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Hall Farm Barn, Hall Lane, Hemsby, Norfolk

Tree-Ring Analysis of Timbers

Alison Arnold and Robert Howard

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SUMMARY

Dendrochronological analysis was undertaken on 23 of the 24 samples obtained from different timbers in the barn at Hall Farm, Hemsby. This analysis produced a single dated site chronology comprising 12 samples with an overall length of 126 rings. These rings were dated as spanning the years AD 1158–1283. Interpretation of the sapwood on the dated samples indicates the timbers represented were all probably cut as part of a single episode of felling in AD 1283 for the construction of the barn.

The remaining 12 samples are all ungrouped and undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

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ARCHIVE LOCATION

Norfolk Historic Environment Record
Norfolk Historic Environment Service
Union House
Gressenhall
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Norfolk
NR20 4DR

DATE OF INVESTIGATION

2012

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CONTENTS

INTRODUCTION

The barn at Hall Farm, Hemsby (Fig 1a/b), is an impressive Grade I listed building. It is of substantial size comprising eight bays formed by seven trusses and the gable walls, with aisles to both north and south sides, and two threshing floors (Fig 2).

The listing entry describes the barn as being an early fourteenth-century timber-frame structure beneath a thatched roof (now half hipped, but originally gabled; the east gable with brick tumbling), with brick walls added in the eighteenth century (although some flint is also used). The north side has two symmetrically placed double timber doors rising into swept eyebrows under the thatch. At intervals there are blocked slit ventilation lights, and four stepped buttresses remain (Fig 3a). The south side has opposing entrances, now blocked, and two, twentieth-century, sloping brick buttresses to the west and several eighteenth-century brick piers throughout (Fig 3b).

The listing entry further describes the interior as having seven pairs of square-section aisle-posts which stand on timber sole spurs running from the base of the outer wall posts. Many of the sole spurs are now replaced with brick, and the wall posts have either been removed in the eighteenth century or else embedded in brickwork of that date. Curved braces rise on both sides of the arcade posts to the arcade plate and inwards to tie beams. Curved passing braces rise from the wall posts, through trenches in the aisle ties and arcade posts and tenon into the underside of tiebeams with notched lap joints. From the tiebeams, queen posts rise to the lower of two tiers of through purlins, both upper and lower purlins being linked by a collar. There are no principal rafters or windbraces (Fig 4a–d). There is a remarkable series of scarf joints in the arcade plate, splayed and tabled with transverse key and sallied under-squinted abutments (Hewett 1980, 265). The barn is believed to share many of the characteristics of the earliest surviving large timber-framed structures in the region, the barns at Cressing and Coggeshall in Essex, for example. Brown (2005) notes that the barns' stylistic and constructional features date it to around AD 1300 making it potentially one of Norfolk's oldest standing timber-framed buildings.

SAMPLING

Sampling and analysis by dendrochronology of Hemsby Hall Farm Barn was requested by Will Fletcher (then English Heritage Inspector of Ancient Monuments) to provide a precise date in order to determine its importance, and contribute to its future management should it be added to the Heritage at Risk register. The aim of analysis was to obtain independent dating evidence for the primary construction of the barn and determine if there was any evidence for historical development.

Thus, having first assessed the timbers as to their suitability for tree-ring analysis, a total of 24 samples was obtained, each sample being given the code HMS-A (for Hemsby, site 'A') and numbered 01–24 (Table 1). The sampling strategy focussed on those timbers with the maximum dating potential, whilst also aiming to ensure that as wide a range of elements as possible were sampled throughout the barn. For the purposes of this programme of analysis the trusses and bays of the barn have been numbered from site east to site west (left to right as the barn is viewed from the front), following the scheme of the drawings provided. Timbers were then further identified on a north-south or east-west basis as appropriate. The locations of these samples were recorded at the time of sampling on the drawings provided, these being shown here as Figure 5a–g.

ANALYSIS AND RESULTS

Each of the 24 samples obtained from the barn was prepared by sanding and polishing. It was seen at this time that one sample, HMS-A01, had less than 50 rings, the minimum here deemed necessary for reliable dating, and it was thus rejected from this programme of analysis. The annual growth ring widths of the remaining 23 samples were, however, measured, the data of these measurements being given at the end of this report. The data of the 23 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix) this resulting in the production of a single-site chronology comprising 12 samples. These 12 samples, cross-matching with each other as shown in Figure 6, were combined at their indicated offset positions to form site chronology HMSASQ01, this having an overall length of 126 rings.

Site chronology HMSASQ01 was then compared to an extensive corpus of reference material for oak, this indicating a consistent and repeated match with a series of these when the date of its first ring is AD 1158 and the date of its last measured ring is AD 1283 (Table 2).

Site chronology HMSASQ01 was also compared to the 11 remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. These 11 ungrouped samples were then compared individually to the full corpus of reference data, but again there was no satisfactory cross-matching and they must, therefore, remain undated.

INTERPRETATION AND CONCLUSION

Analysis by dendrochronology of the timbers has produced a single dated site chronology, HMSASQ01, comprising 12 samples. One of these 12 dated samples, HMS-A02, retains complete sapwood (the last ring produced by the tree before felling), this last ring (and thus the felling of the tree represented) being dated to AD 1283 (Fig 6; Table 1). The analysis indicates that all of the other dated samples also appear likely to have been felled in, or around, AD 1283. The heartwood/sapwood boundary varies by only 11 years, from relative position 103 (AD 1260) on sample HMS-A23, to relative position 114 (AD 1271) on sample HMS-A13 and is highly indicative of a single episode of felling. It thus seems likely that all the timbers were felled as part of a single programme of felling with the construction of the barn occurring shortly afterwards. Thus the dendrochronological evidence indicates that the barn is of late thirteenth-century date, broadly in line with that suggested by the stylistic evidence, and hence is indeed one of Norfolk's oldest timber-framed buildings.

The overall cross-matching between all 12 samples in the dated site chronology suggests the possibility that the trees were derived from a rather disparate woodland source. Perhaps, given the length of some of the timber elements, *ie*, arcade posts and passing braces, it was difficult to locate trees of the required size from a single discrete woodland source.

Some pairs of samples do, however, cross-match sufficiently highly to suggest that the timbers represented may be derived from a single tree, or from two trees growing close to each other in the same woodland. Samples HMS-A03 and A06 for example (respectively the east and west braces between the south arcade post of truss 2 and the arcade plate) cross-match with a value of t=7.0, while samples HMS-A09 and A13 (respectively the south arcade posts of trusses 3 and 5) cross-match with a value of t=7.6.

In respect of the location of the source woodlands, it may be noted from Table 2 that, although site chronology HMSASQ01 has been compared to reference chronologies from all parts of England, the highest levels of similarity (as indicated by the t-values) are generally found with other sites in eastern England. This would suggest that the timbers used in the barn are from a relatively local woodland source.

Despite having sufficient rings for reliable dating and showing no problems, such as compressed or distorted rings, 11 of the 23 measured samples remain ungrouped and undated. Whilst this may be indicative of these trees having been sourced from different woodlands, it is more likely that it is associated with highly localised growth conditions which mask the overall climatic signal required for successful analysis. The presence of undated samples is a frequent feature of tree-ring analysis in Norfolk which has proved to be a difficult area for successful dendrochronological analysis.

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TABLES

Table 1: Details of tree-ring samples from Hall Farm Barn, Hall Lane, Hemsby, Norfolk

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
HMS-A01	North passing brace, truss 2	nm	---	------	------	------
HMS-A02	South passing brace, truss 2	88	19C	1196	1264	1283
HMS-A03	East brace, south arcade post truss 2 to arcade plate	76	h/s	1188	1263	1263
HMS-A04	North arcade plate, truss 2 - 3	89	h/s	1180	1268	1268
HMS-A05	South arcade plate, truss 1 - 2	86	16	1193	1262	1278
HMS-A06	West brace, south arcade post truss 2 to arcade plate	99	9	1177	1266	1275
HMS-A07	West brace, north arcade post truss 2 to arcade plate	87	8	------	------	------
HMS-A08	East brace, north arcade post truss 3 to arcade plate	66	h/s	------	------	------
HMS-A09	South arcade post, truss 3	88	8	1189	1268	1276
HMS-A10	North passing brace, truss 3	83	h/s	1185	1267	1267
HMS-A11	South aisle tie, truss 3	104	11	------	------	------
HMS-A12	South aisle tie, truss 4	61	no h/s	------	------	------
HMS-A13	South arcade post, truss 5	75	h/s	1197	1271	1271
HMS-A14	South passing brace, truss 5	57	h/s	1212	1268	1268
HMS-A15	East brace, north arcade post truss 5 to arcade plate	62	h/s	1204	1265	1265
HMS-A16	West brace, south arcade post truss 5 to arcade plate	58	no h/s	------	------	------
HMS-A17	North aisle tie, truss 5	77	h/s	------	------	------
HMS-A18	South brace truss 5 north side	67	h/s	------	------	------
HMS-A19	North passing brace, truss 6	54	h/s	------	------	------
HMS-A20	South passing brace, truss 6	64	no h/s	------	------	------
HMS-A21	North arcade post, truss 7	76	no h/s	1182	------	1257
HMS-A22	North aisle tie, truss 7	78	h/s	------	------	------
HMS-A23	South arcade post, truss 7	103	h/s	1158	1260	1260
HMS-A24	South aisle tie, truss 7	73	no h/s	------	------	------

nm = not measured; h/s = the heartwood/sapwood ring is the last ring on the sample; C= complete sapwood is retained on the sample, the last measured ring date is the felling date of the tree represented

Table 2: Results of the cross-matching of site sequence HMSASQ01 and relevant reference chronologies when the first-ring date is AD 1158 and the last-ring date is AD 1283

Reference chronology	Span of chronology	*t*-value	Reference
Abbas Hall, Great Cornard, Suffolk	AD 1150–1289	6.6	(Bridge 2000)
Place House, Bluecoat Yard, Ware, Hertfordshire	AD 1179–1253	6.1	(Howard *et al* 1990)
Upton Court, nr Slough, Berkshire	AD 1170–1319	5.9	(Howard *et al* 1988)
Mermaid Theatre, City of London	AD 1143–1234	5.7	(Hillam 1979)
St Albans Cathedral, Hertfordshire	AD 1151–1263	5.6	(Howard *et al* 2002)
Prior's House (south-east wing), Ely Cathedral, Cambridgeshire	AD 1201–1307	5.5	(Arnold *et al* 2004)
Lodge Farm, Denton, Norfolk	AD 1215–1335	5.4	(Groves and Hillam 1993)
Millennium Bridge, City of London	AD 999–1389	5.4	(Tyers 1999)

FIGURES

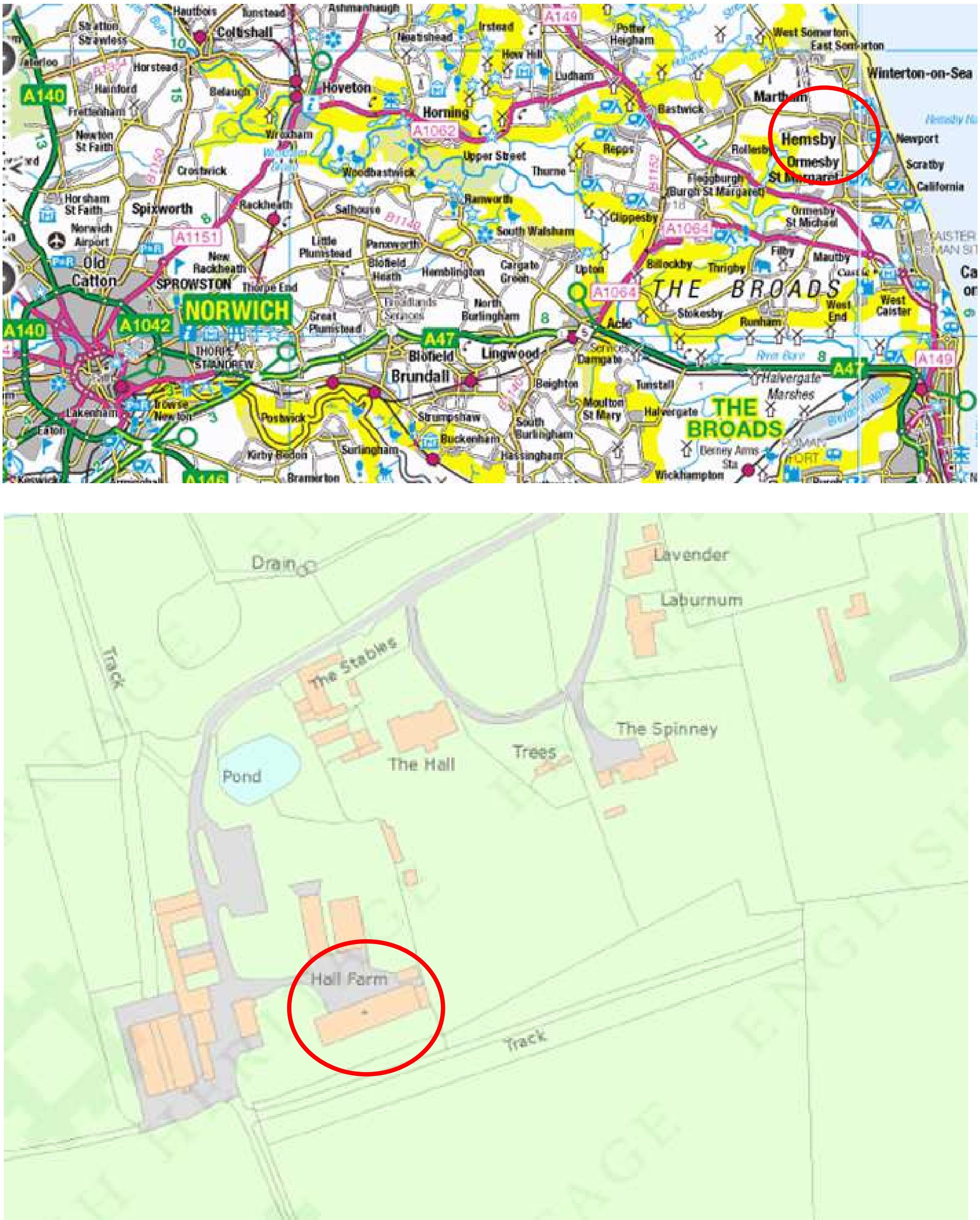


Figure 1a/b: Maps to show the location of Hemsby (top) and Hall Farm Barn, Hemsby, (bottom) © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

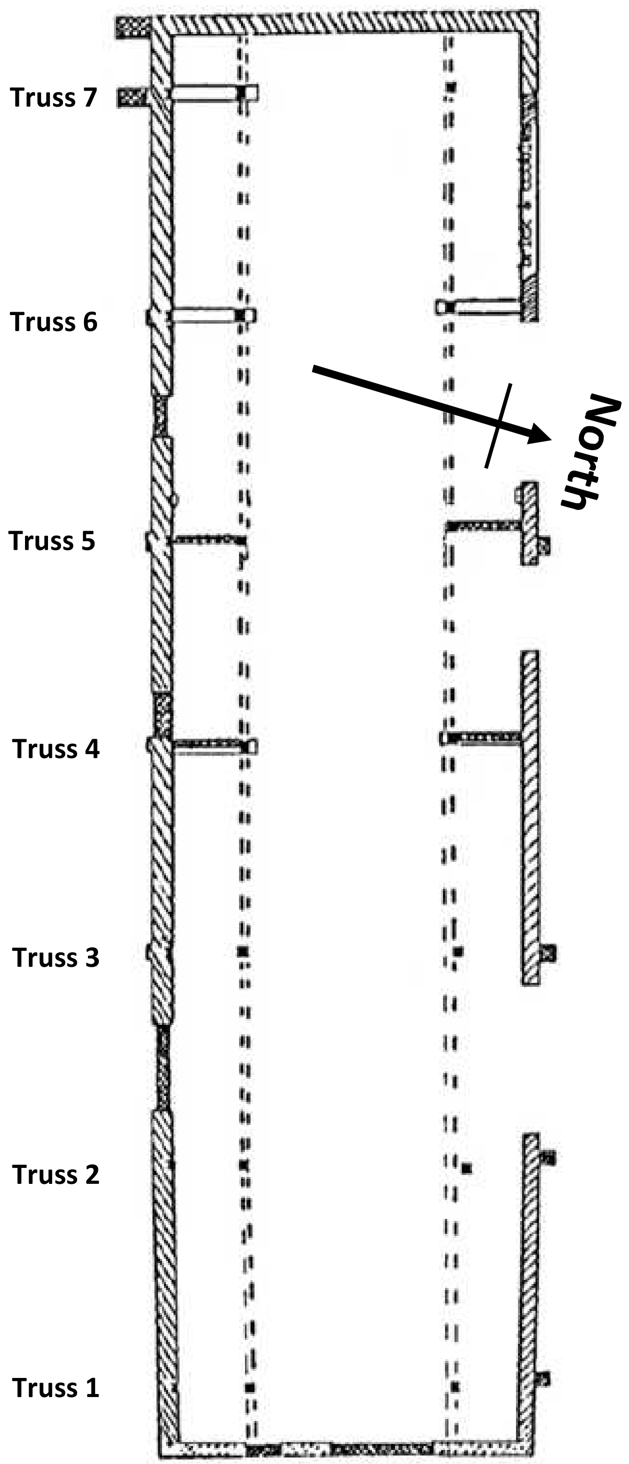


Figure 2: Plan of Hall Farm Barn, Hemsby, to show the layout and arrangement of the trusses (after John Walker)

Figure 3a/b: Views of the front (north) side of the barn (top) and the rear (south) side (bottom, photographs Robert Howard)

Figure 4a/b: Interior views of the barn (photographs Robert Howard)

Figure 4c/d: Interior detail views (photographs Robert Howard)

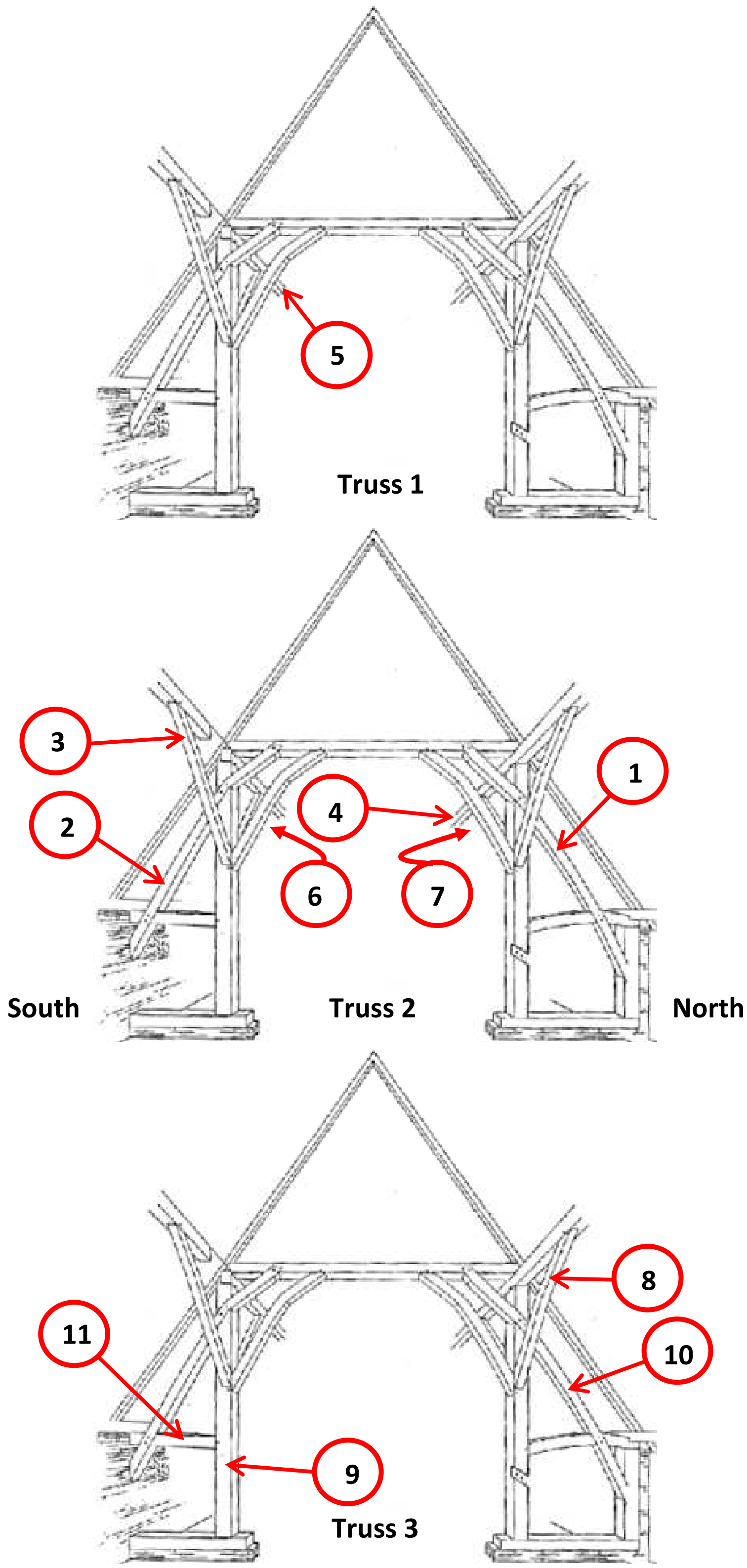


Figure 5a–c: Cross-section through the trusses to help locate sampled timbers, viewed from the east looking west (after John Walker)

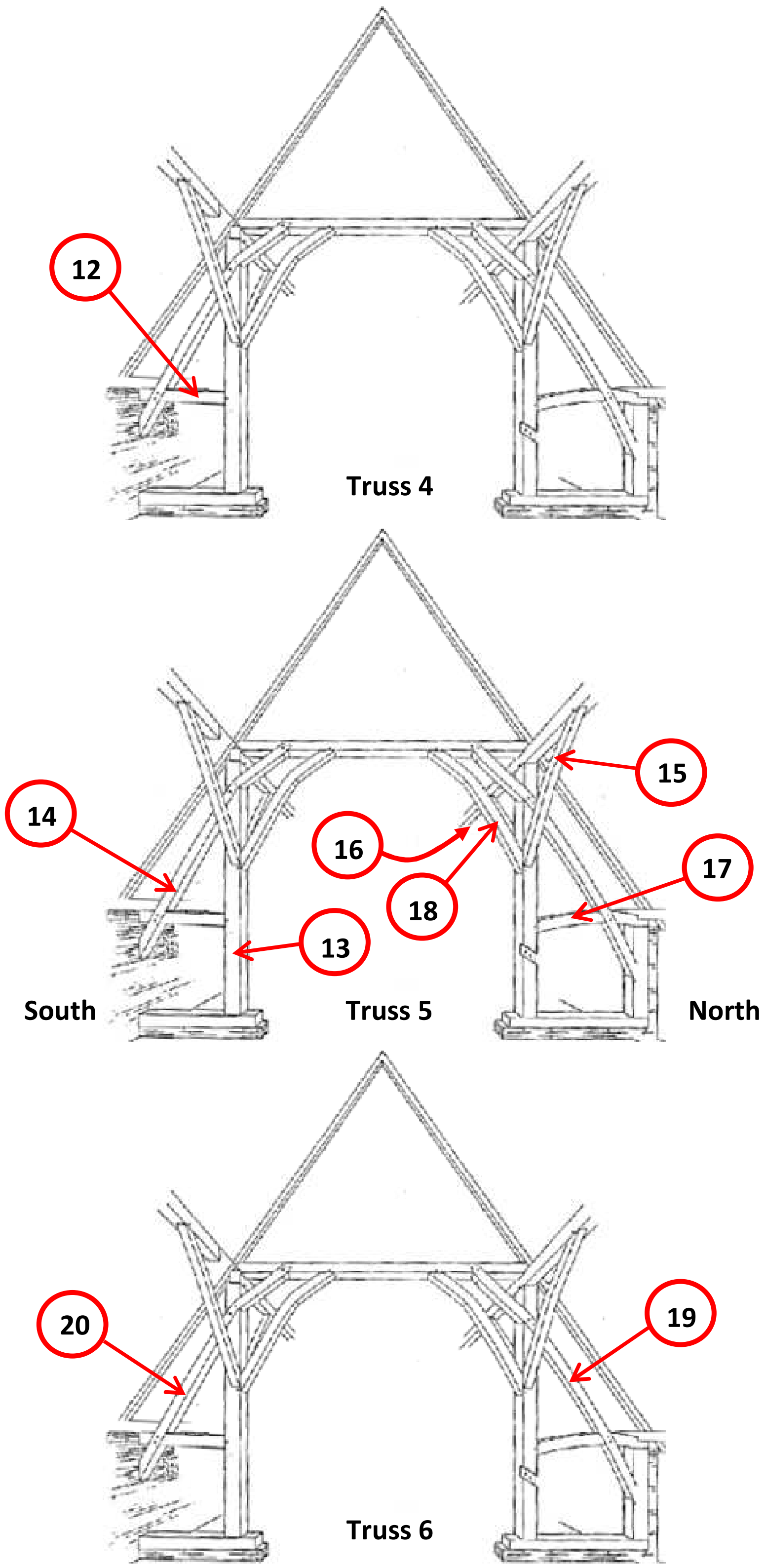


Figure 5d–f: Cross-section through the trusses to help locate sampled timbers, viewed from the east looking west (after John Walker)

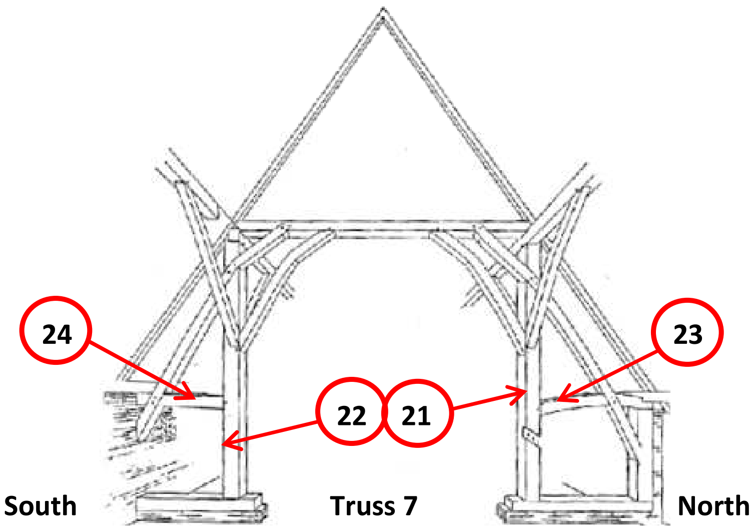
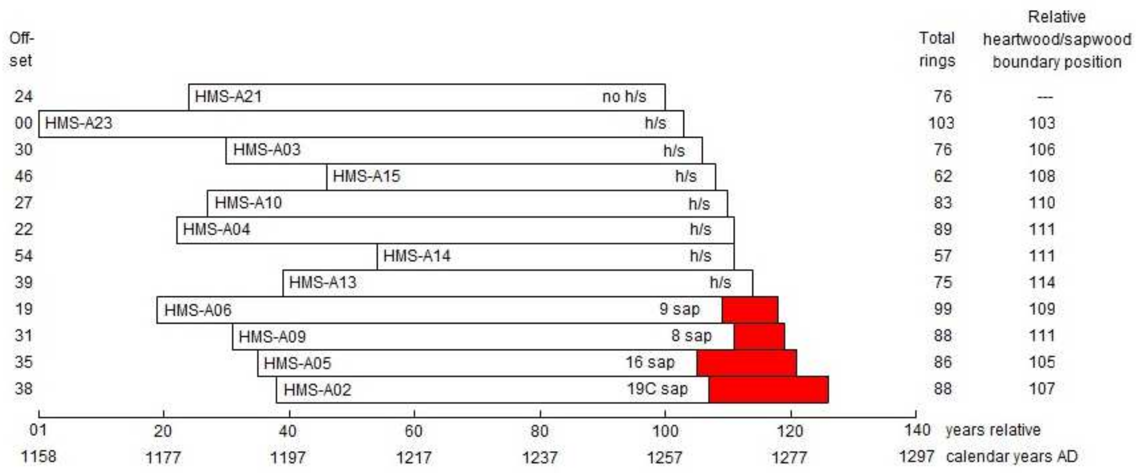


Figure 5g: Cross-section through truss to help locate sampled timbers, viewed from the east looking west (after John Walker)



White bars = heartwood rings; shaded bars = sapwood rings; h/s = heartwood/sapwood boundary; C= complete sapwood is retained on the sample, the last measured ring date is the felling date of the tree represented

Figure 6: Bar diagram of the samples in site chronology HMSASQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

HMS-A02A 88
149 146 175 142 304 315 210 253 210 250 219 367 312 292 261 239 189 293 232 200
213 279 246 342 390 289 307 278 144 162 362 370 358 458 397 271 223 207 95 95
95 76 75 81 40 43 70 92 92 113 278 225 135 250 175 89 60 91 97 79
108 114 76 83 150 117 222 205 139 110 69 68 125 104 88 75 104 105 62 108
87 125 140 77 80 75 56 96
HMS-A02B 88
136 166 188 135 306 325 200 263 205 253 207 368 319 285 254 234 199 315 230 219
213 290 252 353 400 289 325 262 132 160 359 356 364 456 400 276 220 210 89 79
82 78 80 76 45 42 67 81 92 123 275 220 128 242 173 93 69 84 98 79
109 115 75 106 121 112 218 210 121 126 58 78 143 97 97 66 99 116 74 101
93 123 109 94 93 62 65 100
HMS-A03A 76
347 286 388 407 406 562 534 520 573 455 446 555 466 497 401 614 517 489 349 417
340 307 386 308 270 256 267 249 239 285 231 273 316 268 229 168 207 162 165 124
194 234 202 128 143 175 161 96 130 294 167 160 175 144 137 122 89 88 106 133
110 114 110 105 136 125 159 174 150 231 166 171 202 178 186 193
HMS-A03B 76
347 335 401 405 424 536 510 559 539 499 496 570 449 514 415 620 504 488 350 384
337 283 399 314 268 246 292 257 220 285 231 277 304 283 212 168 206 161 159 127
216 239 198 125 143 184 157 126 115 256 163 142 181 153 125 126 94 103 93 126
105 122 114 108 126 125 143 181 149 219 162 180 198 177 211 181
HMS-A04A 89
507 536 552 603 385 416 361 316 239 253 292 393 396 304 244 275 239 168 165 198
221 271 207 269 165 212 181 182 175 139 114 142 129 121 117 82 89 64 83 195
195 198 160 206 303 310 350 373 357 393 353 299 229 379 359 378 202 237 303 370
284 356 242 395 334 503 441 374 303 393 355 419 262 426 294 327 147 303 206 371
400 407 515 353 356 381 314 206 234
HMS-A04B 89
474 544 560 602 379 407 364 311 234 260 296 394 384 307 243 284 225 178 167 199
186 282 210 248 170 224 178 203 156 134 123 140 129 113 126 76 92 60 83 198
198 189 161 204 300 306 351 365 381 396 328 306 221 378 361 382 203 221 293 376
297 338 243 384 320 490 425 365 289 387 342 434 261 418 340 287 133 296 220 346
399 396 535 357 356 361 331 196 243
HMS-A05A 86
550 523 475 400 216 262 238 289 382 222 191 100 99 72 108 150 139 80 88 71
62 70 54 51 60 28 55 76 82 79 54 77 126 230 161 107 214 151 122 150
232 199 267 215 264 271 259 144 124 90 118 128 226 255 403 165 157 96 162 293
313 239 298 196 343 154 243 374 281 331 227 168 132 136 95 159 165 147 137 162
165 137 115 137 181 206
HMS-A05B 86
554 520 482 408 213 266 227 297 374 227 172 96 108 86 125 145 142 91 75 87
56 60 64 55 58 37 52 81 85 73 62 72 127 217 137 106 210 155 128 165
215 204 273 231 255 273 260 148 110 92 120 131 228 260 409 162 153 100 165 312
324 250 278 200 328 142 271 356 300 367 228 171 136 136 96 154 168 132 160 138
200 156 102 113 197 214

HMS-A06A 99
202 374 501 328 299 351 493 303 231 310 376 296 189 217 272 268 305 322 293 316
282 357 365 257 324 218 453 276 226 139 269 244 148 212 180 120 154 171 133 160
172 171 210 220 164 142 157 210 178 146 139 225 212 207 148 189 165 169 152 113
217 176 150 214 159 138 176 100 139 160 164 118 117 119 132 118 167 185 168 85
115 81 87 100 97 150 118 103 131 162 96 150 178 177 188 149 140 129 171
HMS-A06B 99
196 397 410 373 310 325 476 309 248 278 410 279 204 219 268 271 309 354 260 291
270 347 376 300 326 218 437 282 226 142 268 228 147 201 175 123 162 160 140 145
167 156 221 231 143 157 156 207 185 158 143 213 218 218 152 184 164 167 139 128
191 179 156 214 150 153 173 97 165 137 165 120 111 121 134 121 149 203 172 84
108 68 93 100 107 162 115 106 125 133 109 150 168 181 196 138 144 116 169
HMS-A07A 87
342 536 609 660 160 161 166 196 128 189 189 239 235 192 135 146 95 157 171 138
178 353 186 241 196 227 383 246 221 185 300 275 301 343 328 262 225 490 343 323
219 270 254 379 293 506 184 106 258 277 153 189 186 159 130 146 402 196 278 191
311 178 175 121 181 204 215 360 234 67 40 38 81 230 334 395 360 214 131 118
178 210 246 228 177 103 136
HMS-A07B 87
329 528 644 657 142 176 101 177 164 175 210 250 200 173 167 153 95 161 175 143
156 350 196 225 199 238 373 283 212 190 326 275 301 323 360 287 234 512 303 299
182 265 204 346 264 414 192 109 255 265 150 189 178 150 147 150 428 187 284 193
308 179 167 141 171 218 203 365 241 80 34 29 78 217 330 375 346 227 146 132
194 214 245 219 181 124 135
HMS-A08A 66
780 313 482 650 716 304 372 603 543 675 739 590 723 726 837 928 607 565 890 550
516 356 293 434 358 415 231 296 323 239 291 262 259 195 353 269 78 37 33 34
30 37 40 91 93 190 150 151 136 171 209 130 112 131 256 183 263 294 209 240
115 103 149 203 294 280
HMS-A08B 66
864 304 483 643 735 319 403 615 528 675 764 580 688 767 854 895 623 595 879 531
514 349 308 423 365 408 213 303 330 237 308 253 261 212 356 274 87 40 26 37
29 40 40 96 100 181 156 140 137 130 262 125 121 140 240 175 246 302 207 231
122 114 151 226 306 269
HMS-A09A 88
611 505 612 878 589 464 502 500 334 345 464 434 545 306 372 218 240 195 238 247
249 348 351 295 289 271 195 187 264 164 242 321 353 320 229 296 298 270 337 162
318 221 246 165 329 359 496 309 296 269 287 225 178 118 127 206 190 209 296 131
115 108 208 175 185 212 112 96 131 88 93 136 128 185 106 100 80 109 159 296
97 68 71 87 97 77 69 95
HMS-A09B 88
558 514 601 846 589 466 425 519 325 345 473 421 547 304 378 228 229 200 233 264
237 365 350 291 300 281 198 174 246 181 232 314 356 304 245 310 275 268 336 163
316 237 251 162 331 350 495 320 299 259 308 209 175 106 153 201 192 212 297 122
120 104 197 194 183 200 115 101 125 80 88 138 107 211 101 91 80 92 166 303
110 87 58 82 90 82 70 103
HMS-A10A 83
326 241 203 113 176 223 405 553 603 441 575 525 335 261 400 454 696 500 379 162
250 192 310 351 289 311 233 172 193 198 151 142 142 137 210 182 176 187 264 135
132 245 170 185 246 257 212 227 221 196 225 113 109 136 215 116 108 135 337 243
365 386 310 125 144 128 360 240 334 269 227 162 354 98 75 128 103 187 167 84
92 74 157

HMS-A10B 83
321 234 208 120 173 232 401 546 591 419 528 507 351 253 410 455 674 516 371 164
257 173 309 359 284 303 226 181 187 187 160 140 146 141 198 189 165 199 280 124
135 253 168 184 245 260 206 239 235 187 250 148 115 137 219 108 119 125 323 240
348 375 314 131 125 131 374 221 329 267 257 151 357 99 62 135 98 191 153 104
88 86 164
HMS-A11A 104
362 430 383 323 206 323 199 184 187 478 341 361 290 344 286 300 172 122 220 336
118 210 332 337 226 235 96 89 123 115 125 92 96 150 150 139 139 148 314 194
138 222 119 217 140 156 107 160 202 162 135 221 121 275 158 158 119 150 171 164
162 148 192 184 144 131 84 126 114 198 224 219 221 272 227 215 165 221 206 403
394 284 298 158 168 129 274 371 185 170 168 162 93 239 205 137 80 81 134 96
114 125 121 188
HMS-A11B 104
294 454 386 303 208 315 194 182 182 485 328 363 296 344 280 311 177 132 217 347
121 214 403 370 239 236 100 90 125 110 121 93 95 150 151 131 126 143 299 197
145 224 121 226 148 154 101 164 185 161 139 213 125 274 155 179 121 165 172 150
186 128 194 193 134 136 93 117 128 202 227 216 227 272 222 218 162 221 196 406
406 266 296 163 158 133 266 370 193 180 173 170 114 235 197 218 102 112 76 113
114 126 123 181
HMS-A12A 60
174 151 220 155 147 484 220 243 101 151 146 151 94 124 148 76 148 155 125 213
142 140 76 68 71 90 92 92 100 87 132 86 162 157 110 116 176 192 110 107
157 244 91 98 110 154 147 82 110 179 60 87 92 107 103 147 142 125 96 118
HMS-A12B 60
254 199 175 91 373 197 290 142 234 239 212 158 164 180 118 185 160 142 268 138
161 92 75 77 100 103 114 110 112 165 103 206 182 112 144 239 214 135 108 179
300 98 110 112 170 154 90 118 198 76 100 102 107 110 139 148 146 126 95 112
HMS-A13A 75
493 299 566 565 646 568 511 294 200 158 211 200 153 240 355 198 318 314 226 209
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483 305 521 558 652 573 503 288 207 160 214 192 157 223 347 207 331 336 239 207
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220 90 122 203 133 243 245 121 106 143 168 382 317 212 205
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322 390 334 373 241 328 309 315 321 408 328 255 157 145 306 314 359 431 345 342
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HMS-A15A 62
281 220 182 327 351 345 332 223 282 268 273 286 178 271 225 264 271 182 166 146
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110 112

HMS-A15B 62
254 225 182 327 341 349 336 236 282 264 264 271 192 241 209 282 293 174 171 139
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101 109
HMS-A16A 58
370 301 297 476 428 278 154 73 85 167 539 446 354 214 92 195 114 82 139 160
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HMS-A18A 67
313 302 256 277 327 246 273 184 192 226 244 229 287 295 225 293 370 319 320 200
243 227 239 346 373 368 293 292 182 215 276 215 289 254 259 201 167 200 153 145
350 315 305 291 223 209 242 270 300 243 342 258 250 149 112 209 228 194 189 169
178 113 142 202 166 193 196
HMS-A18B 67
291 291 267 266 334 244 280 182 197 216 259 241 293 282 233 294 370 317 309 199
253 220 236 340 367 384 281 317 182 225 292 207 264 254 281 198 178 189 170 154
339 321 285 293 208 210 238 284 288 246 356 250 257 137 99 214 222 210 188 166
165 135 152 168 181 195 210
HMS-A19A 54
407 329 227 315 243 227 250 373 228 334 359 478 369 438 571 486 712 642 395 512
520 356 248 142 89 187 142 112 118 90 87 135 120 137 109 160 223 276 246 367
193 215 248 397 346 195 147 218 128 140 200 224 324 209
HMS-A19B 54
400 337 238 321 238 230 273 369 248 310 400 468 373 416 573 476 689 632 376 528
533 345 239 160 101 189 125 121 109 87 84 144 109 137 114 159 206 278 250 388
242 223 310 398 355 191 134 228 118 142 213 225 315 199
HMS-A20A 64
314 274 411 392 361 384 319 337 365 485 500 300 468 357 360 275 357 295 184 173
153 214 204 248 232 365 279 304 417 384 295 179 89 25 50 170 112 92 156 171
122 133 170 310 381 379 676 371 257 317 216 286 419 284 408 312 259 446 265 313
395 247 308 331
HMS-A20B 64
323 285 416 414 372 370 338 343 389 464 507 310 469 355 351 285 364 302 176 182
170 217 214 256 241 358 282 306 391 375 299 172 109 30 60 168 110 92 154 192
132 120 162 325 381 406 719 416 261 325 203 309 434 308 392 298 241 443 268 297
410 247 304 341

HMS-A21A 76
346 408 513 618 627 349 325 187 118 180 246 147 144 143 117 71 71 115 175 213
226 222 167 217 169 223 258 179 217 206 165 168 243 167 123 151 166 306 228 223
172 164 242 265 287 245 206 310 221 201 143 201 239 321 184 214 251 206 117 103
113 162 228 193 171 131 68 103 124 168 156 168 162 130 94 125
HMS-A21B 76
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181 150 259 267 289 237 220 306 215 184 159 217 234 321 175 220 241 229 104 107
113 165 234 174 181 117 79 105 116 171 142 159 164 131 103 130
HMS-A22A 78
323 536 180 207 225 190 133 173 193 189 223 357 275 250 421 343 379 220 181 343
350 268 207 239 239 164 185 114 123 160 110 103 104 96 109 101 90 229 353 313
190 181 273 232 281 251 248 189 151 153 189 268 198 195 126 129 156 168 206 128
197 119 190 274 279 140 128 155 104 121 218 254 313 283 323 216 282 409
HMS-A22B 78
290 541 267 200 199 172 135 153 203 172 235 357 276 303 405 351 385 264 185 342
346 269 225 216 243 164 183 100 118 172 108 105 95 87 89 113 75 207 331 307
180 187 264 240 279 254 240 185 160 128 171 247 204 179 143 140 165 173 168 131
218 123 221 268 306 153 143 149 107 155 213 231 317 281 328 221 262 403
HMS-A23A 103
143 171 222 288 294 256 246 291 380 371 391 391 320 253 319 197 307 379 260 153
228 344 241 239 321 367 260 297 240 293 198 150 175 171 190 387 340 248 310 333
232 254 290 385 331 321 248 165 165 224 290 275 234 181 153 183 154 117 112 84
121 212 160 93 68 81 119 103 132 91 116 164 141 95 90 91 93 90 97 159
98 135 133 75 88 82 100 100 69 62 36 43 72 89 67 83 102 125 96 149
111 111 172
HMS-A23B 103
142 174 226 265 276 258 238 298 366 366 439 406 314 241 296 232 319 378 275 150
232 343 240 242 321 367 256 300 234 296 196 145 170 182 196 384 353 242 300 329
232 249 281 387 337 329 245 165 162 228 297 277 237 187 147 179 157 130 100 84
115 219 170 93 75 81 125 103 127 96 120 158 140 94 81 96 98 92 96 162
91 130 128 70 84 86 101 90 65 59 58 42 69 75 68 83 99 134 91 161
93 110 176
HMS-A24A 73
242 105 112 128 181 156 112 65 74 111 75 80 113 140 116 86 116 139 96 92
76 130 150 167 189 169 210 161 157 253 232 188 108 195 109 181 125 174 251 250
202 185 166 126 101 45 53 64 67 78 67 60 52 62 59 79 98 137 96 132
115 73 65 60 59 88 76 65 82 107 89 78 62
HMS-A24B 73
240 102 109 127 188 158 109 64 75 117 67 88 109 157 141 100 120 135 94 91
76 139 141 151 160 180 206 153 149 240 214 169 121 188 107 189 124 173 266 239
203 167 180 128 107 53 48 59 55 87 65 65 49 56 54 86 95 131 93 134
114 71 72 59 65 89 81 66 75 101 88 81 67

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 Building* (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

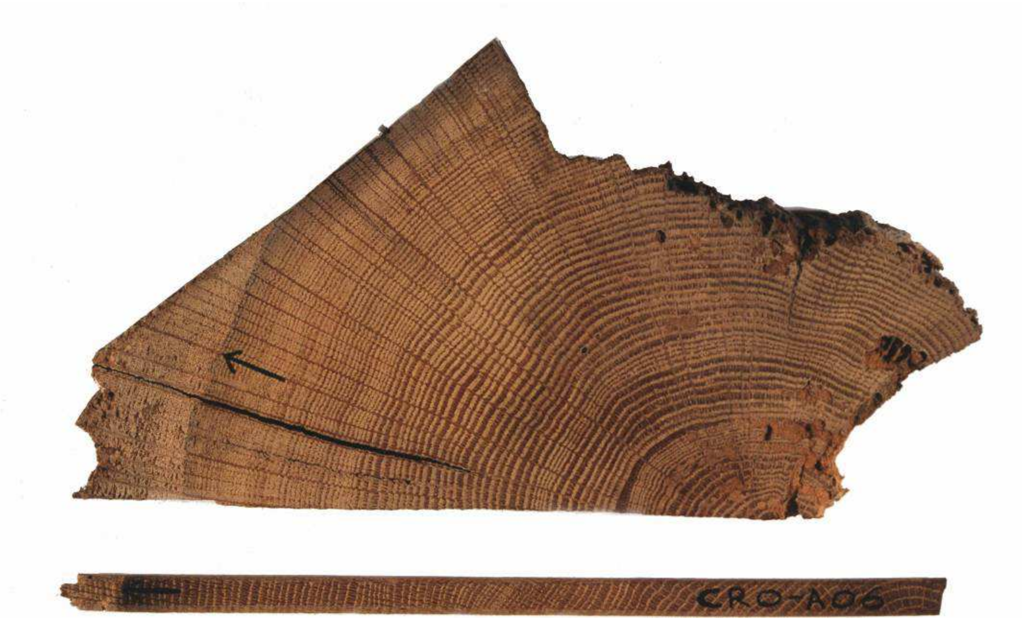


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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 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.

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

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

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

t-value/offset Matrix

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

Bar Diagram

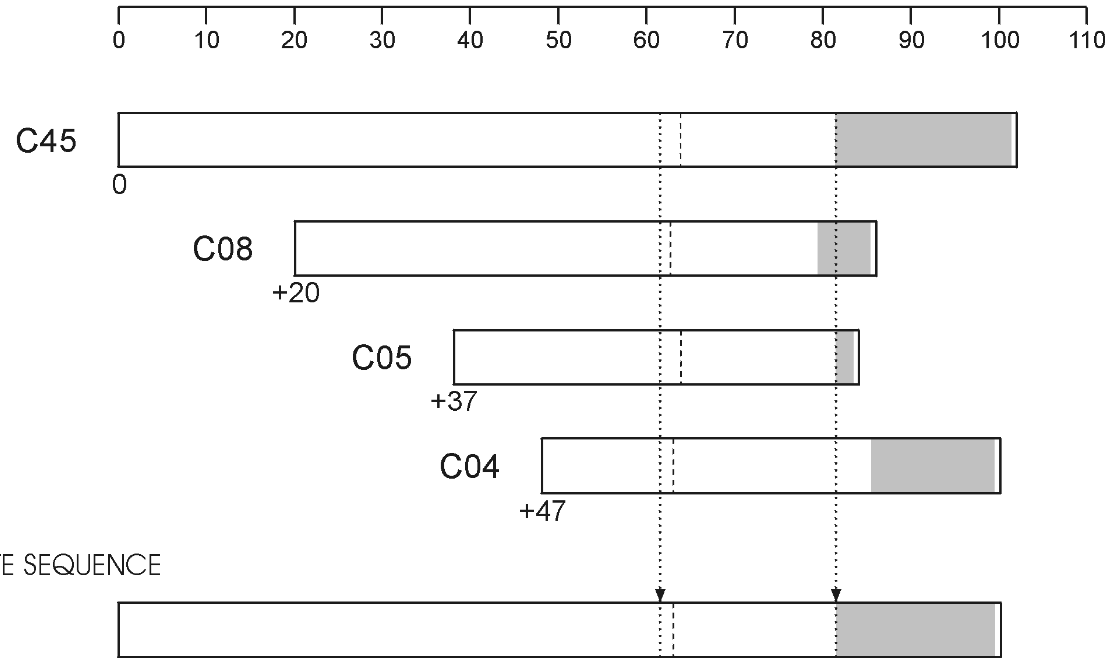


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

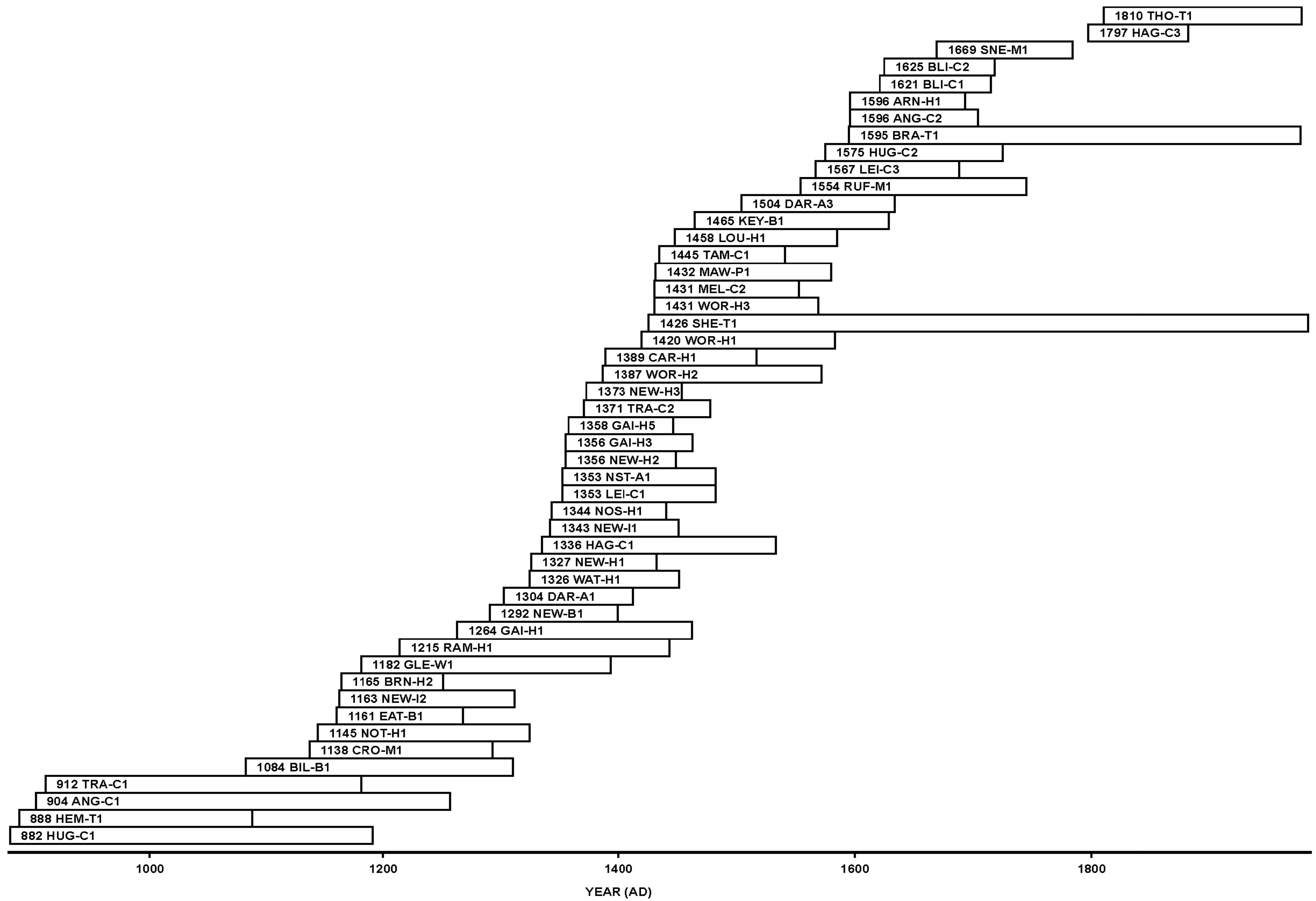
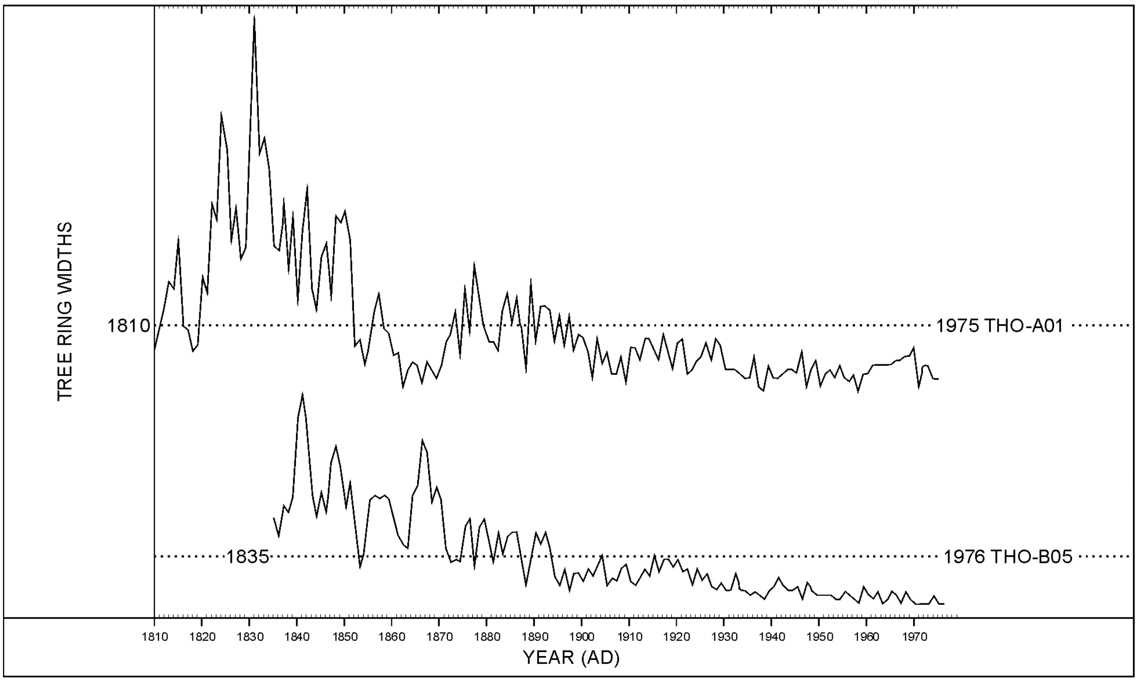


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

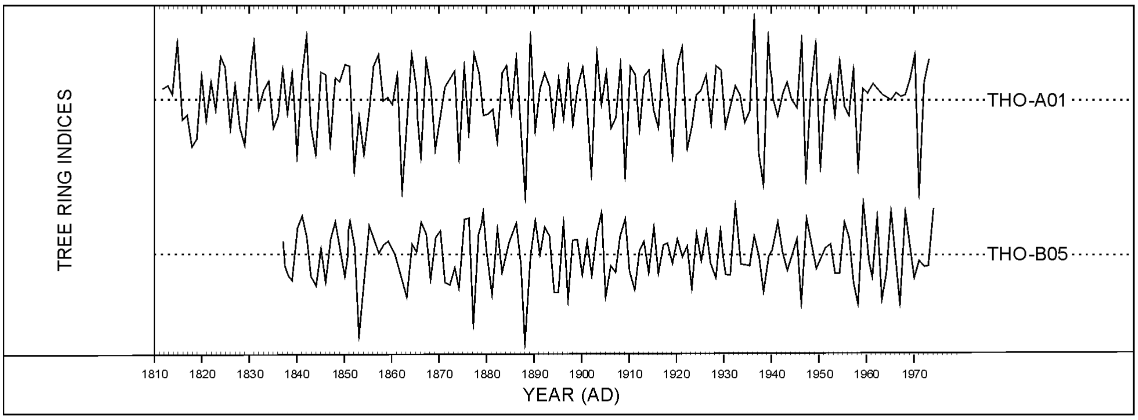


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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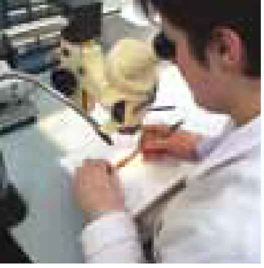
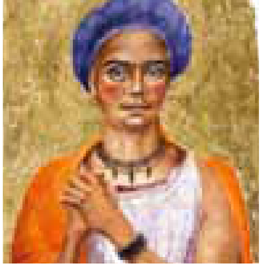


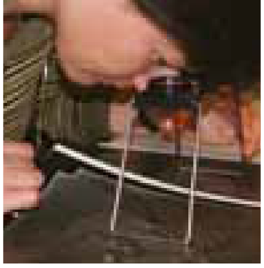


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