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CHURCH OF ST ANDREW, CHURCH ROAD, COTTON, SUFFOLK
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION AND ANALYSIS

ENGLISH HERITAGE

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Research Report Series 19-2012

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TREE-RING ANALYSIS OF TIMBERS

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SUMMARY

Dendrochronological analysis was undertaken on eight samples from the bench ends of a selection of pews in the Church of St Andrew, Cotton. This analysis produced a single dated site chronology, COTASQ01, comprising six samples and having an overall length of 87 rings, these rings dated as spanning the years AD 1375–1461. Interpretation of the sapwood on these samples would indicate that the dated bench ends are derived from timber cut as part of a single programme of felling some time between AD 1476 and AD 1501.

Analysis was also undertaken on12 samples from the nave roof. This produced two site chronologies, COTASQ02 and COTASQ03, comprising three and two samples, of overall lengths 63 and 65 rings respectively. Neither of these site chronologies, or any of the seven remaining ungrouped samples from the roof, could be dated

CONTRIBUTORS

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ACKNOWLEDGEMENTS

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ARCHIVE LOCATION

Suffolk Historic Environment Record
Suffolk County Council Archaeology Service
Shire Hall
Honey Hill
Bury St Edmunds
Suffolk IP33 2AR

DATE OF INVESTIGATION

2010-11

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INTRODUCTION

The parish church of St Andrew is situated in the centre of the village of Cotton, itself approximately six miles north of Stowmarket in Suffolk (TM 0701 6692, Figs 1 and 2). According to the listed building entry (http://list.english-heritage.org.uk/), the main body of the church is believed to be of fourteenth century date, with the clerestory having been added in the fifteenth century. The church has a square three-stage tower at its west end, the west side of which has been given heavy angle buttresses. Between the buttresses is a very tall arched opening, said to be of later date, to light the west nave window. The nave has an exceptionally fine roof of 10 bays formed by 11 highly decorated alternate double hammer beam and arched-braced trusses (Figs 3a/b).

The insertion of a full, high-level, scaffold to the nave in 2011 for repairs and conservation allowed a close inspection of the entire roof structure to be undertaken. During this survey some anomalies in the junctions of the framing emerged, and it is now considered possible that the elaborate hammer beam system may have been cosmetically added to a surviving earlier roof.

The church also contains a series of pews which, during their assessment and sampling were observed to be of two types. The first type, found only in the nave, appear to be of relatively modern, possibly late-nineteenth century or, more probably, twentieth century date. These 'modern' pews are relatively lightweight, plain, formed of very square and cleanly cut pieces of timber, and have 'gates' at each end. The second type, found in the nave, the north aisle, and at the west end of the church, is of a heavier and more substantial build, and do not have 'gates' (Fig 4a/b). This latter type are generally also rather plain and cannot be reliably dated on the basis of their scant stylistic evidence, the only decoration to these being a roll-moulded top to the bench ends of each pew, though, according to the listing description, they are of medieval date. In addition, according to the listing description, there is one, supposedly fifteenth century, pew which has carved poppyhead ends (though this pew was not sampled). The pews to the nave, of both types, are fixed in two rows to a low platform base, while those to the north aisle and the west end are loose and stand on their own legs.

SAMPLING

Sampling and analysis by dendrochronology of the nave roof timbers was requested by Malcolm Starr, English Heritage Historic Buildings Architect, East of England Region. The analysis was undertaken to inform grant aided repairs to the roof by attempting to determine whether or not it was all of a single date, or if, as suggested by the anomalies seen during inspection, it was of more than one phase. In addition it was also requested that samples be obtained from the potentially medieval pews in an attempt to reliably determine their date and hence aid the understanding of their significance.

To this end, an examination was made of all the roof timbers accessible from the inserted scaffold. It was seen at this time that, despite the considerable quantity of material available throughout the 10 bay roof structure, only a relatively small number of beams appeared to retain sufficient rings, here deemed to be a minimum of 50, for reliable analysis. Unfortunately, not only did the majority of beams appear to be derived from moderately fast grown trees, and thus not have sufficiently high numbers of rings for analysis, but also, as a result of the decorated nature of the roof, to have had their outermost rings, particularly the sapwood, removed by being heavily carved and moulded, the loss of sapwood reducing the possibility of obtaining precise felling dates for the timbers. Despite this, it was seen that sufficient suitable samples could be obtained. It was also noted that there appeared to be no difference in the overall visual characteristics of the timbers of any part of the roof as might possibly have been the case were there timbers of two or more phases present.

The pre-sampling assessment also showed that the more substantial, potentially medieval, pews contained some suitable timber for tree-ring analysis, though such material was restricted to the bench ends. The other parts of the pews, the backs, and the bench seats themselves for example, while being of oak, were made from fast-grown trees and thus had only low numbers of rings. It also appeared that the bench seats might be relatively modern replacements. The kneelers were all of pine.

Thus, from the suitable timbers available, a total of 21 samples was obtained by coring. Each sample was given the code COT-A (for Cotton, site 'A') and numbered 01–21. Thirteen samples, COT-A01–13, were obtained from the roof timbers using a standard corer, with a bore of approximately 11mm. As far as was evident from their growth characteristics, all the sampled timbers from the roof appeared to represent a homogenous group of trees, showing no evidence, by way of redundant mortices or peg holes, of reuse, insertion, or alteration. A further eight samples, COT-A14–21, were obtained from the most suitable looking bench ends using a corer with a smaller bore of approximately 8mm.

The positions of the sampled timbers from the roof are shown on the truss drawings provided, these being reproduced here as Figures 5a-g. Details of the samples are given in Table 1. In this table the roof trusses have been numbered 1-11 from east to west, with individual timbers being further identified on a north–south basis as appropriate.

Details of the pew samples are also given in Table 1. In this case, the pews have been numbered from east to west firstly along the north row (pews 1–11), and then east to west along the south row (pews 12 – 22). The other pews, those scattered about the aisle and at west end of the church, have been numbered consecutively from east to west (pews 23–29), though, given that these pews are not fixed, it would be quite possible to change their positions. The pew samples are then further located as being either from the north or south bench end of each numbered pew. The positions of these samples are shown in Figure 6.

ANALYSIS

Each of the 21 samples obtained in this programme of tree-ring dating was initially prepared by sanding and polishing. It was seen at this time that one sample had fewer than the minimum of 50 rings here deemed necessary for reliable dating, and it was rejected from this programme of analysis. The annual growth-ring widths of the remaining 20 samples were, however, measured, the data of these measurements being given at the end of this report. The data of the measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing three separate groups comprising six, three, and two cross-matching samples to be formed at a minimum value of t=4.5. The samples of each group, cross-matching with each other at off-sets as shown in Figures 7a-c, were combined at their indicated offsets positions to form site chronologies COTASQ01, COTASQ02, and COTASQ03, these site chronologies having overall lengths of 87, 63, and 65 rings respectively.

Each of the three site chronologies was then compared with an extensive series of reference chronologies for oak, this indicating a repeated and consistent match with a series of these for site chronology COTASQ01, when the date of its first ring is AD 1375 and the date of its last measured ring is AD 1461. The evidence for this dating is given in Table 2. COTASQ02 and COTASQ03 remain undated.

Each of the three site chronologies was also compared with the nine remaining measured but ungrouped single samples, but there was no further satisfactory matching. The nine remaining ungrouped samples were than compared individually with the full range of reference chronologies for the oak, but again there was no satisfactory cross-matching, and these samples must remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
COTASQ01	6	88	1375–1461
COTASQ02	3	63	undated
COTASQ03	2	65	undated
Ungrouped	9	---	undated
Unmeasured	1	---	---

INTERPRETATION AND DISCUSSION

Site chronology COTASQ01

None of the six dated samples in site chronology COTASQ01 (Fig 7a), all of them from bench ends of pews, retain complete sapwood, and it is thus not possible to indicate a precise felling date for any of the trees represented. One sample, COT-A18, does, however, retain the heartwood/sapwood boundary, meaning that only the sapwood rings are missing; this boundary is dated AD 1461. Using a 95% confidence limit of 15–40 for the number of sapwood rings the tree is likely to have had would give the timber represented by sample COT-A18 an estimated felling date in the range AD 1476–1501.

None of the other five dated samples in site chronology COTASQ01 retain the heartwood/sapwood boundary, and it is thus not possible to calculate the likely felling date ranges for these timbers. However, all six samples in this site chronology cross-match extremely well with each other, with values of t=10.0 found between samples COT-A14 and A15, and values as high as t=17.6 and t=17.7 between samples COT-A16, A18, and A21. Such high t-values would at the very least suggest that the timber used for these bench ends has come from trees which were growing very close to each other in the same copse or stand of woodland. Although in theory it is possible that trees originally growing close together, but felled at different times, might come to be used for the same purpose in the same place, this would perhaps be considered a relatively unlikely coincidence, and it is more likely that the trees were felled at the same time as each other. Indeed, the strength of cross-matching between some samples is sufficiently high to suggest that some of the dated bench ends may be derived from the same tree, and that possibly only two or three trees have been utilised overall.

Site chronology COTASQ02

None of the three samples in site chronology COTASQ02 (Fig 7b), representing two collars and a hammer beam, have been dated. It is likely, however, given that the heartwood/sapwood boundary on these three samples varies by only four years from relative position 55 on sample COT-A12, to relative position 59 on samples COT-A09 and A13, that the trees represented were felled at the same time as each other.

Site chronology COTASQ03

Likewise, neither of the two samples in site chronology COTASQ03 (Fig 7c), which represent a wall post and a wall tie, has been dated, though it is again likely, that they were felled at the same time as each other. The high degree of cross-matching between these two samples, with a value of t=10.6, suggests that either these two structural elements have been derived from a single tree, or from two trees growing close to each other. While it is again in theory possible that trees originally growing close together, but felled at different times, might come to be used for the same purpose in the same place, this again seems relatively unlikely.

Undated samples

It will be seen from this analysis that eight samples from the roof and one measured sample from a bench end are ungrouped and undated. As may be seen from Table 1, several of these samples are borderline with respect to numbers of rings present, although some of similar lengths have been successfully dated. None of the samples have any obvious anomalies such as distorted or compressed rings which might make cross-matching and dating difficult. Thus the lack of cross-matching and dating is disappointing.

CONCLUSION

Although a number of buildings in Suffolk have been dated by tree-ring analysis many others in the county have not been amenable to the method, many of them producing samples of a similar nature to those found here. It is possible that some of the sampled timbers are from different locations, and of a particular time, not as yet sufficiently well represented in the reference material to produce reliable dating.

Thus, although the lack of dating for the roof is naturally disappointing, the data is now archived and it is possible that when further site chronologies from within the region are produced in the future, the roof samples will be dated. This disappointment is, however, moderated by the success in dating the bench ends. Whereas the date of these was previously unknown, they are now identified as being late-fifteenth century, a date which, it may be of interest to note, is similar to that ascribed in the building listing to the poppyhead pew. Given that the clerestory is of about this time, the pews may represent the remains of seating installed when that work was undertaken making them amongst the earliest dendrochronologically dated bench ends. The dating of these bench ends, furthermore, may now be of use in the possible dating of similar pew types in other churches in Suffolk and potentially elsewhere in the country.

BIBLIOGRAPHY

Arnold, A, J, Howard, R E, and Litton C D, 2006 *St Peter's Church, West Molesey, Elmbridge, Surrey: Tree-ring analysis of timbers,* Centre for Archaeol Rep, 90/2006

Arnold, A J, Howard, R E, and Litton, C D, 2008 – Nottingham Tree-ring Dating Laboratory: additional dendrochronology dates, no 28, Vernacular Architect, 39, 107–11

Arnold, A J, and Howard, R E, 2009 *St Mary's Church, Feltwell, Norfolk: tree-ring analysis of timbers*, EH Res Dept Rep Ser, 66/2009

Boswijk, G, and Tyers, I, 1998 *Tree-ring analysis of oak timbers from Dragon Hall, King Street, Norwich*, ARCUS Rep, 365

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1987 List 20 no 2a – Nottingham University Tree-Ring Dating Laboratory results, Vernacular Architect, 18, 53–4

Howard, R E, Laxton, R R, and Litton, C D, 2000 *Tree-ring analysis of timbers from The Barn and Cottage, Abbey Farm, Thetford, Norfolk,* Anc Mon Lab Rep, 48/2000

Tyers, I, 1996a *Draft Dendrochronology Assessment: Fastolfs sites*, ARCUS Rep, 255

Tyers, I, 1996b *Draft Dendrochronology Assessment: Rosary sites*, ARCUS Rep, 256

Tyers, I, 2004 *Tree-Ring Analysis of Oak Boards and Structural Timbers from the Transepts, Presbytery, and Tower of Peterborough Cathedral, City of Peterborough*, Centre for Archaeol Rep, 77/2004

TABLES

Table 1: Details of tree-ring samples from the Church of St Andrew, Cotton, Suffolk

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Roof timbers					
COT-A01	South hammer beam, truss 7	69	h/s	------	------	------
COT-A02	South pendant, truss 3	60	h/s	------	------	------
COT-A03	South wall tie, truss 2	58	h/s	------	------	------
COT-A04	South hammer beam, truss 9	57	h/s	------	------	------
COT-A05	South wall post, truss 3	60	h/s	------	------	------
COT-A06	South wall post, truss 9	63	no h/s	------	------	------
COT-A07	North wall tie, truss 2	65	no h/s	------	------	------
COT-A08	North wall tie, truss 6	54	no h/s	------	------	------
COT-A09	North hammer beam, truss 5	58	4	------	------	------
COT-A10	North principal rafter, truss 7	60	h/s	------	------	------
COT-A11	North principal rafter, truss 9	58	h/s	------	------	------
COT-A12	Collar, truss 9	59	4	------	------	------
COT-A13	Collar, truss 8	54	4	------	------	------
	Pews					
COT-A14	Pew 6, north bench end	70	no h/s	1383	------	1452
COT-A15	Pew 7, north bench end	55	no h/s	1405	------	1459
COT-A16	Pew 7, south bench end	71	no h/s	1375	------	1445
COT-A17	Pew 8, north bench end	54	no h/s	1395	------	1448
COT-A18	Pew 8, south bench end	76	h/s	1386	1461	1461
COT-A19	Pew 20, south bench end	nm	---	------	------	------
COT-A20	Pew 21, south bench end	51	no h/s	------	------	------
COT-A21	Pew 23, south bench end	50	no h/s	1405	------	1454

h/s = the heartwood/sapwood ring is the last ring on the sample
nm = sample not measured

Table 2: Results of the cross-matching of site sequence COTASQ01 and relevant reference chronologies when first ring date is AD 1375 and last ring date is AD 1461

Reference chronology	Span of chronology	*t*-value	Reference
Abbey Farm, Thetford, Norfolk	AD 1332–1536	7.3	(Howard *et al* 2000)
Hays Wharf, Southwark, London	AD 1248–1647	7.2	(Tyers 1996a; Tyers 1996b)
Chalgrove Manor, Chalgrove, Oxfordshire	AD 1355–1503	6.3	(Arnold *et al* 2008)
Dragon Hall, Norwich, Norfolk	AD 1289–1426	6.2	(Boswijk and Tyers 1998)
Presbytery roof, Peterborough Cathedral, Cambridgeshire	AD 1208–1500	6.0	(Tyers 2004)
St Peter's Church, West Molesey, Elmbridge, Surrey	AD 1364–1503	5.6	(Arnold and Howard 2006)
St Mary's Church, Feltwell, Norfolk	AD 1303–1494	5.4	(Arnold and Howard 2009)
Gainsborough Old Hall, Gainsborough, Lincolnshire	AD 1356–1462	5.3	(Howard *et al* 1987)

FIGURES

Figure 1: Map to show the general location of Cotton. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

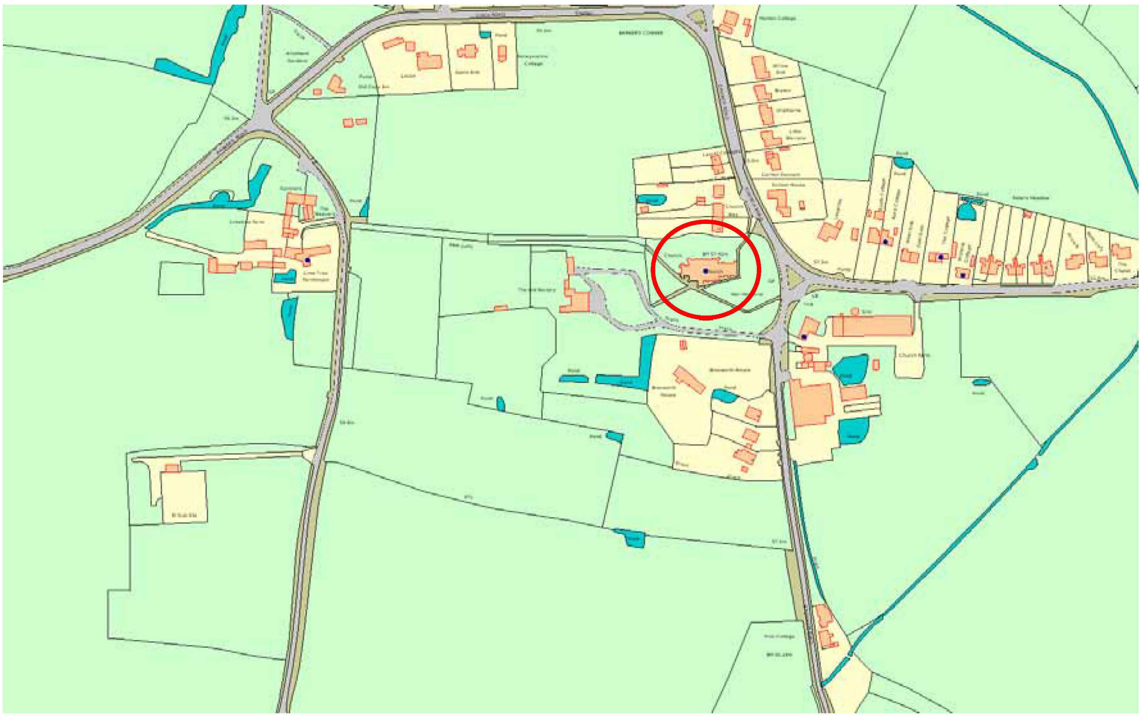


Figure 2: Map to show the general location of the Church of St Andrew, Cotton. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 3a: View of the nave roof showing the alternating double hammer beam and arch-braced trusses

Figure 3b: Detail of a hammer beam truss

Figure 4a: View of the two different types of pews

Figure 4b: Detail of the bench ends of the early pews

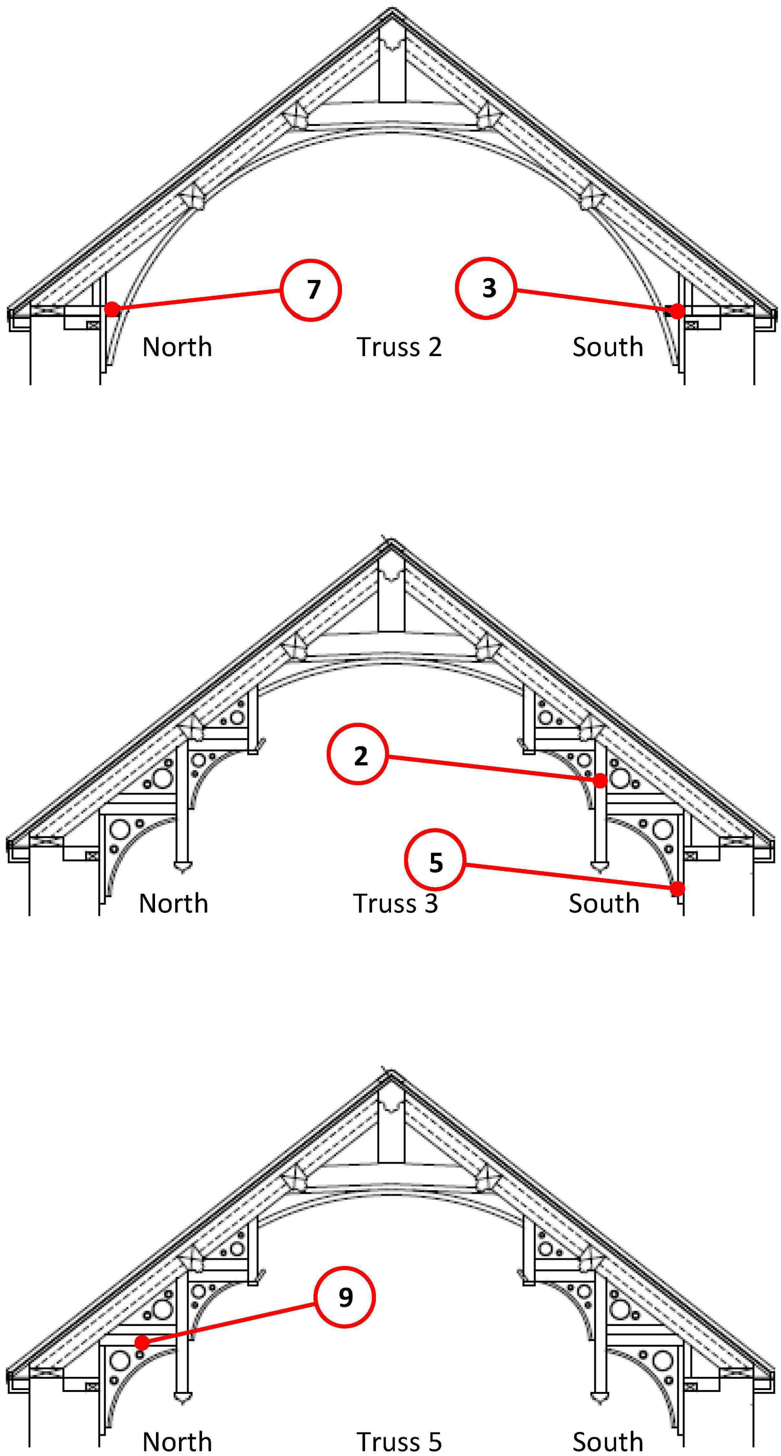


Figure 5a-c: Sections through the nave roof trusses to locate sampled timbers

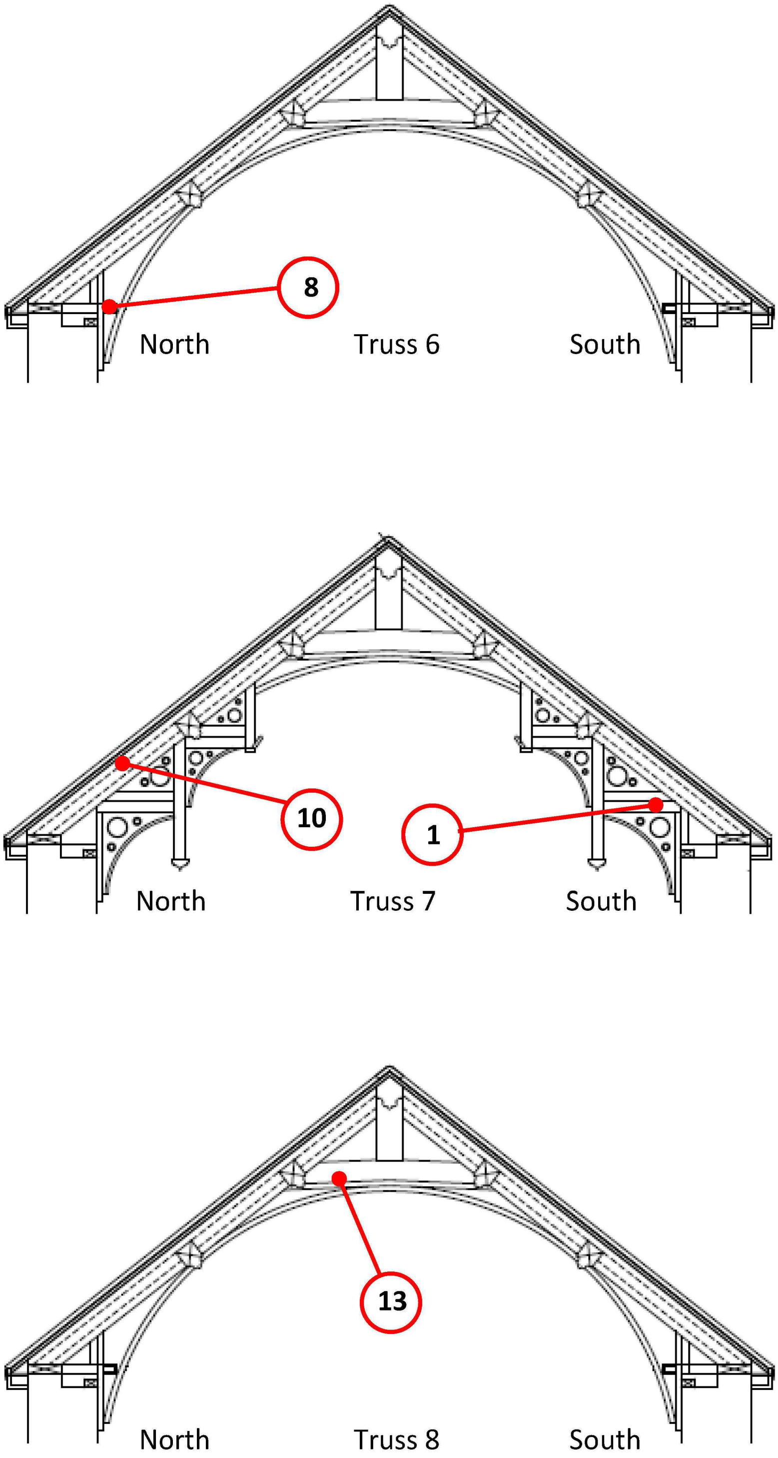


Figure 5d-f: Sections through the nave roof trusses to locate sampled timbers

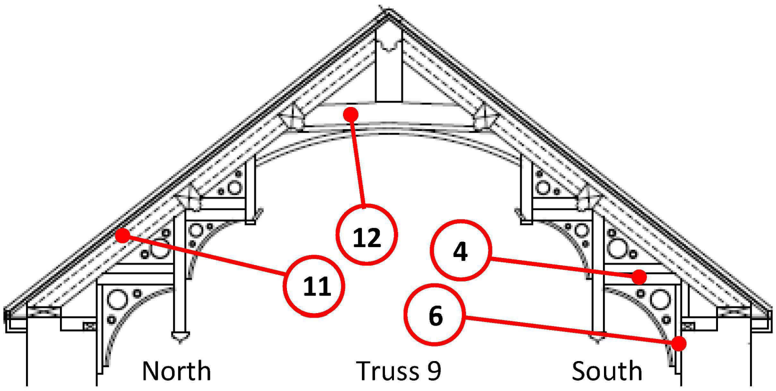


Figure 5g: Sections through the nave roof trusses to locate sampled timbers

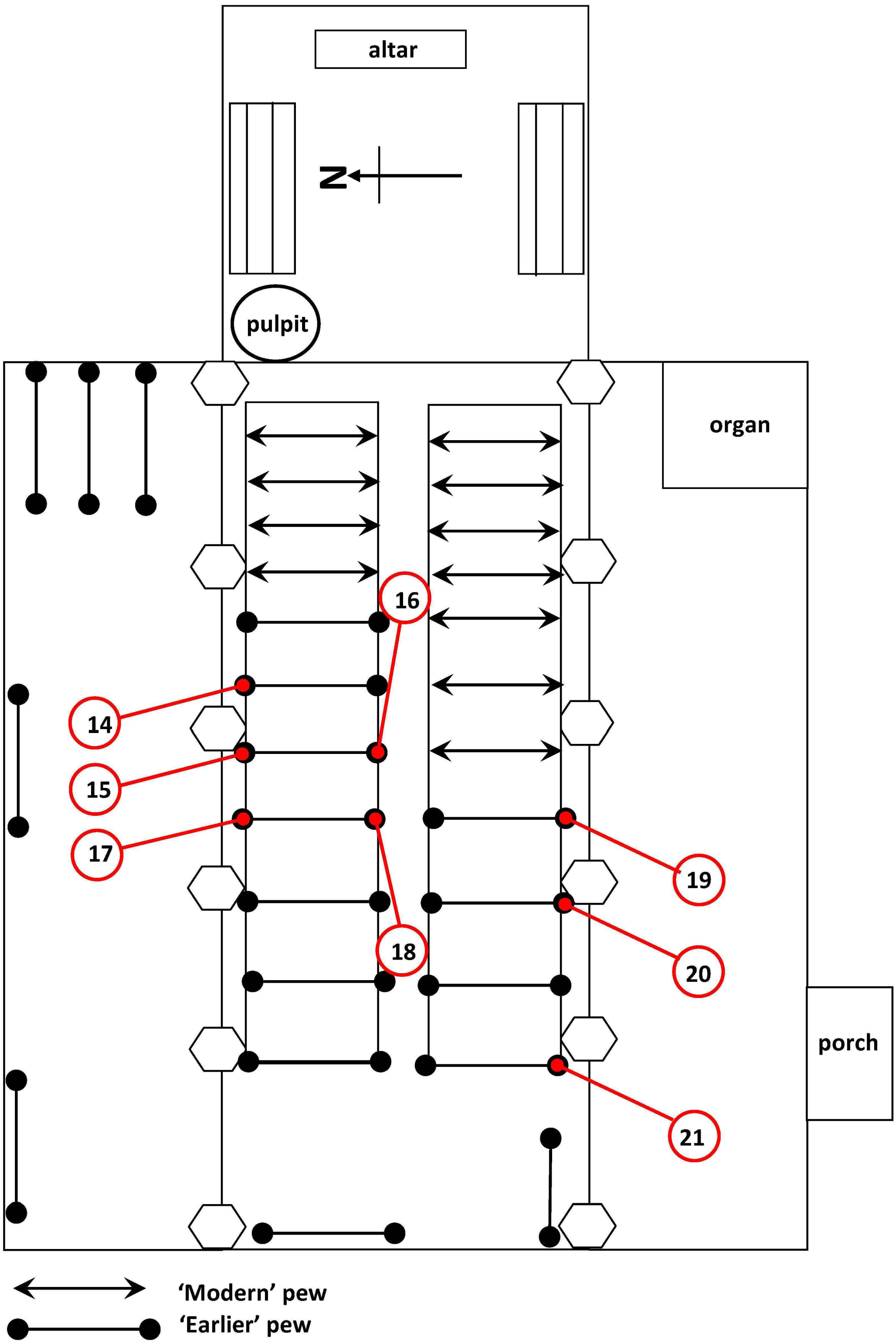
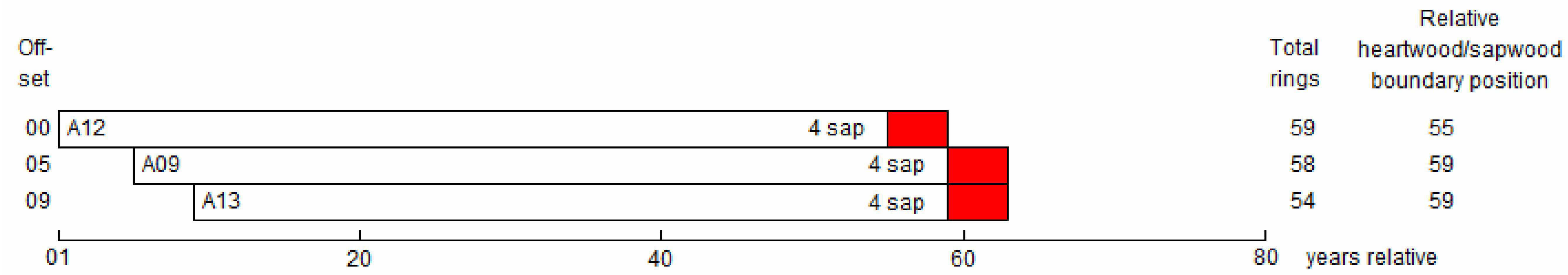
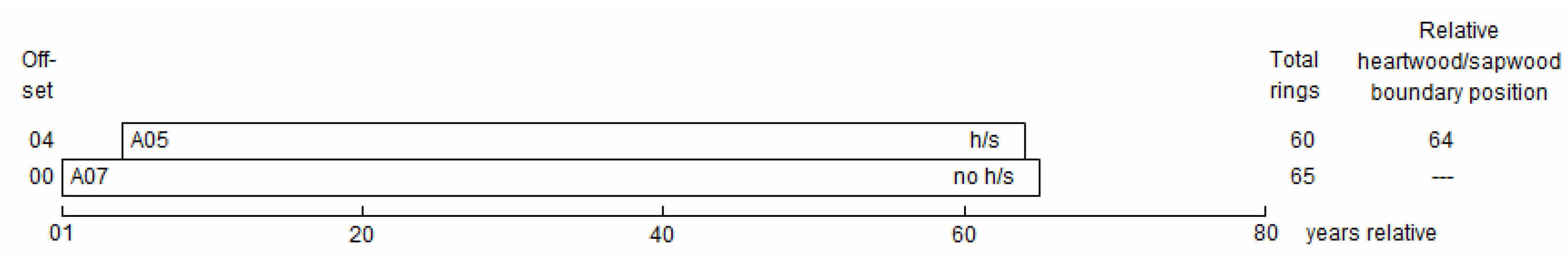


Figure 6: Basic plan of the nave and aisles to locate the sampled pews



White bars = heartwood rings; red bars = sapwood rings;
h/s = the last measured ring on the sample is at the heartwood/sapwood boundary, ie, only the sapwood rings are missing

Figure 7a/b: Bar diagrams of the samples in site chronology COTASQ01 (top) and COTASQ02 (bottom)



White bars = heartwood rings
h/s = the last measured ring on the sample is at the heartwood/sapwood boundary, ie, only the sapwood rings are missing

Figure 7c: Bar diagram of the samples in site chronology COTASQ03

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

COT-A01A 69
219 121 214 213 195 212 174 209 154 183 164 186 201 169 205 188 159 188 114 111
81 145 166 154 236 127 159 137 148 118 159 142 148 149 102 144 127 212 200 224
119 198 195 167 149 151 128 211 188 125 204 85 82 56 43 47 41 64 58 72
62 114 132 92 103 72 91 66 84
COT-A01B 69
210 111 226 219 175 200 183 200 148 181 158 181 199 176 220 197 163 178 123 106
89 133 152 149 242 117 163 117 140 111 150 129 133 134 108 137 120 202 200 225
112 178 186 160 139 150 126 201 168 115 200 86 79 55 40 44 43 69 59 75
59 103 122 85 100 65 88 61 89
COT-A02A 60
134 182 235 332 252 288 262 224 221 298 398 855 798 285 334 286 298 292 374 433
303 293 324 378 272 359 257 311 196 350 232 209 273 317 314 266 308 286 252 277
239 252 270 331 310 365 396 369 366 456 406 339 246 281 399 286 188 185 323 253
COT-A02B 60
138 177 217 325 243 295 264 206 227 304 379 832 759 268 330 298 307 289 377 457
300 299 334 400 267 344 279 310 202 339 229 190 282 314 299 262 337 266 250 263
229 245 280 322 307 361 404 362 361 448 405 342 225 282 385 300 186 180 328 250
COT-A03A 58
429 163 251 244 370 386 292 400 440 465 484 474 435 388 730 560 308 241 206 232
288 359 336 298 385 413 408 409 439 412 192 249 218 397 526 416 461 318 356 399
157 174 161 194 183 271 255 325 269 230 243 197 275 263 133 118 142 233
COT-A03B 58
417 158 245 239 374 372 287 391 432 456 497 474 429 402 703 543 309 259 193 229
298 368 314 304 389 401 396 405 444 399 197 228 211 394 527 417 444 306 357 412
167 177 166 187 186 270 261 325 266 249 241 183 269 261 136 125 139 229
COT-A04A 57
252 305 350 328 357 481 467 416 313 341 343 299 313 326 414 304 334 351 314 315
328 268 274 282 312 299 276 378 401 388 351 511 503 410 401 402 290 289 315 308
263 320 276 240 261 218 195 201 217 324 232 209 234 158 197 186 53
COT-A04B 57
261 300 347 329 360 500 470 414 311 337 329 320 315 337 399 299 331 354 330 298
346 265 276 279 300 300 273 367 395 384 359 493 479 450 392 408 290 305 284 307
253 309 263 244 262 218 195 215 226 313 233 212 238 157 197 180 59
COT-A05A 60
300 363 424 392 269 370 351 270 247 307 256 226 229 69 55 40 35 51 56 55
60 69 68 97 102 80 69 114 119 99 140 130 126 80 45 50 69 59 76 64
97 99 84 100 91 102 99 90 61 38 20 19 32 37 61 56 75 84 111 89
COT-A05B 60
287 364 414 404 264 371 359 257 233 342 244 228 233 71 52 47 38 46 56 56
60 72 67 88 103 85 68 125 126 100 142 131 123 83 39 52 87 76 70 65
93 102 85 95 91 102 97 95 63 33 19 19 35 38 52 58 73 87 99 91
COT-A06A 63
234 288 32 58 83 78 70 63 74 79 79 119 120 145 97 73 100 128 136 122
146 140 64 55 71 40 61 64 91 109 121 96 150 152 119 120 109 45 47 57
52 45 32 45 52 88 109 128 228 195 121 57 34 36 34 37 35 46 49 55
58 86 88
COT-A06B 63

199 262 40 52 69 66 72 60 76 78 80 108 119 149 88 69 96 126 142 130
146 144 75 48 61 48 63 69 99 108 120 100 146 149 114 130 101 48 49 59
57 50 36 40 54 80 110 132 214 200 121 61 28 37 36 39 38 45 55 55
57 84 89
COT-A07A 65
372 322 391 405 400 410 425 406 314 335 297 392 258 322 285 246 253 74 41 41
35 48 53 57 69 75 80 106 105 82 63 91 111 78 115 129 126 76 28 46
79 65 76 69 100 90 103 94 82 94 112 129 60 35 31 51 63 80 85 93
94 106 99 104 132
COT-A07B 65
368 319 387 411 390 415 426 411 307 343 308 382 247 336 281 261 246 80 45 37
33 53 53 52 70 72 79 107 108 78 64 91 114 78 117 133 123 78 27 43
79 65 80 71 91 97 93 104 85 98 103 129 54 30 32 53 61 75 86 94
94 111 95 97 137
COT-A08A 54
612 443 330 400 339 420 370 405 409 329 300 323 259 260 298 189 300 322 338 305
209 165 162 122 166 142 306 242 161 206 272 266 259 233 234 163 82 69 83 91
124 147 183 203 167 285 269 324 255 327 311 273 159 201
COT-A08B 54
592 424 338 427 362 416 377 415 403 334 294 326 270 274 294 199 296 323 328 291
204 163 162 122 156 144 300 225 166 205 267 267 254 233 240 173 74 70 90 91
127 151 188 200 162 276 266 335 246 318 299 277 156 199
COT-A09A 58
119 170 136 134 160 107 82 88 118 167 203 170 200 223 171 228 149 178 164 164
251 250 210 212 146 111 91 76 82 73 90 71 73 71 109 189 173 141 232 215
262 266 352 247 243 215 223 279 234 176 104 61 60 56 78 82 131 156
COT-A09B 58
116 170 133 127 153 113 82 93 120 163 198 166 204 226 169 227 148 165 162 164
253 244 210 200 143 114 89 80 88 72 89 70 75 69 121 181 167 143 215 215
269 268 343 241 238 212 203 279 223 187 90 57 65 54 84 86 127 161
COT-A10A 60
243 211 262 255 241 180 91 71 42 42 26 46 46 66 110 111 174 150 95 70
62 63 81 123 106 111 121 75 65 82 123 132 155 119 120 207 136 156 106 120
145 129 166 171 144 143 89 65 56 66 51 68 61 61 55 73 104 142 137 129
COT-A10B 60
232 201 253 264 229 184 98 62 39 43 21 54 49 92 102 91 164 159 103 75
74 67 79 117 97 89 118 71 69 77 126 128 155 115 142 188 142 157 97 116
154 132 174 168 154 153 83 63 60 65 51 62 70 52 50 81 102 143 136 129
COT-A11A 58
74 108 175 155 141 106 107 129 152 173 141 168 159 87 83 115 130 164 111 102
186 133 149 130 123 134 117 126 116 134 122 118 73 56 64 91 91 81 96 101
80 49 80 92 80 61 107 83 94 114 58 88 94 77 65 79 91 100
COT-A11B 58
75 100 178 141 133 100 111 130 154 188 155 153 152 96 75 115 143 168 97 100
168 129 160 130 126 138 114 131 117 130 133 115 71 60 62 93 94 81 95 101
85 44 80 99 79 65 109 91 102 118 76 82 90 77 65 87 100 112
COT-A12A 59
170 158 65 125 122 103 163 94 143 178 134 107 99 131 198 216 137 154 178 139
181 138 155 153 152 199 184 144 115 89 66 56 52 62 59 52 90 74 70 90
141 130 77 126 120 151 152 173 109 115 88 101 145 150 83 66 59 61 70
COT-A12B 59
189 166 78 127 119 99 176 87 148 178 132 99 98 113 217 206 148 170 172 145
174 140 144 152 157 192 185 154 117 82 68 53 57 60 59 49 99 63 66 85

150 127 73 134 112 150 152 168 110 119 90 106 151 139 76 63 63 59 65
COT-A13A 54
165 187 162 139 162 177 176 143 221 232 187 266 179 171 132 209 178 151 142 160
133 98 124 148 118 105 73 76 60 57 81 113 101 86 79 123 141 108 159 122
127 124 139 161 155 119 94 66 66 43 98 104 146 138
COT-A13B 54
166 183 160 140 165 176 170 153 218 235 178 261 170 176 136 201 177 157 148 165
128 100 132 146 113 104 72 86 58 55 84 99 96 81 72 126 135 105 163 127
128 123 146 159 150 119 93 69 69 45 97 107 145 130
COT-A14A 70
105 74 172 207 213 172 240 208 145 87 103 130 125 163 179 135 129 138 112 140
211 218 169 227 243 237 217 138 191 244 230 166 190 189 163 168 145 158 164 145
194 194 148 130 125 159 222 133 197 282 164 158 189 120 230 234 178 195 121 140
174 113 193 195 265 143 201 158 219 254
COT-A14B 70
111 87 144 184 219 175 220 231 157 84 94 110 105 209 171 136 122 137 136 139
209 207 192 229 232 264 207 141 179 250 220 172 193 167 180 164 142 157 170 146
193 198 158 133 118 152 227 142 194 293 189 158 178 125 230 264 171 194 136 132
182 108 190 189 232 139 180 182 187 237
COT-A15A 55
251 458 359 366 327 248 293 374 502 297 329 238 362 371 252 316 421 336 375 435
333 318 258 286 383 255 313 534 327 309 309 209 349 403 290 288 189 203 208 165
299 253 340 237 298 295 313 360 339 386 488 427 416 248 181
COT-A15B 55
248 447 353 394 327 250 289 372 449 334 301 239 373 393 251 338 409 347 377 422
354 315 252 354 363 253 320 525 328 329 280 198 370 383 297 293 184 200 213 160
266 263 340 227 306 302 320 341 346 388 466 423 403 241 182
COT-A16A 71
228 286 268 412 308 347 378 439 309 321 357 450 445 408 323 343 404 271 339 355
390 536 469 389 318 320 373 322 303 409 345 424 333 393 268 286 293 284 340 304
275 211 211 238 210 306 321 287 330 316 237 244 166 256 283 165 217 354 243 181
246 193 298 311 288 279 257 248 319 198 250
COT-A16B 71
211 287 271 372 319 362 360 471 314 285 361 455 443 409 350 339 411 271 330 356
403 509 506 382 316 315 375 337 284 407 346 413 348 359 304 255 311 264 367 310
284 225 191 240 203 313 318 291 342 329 228 242 166 249 276 179 207 358 239 165
265 189 294 303 285 279 264 242 326 183 259
COT-A17A 54
399 498 502 372 309 311 365 328 279 400 248 461 361 352 170 148 218 258 345 225
205 195 235 190 174 203 233 184 261 187 137 103 93 161 170 129 145 180 124 89
138 80 142 149 107 132 120 146 158 89 131 169 229 141
COT-A17B 54
389 490 499 381 308 312 370 319 290 406 330 477 343 352 182 146 203 286 332 215
194 164 235 203 176 223 240 181 283 192 157 107 100 150 168 127 142 191 140 90
133 84 140 162 88 144 112 115 150 101 131 170 222 150
COT-A18A 76
411 399 402 352 417 419 283 291 367 366 467 392 362 398 461 530 394 334 389 321
412 301 363 255 278 313 294 428 380 294 270 265 282 274 401 386 309 385 305 265
244 169 248 275 183 227 374 234 156 246 180 308 285 255 267 232 210 277 159 241
273 240 170 213 177 226 258 240 296 284 302 273 257 173 214 200
COT-A18B 76
399 383 406 344 416 415 287 296 364 359 471 377 373 393 465 531 396 339 383 318
407 302 373 245 252 308 291 434 376 292 260 281 309 255 364 371 308 379 324 242

254 153 248 277 174 227 370 224 160 247 167 301 271 257 271 236 236 257 146 239
280 229 174 238 193 230 273 240 280 306 283 274 251 177 226 203
COT-A20A 51
414 259 253 469 444 488 548 540 333 501 375 543 298 228 108 86 133 215 322 238
157 131 159 207 207 192 221 284 277 201 153 189 213 218 228 316 222 270 196 124
108 223 168 211 50 98 119 173 143 101 193
COT-A20B 51
400 237 279 412 497 483 552 543 328 476 363 543 284 246 101 89 96 221 323 238
156 118 158 226 203 227 212 281 287 196 144 182 214 217 218 309 239 256 191 130
108 230 173 205 53 100 109 174 147 97 190
COT-A21A 50
311 398 300 354 249 284 308 281 400 373 325 253 268 290 252 319 329 293 320 322
290 291 217 298 349 239 302 502 284 249 297 200 368 378 282 302 202 218 239 158
300 302 287 234 296 268 308 305 301 316
COT-A21B 50
307 400 291 343 245 272 299 272 404 369 354 255 251 290 229 317 325 280 342 306
284 295 200 316 336 249 295 507 298 224 313 202 362 380 275 297 201 232 224 152
280 311 294 222 313 263 299 309 312 320

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 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 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

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

3. Cross-Matching and Dating the Samples. Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the t-value (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton et al 1988; Howard et al 1984–1995).

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

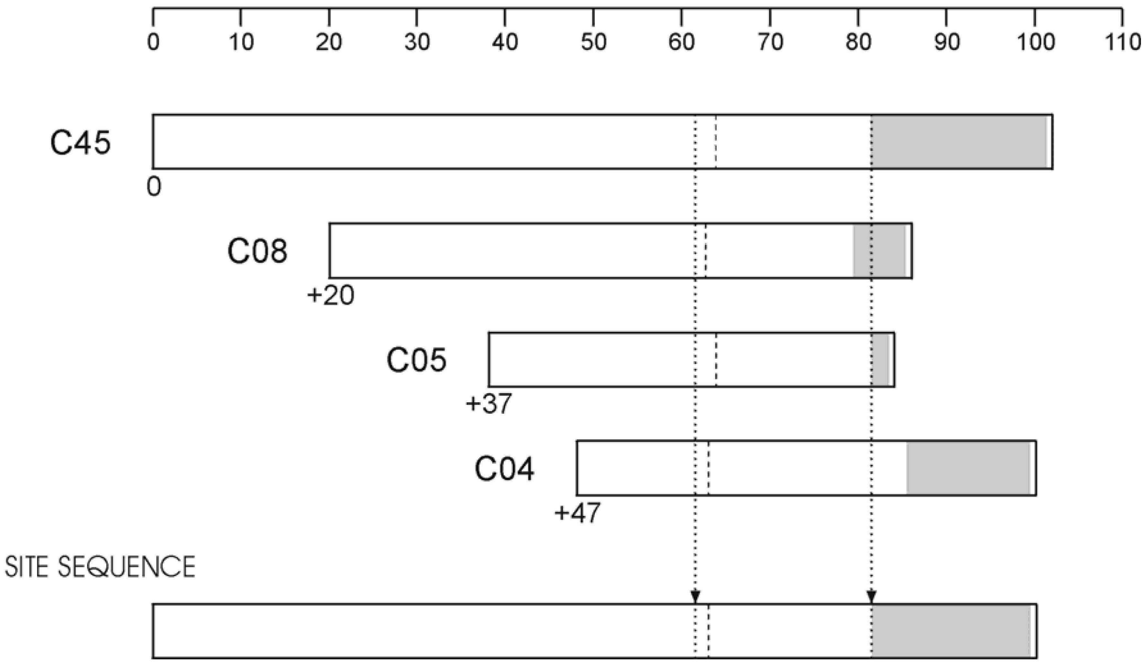


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

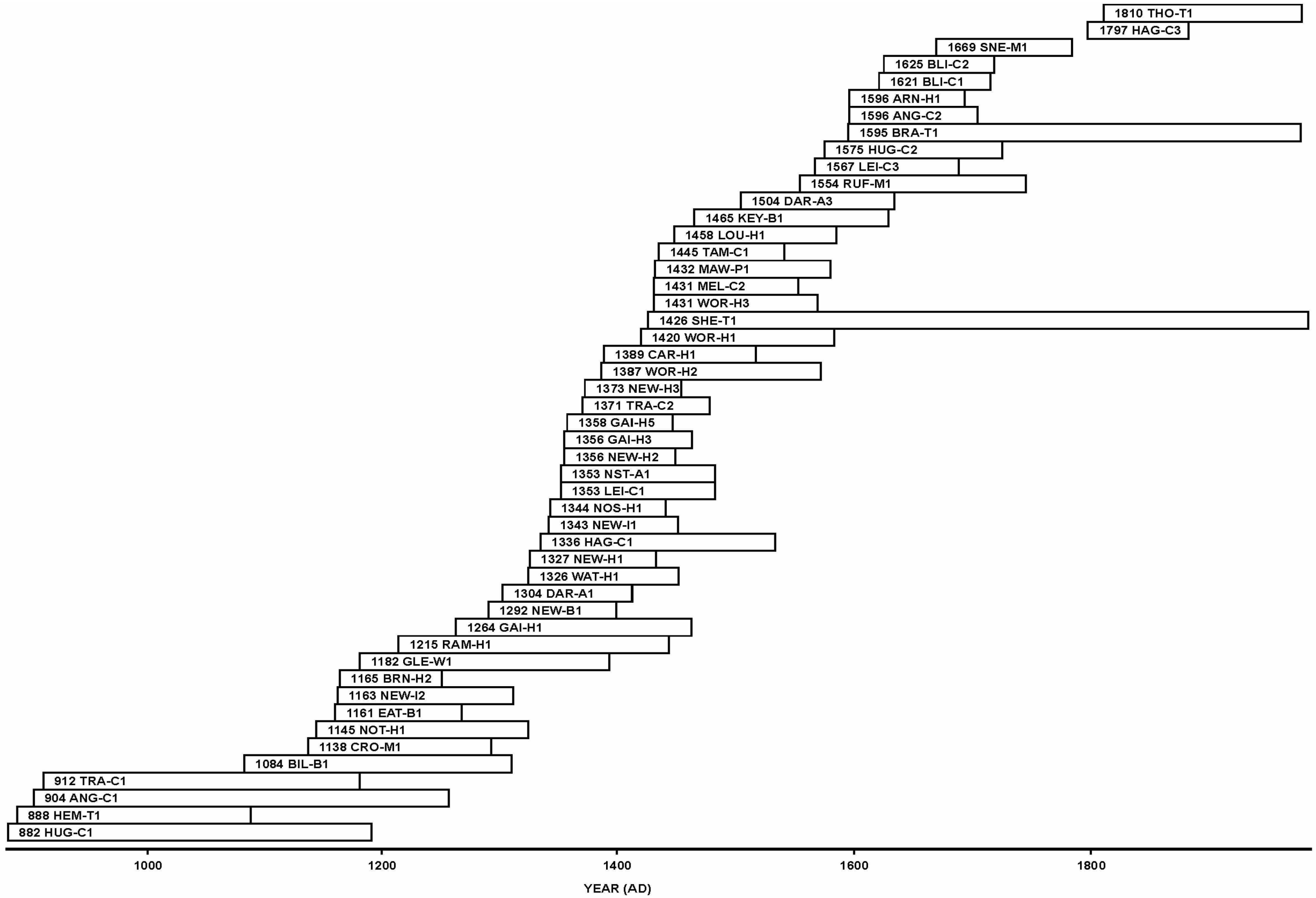
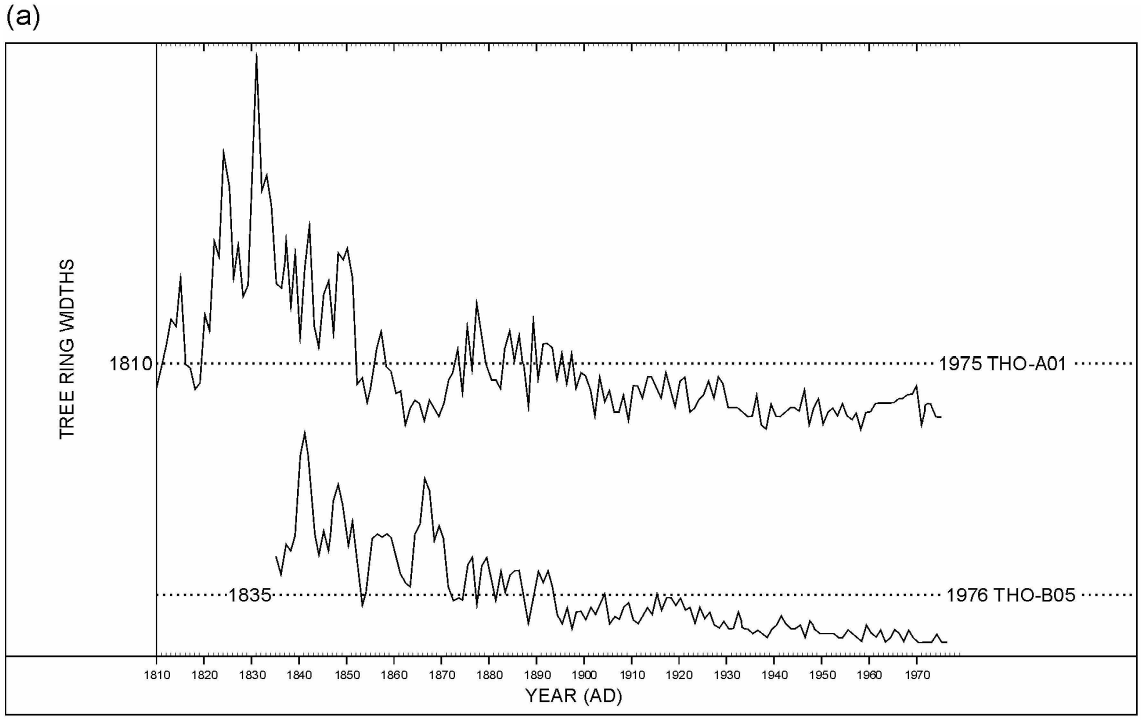


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



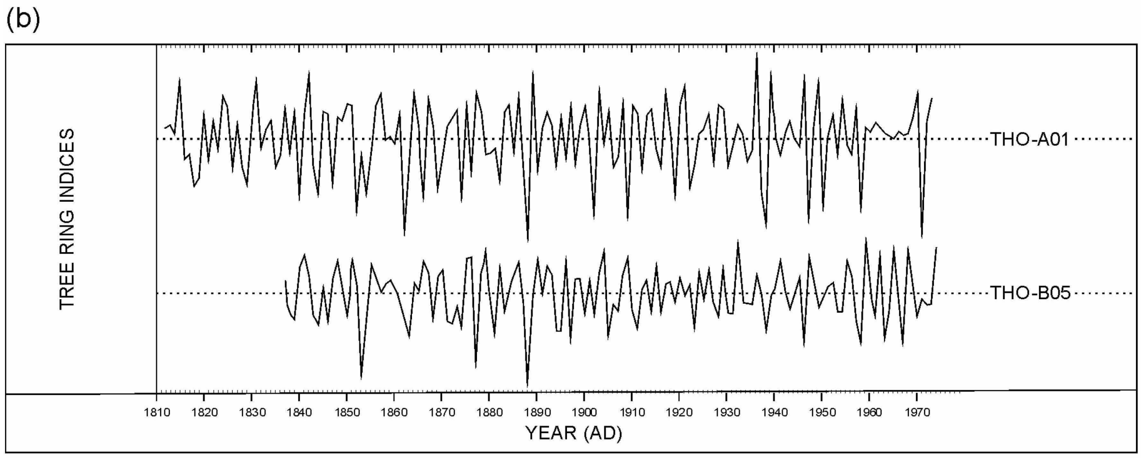


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, Tree-Ring Bull, 33, 7–14

English Heritage, 1998 Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, Applications of tree-ring studies, BAR Int Ser, 3, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, Vernacular Architect, 15–26

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, J Archaeol Sci, 8, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, P A C T, 22, 25–35

Laxton, R R, and Litton, C D, 1988 An East Midlands Master Chronology and its use for dating vernacular buildings, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, Medieval Archaeol, 33, 90–8

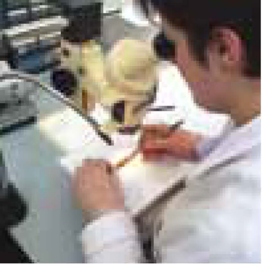
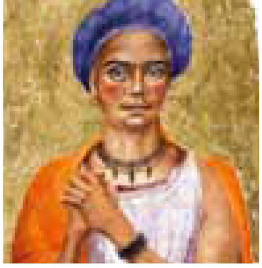
Laxton, R R, Litton, C D, and Howard, R E, 2001 Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral, Engl Heritage Res Trans, 7

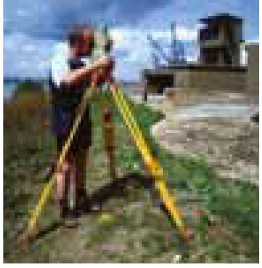
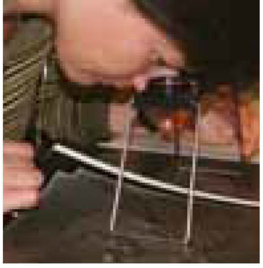
Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, J Archaeol Sci¸18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, Vernacular Architect, 28, 40–56

Pearson, S, 1995 The Medieval Houses of Kent, an Historical Analysis, London

Rackham, O, 1976 Trees and Woodland in the British Landscape, London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