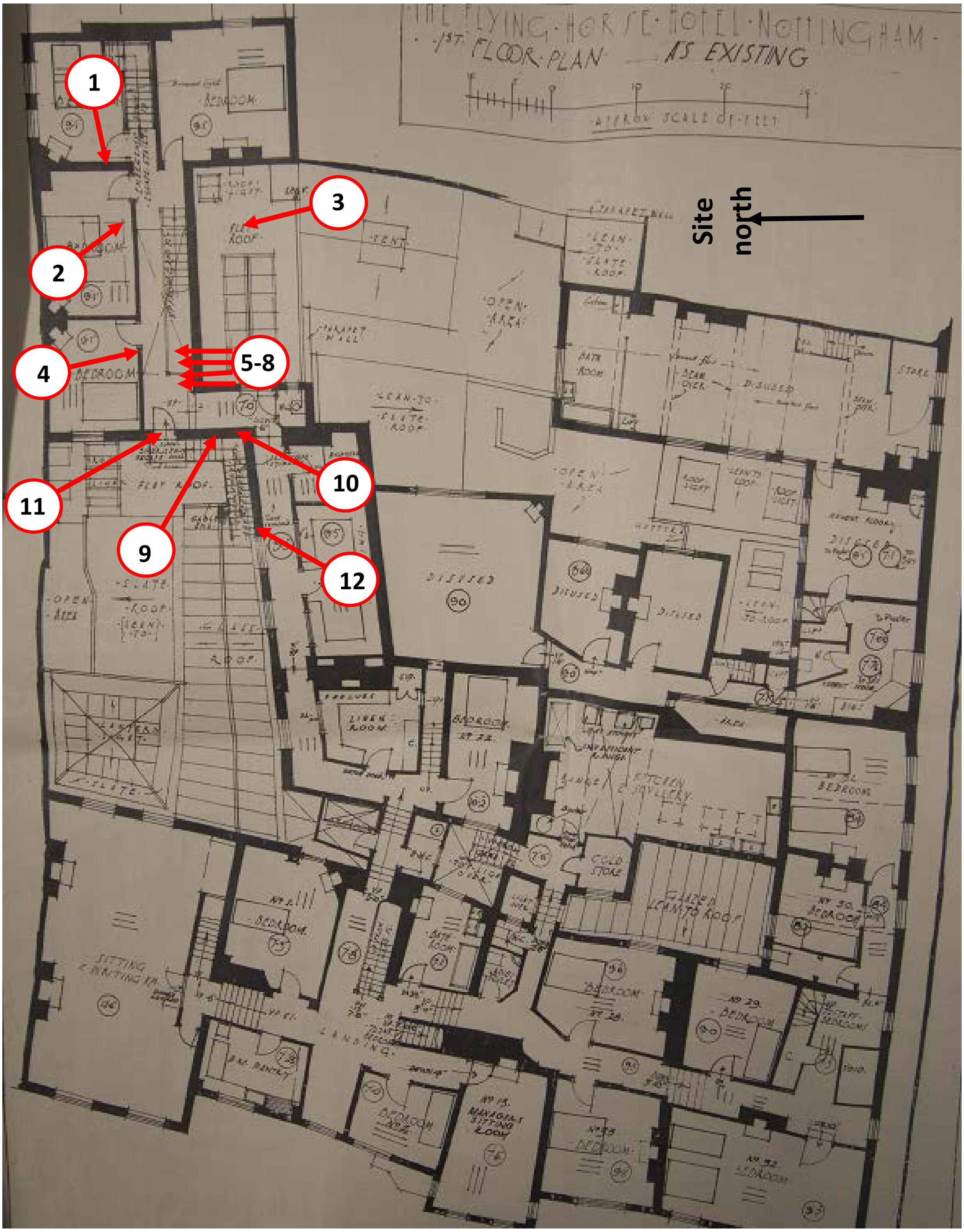


Figure 2a: Basic outline plan at first-floor level to help locate sampled timbers [© D G Millet. Source: Inspire Nottinghamshire Archives - CA/PL/2 The Poultry: Flying Horse Hotel, 27 Jul 1934 (no 16986), vol 1/24, p99]

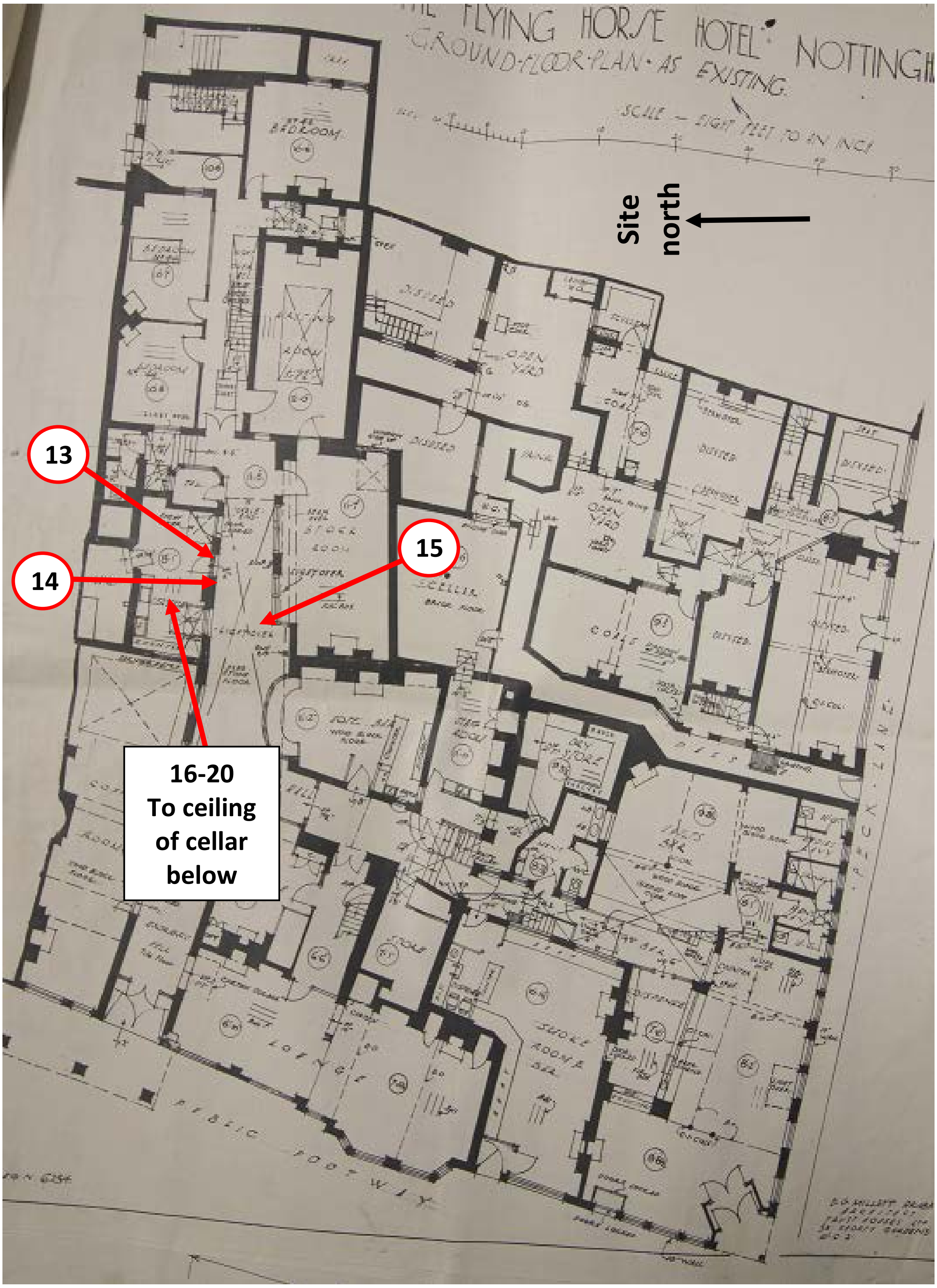


Figure 2b: Basic outline plan at ground/shop floor level to help locate sampled timbers, with approximate position of cellar timbers also [© D G Millet. Source: Inspire Nottinghamshire Archives - CA/PL/2 The Poultry: Flying Horse Hotel, 27 Jul 1934 (no 16986), vol 1/24, p99]

Figure 3a/b: Annotated photographs to help identify sample locations, first floor looking south-east (top) and looking south-west (bottom) [photographs Robert Howard]

Figure 3c/d: Annotated photographs to help identify sample locations, first floor looking south-west (top) and looking south (bottom) [photographs Robert Howard]

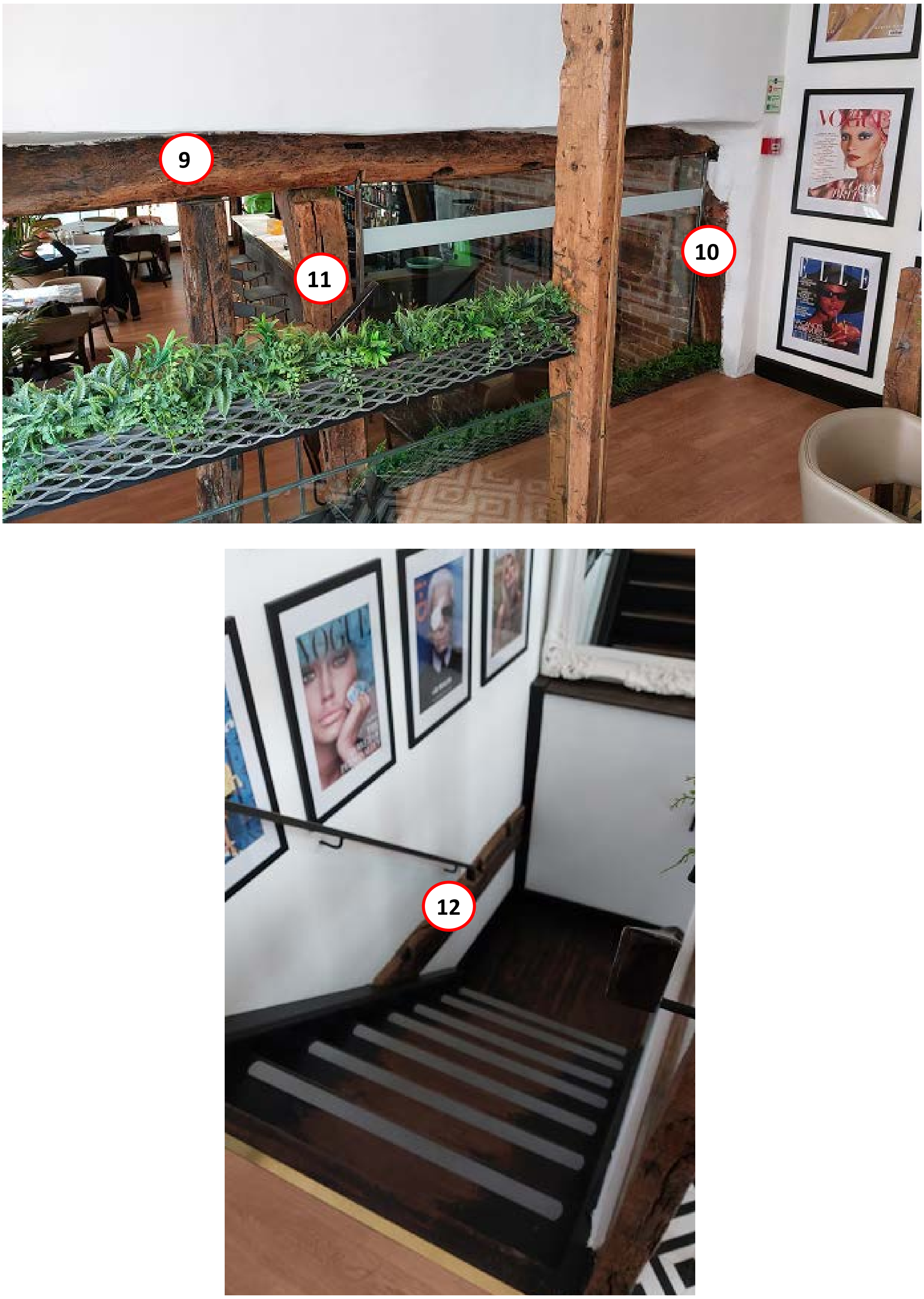


Figure 3e/f: Annotated photographs to help identify sample locations, first floor looking south-east (top) and looking south-west (bottom) [photographs Robert Howard]

Figure 3g/h: Annotated photographs to help identify sample locations, ground/shop floor looking north (top) and looking west (bottom) [photographs Robert Howard]

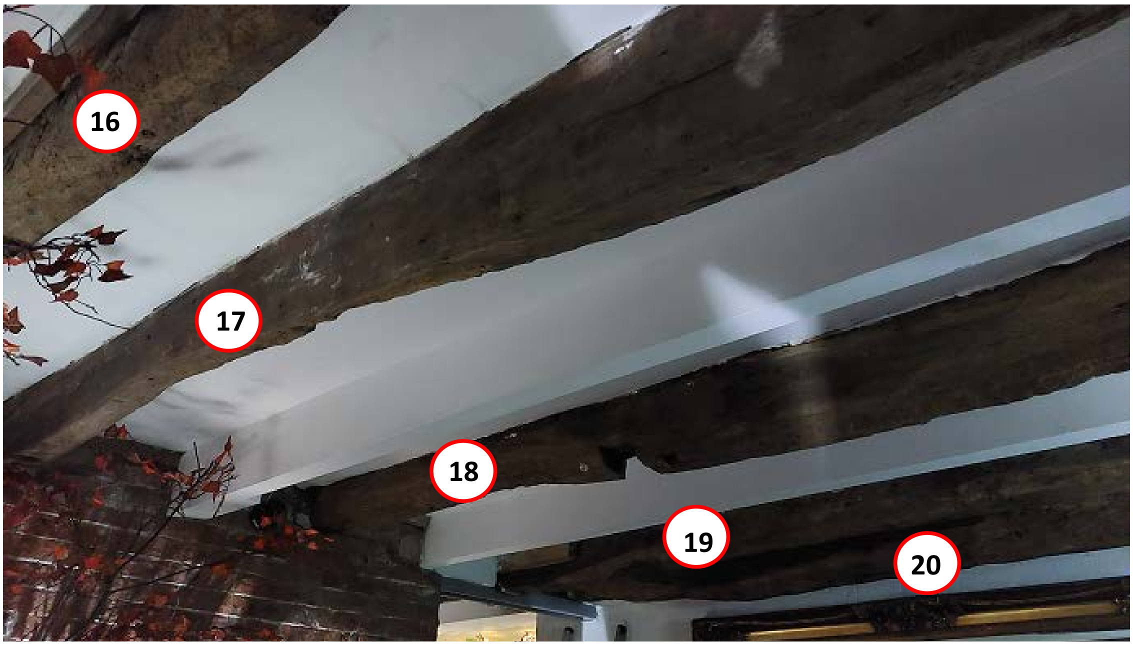


Figure 3i: Annotated photograph to help identify sample locations to the cellar ceiling looking south-east [photograph Robert Howard]

Table 1: Details of tree-ring samples from Gigi Bottega, Flying Horse Walk, Nottingham

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 timbers					
NGB-A01	Main ceiling beam 1 (from east end)	72	18C	1576	1629	1647
NGB-A02	Main ceiling beam 2 (north section)	47	17	1598	1627	1644
NGB-A03	Main ceiling beam 2 (south section)	63	18C	1585	1629	1647
NGB-A04	Main east–west ceiling beam between beams 3 & 4	89	17C	1567	1638	1655
NGB-A05	Common ceiling joist 1	72	16C	1576	1631	1647
NGB-A06	Common ceiling joist 2	37	17c	1616	1635	1652
NGB-A07	Common ceiling joist 3	34	no h/s	------	------	------
NGB-A08	Common ceiling joist 4	nm	------	------	------	------
NGB-A09	Main ceiling beam 4	86	24C	1570	1631	1655
NGB-A10	Main south wall post to line of ceiling beam 4	82	16	------	------	------
NGB-A11	Stud post to line of ceiling beam 4	60	h/s	1569	1628	1628
NGB-A12	Horizontal plate to stairway south wall	90	27C	------	------	------
	Ground/shop floor timbers					
NGB-A13	Bresummer to wall opening	43	5	------	------	------
NGB-A14	West post to wall opening	46	no h/s	------	------	------
NGB-A15	Post	102	h/s	------	------	------
	Cellar timbers					
NGB-A16	Ceiling beam 1 (from North	62	13	1580	1628	1641
NGB-A17	Ceiling beam 2	55	12	1594	1636	1648
NGB-A18	Ceiling beam 3	62	23C	1594	1632	1655
NGB-A19	Ceiling beam 4	50	h/s	1585	1634	1634
NGB-A20	Ceiling beam 5	63	13	1581	1630	1643

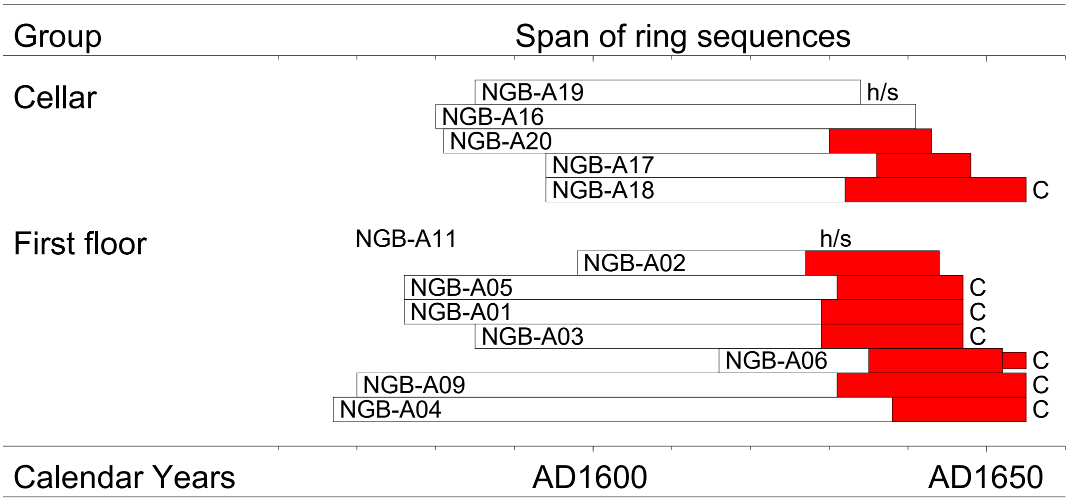
h/s = the heartwood/sapwood ring is the last ring on the sample; nm = sample not measured; C= complete sapwood is retained on the sample; c= complete sapwood is found on the timber but all or part has been lost from the sample in coring.

Analysis and results

Each of the 20 samples obtained from the oak timbers within Gigi Bottega was prepared by sanding and polishing and, although it was seen at this time that some samples had quite low numbers of annual growth rings, they were all measured apart from sample NGB-A08, which had only approximately 20 rings. These data are given at the end of this report. The 19 measured oak series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the production of a single group of 13 samples, these cross-matching with each other at a minimum value of *t*=3.5 (Fig 4).

These 13 cross-matching samples were combined at their indicated offset positions to form NGBASQ01, a site chronology with an overall length of 89 rings. This site chronology was then compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1567 and the date of its last measured ring is AD 1655 (Table 2).

Site chronology NGBASQ01 was then compared with the six remaining measured but ungrouped samples. There was, however, no further satisfactory cross-matching. These six measured but ungrouped samples were then compared individually with the full complement of oak reference chronologies, but there was no further satisfactory cross-matching, and all six samples must remain undated for the moment. In due course, as further Nottingham HAZ project data is acquired, or indeed buildings analysed outside of the HAZ project, these currently undated samples will be reanalysed.



White bars = heartwood rings; red bars = sapwood rings; narrow red bars = complete sapwood on timber but part lost during coring, the number of lost rings is estimated; h/s = outmost measured ring marks the heart-wood/sapwood boundary; C = completed sapwood present, the outermost measured ring lies immediately below the bark surface and represents the final year's growth of the tree prior to felling

Figure 4: Bar diagram of the dated samples sorted by floor level and date of end ring

Table 2: Results of the cross-matching of site sequence NGBASQ01 and relevant reference chronologies when the first-ring date is AD 1567 and the last-ring date is AD 1655

Reference chronology	Span of chronology	*t*-value	Reference
Bingham, Nottinghamshire; Working Mean Chronology	AD 1445–1752	10.0	Arnold and Howard 2014 unpubl
15/17 St John's Street, Wirksworth, Derbyshire	AD 1586–1676	9.5	Howard et al. 1995
Black Ladies, near Brewood, Staffordshire	AD 1372–1671	8.3	Tyers 1999
Ledston Hall, Ledston, West Yorkshire	AD 1424–1668	8.2	Arnold et al. 2015
Brewhouse Yard Museum, Nottingham	AD 1544–1701	8.1	Howard et al. 1994
St Stephen's Church, Sneinton, Nottingham	AD 1484–1654	8.0	Arnold et al. 2007
6 Market Street, Tamworth, Shropshire	AD 1558–1695	8.0	Howard et al. 1994
Fieldgate Farm, Acocks Green, Birmingham	AD 1496–1653	7.7	Howard et al. 1989 unpubl
Church of the Holy Cross, Epperstone, Nottinghamshire	AD 1477–1647	7.6	Arnold and Howard 2020 unpubl
Manor House, Sutton Scarsdale, Nottinghamshire	AD 1521–1658	7.5	Howard et al. 1996 unpubl

Interpretation

Dendrochronological analysis has thus successfully dated 13 samples from both the first floor and cellar timbers but unfortunately none of the three samples from the ground/shop floor. The presence of sapwood on a number of samples, some of it complete to the final growth ring of the tree before it was felled, and the presence of at least the heartwood/sapwood boundary ring on others, suggests that overall, while there are slight differences in the felling dates obtained, the dated timbers appear to be largely coeval.

First floor

Three samples from the first floor, NGB-A01, NGB-A03, and NGB-A05, retain complete sapwood, this giving each of the three timbers a precise felling date of AD 1647 (Table 1; Fig 4). Two other first-floor samples, NGB-A04 and NGB-A09, also have complete sapwood, but are slightly later, both timbers having a precise felling date of AD 1655 (Table 1; Fig 4). In addition, although the timber from which sample NGB-A06 was obtained appeared to have complete sapwood present, a small portion of the sapwood was lost during coring due to its friable nature. The amount of sapwood lost was approximately 3-4mm, equating to 3-4 rings using the average ring width of 1.11mm for the outermost 10 rings, which suggests, along with a heartwood/sapwood boundary date of AD 1635 that lies between that for NGB-A09 and NGB-A04, that it too was probably felled in AD 1655.

Two further first-floor samples, NGB-A02 and NGB-A11, have heartwood/sapwood boundary dates (respectively AD 1627 and AD 1628) similar to, but very slightly earlier than, those on NGB-A01, NGB-A03, and NGB-A05. Applying the 95% confidence interval of 15–40 for the number of sapwood rings the trees might have had indicates they could have been felled at any time between AD 1643–68. They could, therefore, be felled as part of the AD 1647 or AD 1655 felling events identified but it could be argued that the similarity of their heartwood/sapwood boundary dates to the three timbers felled in AD 1647 suggests that this is the more likely felling date for the timbers represented by samples NGB-A02 and NGB-A11.

Cellar

One sample from the cellar ceiling, NGB-A18, also retains complete sapwood, this giving the timber a precise felling date of AD 1655 (Table 1; Fig 4). It is likely, furthermore, that the timber represented by sample NGB-A17 is the same because it matches so closely with sample NGB-A18 at a *t*-value of 11.1 and is potentially derived from the same tree.

The likely felling date of the three other cellar samples can be estimated by calcuating their average heartwood/sapwood boundary ring date, in this case AD 1631. Using the same sapwood estimate as above, 15–40 rings, indicates that they could have been felled at any time between AD 1646–71. It thus appears likely that they too are part of either the AD 1647 felling or of the felling of AD 1655.

Discussion and conclusion

Dating

Tree-ring analysis of timbers from Gigi Bottega has thus successfully dated 13 of the 19 samples that were measured. This analysis suggests that at least two timbers to the ceiling of the cellar, along with three timbers to the first floor, were felled in AD 1655. The first floor also contains timbers which were, or were likely to have been, felled in AD 1647 and it is possible that some of the cellar timbers could have been felled at the same time. As such, all of these timbers appear to represent either a hitherto unknown period of alteration or repair to the Flying Horse Inn complex in the mid-seventeenth century or, potentially, a completely new build of this date, with, in either case, possibly a few old (presently undated) timbers being reused.

Woodland sources

As may be seen in Table 2, although the dated site chronology NGBASQ01 has been compared with reference material from across the British Isles, there is a tendency for it to cross-match at the highest levels of similarity with chronologies from other sites across the Midlands, and particularly with other Nottinghamshire sites, with perhaps a slight trend towards the north of the county, perhaps in the direction of Sherwood Forest. Thus, although the source of the timber used at Gigi Bottega cannot be determined precisely, this strongly suggests that it was derived relatively locally.

Undated samples

As may be seen in Table 1, six of the 19 measured samples remain ungrouped and undated. This is despite at least three of them having well in excess of the number of rings required for reliable analysis and not showing any features such as distortion or compression which might cause problems with cross-matching. It is possible that the timbers grew somewhere, or during a time period, for which there is currently insufficient reference data available to provide secure cross-matching. A few of the shorter samples, NGB-A13 and NGB-A14 for example, do show some possible distortion, and it is possibly this which accounts for its lack of cross-matching. For whatever reason, it is a very common, if inexplicable, feature of tree-ring analysis to find that some samples will not date. This undated material will be reviewed periodically as further reference chronologies become available and these timbers may, in due course, also be dated.

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Data of measured samples

Measurements in 0.01mm units

NGB-A01A 72
289 181 106 207 355 329 374 369 491 450 428 438 400 279 142 234 232 374 311 260
339 240 206 120 92 78 115 159 201 162 220 195 200 228 213 226 151 260 243 115
153 265 309 231 282 320 279 331 192 121 201 219 172 210 140 131 140 155 93 163
64 115 200 128 143 124 58 106 153 192 222 212

NGB-A01B 72
272 181 106 211 359 327 370 358 498 451 405 441 391 285 150 213 237 331 321 271
321 259 201 118 99 72 123 157 198 154 223 190 198 250 199 226 148 259 239 104
159 284 295 225 290 321 285 320 178 123 189 220 165 220 153 125 150 163 88 168
65 112 193 128 147 125 60 101 168 186 225 196

NGB-A02A 47
220 229 170 233 185 249 218 162 241 309 284 228 275 239 262 210 182 147 200 271
256 246 271 217 353 283 211 176 219 244 234 256 198 189 234 204 162 137 117 151
128 112 164 129 109 114 155

NGB-A02B 47
189 237 175 220 192 253 217 166 241 322 264 230 275 234 263 215 185 152 193 261
265 232 265 218 348 282 206 196 203 260 239 271 176 176 256 201 151 143 134 129
135 117 160 121 122 128 140

NGB-A03A 63
468 458 439 379 428 291 265 241 364 393 364 363 322 372 396 182 236 277 300 257
185 295 342 271 343 317 329 298 373 245 198 282 325 311 317 313 256 360 343 169
171 206 292 265 337 200 196 247 201 162 116 121 162 222 173 221 215 92 133 138
159 223 225

NGB-A03B 63
444 477 432 367 451 294 257 259 354 393 354 352 326 373 380 166 221 275 302 256
182 300 332 270 362 318 340 284 370 250 189 276 279 320 318 297 270 351 340 187
167 211 295 259 333 181 193 246 209 158 136 113 152 240 165 221 209 88 132 157
145 219 203

NGB-A04A 89
264 219 217 251 268 180 152 80 87 119 105 89 139 116 117 135 151 244 368 300
220 164 162 100 125 153 272 378 215 260 187 243 217 148 117 175 267 232 179 285
256 191 212 225 281 153 185 134 128 87 104 154 179 233 195 160 196 179 143 135
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106 89 109 96 68 54 71 140 273

NGB-A04B 89
286 202 222 256 268 190 142 86 91 110 114 96 126 117 116 138 147 242 360 303
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96 87 108 93 65 65 64 140 287

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55 70 74 50 65 132 142 106 210 151 221 189 165 245

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124 185 334 146 218 143 124 201 271 255 114 110 166 158 117 110 169 178 144 138
117 144 194 139 190 127 103 131 115 132 135 207 156 156 121 143 155 142 147 106
147 103 157 154 207 231 196 150 216 153 215 150 189 171 187 195 170 153 184 123
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145 131 143 160 270 212 112 128 155 186

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142 132 145 153 248 219 112 125 157 183

NGB-A13A 43
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103 117 96 89 116 89 127 121 196 192 141 182 150 300 325 198 329 231 334 151
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NGB-A13B 43
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101 104 104 83 120 89 130 119 201 194 146 177 142 307 316 205 314 218 354 148
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NGB-A14A 46
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NGB-A14B 46
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125 126 139 185 130 169 185 87 201 205 107 103 75 85 71 103 157 121 205 150
104 124 115 92 67 79

NGB-A15A 102
252 162 159 161 172 172 258 251 294 209 330 343 378 307 200 140 127 116 142 153
171 129 139 150 117 128 158 180 158 101 86 115 140 169 118 93 122 136 126 124
179 220 206 140 120 140 150 110 123 133 128 170 184 201 218 154 123 78 154 178
107 105 178 262 175 98 64 106 148 134 140 98 90 88 93 65 57 63 84 95
136 115 101 71 72 89 117 118 114 78 92 98 113 109 119 91 94 87 50 105
113 235

NGB-A15B 102
264 148 163 159 178 173 261 255 294 223 329 346 371 305 198 132 126 107 153 154
171 135 134 150 131 119 173 167 154 111 104 90 147 162 112 93 128 140 123 119
185 222 209 140 114 150 151 101 123 137 129 166 181 206 209 157 120 83 157 173
103 100 184 271 181 101 60 107 165 135 126 107 90 78 98 71 58 60 82 100
120 118 92 71 68 87 119 120 109 81 78 103 108 115 121 103 90 90 58 112
115 221

NGB-A16A 62
174 167 141 167 298 280 234 210 121 153 117 121 114 149 227 213 244 201 236 196
149 164 157 174 147 116 140 164 156 164 173 228 173 143 99 91 74 99 142 122
166 137 171 200 160 118 121 153 172 246 115 154 112 156 89 126 121 102 142 114
152 142

NGB-A16B 62
183 164 129 177 305 281 225 201 132 144 125 112 116 155 215 230 205 197 230 203
152 167 156 165 155 114 135 161 167 157 170 245 178 136 110 84 58 102 147 118
164 135 184 193 167 109 131 157 159 253 132 114 118 167 93 137 135 84 106 129
126 148

NGB-A17A 55
491 402 515 494 407 412 301 275 260 348 338 210 277 343 293 300 234 279 183 240
198 166 125 133 233 256 418 318 293 250 126 107 135 193 181 274 178 181 168 228
156 185 101 107 125 110 143 190 70 156 151 170 240 146 184

NGB-A17B 55
484 402 501 492 377 418 303 259 271 354 325 201 275 297 256 289 242 264 195 221
198 176 126 140 218 248 432 329 293 248 126 103 149 190 175 282 179 165 175 206
156 170 114 110 137 106 145 179 70 146 151 174 251 150 179

NGB-A18A 62
319 295 329 345 306 274 223 205 190 257 264 180 266 292 197 192 191 253 164 229
198 143 99 117 177 255 478 423 408 285 120 107 142 192 156 215 120 143 139 175
108 146 84 105 113 78 137 159 86 127 119 167 220 135 157 196 120 98 106 109
85 151

NGB-A18B 62
354 305 330 337 310 265 232 192 187 260 250 182 264 296 200 182 207 242 175 224
207 151 94 114 172 250 481 410 395 279 128 117 140 190 175 201 112 132 153 167
110 140 91 101 110 93 101 178 101 115 105 176 210 142 156 195 106 128 95 104
73 158

NGB-A19A 50

317 486 523 384 305 162 164 192 250 393 375 434 326 319 338 242 207 190 182 250
193 313 354 328 338 239 251 212 260 239 251 146 140 168 164 173 134 191 198 179
98 142 157 181 202 150 136 173 162 192

NGB-A19B 50
264 486 548 384 296 157 162 210 252 393 391 439 352 336 339 234 193 181 181 248
194 318 335 331 318 262 242 225 265 240 234 165 129 178 154 159 137 200 210 173
98 137 159 167 181 129 156 165 160 181

NGB-A20A 63
183 142 185 291 250 538 281 242 241 135 108 93 167 250 255 343 330 285 246 167
160 177 158 152 121 200 238 257 214 256 178 160 200 154 155 89 128 153 115 129
101 179 162 98 60 68 64 92 76 65 63 69 70 53 46 25 43 51 42 56
57 34 54

NGB-A20B 63
180 144 201 274 215 366 411 284 192 103 92 85 138 245 251 315 309 250 295 189
164 167 156 157 114 197 244 254 213 235 182 165 199 156 160 85 130 150 128 121
101 190 170 85 56 67 68 90 83 54 53 80 75 49 44 25 46 43 46 63 52 32 42

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 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	

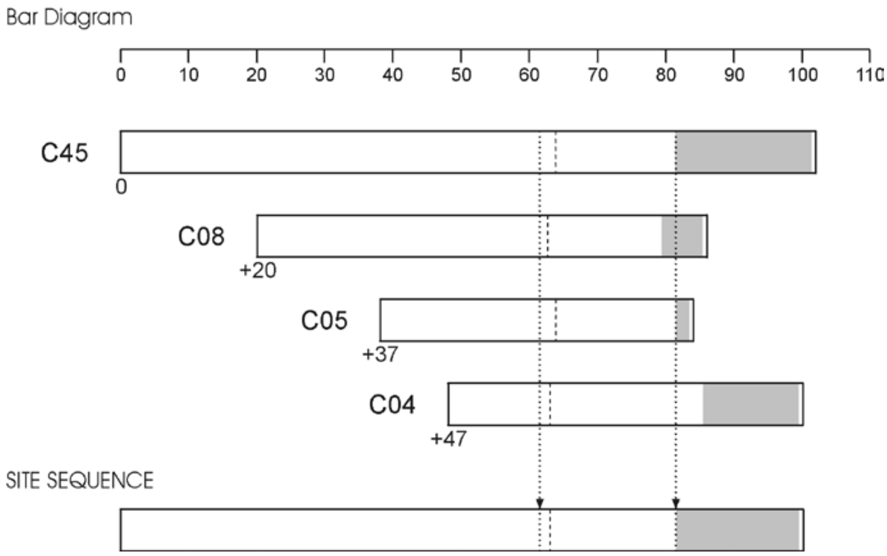


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

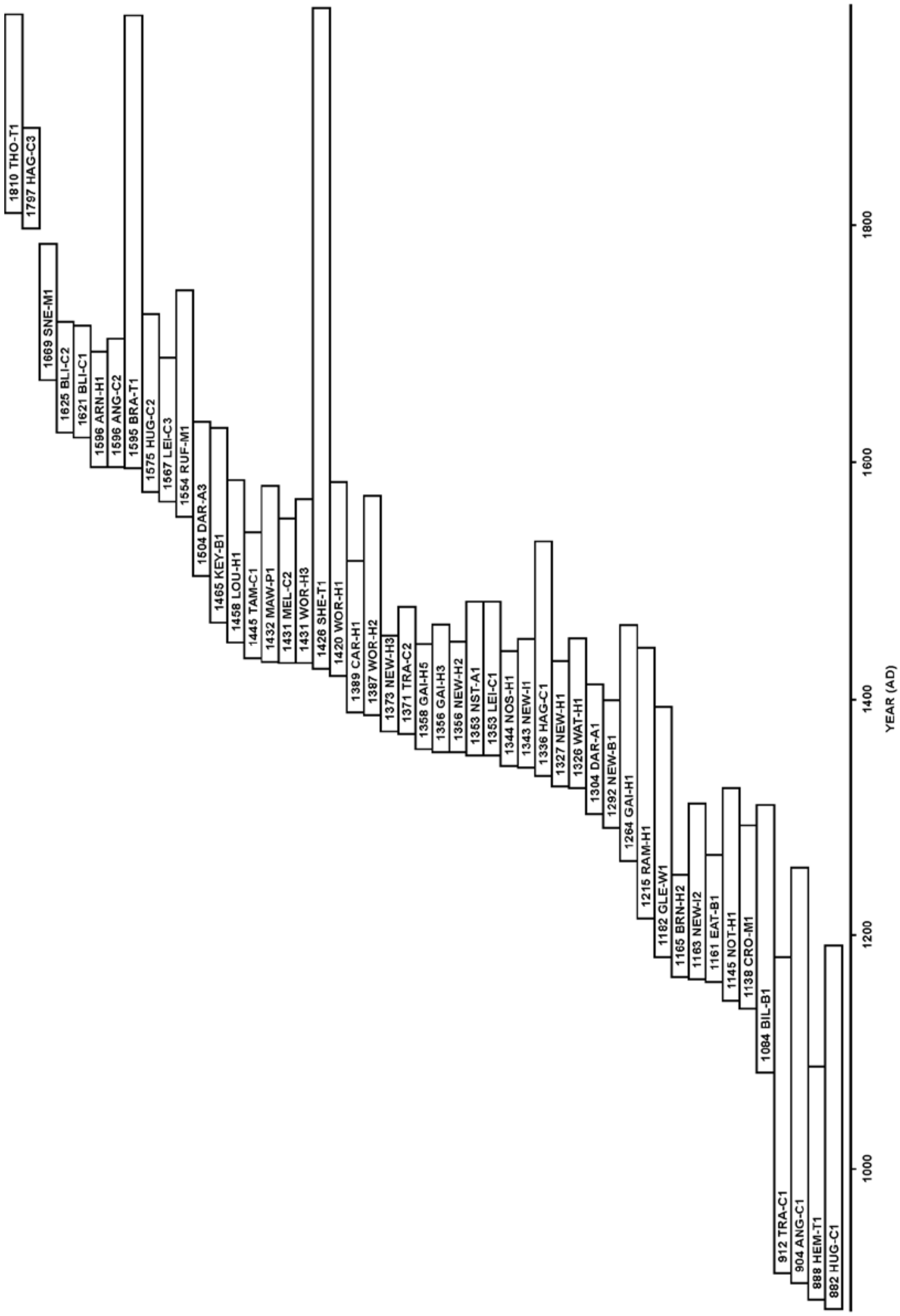
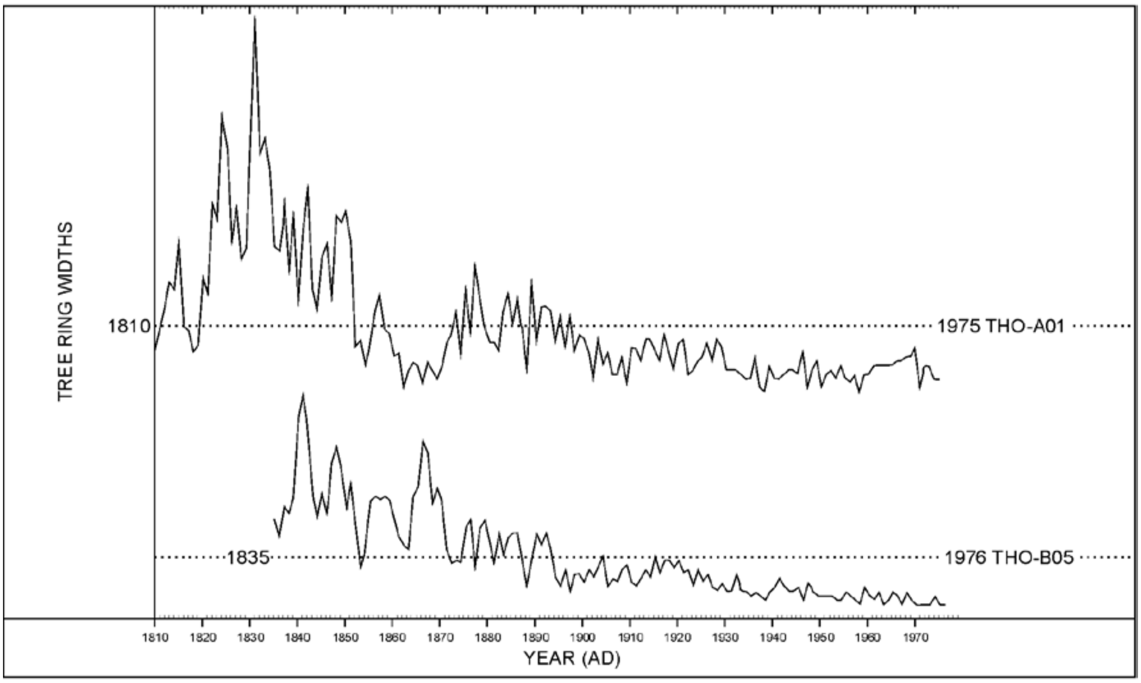


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

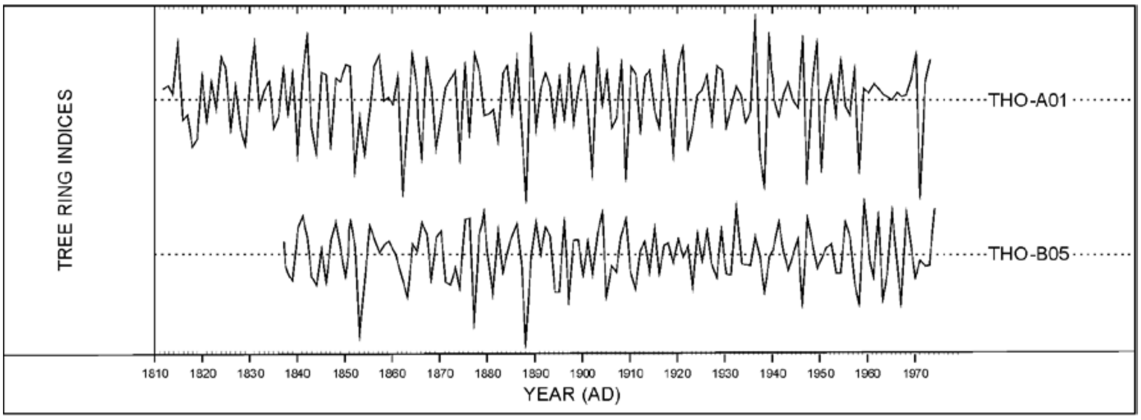


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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