Centre for Archaeology Report 70/2003

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Summary

Twelve core samples were obtained from the single remaining spere truss associated with the original open hall found within this building. Analysis of these produced a single site chronology comprising seven samples with a combined overall length of 141 rings. This site chronology was dated as spanning the years AD 1287 to AD 1427.

Interpretation of the sapwood indicates that the dated timbers represented were probably felled in AD 1427.

The samples from five other timbers of the spere truss could not be dated, but there is no structural or architectural reason to suppose that they are not of the same date.

Other, probably later, timbers within the building which might have been dated were not sampled because they appeared to have too few rings for satisfactory analysis.

Keywords

Dendrochronology
Standing Building

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Introduction

Hopwood Hall is located just over 2 kilometres north of Middleton town centre, just off the A664 between Middleton and Rochdale (SD 874082; Figs 1, 2, and 3). The building is listed Grade II* and is priority C on the English Heritage Buildings at Risk Register. The hall has been the subject of a Level 2 Archaeological Survey (University of Manchester Archaeological Unit 1996).

The hall consists of a quadrangular arrangement of buildings around an open courtyard. A plan of the building is given in Figure 4. The earliest part of the hall is a single spere truss in the south wing. Almost all the buildings around the courtyard represent building phases of the seventeenth century or later and possibly all represent replacements of earlier timber framed buildings. Several of the rooms, mainly in the south range, contain high quality decoration in the form of wainscotting and carved panels. The later phases of development are also represented by a small number of beams in the ceilings of some of the ground floor rooms.

Of the earliest fragment, the spere truss, only the upper parts are visible. It is believed that in its original form the truss would have been located towards the lower end of the medieval open hall. The spere truss itself is composed of a cambered tiebeam and collar with a king stud rising between the two. The stud is supported by pairs of braces, which are moulded on their undersides in trefoil decoration. Short angled braces provide additional support between the tiebeam and the principal rafters. The spere posts themselves are decorated with chamfered and stopped moulding, and together with two large curved braces form an archway beneath the tiebeam. Several examples of spere trusses survive in North-west England with examples at Smithills Hall, Bolton, and Ordsall Hall, Salford.

The Laboratory would to take this opportunity to thank Philip Glynn and his staff at Rochdale Borough Council Land and Property Division for so helpfully providing keys and arranging access to site, and to the staff of Hopwood College in whose grounds the Hall stands. We would also like to thank Richard Bond of English Heritage for his visit to site and his helpful interpretation and comments. The Laboratory would also like to thank William Howard for his assistance during sampling in producing a sketch diagram and recording sample locations.

Sampling

Sampling and analysis by tree-ring dating of the spere truss timbers were commissioned by English Heritage. The purpose of this was to provide a precise date for the spere truss and the original medieval open hall to help better understand this building. On stylistic evidence, and in comparison to other examples, it is believed that the spere at Hopwood is likely to be of fifteenth or early-sixteenth century date.

The English Heritage brief also requested samples be taken from the supposedly later ceiling beams of the ground-floor rooms, the purpose of this being to date the subsequent development of the building. These timbers, however, had wide rings. It was considered very unlikely that such timbers would have sufficient rings, ie, more than 54, for satisfactory analysis and they were not sampled.

Thus, from the available timbers of the spere truss only a total of twelve core samples was obtained. Each sample was given the code HOP-A (for Hopwood, site "A") and numbered 01 - 12. Timbers were selected on the basis of their having sufficient rings for suitable analysis (it was seen that some timbers, despite their large size probably had too few rings) and for having sapwood, or at least the heartwood/sapwood boundary.

At the time of sampling a measured drawing or illustration of the spere truss was not available. However, for Laboratory purposes, a sketch was made and the positions of the samples recorded on this. This sketch is shown as Figure 5. Details of the samples are given in Table 1. In this Table the positions of the timbers are located and described on a north-south basis as appropriate.

Analysis

Each of the twelve samples was prepared by sanding and polishing and the width of their annual growth-rings measured. The data of these measurements are given at the end of this report. The samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of t=4.5 a groups of seven samples cross-match with each other at relative positions as shown in the bar diagram Figure 6.

These seven samples were combined with each other at their relative offset positions to form HOPASQ01, a site chronology with a combined overall length of 141 rings. Site chronology HOPASQ01 was compared with a full series of relevant reference chronologies for oak, giving it a first ring date of AD 1287 and a last measured ring date of AD 1427. Evidence for this dating is given in the t-values of Table 2.

Site chronology HOPASQ01 was compared with the five remaining ungrouped samples but there was no satisfactory cross-matching. These five ungrouped samples were then compared individually with a full range of reference chronologies but again there was no further satisfactory cross-matching. These samples must, therefore, remain undated.

Interpretation

Three of the dated samples, HOP-A04, A06, and A08, in site chronology HOPASQ01 retain complete sapwood and thus have the last ring produced by the trees they represent before they were felled. In each case the last measured ring date is the same, AD 1427 and this is thus the felling date of the trees. The relative position of the heartwood/sapwood boundary on the other samples where it exists indicates that these timbers were almost certainly felled in AD 1427 too. There is no reason to suspect that the timber represented by sample HOP-A01, which does not have the heartwood/sapwood boundary, was not also felled in AD 1427.

Conclusions

Analysis by tree-ring dating has produced a single site chronology, HOPASQ01, of seven samples with a combined overall length of 141 rings. This chronology has been dated as spanning the years AD 1287 to AD 1427. Interpretation of the sapwood indicates that the dated timbers represented were all felled in AD 1427.

Such a date is perhaps somewhat earlier than the late fifteenth- or early sixteenth-century date suggested on the basis of architectural or stylistic grounds. The precise date obtained through tree-ring analysis will not only help in the understanding of this building, but in the dating and interpretation of other buildings in the region. Such results show the benefit of tree-ring dating.

It might be worth pointing out that some of the samples in site chronology HOPASQ01, HOP-A01 and A03, in particular cross-match with each other very well, with values as high as t=45.8 being found. Such high values indicate that the timbers represented are from the same portion of the tree, with the timber probably simply being split in half. Other timbers are possibly from the same tree, or certainly from trees growing very close to each other.

The samples from five other timbers could not be dated. There is no clear structural or architectural reason to suppose that these timbers are not of the same date as those that have been satisfactorily dated. There is no obvious reason why these five samples should not cross-match and date with the other material but some do have bands of very narrow rings. These may be representative of some non-climatic stress growth.

Bibliography

Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *MGB-EOI,* Queens Univ, Belfast

Bridge, M, 1988 The dendrochronological dating of buildings in Southern England, *Medieval Archaeol*, **32**, 166 – 74

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1990 List 33 no 3 - Nottingham University Tree-Ring Dating Laboratory Results: General list, *Vernacular Architect,* **21**, 37 – 40

Groves, C, 1997 *Dendrochronological analysis of Ightfield Hall Farm Barn, Ightfield, Whitchurch,* Shropshire, 1997, Anc Mon Lab Rep, **91/97**

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, Roberts, M, North East Vernacular Architecture Group, 1995 List 62 no 1 - Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in medieval Durham; dendrochronological survey 1994 - 5, *Vernacular Architect,* **26**, 55 – 6

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, Roberts, M, North East Vernacular Architecture Group, 1996 List 67 no 2 - Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in medieval Durham; dendrochronological survey 1994 - 5, *Vernacular Architect,* **27**, 85 – 6

University of Manchester Archaeological Unit, 1996 *Hopwood Hall, Level 2 Archaeological Survey,* unpubl report.

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

Tyers, I, 1997 *Tree-ring analysis of timbers from Sinai Park, Staffordshire*, Anc Mon Lab Rep, **80/97**

Tyers, I, 1998 *Tree-ring analysis of oak timbers from St Nicholas' Church, Warndon, Worcestershire,* Anc Mon Lab Rep, **34/98**

Tyers, I, 2002 *Tree-ring analysis of timbers from Chethams Library and School, Long Millgate, Manchester*, Centre for Archaeol Rep, **5/2002**

Tyers, I, and Groves C, 1999 unpubl England London, unpubl computer file *LON1175,* Sheffield Univ

Table 1: Details of samples from Hopwood Hall, Rochdale Road, Middleton, Rochdale, Greater Manchester

Sample no	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
HOP-A01	South archbrace	56	no h/s	AD 1334	------	AD 1389
HOP-A02	South spere post	91	8	------	------	------
HOP-A03	North spere post	81	4	AD 1325	AD 1401	AD 1405
HOP-A04	North brace, tie to rafter	90	37C	AD 1338	AD 1390	AD 1427
HOP-A05	North aisle tie	73	4	------	------	------
HOP-A06	North wall post	141	34C	AD 1287	AD 1393	AD 1427
HOP-A07	Lower left quatrefoil, south side	87	2	------	------	------
HOP-A08	King stud	82	31C	AD 1346	AD 1396	AD 1427
HOP-A09	Strut to south king stud brace	54	2	AD 1339	AD 1390	AD 1392
HOP-A10	Tiebeam	107	2	------	------	------
HOP-A11	South brace, tie to rafter	82	no h/s	------	------	------
HOP-A12	South rafter	54	2	AD 1348	AD 1399	AD 1401

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample; last measured ring date is felling date of timber

Table 2: Results of the cross-matching of site chronology HOPASQ01 and relevant reference chronologies when first ring date is AD 1287 and last ring date is AD 1427

Reference chronology	Span of chronology	*t*-value	
East Midlands	AD 882 – 1981	7.4	(Laxton and Litton 1988)
Ightfield, Whitchurch, Shropshire	AD 1361 – 1566	6.6	(Groves 1997)
England	AD 401 – 1981	6.0	(Baillie and Pilcher 1982 unpubl)
Warndon, Worcs	AD 1120 – 1360	5.7	(Tyers 1998)
Southern England	AD 1083 – 1589	5.2	(Bridge 1988)
Sinai Park, Staffs	AD 1227 – 1750	5.1	(Tyers 1997)
Chethams, Long Millgate, Manchester	AD 1185 – 1428	5.1	(Tyers 2002)
England London	AD 413 – 1728	4.9	(Tyers and Groves 1999 unpubl)
Witton Hall Barn, Witton Gilbert, Tyne and Wear	AD 1342 – 1441	4.8	(Howard *et al* 1996)
Byers Garth, Sherburn, Durham	AD 1330 – 1439	4.7	(Howard *et al* 1995)
Askerton Castle, Kirkcambeck, Cumbria	AD 1324 – 1493	4.7	(Esling *et al* 1990)

Figure 1: Map to show general location of Hopwood Hall

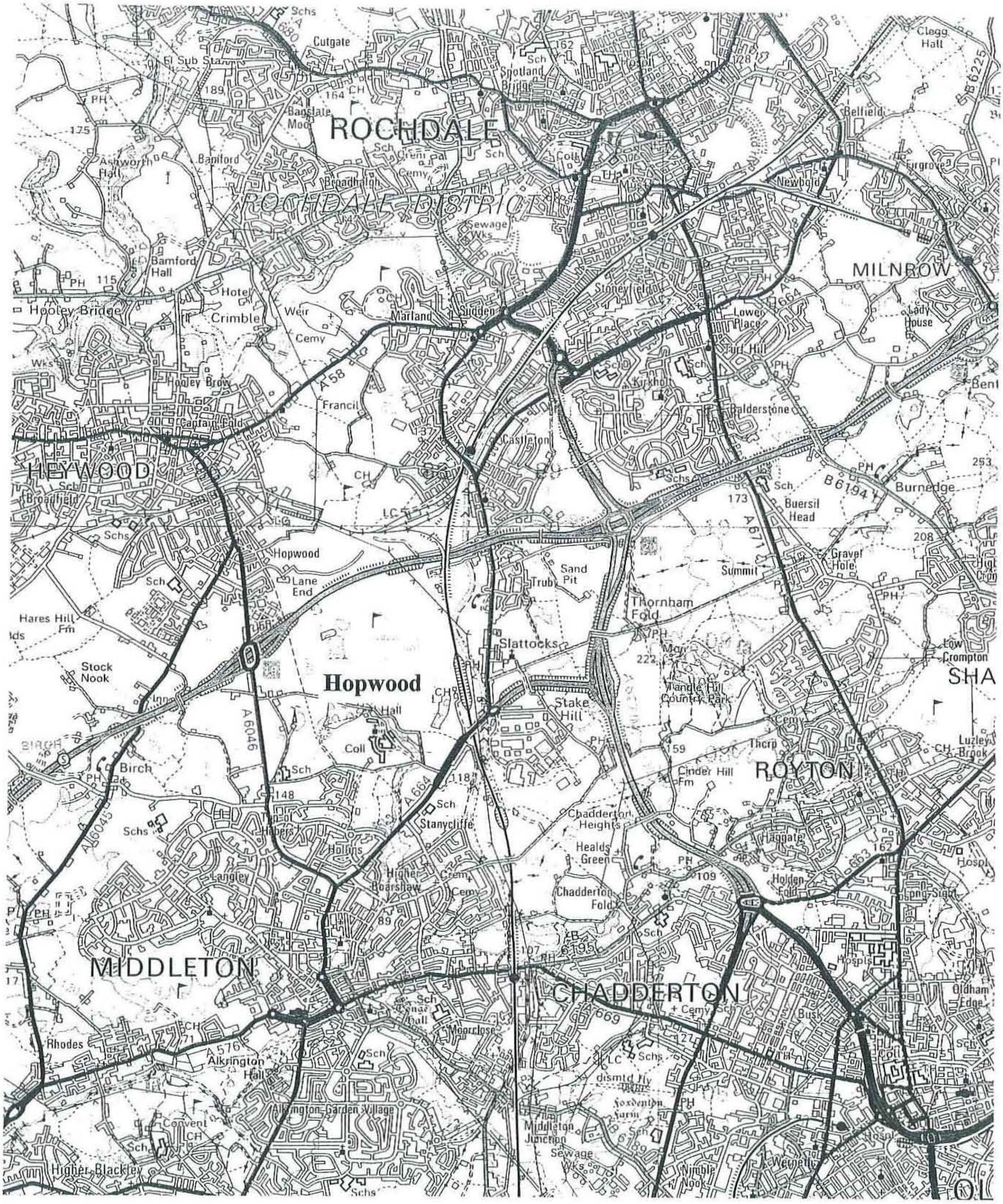


Figure 2: Map to show specific location of Hopwood Hall

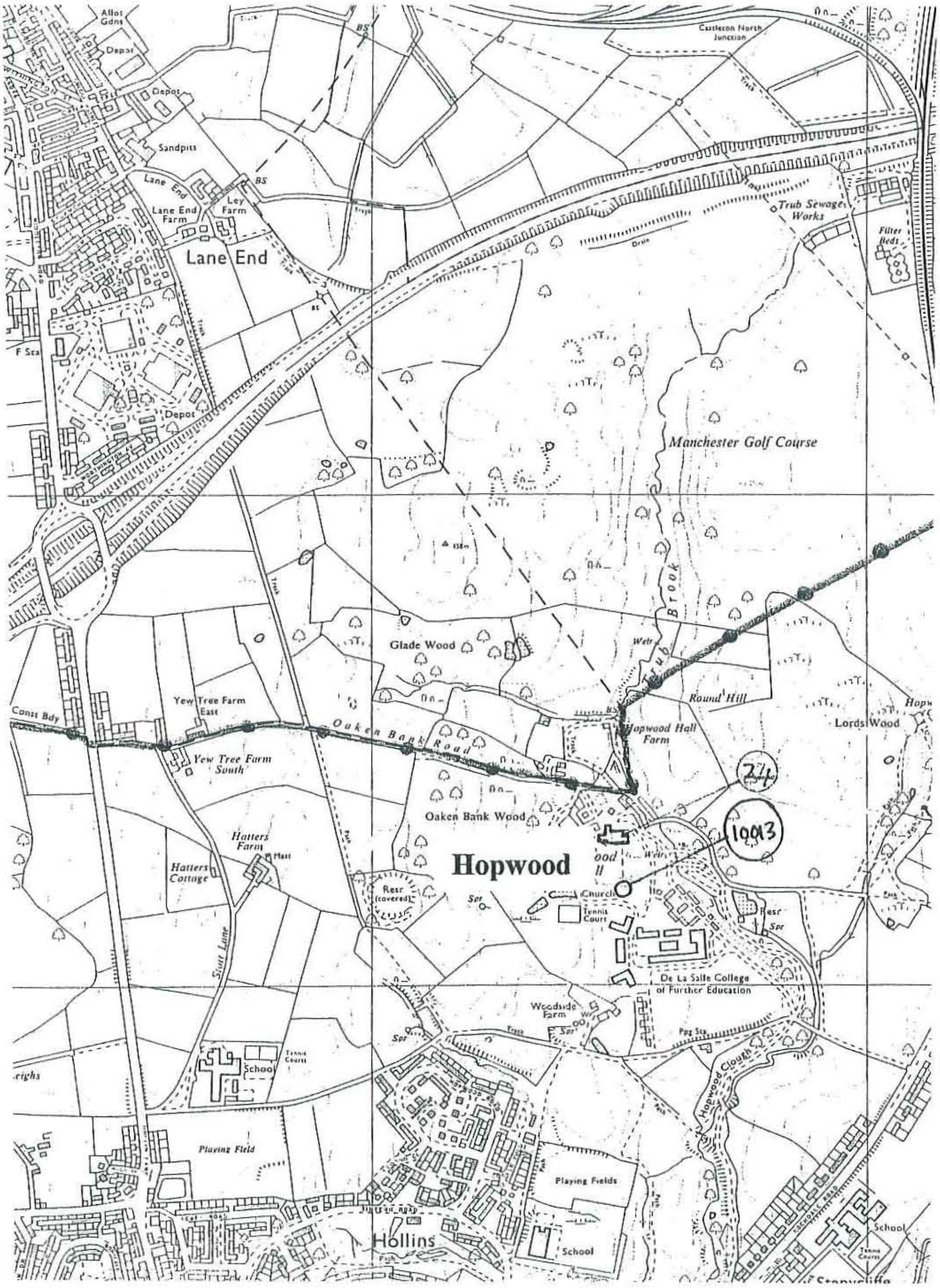


Figure 3: Plan to show position of hall at Hopwood

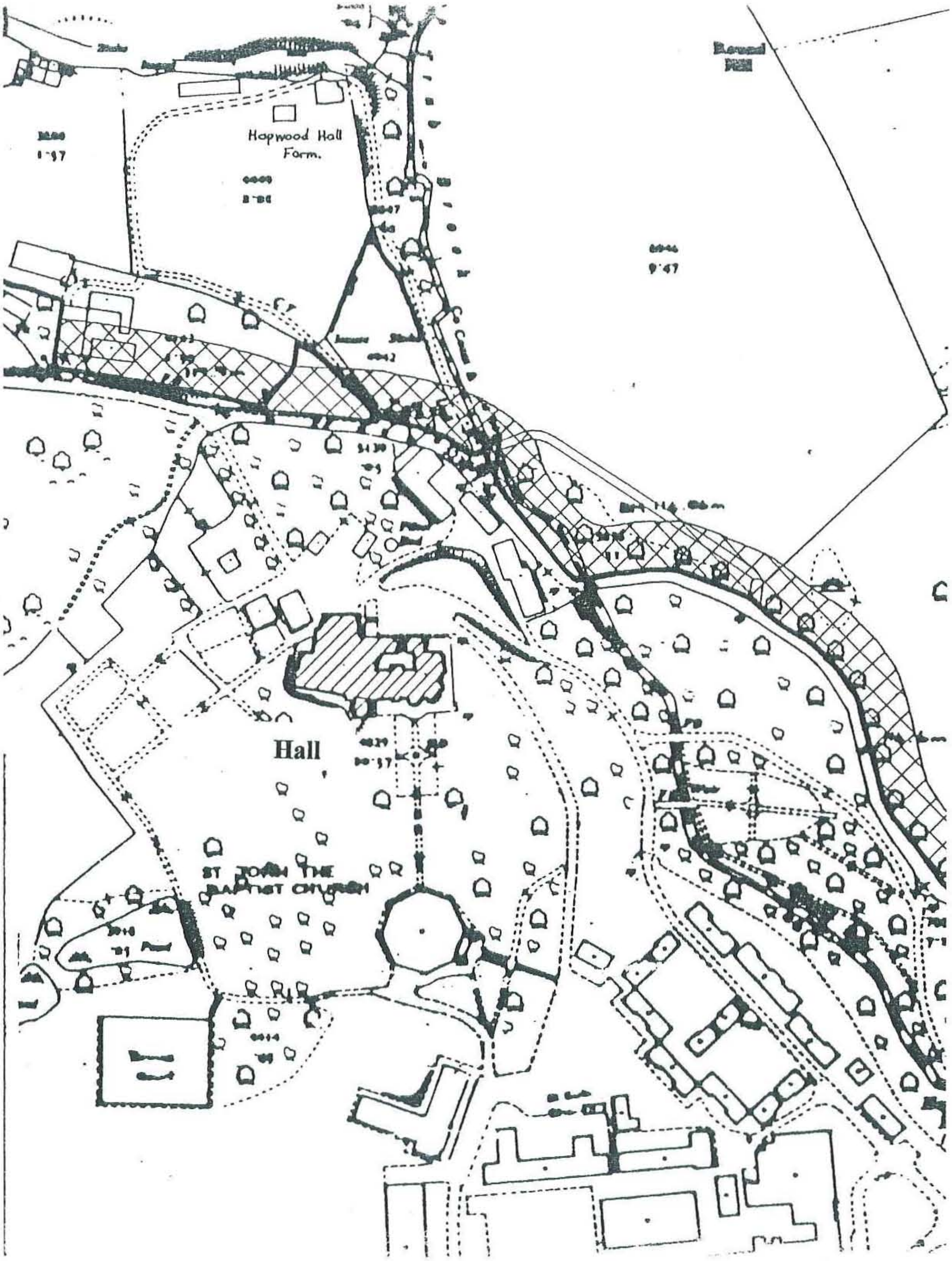


Figure 4: First-floor plan of Hopwood Hall

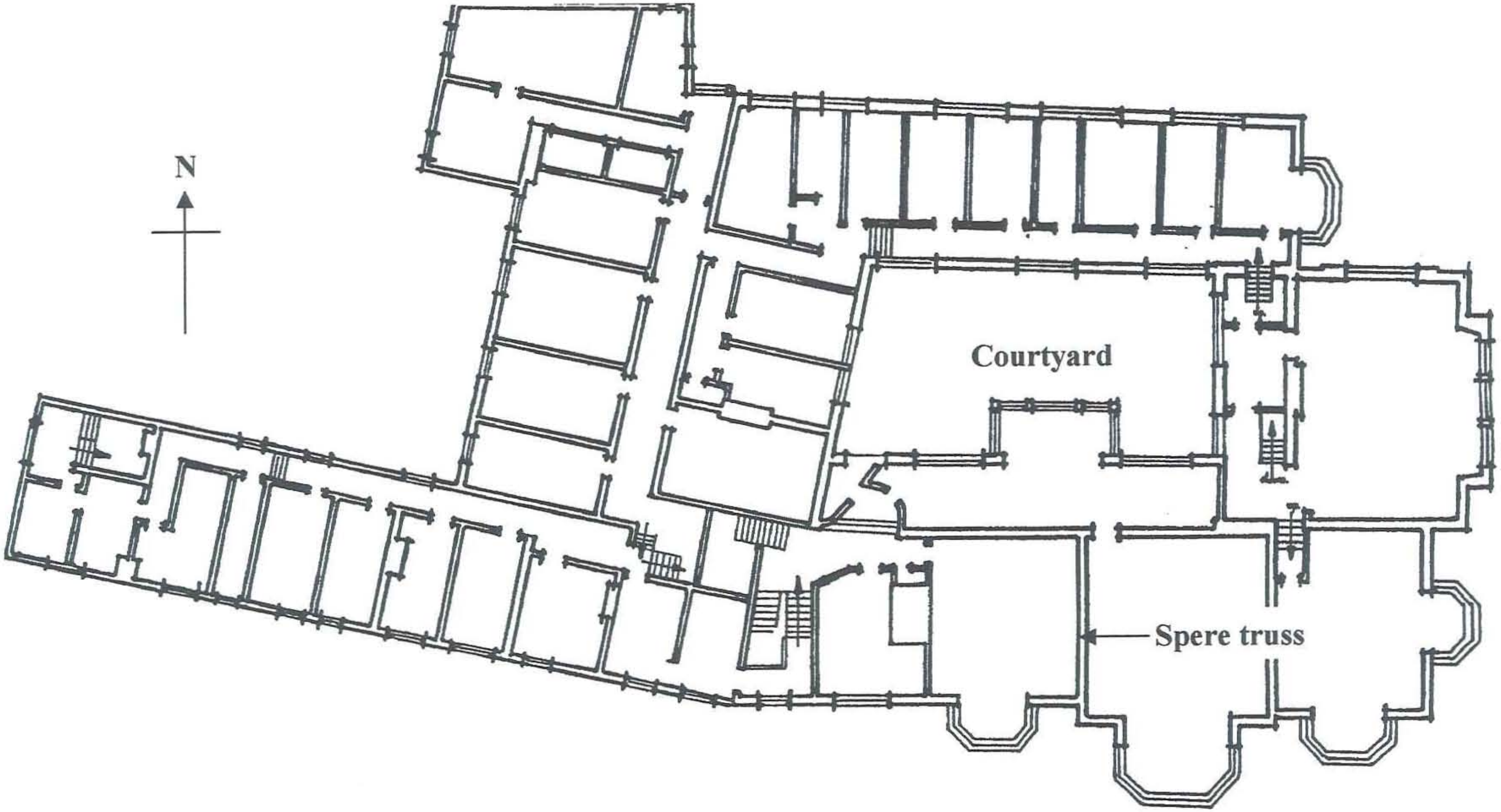


Figure 5: Sketch drawing of spere truss to show timbers sampled (viewed from the west looking east)

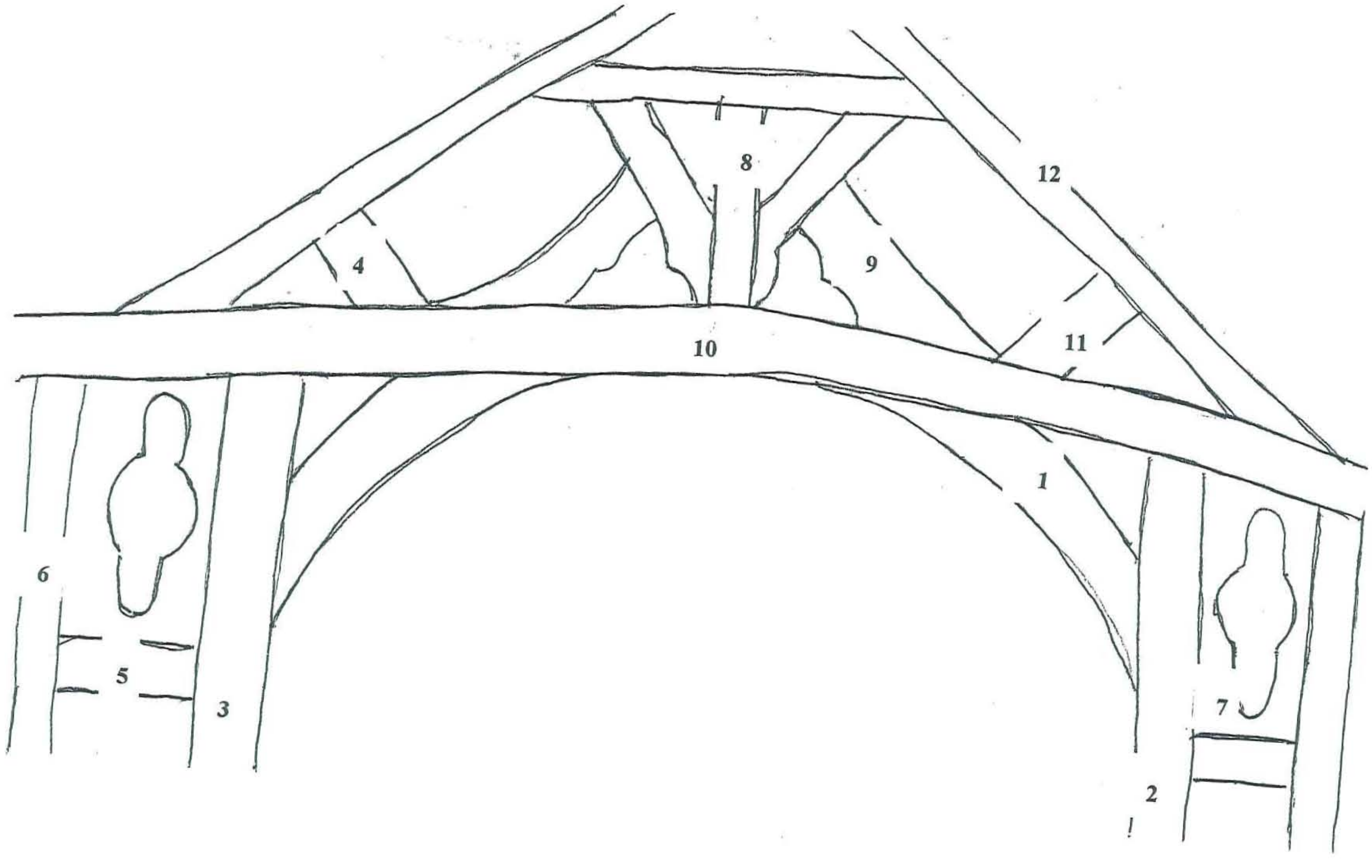
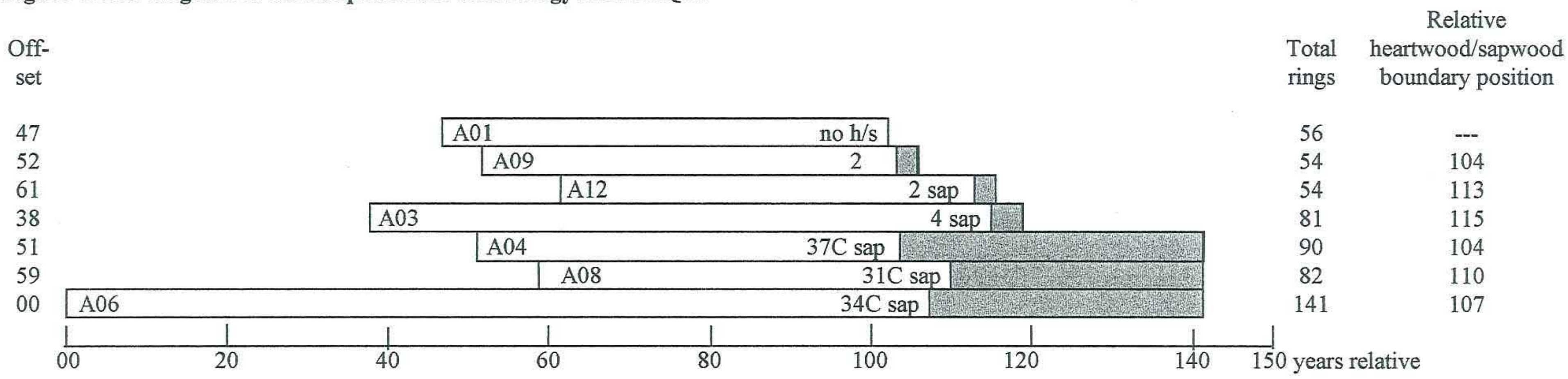


Figure 6: Bar diagram of the samples in site chronology HOPASQ01



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Data of measured samples – measurements in 0.01 mm units

HOP-A01A 56
177 127 106 75 137 212 447 446 496 352 475 637 278 295 255 280 141 75 87 110
85 158 102 160 130 137 111 183 351 274 292 192 241 210 96 150 105 141 192 177
222 127 135 154 150 285 287 319 188 367 320 352 366 250 209 246
HOP-A01B 56
124 113 134 82 138 218 480 486 481 347 489 623 288 294 267 274 142 78 71 125
83 142 110 154 119 136 99 211 352 250 295 182 224 187 107 122 96 144 172 155
210 144 139 154 160 279 283 324 190 379 327 360 367 252 217 234
HOP-A02A 91
686 658 520 615 484 621 536 627 396 378 284 200 148 261 166 171 267 312 507 281
382 318 372 434 396 247 148 160 308 436 237 87 96 87 95 113 159 144 182 189
133 225 344 222 210 218 193 208 175 299 157 217 186 148 272 200 265 232 256 282
379 314 376 430 344 390 302 375 546 489 505 464 249 381 336 323 313 227 216 149
332 235 426 434 247 291 238 175 275 408 256
HOP-A02B 91
692 649 526 620 487 626 546 623 396 374 303 192 148 257 191 166 262 310 481 322
374 322 367 420 392 241 147 169 295 459 251 86 83 87 99 86 172 136 206 179
146 210 333 227 207 203 166 218 168 305 159 229 184 144 277 214 259 224 268 294
357 312 385 433 360 387 325 406 528 453 506 470 242 386 322 326 306 229 214 148
334 242 435 418 241 266 224 147 286 377 265
HOP-A03A 81
817 687 656 556 610 468 123 204 306 161 120 138 64 139 202 448 445 494 344 486
628 295 293 272 280 140 77 66 115 84 160 101 162 122 137 100 196 354 257 294
197 253 211 118 134 101 143 192 182 227 131 135 163 131 303 277 339 167 363 318
376 355 286 207 239 212 294 195 462 251 195 250 229 281 203 480 370 243 274 238
219
HOP-A03B 81
818 668 643 519 586 445 129 209 292 170 115 124 77 137 214 409 414 504 366 491
621 297 285 270 280 138 64 73 112 91 151 108 159 117 149 105 193 320 257 294
189 250 209 104 145 95 151 187 171 209 139 130 151 157 287 278 326 183 374 315
382 360 270 192 236 235 269 221 470 254 190 263 218 278 205 472 368 241 268 218
221
HOP-A04A 90
135 182 213 163 199 181 152 178 147 162 165 225 167 173 193 185 183 191 168 193
191 161 123 131 197 202 191 167 186 155 126 147 135 129 211 176 168 160 159 146
167 174 113 163 114 188 215 189 248 269 269 195 190 168 173 195 143 138 172 159
217 194 226 206 242 237 293 227 222 249 163 150 167 140 188 198 168 187 183 195
169 127 191 154 171 220 195 195 153 162
HOP-A04B 90
184 177 187 166 195 182 151 174 150 138 177 233 157 175 196 189 181 206 173 174
174 157 125 127 189 189 178 173 191 154 125 138 134 133 221 177 193 149 156 150
167 170 102 162 150 164 200 207 247 249 286 209 182 175 166 199 145 140 164 163
217 201 227 227 223 246 296 221 229 235 174 146 171 156 173 197 177 185 172 201
171 124 201 159 183 186 218 186 154 164

HOP-A08B 82
104 130 150 185 151 154 145 129 134 146 138 123 145 135 125 128 194 205 184 142
156 133 105 138 127 142 195 206 190 159 119 127 169 202 140 167 147 167 137 185
162 191 207 162 138 148 139 170 170 154 178 145 183 193 299 347 432 432 376 342
270 245 202 191 201 171 177 213 177 174 125 156 173 114 213 148 138 214 203 197
122 152
HOP-A09A 54
165 203 181 187 180 157 180 148 158 164 228 161 177 192 181 181 203 176 173 174
148 132 132 176 195 186 156 184 158 138 136 128 136 202 183 177 165 148 144 160
176 110 154 136 184 221 212 225 256 297 190 178 178 181
HOP-A09B 54
187 202 179 186 181 153 177 144 158 171 226 167 167 193 196 188 185 175 183 176
161 121 115 195 185 184 147 207 128 150 145 118 159 187 181 184 166 141 134 159
156 143 164 132 177 204 205 247 260 296 189 178 190 171
HOP-A10A 107
415 513 478 306 242 182 156 306 313 309 328 306 254 325 227 293 205 345 471 407
428 372 412 339 279 322 473 417 395 376 385 318 313 405 249 317 312 336 127 74
50 68 81 130 155 209 237 290 353 214 222 316 349 236 205 170 114 79 79 59
67 71 90 83 76 94 100 123 82 68 75 138 178 169 224 217 193 283 191 182
178 369 300 468 372 382 442 432 476 450 431 429 452 329 510 401 326 325 262 290
335 328 317 375 264 392 329
HOP-A10B 107
351 509 483 291 239 179 165 305 316 304 334 299 257 323 223 285 204 343 476 398
440 365 438 334 271 323 486 411 418 374 389 316 307 408 243 328 319 352 108 63
71 67 82 132 146 208 236 311 332 214 227 308 348 248 194 179 107 73 70 60
81 73 81 94 78 83 101 125 84 70 81 131 176 160 243 196 199 289 204 152
180 367 323 453 371 392 447 431 477 464 410 425 486 329 510 384 341 311 262 296
333 317 320 371 271 372 282
HOP-A11A 88
321 359 360 326 322 389 403 422 349 135 126 188 220 308 330 390 506 575 658 443
510 159 82 74 184 245 246 261 219 321 262 269 398 161 96 95 113 88 79 83
132 215 221 147 213 179 222 347 286 237 176 152 173 187 155 116 158 185 144 109
117 157 146 215 182 200 215 225 233 165 132 174 199 160 269 177 137 107 202 138
141 214 118 137 103 111 112 156
HOP-A11B 82
369 353 361 312 301 372 411 425 302 151 146 180 224 289 346 388 513 564 645 452
498 164 83 73 187 241 253 250 223 331 259 287 389 162 89 105 113 76 77 86
136 215 217 145 214 175 240 339 291 235 160 164 150 194 155 117 154 180 139 111
114 159 150 200 198 189 212 208 244 167 130 163 200 166 251 176 125 115 107 127
113 146
HOP-A12A 54
157 224 166 166 201 187 184 198 179 177 174 151 132 120 175 198 180 163 182 170
125 148 126 149 200 179 180 161 153 142 152 156 130 160 142 199 217 212 290 266
292 189 186 178 171 200 143 139 144 168 221 191 240 218
HOP-A12B 54
147 239 168 166 195 194 188 195 177 173 175 154 130 119 180 195 180 162 201 134
125 149 128 139 204 181 175 172 144 150 153 162 120 164 145 194 217 213 305 250
289 190 180 173 173 190 154 144 138 169 215 191 244 214

HOP-A05A 73
308 542 457 558 347 339 227 149 163 185 266 242 141 166 128 153 211 245 173 128
185 175 147 178 225 163 121 152 159 164 231 204 211 222 190 137 111 100 87 94
219 169 228 349 217 133 170 249 271 253 148 205 216 155 190 169 148 134 110 92
129 162 153 108 145 183 174 191 272 187 206 230 210
HOP-A05B 73
377 536 496 547 342 334 229 150 155 190 262 246 150 152 132 160 200 245 185 122
200 167 149 172 227 164 118 155 163 155 232 200 215 215 196 114 120 100 81 111
208 172 236 358 219 142 134 262 237 265 177 213 202 147 163 150 170 120 106 108
129 165 162 89 159 172 174 190 263 166 208 231 212
HOP-A06A 141
313 320 438 362 331 292 345 255 152 223 150 158 153 228 315 222 203 220 263 374
470 397 410 279 221 259 206 256 329 304 160 146 160 145 140 163 138 153 136 91
131 130 132 260 134 184 197 197 314 324 193 282 241 281 172 124 61 36 42 23
40 43 63 38 68 108 105 81 164 62 102 124 75 77 89 113 169 127 129 97
82 74 63 60 64 103 56 76 85 63 64 103 47 33 21 26 34 34 29 42
35 44 44 43 39 31 42 53 41 58 70 103 93 84 127 82 109 113 98 129
104 121 40 34 32 33 33 33 40 39 58 60 56 55 84 49 86 50 48 43
58
HOP-A06B 141
313 319 444 418 338 296 325 261 156 235 153 172 151 220 310 254 227 209 264 380
473 406 395 250 273 244 200 254 304 287 160 157 161 153 147 161 123 167 153 87
144 105 147 250 120 178 209 195 299 316 186 269 242 252 175 126 60 40 42 27
29 50 59 38 62 110 113 65 170 66 98 120 76 73 90 108 177 121 127 98
73 69 70 49 59 96 53 78 76 64 71 111 50 22 25 27 31 31 36 34
39 44 46 36 41 34 53 49 42 51 72 96 82 93 120 87 97 124 95 126
111 105 49 30 29 30 41 28 37 36 58 66 44 64 83 49 93 54 34 51
54
HOP-A07A 87
31 62 52 52 71 79 86 76 85 50 49 54 92 87 72 72 82 62 77 89
109 120 110 104 80 104 86 77 158 172 141 110 112 86 85 97 91 102 86 81
85 90 109 122 129 122 86 94 88 89 71 90 119 119 150 135 87 74 79 114
91 126 125 124 155 125 140 122 152 192 125 192 120 128 133 145 122 135 134 130
207 139 188 242 200 200 228
HOP-A07B 87
48 64 50 61 68 77 72 87 74 55 43 65 81 74 80 81 71 80 65 101
111 126 108 109 82 101 89 80 153 162 129 115 115 81 91 83 94 112 89 82
70 102 98 120 120 104 94 99 85 88 77 86 122 114 150 105 86 73 95 89
93 129 120 131 146 126 134 128 146 169 145 180 131 133 129 126 128 136 145 153
210 166 197 247 227 208 242
HOP-A08A 82
112 125 151 192 153 151 148 132 126 160 130 126 146 128 122 137 183 204 179 149
153 135 105 137 117 157 196 196 197 162 149 108 167 200 147 168 145 161 140 180
178 174 201 165 141 150 128 171 166 162 177 138 185 194 305 355 435 434 390 340
268 243 202 199 200 166 176 207 182 176 123 160 167 122 195 153 144 214 190 198
128 162

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 straight forward 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. Actually it could be the year after if it had been felled in the first three months 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 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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 *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

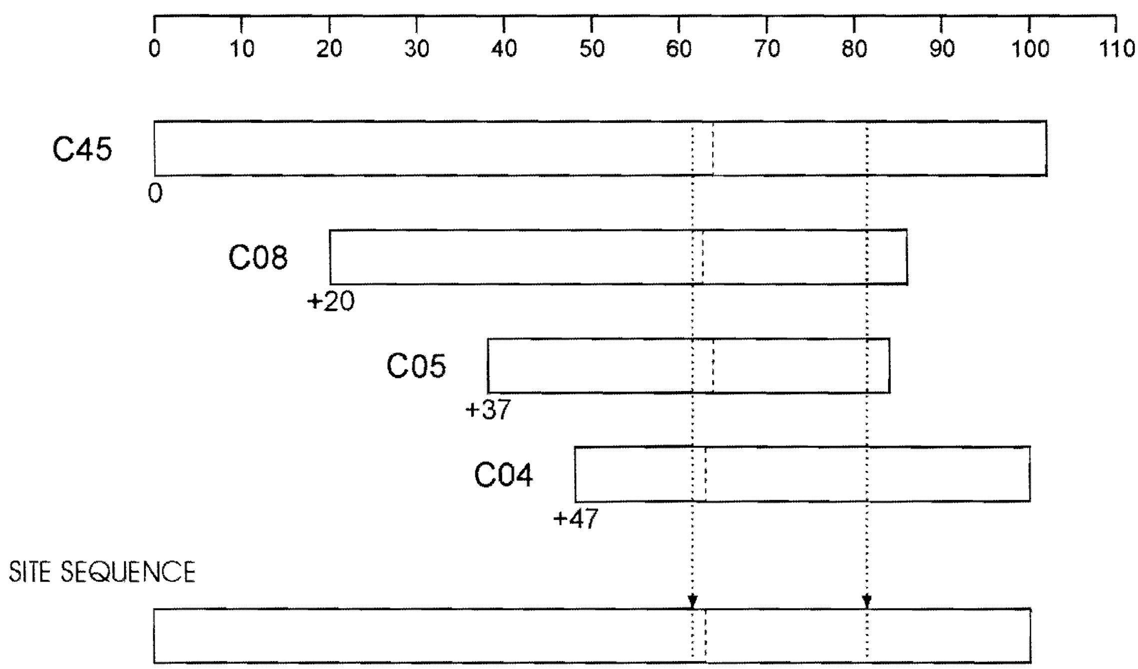


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 Fig 6 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 Fig 6. 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 Fig 7. 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 phenomena 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.

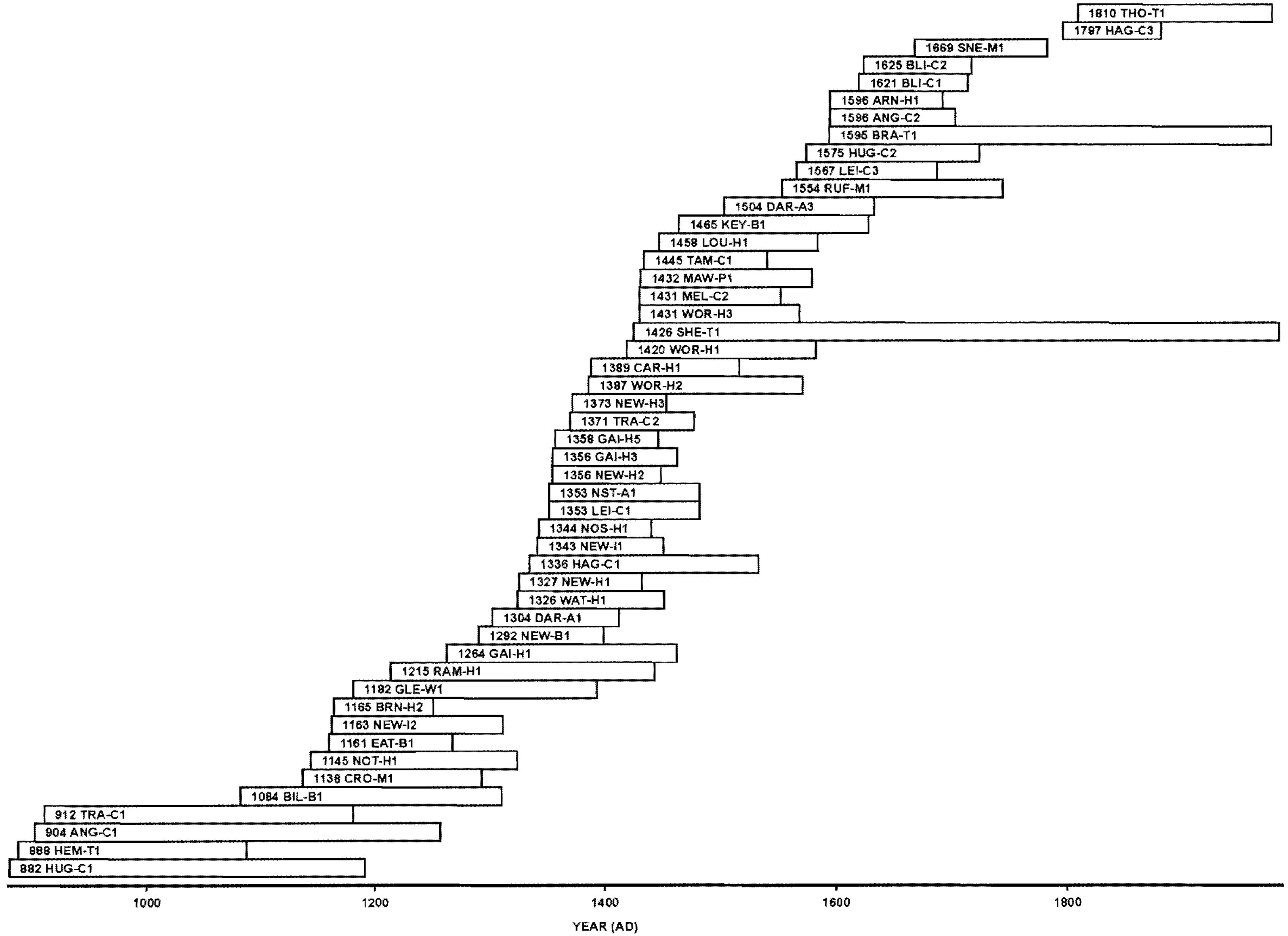
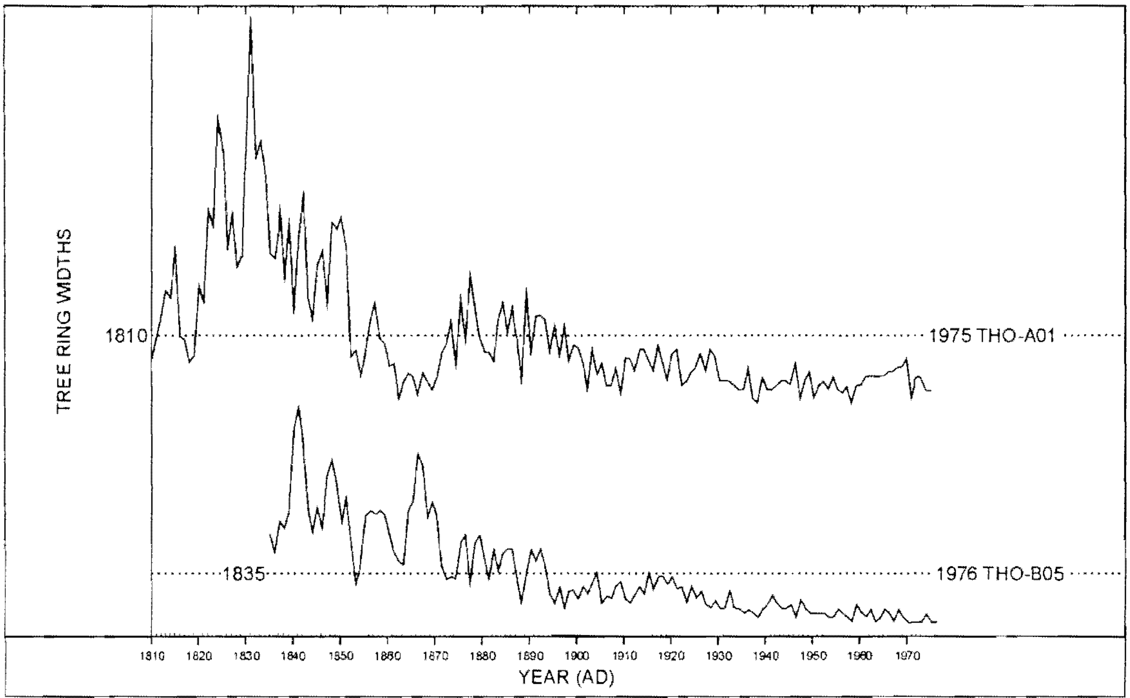


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

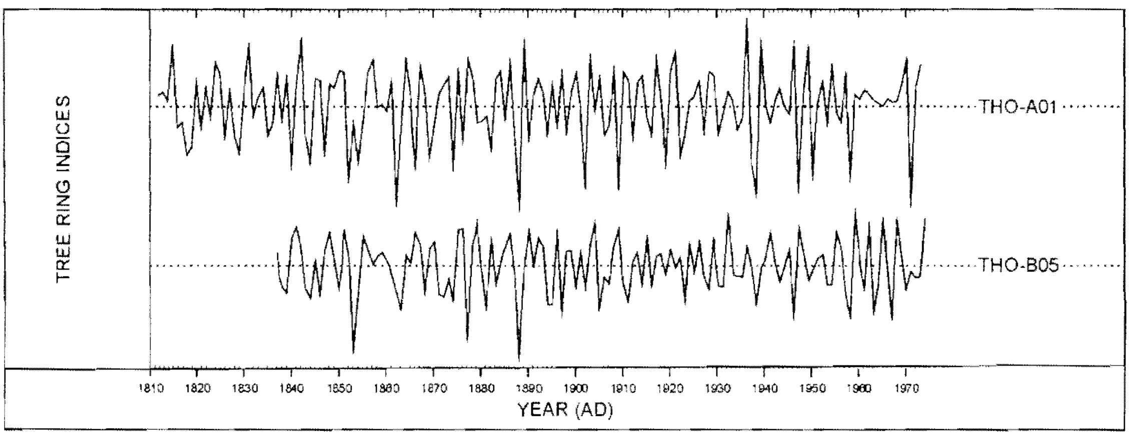


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Fig 7. (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 Bulletin*, **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 Architecture*, **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

Laxon, R R, Litton, C D, and Howard, R E, 2001 *Timber; Dendrochronology of Roof Timbers at Lincoln Cathedral*, English Heritage Research Transactions, **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 Architecture*, **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