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The Crown Hotel and 32 Main Road (The Crown Inn), Higham, Derbyshire

Tree-ring Analysis of Oak and Elm Timbers

Alison Arnold and Robert Howard

Scientific Dating

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Summary

Dendrochronological analysis was undertaken on 22 of the 32 timbers sampled from this multi-element building, the remaining samples having too few rings for secure dating purposes. This analysis produced four separate site chronologies, accounting for a total of 17 samples. Only one of these site chronologies, HIHCSQ01, accounting for eight samples, could be dated. This site chronology is 104 rings long, these rings dated as spanning the years AD 1353–1456. These timbers, all common joists to the ground-floor ceiling of the north cottage, have an estimated felling date in the range of AD 1464–89. The five remaining ungrouped individual samples also remain undated

Contributors

Alison Arnold and Robert Howard

Acknowledgements

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Front cover image

The Crown Hotel and 32 Main Road, Higham, Derbyshire. [© North East Derbyshire District Council]

Archive location

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

Historic Environment Record

Derbyshire Historic Environment Record, Derbyshire County Council, Shand House, Dale Road South, Matlock, Derbyshire, DE4 3RY

Date of investigation

2024

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Introduction

The Crown Hotel and 32 Main Road, also previously known as the Crown Inn, Higham (Fig 1), is a Grade II listed building (List Entry Number: 1158913 https://historicengland.org.uk/listing/the-list/list-entry/1158913). It originally comprised four properties, but the Crown Inn appears, on mapping evidence, to have been in existence by the late-nineteenth century with Archaeological Research Services (2023) indicating that the building is perhaps best described as "a large historic inn flanked by smaller cottage-type dwellings which were latterly absorbed into the premises". As of 2019, the building had ceased to operate as a hotel.

Much of the building is thought to date to the eighteenth century with refronting having occurred in the nineteenth century. The research undertaken by Archaeological Research Services (2023) indicates that the extant footprint of the building remains largely similar to that of the late-nineteenth century, as evidenced by the Ordnance Survey Map published in AD 1878. There are a number of extant historic features including elements of potentially original timber framing and wall or jowl posts in the south and centre cottages, and apparently in situ historic joists and main beams in the paired north cottages with the conclusion being that a half-timbered, half-stone building initially occupied the footprint (Fig 2).

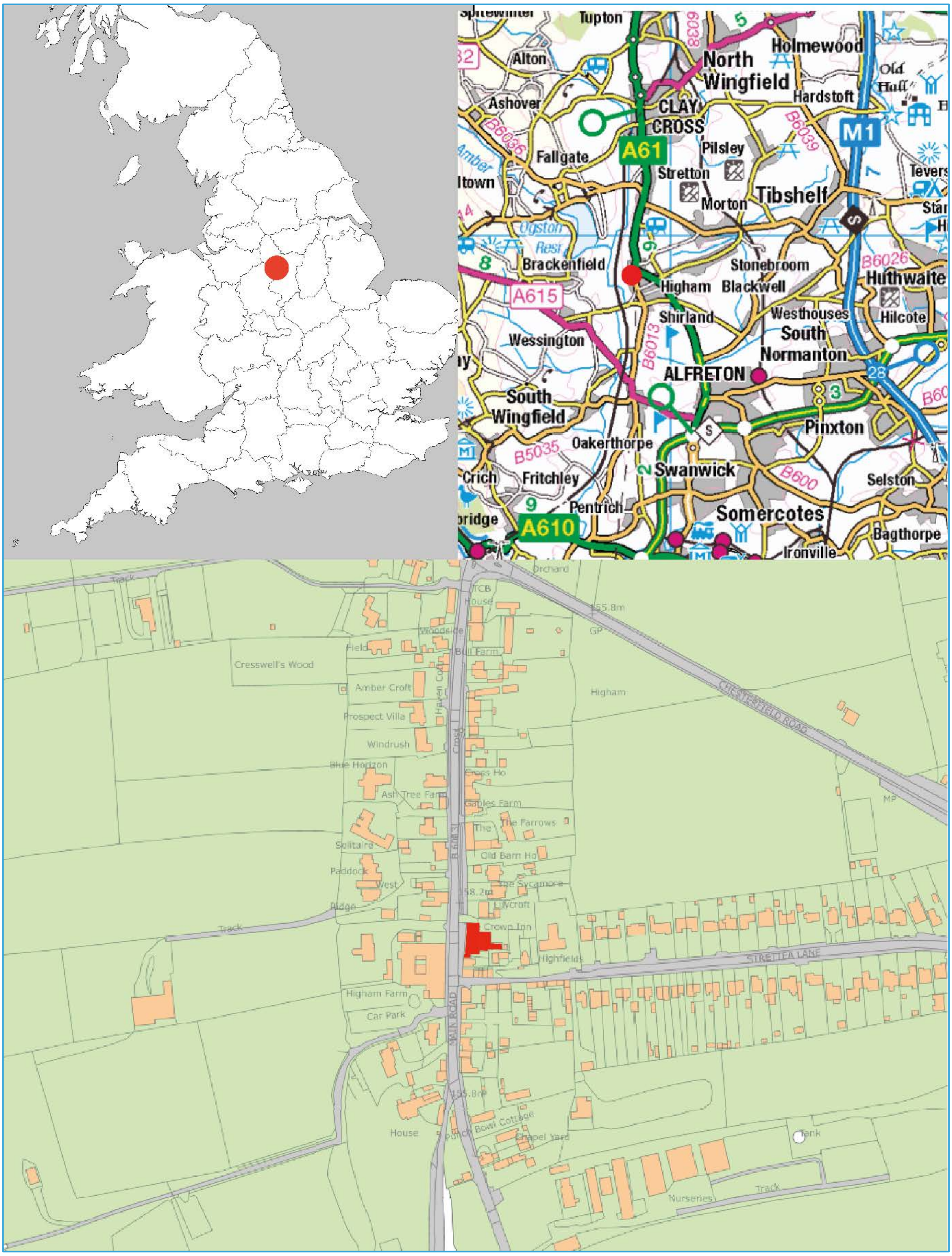


Figure 1: Maps to show the location of The Crown Inn, Higham in Derbyshire, marked in red. Scale: top right 1:105;800, bottom: 1:3,300. [© Crown Copyright and database right 2025. All rights reserved. Ordnance Survey Licence number 100024900]

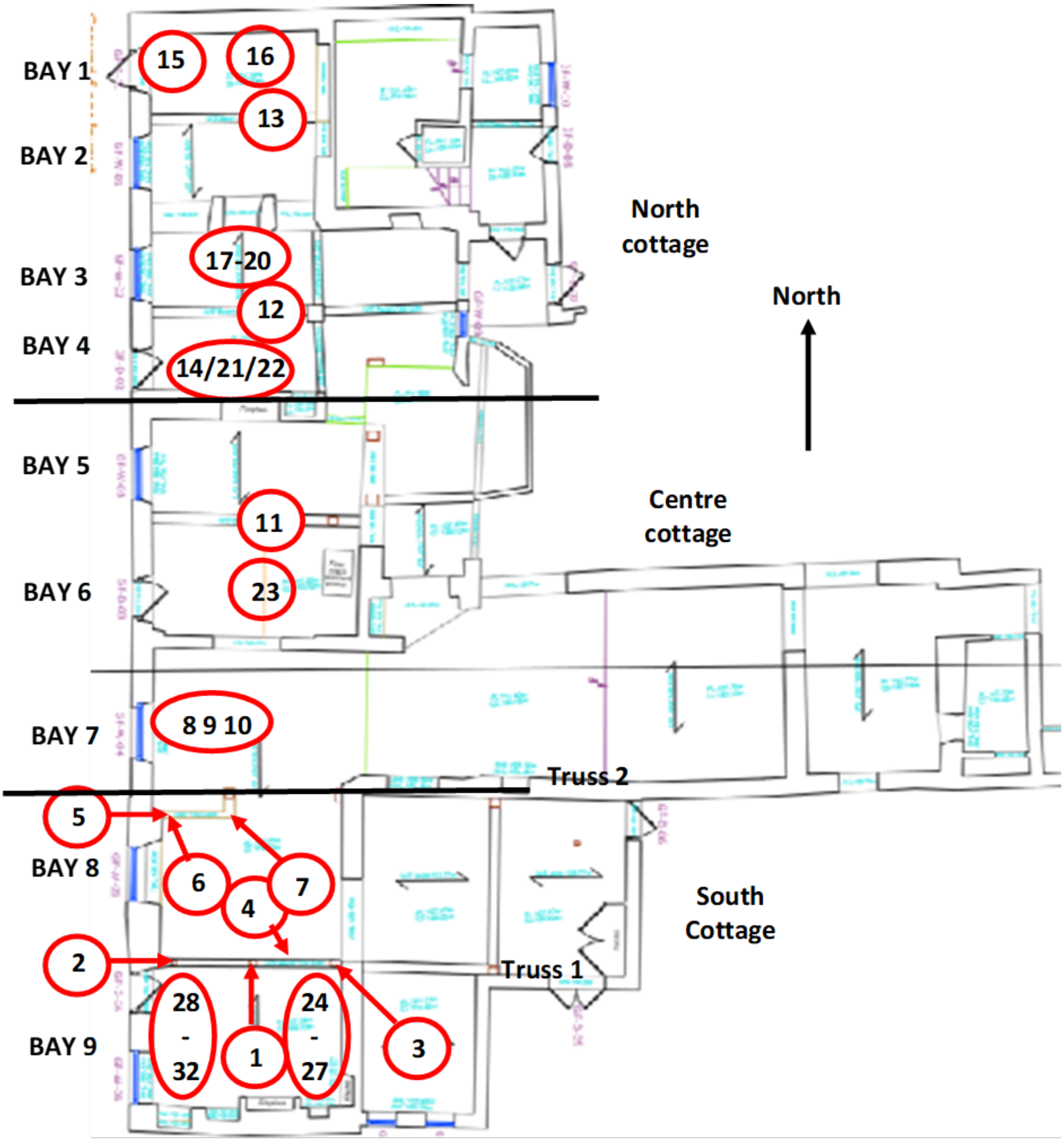


Figure 2: Plan of the ground floor to help locate sampled timbers. [after 2K Design Ltd.]

Sampling

A programme of renovation and redevelopment revealed historic timbers potentially related to the primary construction of the building and its subsequent change and development. Dendrochronological analysis was requested by Tim Allen of Historic England to provide independent dating evidence to enhance understanding of the building and inform significance.

An initial inspection of the timbers showed that while the building contained a number of oak timbers, there appeared to be other, potentially historic, timber types such as elm and conifer (particularly to the long rear-range extension), as well as a substantial number of modern, or relatively modern, conifer timbers. As such, while timbers other than oak can sometimes be dated by dendrochronology, it was seen at this time that the elm timbers appeared to have a very low number of annual growth rings and were thus considered unsuitable for secure dating purposes. The conifer timbers to the rear range, along with the modern conifer timbers, were outside the scope of the immediate programme of tree-ring analysis which focussed on the historic core of the building.

In addition, it appeared likely that those timbers thought to be associated with the historic core did not represent an integrated single phase of building works. This is perhaps unsurprising given that the site appears to have been several separate properties initially, which have subsequently been modified, and it is possible that some inserted timbers may relate to inspiring the illusion of historical antiquity and hence possibly be relatively modern.

Thus, despite the possible variation of timber in this assemblage, a total of 32 timbers were sampled by coring. All were oak (*Quercus* spp.) with the exception of a single elm (*Ulmus* spp.) timber sampled to confirm the presence of elm and confirm the limited number of rings in the elm timbers. Each sample was given the code HIH-C (for Higham, Crown) and numbered 01–32 (Table 1). The sampled timbers have been located by reference to a survey drawing, shown here as Figure 2, with individual timbers being further identified in a series of annotated photographs shown here as Figures 3a–k.

Table 1: Details of tree-ring samples from The Crown Inn, Main Road, Shirland and Higham, North East Derbyshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	South Cottage					
HIH-C01	Ground floor ceiling beam, truss 1	59	10	------	------	------
HIH-C02	West/front main wall post, truss 1	62	h/s	------	------	------
HIH-C03	East/ rear main wall post, truss 1	40	h/s	------	------	------
HIH-C04	Tiebeam, truss 1	31	no h/s	------	------	------
HIH-C05	West/front main wall post, truss 2	49	h/s	------	------	------
HIH-C06	Brace to west/front main wall post, truss 2	50	h/s	------	------	------
HIH-C07	Tiebeam, truss 2	67	h/s	------	------	------
HIH-C24	East common rafter 3, bay 9	nm (22)	h/s	------	------	------
HIH-C25	East common rafter 4, bay 9	nm (17)	h/s	------	------	------
HIH-C26	East common rafter 5, bay 9	nm (13)	h/s	------	------	------
HIH-C27	East common rafter 6, bay 9	nm (18)	h/s	------	------	------
HIH-C28	West common rafter 3, bay 9	nm (20)	h/s	------	------	------
HIH-C29	West common rafter 4, bay 9	nm (20)	h/s	------	------	------
HIH-C30	West common rafter 5, bay 9	nm (13)	h/s	------	------	------
HIH-C31	West common rafter 6, bay 9	nm (17)	h/s	------	------	------
HIH-C32	West wall plate, bay 9	39	no h/s			
	Centre Cottage					
HIH-C08	Ground floor ceiling joist 2 (from west), bay 7	73	11	------	------	------
HIH-C09	Ground floor ceiling joist 3, bay 7	73	21C	------	------	------
HIH-C10	Ground floor ceiling joist 4, bay 7	67	h/s	------	------	------
HIH-C11	Ground floor ceiling beam, bay 5/6	41	h/s	------	------	------
HIH-C23	Common joist 6 (from west), bay 6 (elm)	nm (16)	no h/s	------	------	------
	North Cottage					
HIH-C12	Ground floor ceiling beam, bay 2/3	77	9	------	------	------
HIH-C13	Ground floor ceiling beam, bay 1/2	67	12	------	------	------
HIH-C14	Common joist 2 (from west), bay 4	69	no h/s	1362	------	1430
HIH-C15	Common joist 2 (from west), bay 1	70	no h/s	1353	------	1422
HIH-C16	Common joist 6 (from west), bay 1	nm (28)	no h/s	------	------	------
HIH-C17	Common joist 1 (from west), bay 3	54	4	1402	1451	1455
HIH-C18	Common joist 4 (from west), bay 3	73	7	1383	1448	1455

HIH-C19	Common joist 5 (from west), bay 3	70	8	1387	1448	1456
HIH-C20	Common joist 9 (from west), bay 3	68	no h/s	1354	------	1421
HIH-C21	Common joist 7 (from west), bay 4	61	no h/s	1371	------	1431
HIH-C22	Common joist 1 (from west), bay 4	68	no h/s	1371	------	1438

nm = sample not measured; C = complete sapwood is retained on the sample; h/s = the sample retains the heartwood/sapwood boundary

Figure 3a: South Cottage, truss 1, viewed looking south. [photograph Robert Howard]

Figure 3b: South Cottage, truss 2 (party wall to Centre Cottage), viewed looking north. [photograph Robert Howard]

Figure 3c: Centre Cottage viewed looking north. [photograph Robert Howard]

Figure 3d: Centre Cottage viewed looking south. [photograph Robert Howard]

Figure 3e: North Cottage, south bay, viewed looking north east. [photograph Robert Howard]

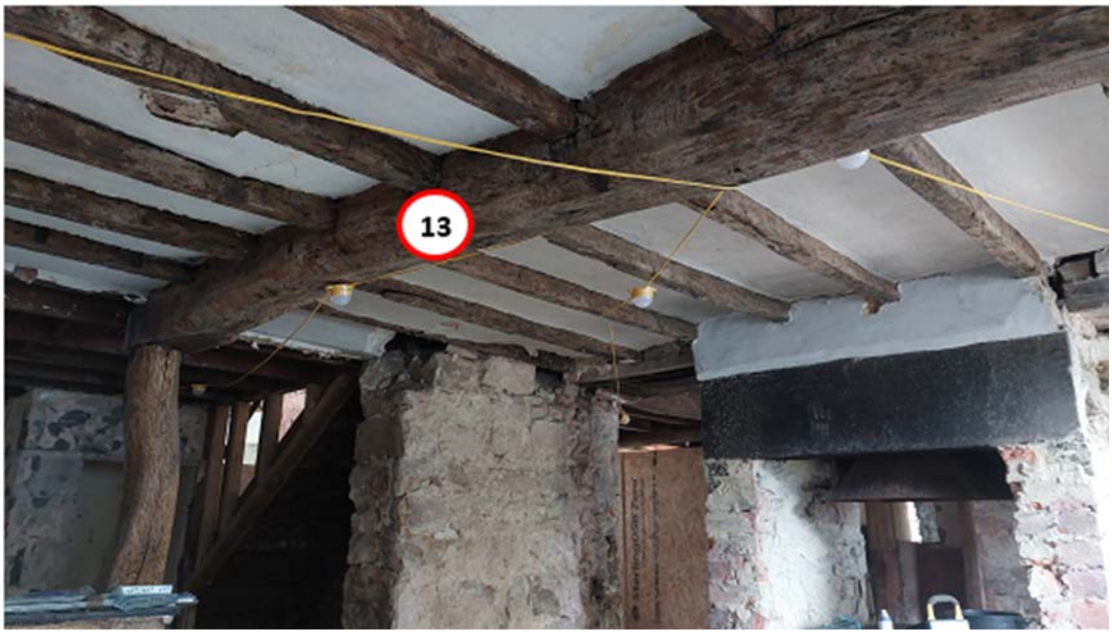


Figure 3f: North Cottage, north bay, viewed looking south west. [photograph Robert Howard]

Figure 3g: North Cottage, south bay, viewed looking southeast. [photograph Robert Howard]

Figure 3h: North Cottage, north bay, viewed looking northwest. [photograph Robert Howard]

Figure 3i: Centre Cottage, south bay, viewed looking southeast. [photograph Robert Howard]

Figure 3j: South Cottage, viewed looking east. [photograph Robert Howard]

Figure 3k: South Cottage, viewed looking west. [photograph Robert Howard]

Analysis and Results

Each of the samples obtained from the various timbers was prepared by sanding and polishing to allow the ring boundaries to be clearly distinguished. It was seen at this time that 10 samples, including the only elm sample, had no more than 30 rings, too few for secure dating by ring-width dendrochronology, and they were rejected from this programme of analysis, although the number of rings present was recorded. The growth ring widths of the remaining 22 samples were, however, measured, the data being given at the end of this report. The 22 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the production of four separate groups of cross-matching samples.

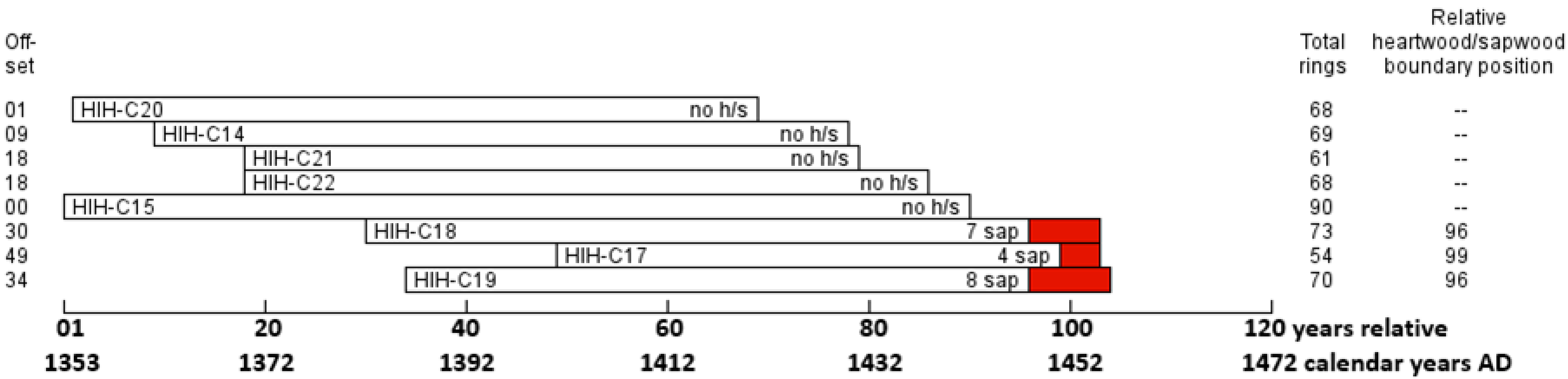
The first group comprises eight samples which cross-match at a minimum value of *t*=5.2 at the positions illustrated in Figure 4. These samples were combined at their indicated offset positions to form HIHCSQ01, a site chronology with an overall length of 104 rings. Site chronology HIHCSQ01 was then compared with an extensive range of reference chronologies for oak, this indicating a repeated series of cross-matches when the date of its first ring is AD 1353 and the date of its latest ring is AD 1456 (Table 2).

The second group comprises five samples, grouping at a minimum value of *t*=5.9 at the positions illustrated in Figure 5. These five samples were similarly combined at their indicated offset positions to form HIHCSQ02, a site chronology with an overall length of 86 rings. This site chronology was also compared with an extensive range of oak reference chronologies, but in this case there was no secure cross-matching identified and these five samples remain undated.

The third group comprises two samples cross-matching at a value of *t*=6.3 at the positions illustrated in Figure 6. These two samples were combined to form HIHCSQ03, a site chronology with an overall length of 77 rings. This site chronology was compared with an extensive range of oak reference chronologies, but again there was no secure cross-matching identified and these three samples therefore also remain undated.

The fourth and final group also comprises two samples which cross-match at a value of *t*=5.8 at the positions illustrated in Figure 7. These two samples were again combined at their indicated offset positions to form HIHCSQ04, a site chronology with an overall length of 59 rings. This site chronology again produced no secure cross-matching when compared with an extensive range of oak reference chronologies and these two samples also remain undated.

The four site chronologies were compared with each other and the five remaining measured but ungrouped samples, but no further secure cross-matching was obtained. The five ungrouped samples were, therefore, compared individually with the same extensive range of oak reference chronologies, but to no avail and thus these five samples also remain undated.

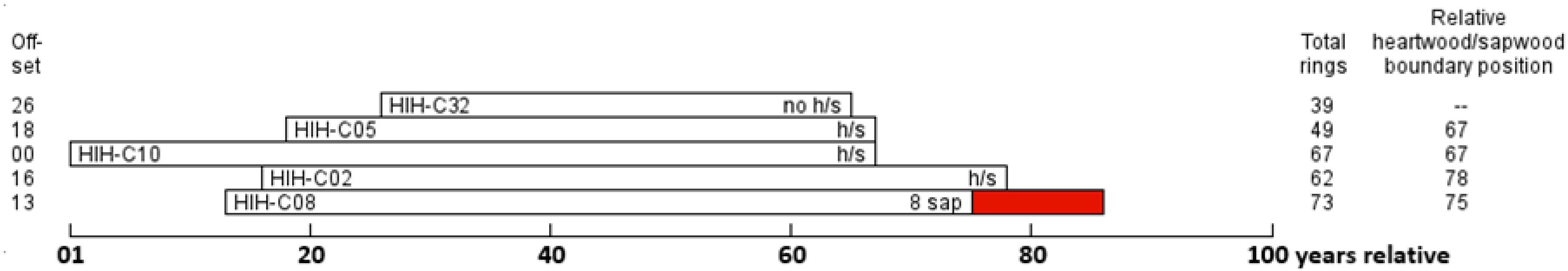


White bars = heartwood rings; red bars = sapwood rings; no h/s = there is no heartwood/sapwood boundary on the sample

Figure 4: Bar diagram showing the relative position of overlap of the samples in the dated site chronology HIHCSQ01.

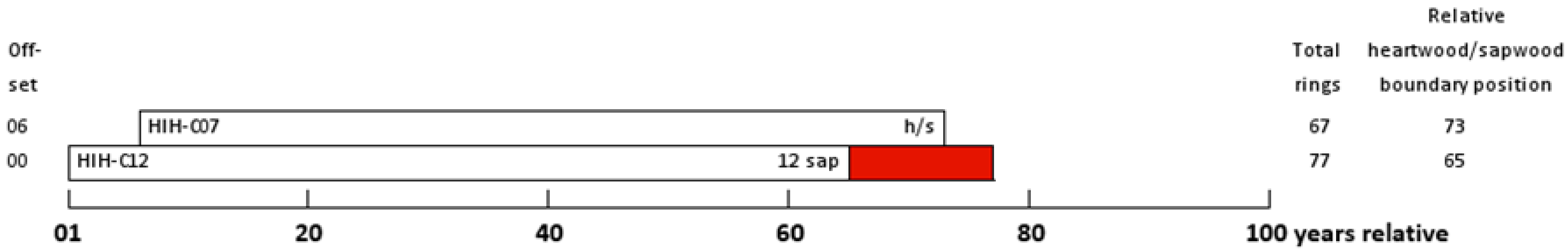
Table 2: Results of the cross-matching of site sequence HIHCSQ01 and relevant reference chronologies when the first-ring date is AD 1353 and the last-ring date is AD 1456

Reference chronology	Span of chronology	t-value	Reference
Groby Old Hall, Groby, Leicestershire	AD 1321 – 1516	7.5	Arnold and Howard 2014
Central tower, York Minster, North Yorkshire	AD 1214 – 1462	6.9	Hillam pers. comm. 1997
Norton Conyers Hall, Wath, North Yorkshire	AD 1365 – 1486	6.7	Arnold and Howard 2008 unpubl
Trinity House, Newcastle upon Tyne, Tyne and Wear	AD 1397 – 1524	6.3	Howard et al. 2002
Upper Spon Street, Coventry, Warwickshire	AD 1327 – 1454	6.2	Miles and Worthington 1999
Gotham Manor, Gotham, Nottinghamshire	AD 1330 – 1460	6.1	Howard et al. 1991 unpubl
Lyddington Manor, Rutland	AD 1239 – 1487	6.1	Arnold and Howard 2015 unpubl
Nappa Hall, Askrigg, North Yorkshire	AD 1300 – 1476	6.1	Arnold and Howard 2013
Abbey House, Winchcombe, Gloucestershire	AD 1250 – 1499	6.0	Arnold et al. 2008
The Governor's House, Newark, Nottinghamshire	AD 1319 – 1471	5.7	Arnold et al. 2002



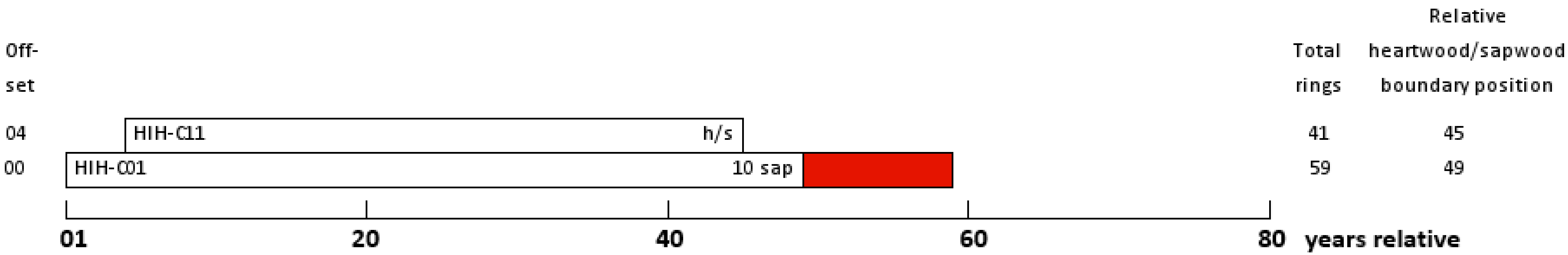
White bars = heartwood rings; red bars = sapwood rings; no h/s = there is no heartwood/sapwood boundary on the sample; h/s = heartwood/sapwood boundary

Figure 5: Bar diagram showing the relative position of overlap of the samples in site chronology HIHCSQ02.



White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary

Figure 6: Bar diagram showing the relative overlap of the samples in site chronology HIHCSQ03.



White bars = heartwood rings; red bars = sapwood rings; no h/s = there is no heartwood/sapwood boundary on the sample; h/s = heartwood/sapwood boundary

Figure 7: Bar diagram showing the relative overlap of the samples in site chronology HIHCSQ04.

Interpretation

As may be seen from Table 1 and the bar diagram Figure 4, none of the eight samples in dated site chronology HIHCSQ01, all from common joists in the north cottage, retain sapwood complete to the bark, and it is thus, not possible to provide a felling date precise to the year. Three samples do, however, retain some sapwood, the average heartwood/sapwood boundary on these samples being dated to AD 1449. Allowing for the standard minimum and maximum number sapwood rings these trees might have had 15 to 40 sapwood rings (the 95% confidence interval), which produces an estimated felling date range of AD 1464–89 for the trees from which these timbers were derived.

The five other dated samples of this group have no sapwood, this potentially having been removed when the joists were given chamfered arrises. As such, it is in theory, possible that they went on growing for many years after their last extant heartwood rings dates. However, given the broadly coeval nature of the samples and the level of similarity between all eight samples, it is likely that the source trees were growing relatively close to each other in the same woodland. As such, it appears likely that they were all felled at, or at least about, the same time as each other (it being considered something of a coincidence that trees, once close neighbours of each other in the same woodland, had they been felled at very different times, should come to be used for the same purpose in the same building), towards the middle of the latter half of the fifteenth century.

The samples in each of the other undated group appear to be coeval and most likely felled at the same, or similar, time, but a felling date for each of these groups of related timbers cannot be determined.

Discussion and Conclusion

It appears likely that the extant historic material within this building complex are an eclectic assemblage of possible different date and different source timbers, this making dating by dendrochronology more challenging than had they been a large single-phase collection of timbers. Despite this, it has been possible to successfully date eight common joists from the north cottage to the later fifteenth century. This dating evidence is significantly earlier than the eighteenth-century date assumed for the construction of these properties. Thus, these results need to be considered carefully in relation to their structural integrity within the north cottage. However, in short, the dendrochronological analysis has identified the presence of medieval timbers in at least part of this building complex.

Woodland sources

In some programmes of tree-ring analysis it is possible to suggest the general locality or region from which the dated timbers used in a particular building might have been sourced. This is usually intimated by any site chronology created during analysis, although having been compared with reference material from all over England, tending to match more strongly with reference chronologies from some particular region or area rather than elsewhere. However, as may be seen in Table 2 for site chronology HIHCSQ01, the reference chronologies listed show a very wide geographical dispersion and no particular locality or regional trend can be discerned.

Undated samples

Tree-ring dating is usually most successful when groups of well-replicated, coeval timbers, are sampled. Even so, in most programmes of tree-ring analysis a small percentage of samples will remain both ungrouped and undated, the lack of dating sometimes being due to obvious problems with the growth rings such as distortion or stress, although often there is no apparent reason for non-dating.

In this case, the lack of dating amongst the measured samples is somewhat unusual, most samples showing no signs of abnormalities to their growth rings. It is possible, however, given the known history of this site, with the present building having originated as a number of separate properties, perhaps each of a different date, and the propensity for change and alteration during its time as an Inn, that the assemblage of timbers found is too diverse and does not contain sufficient numbers of coeval timbers to provide a suitable, well-replicated group of samples. It is possible that some timbers are individual ‘singletons’ of quite different date, and while single samples can sometimes be dated individually, it is usually much less successful than with groups of same-phase samples.

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Data of measured samples

Units of 0.01mm

HIH-C01A 59
530 771 672 675 547 565 605 517 427 426 376 497 381 372 242 415 263 486 421 104
34 33 65 73 90 135 151 118 120 96 96 94 116 111 190 163 93 128 118 134
133 140 148 135 128 100 140 106 81 110 143 246 318 284 209 134 87 103 153

HIH-C01B 59
556 757 670 669 553 558 614 507 432 428 375 477 375 381 250 399 265 493 424 104
50 57 62 68 99 154 165 113 115 92 112 90 113 113 182 154 87 134 121 146
115 151 159 137 132 98 143 100 93 112 173 229 315 280 211 136 84 104 162

HIH-C02A 62
443 393 333 279 276 278 260 187 235 188 151 120 129 104 112 86 131 115 155 160
97 92 132 196 288 256 275 286 285 251 207 242 225 185 178 134 135 203 184 192
232 248 356 279 298 276 171 156 137 150 228 360 291 312 145 109 112 164 203 160
143 248

HIH-C02B 62
441 395 347 287 282 289 217 208 226 180 159 102 129 119 131 85 115 137 142 148
87 100 142 197 281 272 281 271 278 253 213 248 220 175 180 131 137 197 189 200
232 248 365 264 304 279 162 165 135 156 224 343 289 331 146 111 102 170 189 167
157 241

HIH-C03A 40
165 155 71 72 225 268 203 165 195 309 162 167 227 348 265 221 217 88 122 175
153 182 174 264 299 235 232 128 106 225 367 358 320 196 126 107 98 104 199 297

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163 164 81 89 230 279 208 176 198 296 167 175 230 336 323 227 201 94 124 189
142 175 182 260 300 242 243 110 115 223 382 361 334 204 126 92 96 109 203 301

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356 392 367 359 301 364 285 312 275 356 282 428 510 411 369 135 139 139 145 279
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403 376 361 352 289 351 287 301 267 359 278 432 503 400 361 137 150 139 138 267
294 229 290 315 368 261 401 295 181 325 266

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HIH-C09B 73
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284

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315

HIH-C12A 77
238 272 282 227 318 365 382 310 291 226 275 374 456 404 264 207 192 164 165 135
160 214 228 238 167 239 221 260 296 373 270 282 173 151 123 170 185 294 360 209
296 140 73 60 60 121 118 142 135 176 143 139 145 207 209 156 150 67 70 80
104 136 143 150 115 151 214 299 206 199 227 240 318 220 176 173 162

HIH-C12B 77
231 269 272 243 344 316 348 346 314 230 281 364 457 424 252 220 178 167 166 146
153 212 228 247 168 231 212 270 303 382 268 289 177 142 119 182 192 289 345 215
289 142 74 60 71 106 115 146 143 179 158 145 146 204 203 158 62 84 73 85
100 131 168 143 127 142 211 293 222 177 217 224 325 219 188 167 175

HIH-C13A 67
130 54 231 304 334 266 293 341 459 406 261 328 335 298 357 423 299 402 387 341
235 356 448 289 117 109 242 151 149 165 203 253 298 300 154 287 132 196 153 173
173 129 148 164 117 178 176 170 226 142 237 221 330 259 137 168 221 235 196 228
205 175 160 186 98 81 112

HIH-C13B 67
103 60 221 315 337 245 300 496 457 410 266 318 304 296 382 431 303 400 371 318
223 350 467 279 121 104 239 154 156 165 190 252 300 294 146 304 126 198 144 178
168 123 148 168 125 160 182 170 228 139 233 235 327 263 134 173 212 228 197 232
200 165 158 187 105 92 110

HIH-C14A 69
195 172 206 151 99 77 121 175 134 142 210 141 218 293 226 192 216 190 126 113
53 75 85 114 128 117 99 101 111 108 148 104 98 126 230 260 278 210 298 241
320 260 243 167 154 98 115 139 223 175 204 191 145 115 115 148 203 162 199 182
175 217 179 121 79 104 120 153 174

HIH-C14B 69
199 178 190 163 87 88 103 182 131 143 202 147 228 300 242 187 229 192 133 100

57 73 84 115 130 110 105 101 110 121 144 100 92 126 231 257 268 215 306 253
318 250 248 165 157 95 123 134 218 178 203 178 154 123 112 146 196 167 200 182
164 206 183 131 71 107 122 184 170

HIH-C15A 70
108 110 136 157 134 91 86 99 145 126 149 166 110 67 55 76 119 89 72 76
82 114 128 106 150 155 116 154 144 85 82 142 162 231 225 182 117 96 100 101
82 67 86 110 92 114 107 120 117 116 111 96 85 82 72 66 92 106 85 83
69 72 74 48 43 57 56 81 95 108

HIH-C15B 70
128 114 134 161 116 96 90 100 143 122 152 177 98 69 52 83 120 82 79 78
80 109 133 105 148 155 114 153 150 85 81 140 159 225 243 206 128 107 117 90
92 78 85 111 104 111 106 134 130 129 145 107 86 84 68 67 89 108 94 84
81 62 75 50 41 57 58 90 90 98

HIH-C17A 54
180 192 249 165 127 113 72 115 162 143 189 194 184 173 134 180 203 146 171 236
209 260 218 210 125 167 208 325 260 344 259 141 115 143 95 210 231 194 271 251
224 269 263 201 131 154 159 225 206 241 228 143 237 242

HIH-C17B 54
165 196 257 169 131 109 76 117 162 148 194 192 187 164 147 182 198 137 186 219
221 267 232 203 122 171 203 318 275 339 260 146 121 137 101 206 223 199 253 240
231 267 264 201 128 159 147 206 229 246 201 160 226 253

HIH-C18A 73
24 96 129 178 242 246 242 183 187 196 167 117 169 271 217 270 171 201 139 164
160 182 141 160 102 99 114 188 139 173 188 102 90 77 82 108 88 117 165 184
146 134 81 63 95 109 143 98 86 87 73 60 75 79 129 112 98 115 128 100
117 135 121 92 103 78 89 96 123 139 136 118 123

HIH-C18B 73
85 95 128 175 259 234 235 184 184 193 162 117 166 273 221 267 178 200 139 169
150 185 147 152 107 105 107 190 136 171 186 111 77 80 71 100 99 111 156 179
154 142 75 52 94 105 142 112 89 79 71 68 67 76 112 125 93 109 120 93
117 140 117 103 95 82 100 110 114 125 128 110 124

HIH-C19A 70
84 118 79 81 108 107 116 92 121 228 265 278 201 216 184 174 191 261 143 157
109 100 119 171 134 157 169 150 96 95 125 154 135 185 207 178 203 191 117 97
151 143 171 132 115 111 103 90 105 104 160 157 101 143 131 131 115 146 150 102
120 90 106 121 135 131 135 128 150 132

HIH-C19B 70
82 121 74 81 108 116 104 92 112 215 274 276 205 209 179 175 193 251 162 146
105 97 123 175 132 175 155 153 96 87 126 145 137 178 207 175 194 195 121 96
157 129 178 129 114 109 96 97 99 103 154 164 103 133 143 129 115 150 147 105
120 96 103 121 135 132 128 138 134 157

HIH-C20A 68

186 238 273 245 174 230 182 321 393 391 309 261 166 188 166 188 174 164 228 189
157 139 100 114 93 110 100 60 52 43 67 97 89 108 112 93 75 108 119 114
106 112 193 151 178 106 114 110 126 181 139 93 87 57 60 92 117 106 120 128
96 60 61 81 104 101 92 106

HIH-C20B 68
199 234 278 255 167 236 177 325 396 401 309 253 177 180 176 182 177 169 228 182
161 139 99 107 98 110 96 72 41 46 63 101 86 110 114 87 80 102 122 120
109 110 212 151 184 98 112 114 125 163 159 90 88 50 71 93 120 100 117 151
96 64 59 86 101 100 91 115

HIH-C21A 61
70 83 78 83 64 54 60 72 98 82 76 51 49 81 87 83 72 83 59 56
60 64 48 41 40 71 58 79 82 64 73 67 87 80 97 48 53 50 60 89
57 69 70 67 68 55 35 51 50 87 94 74 94 83 44 55 48 60 58 78
72

HIH-C21B 61
75 92 77 75 66 52 62 71 101 75 85 46 54 86 76 85 70 88 58 63
58 61 47 40 41 75 56 78 76 76 61 79 79 76 89 69 53 53 57 82
58 76 71 62 71 51 38 52 46 89 78 67 95 89 46 51 52 60 57 75
75

HIH-C22A 68
175 296 219 168 205 155 124 175 187 153 119 75 72 73 119 142 143 106 89 98
90 159 205 155 200 357 224 311 189 189 125 209 224 230 150 169 93 85 125 179
125 173 150 101 78 68 95 125 128 164 173 159 145 176 110 75 143 178 217 156
101 107 79 73 92 96 131 200

HIH-C22B 68
196 300 219 166 201 158 131 164 193 144 121 81 69 75 115 141 124 108 94 89
89 169 192 177 208 350 206 303 185 211 150 194 165 232 163 170 85 92 126 196
132 171 153 105 73 76 97 114 124 168 164 148 129 180 108 83 135 164 213 163
112 101 90 79 85 92 135 201

HIH-C32A 39
321 286 292 204 208 178 199 385 330 307 148 178 192 269 259 326 307 332 278 277
271 319 471 269 245 150 145 232 243 245 346 396 356 250 346 272 168 168 179

HIH-C32B 39
364 291 294 199 202 190 188 393 334 303 146 177 193 285 253 314 314 313 266 253
283 332 458 281 235 148 142 214 270 218 352 396 342 264 354 283 134 196 157

Appendix: Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating Laboratory's Monograph, An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings (Laxton and Litton 1988) and Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and in particular, the last ring.

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

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

Inspecting the Building and Sampling the Timbers

Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly, the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

Measuring Ring Widths

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

Cross-Matching and Dating the Samples

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in

Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus, in Figure A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

Estimating the Felling Date

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

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

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

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

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

Estimating the Date of Construction

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

Master Chronological Sequences

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

Ring-Width Indices

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

t-value/offset Matrix

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

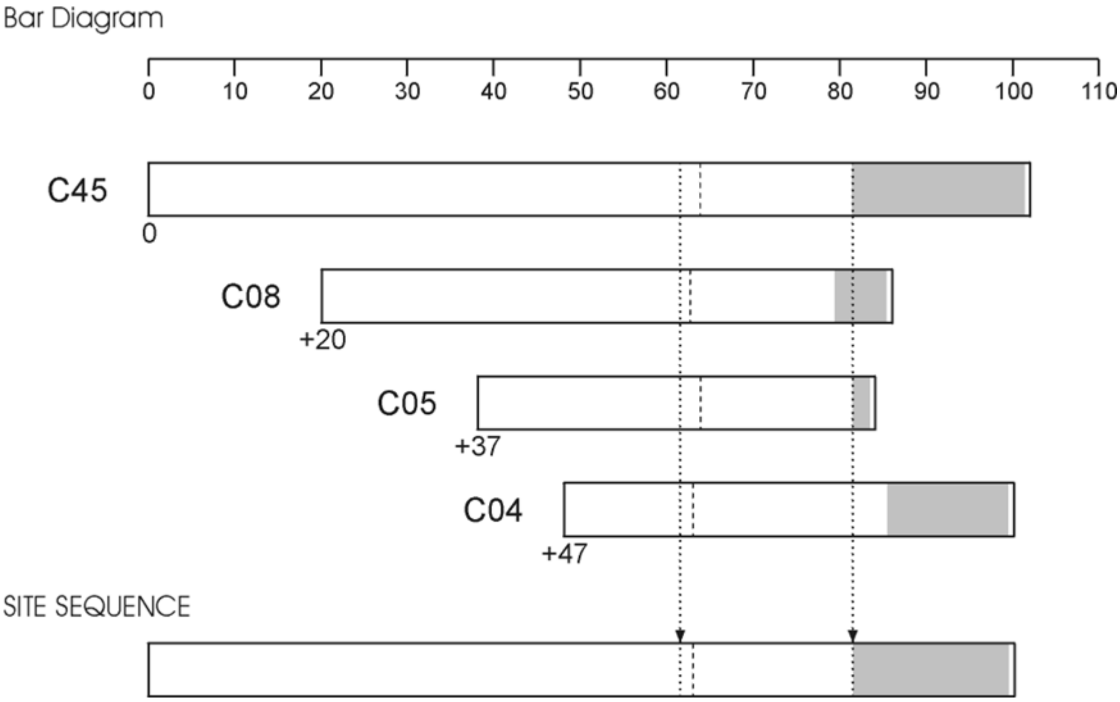

Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them. The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the t-values. The t-value/offset matrix contains the maximum t-values below the diagonal and the offsets above it. Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

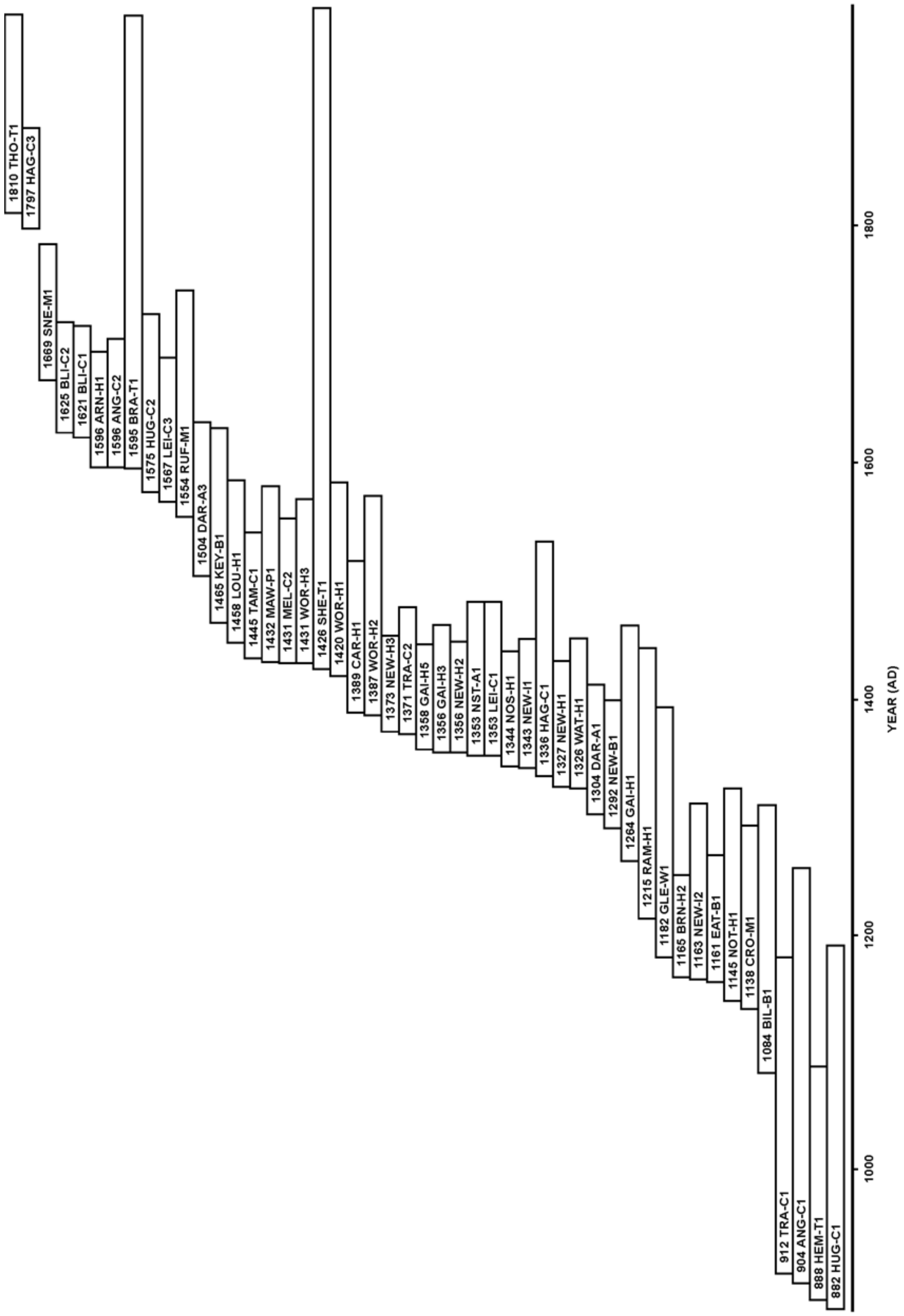

Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

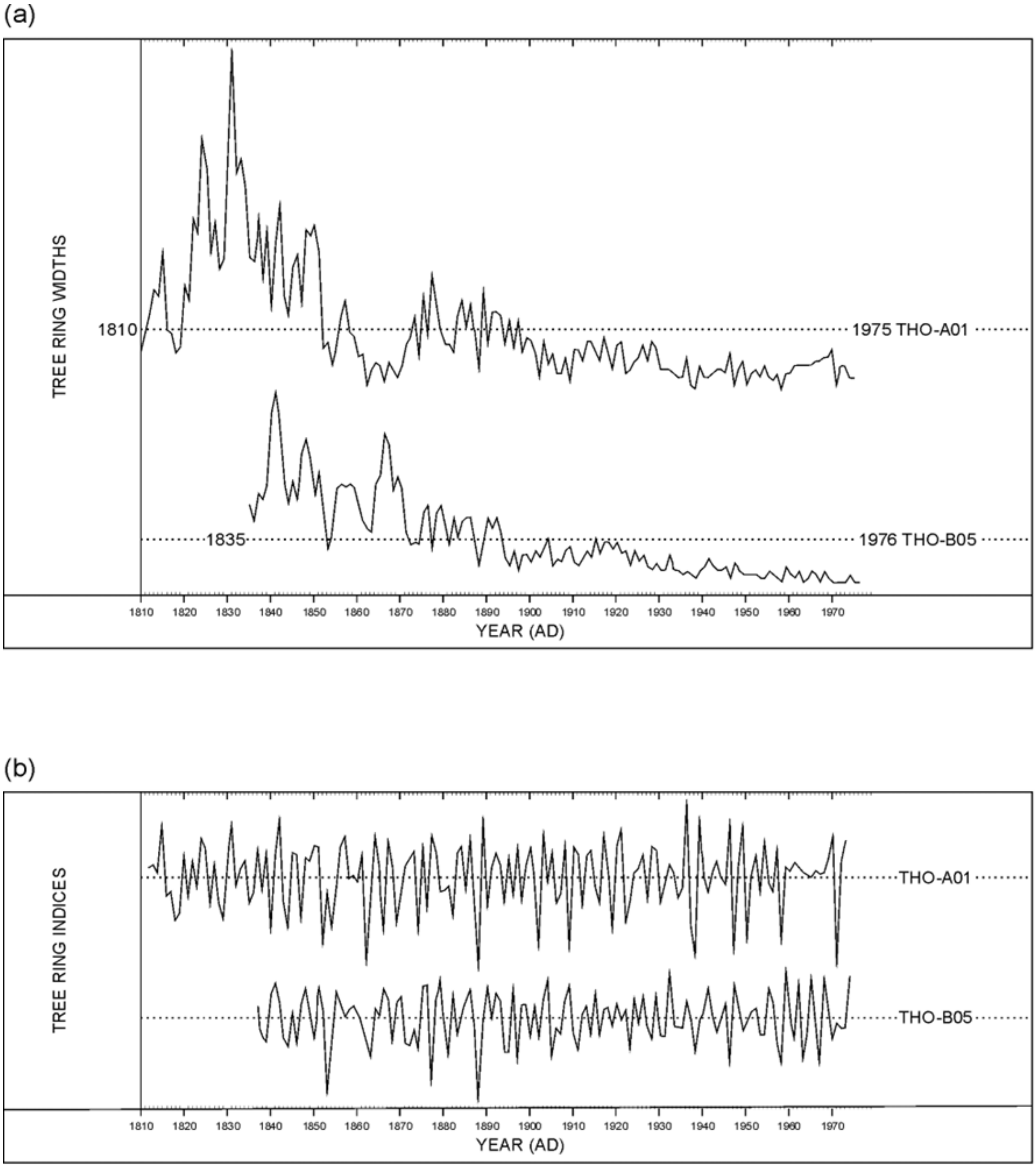

Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely.

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