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Kings Farm Livery Road West Winterslow Wiltshire

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

Discovery, Innovation and Science in the Historic Environment

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Front Cover: Kings Farm, view from the west. Photograph Robert Howard.

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KINGS FARM
LIVERY ROAD
WEST WINTERSLOW
WILTSHIRE

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SUMMARY
Dendrochronological analysis was undertaken on cores from 23 of the 25 timbers sampled in this building, the samples from the remaining two timbers having too few rings for reliable analysis. This analysis produced a first site chronology comprising 11 samples from the cruck trusses and associated timbers, as well as from the primary ground-floor ceiling joists to the northern bay. This site chronology is 66 rings long, these rings dated as spanning the years AD 1395–1460. It is likely that these timbers were all felled in, or about, the spring of AD 1461. A second site chronology comprising six samples, all from the inserted ceiling to the former open hall, was also formed, its 220 rings spanning the years AD 1336–1555. It is likely that these timbers were all felled in, or about, the spring of AD 1556. Six measured samples remain ungrouped and undated.

CONTRIBUTORS
Alison Arnold, Robert Howard, and Cathy Tyers

ACKNOWLEDGEMENTS
We would firstly like to thank the family for permitting tree-ring analysis at their property and for their enthusiasm for this programme of analysis. We would also like to thank Rebecca Lane, Historic England Senior Architectural Investigator, for not only helping in arranging access to these timbers, but also for providing drawings and photographs, as well as for additional background information and other input into this report. Finally, we would like to thank Shahina Farid, Scientific Dating Coordinator for Historic England, for commissioning this programme of tree-ring dating and for her valuable contributions to this report.

ARCHIVE LOCATION
Historic England Archive
The Engine House
Firefly Avenue
Swindon SN2 2EH

HISTORIC ENVIRONMENT RECORD OFFICE
Wiltshire and Swindon Historic Environment Record
Wiltshire Archaeology Service
The Wiltshire and Swindon History Centre
Cocklebury Road
Chippenham SN15 3QN

DATE OF INVESTIGATION
2021

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CONTENTS

INTRODUCTION

The farmhouse at Kings Farm in West Winterslow, Wiltshire (Fig 1), was at the time of this analysis unlisted but was in the process of being considered for a listing recommendation. It was subsequently listed in February 2022 at Grade II* (List Entry Number 1477853 here). The original house, aligned north-south, is a four-bay cruck-framed range. It comprised a two-bay open hall with a room at either end, whilst the cross passage is thought to have been in the north bay of the hall. The stylistic evidence meant that there was considerable uncertainty as to the date of the cruck-framed range. At the north end of this cruck-framed range is a cross-wing thought to date to the eighteenth century. Further detailed information on the building can be found in Lane (forthcoming), but a brief summary is provided below.

There are four extant cruck trusses, with associated collars, purlins, and some common rafters, but the southern two bays appear to have been modified in the seventeenth century with the fifth cruck truss being removed during the complete reconstruction of the south gable-end wall and the east wall at this time. The cruck blades appear to be formed of two jointed sections, a main lower blade into which a second, shorter, upper section of blade has been jointed (Fig 2a/b), although it should be noted that each cruck truss is different in form above the collar and the northernmost truss is half hipped above the collar. The roof structure is most intact over the northern two bays, where there is heavy smoke blackening to the timbers, and a considerable amount of blackened thatch. It is believed that these timbers are original and primary to the construction of the open hall house. In addition, there is a ground-floor joist arrangement in the northern bay of the house, which is also thought to be original (Fig 2c).

A ceiling and brick chimney stack were inserted into the south bay (high end) of the open hall with the first floor probably being ceiled over at the same time. This ceiling has a series of substantial timbers, including a main spine beam, trimmer beams, and joists (Fig 2d). The ceiling in the north bay (low end) of the open hall is of a somewhat lesser form and appears to be a later modification.

SAMPLING

Dendrochronology was requested by Lucy Foster, Historic England Assistant Listing Adviser, and by Rebecca Lane, Historic England Senior Architectural Investigator. It was hoped that tree-ring analysis would provide independent dating evidence to inform the listing recommendation report and to thus help identify the grade at which to designate Kings Farm.

Thus, from the timbers available, 25 timbers were sampled by coring. Each sample was given the code WTL-A (for Winterslow, site ‘A’) and numbered 01–25. Samples were obtained from as many primary-phase cruck trusses and associated timbers as could be accessed and which appeared suitable for tree-ring analysis, plus a selection of what were believed to be primary ground-floor ceiling joists to the north bay of this range. In addition, a number of samples were obtained from the joists to the inserted ceiling in the south bay of the former open hall. It was noted at the time of sampling that while all the joists to the east side of the spine beam of this inserted ceiling appeared to be oak (*Quercus* spp), all those to the west side appeared to be of elm (*Ulmus* spp). A single sample, WTL-A19, was obtained from these west joists to confirm this.

The sampled timbers have been located by reference to a set of preliminary plans provided by Rebecca Lane, shown here as Figure 3a/b. Details of the samples are given in Table 1.

ANALYSIS AND RESULTS

Each of the samples obtained from the 25 timbers spread throughout this building was prepared by sanding and polishing. It was seen at this time that sample WTL-A08 had fewer than 25 rings, less than here deemed necessary for reliable dating purposes, while another sample, WTL-A19, was confirmed as being of elm. Both samples were therefore rejected from this programme of analysis. The annual growth rings widths of the remaining samples were, however, measured, these measured data being given at the end of this report. The 23 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the production of two groups of cross-matching samples.

The first group comprises 11 samples, eight of them from the primary cruck trusses and associated timbers, and three from the primary ground-floor ceiling joists. These samples, combining at a minimum value of t=4.5, cross-match at the positions illustrated in Figure 4. These 11 samples were combined at their indicted offset positions to form WTLASQ01, a site chronology with an overall length of 66 rings. Site chronology WTLASQ01 was then compared with an extensive range of oak reference chronologies, this indicating a repeated series of cross-matches when the date of its first ring is AD 1395 and the date of its latest ring is AD 1460 (Table 2).

The second group comprises six samples, all of them from the inserted ceiling to the north bay of the former open hall. These samples, combining at a minimum value of t=7.5, cross-match at the positions illustrated in Figure 5. These six samples were also combined at their indicted offset positions to form WTLASQ02, a site chronology with an overall length of 220 rings. Site chronology WTLASQ02 was also compared with an extensive range of oak reference chronologies, this indicating a repeated series of cross-matches when the date of its first ring is AD 1336 and the date of its latest ring is AD 1555 (Table 3).

These two site chronologies were then compared with the six remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. The six ungrouped samples were, therefore, compared individually with the same extensive range of oak reference chronologies, but again there was no satisfactory cross-matching and all six samples must remain undated.

INTERPRETATION

Dendrochronological analysis has thus successfully dated 17 of the 23 timbers from which samples were measured. Three of the dated samples in site chronology WTLASQ01, WTL-A04 from a cruck blade, and WTL-A22 and WTL-A23 from the primary ground-floor ceiling joists, retain complete sapwood. This means that each sample has the last growth ring produced by the tree it represents before it was cut down (this being indicated by upper case 'C' in Table 1 and Figs 4 and 5). The last measured, complete, sapwood ring is the same, being dated in each case to AD 1460. The spring cell growth for the following year is present on sample WTL-A22 and is just forming on samples WTL-A04 and WTL-A23, and thus the felling of the trees represented dates to the spring of AD 1461. The remaining eight samples all have some sapwood present. The dates of the heartwood-sapwood boundary on these eight samples ranges from AD 1440 (WTL-A21) to AD 1453 (WTL-A11), are not dissimilar to the three samples with bark edge present whose heartwood-sapwood boundary rings date to AD 1433 (WTL-A23), AD 1443 (WTL-A04), and AD 1446 (WTL-A22). This, combined with the overall level of cross-matching within this group of samples, suggests that all were therefore likely to have been felled in, or around, the spring of AD 1461 and thus represent trees with generally relatively low numbers of sapwood rings present.

Of the six dated samples in site chronology WTLASQ02, all from joists to the inserted ceiling to the south bay of the former open hall, one (WTL-A12) retains complete sapwood. In this case the last measured, complete, sapwood ring, is dated to AD 1555 but, once again, the spring cell growth for the following year is present, thus indicating that the tree represented was felled in the spring of AD 1556. One of the other samples, WTL-A14, has a heartwood-sapwood boundary dating to AD 1531, only three years later than that of WTL-A12, and is therefore likely to have a similar felling date. The remaining four timbers represented show no trace of sapwood and their visual characteristics suggest that they have been heavily trimmed during conversion into square beams, with some potentially representing the inner sections of long-lived trees. Their outermost extant heartwood ring varies in date from AD 1418 (WTL-A13) to AD 1518 (WTL-A18), these being consistent with these timbers have a similar felling date. Such an interpretation is supported furthermore by the very high level of cross-matching between some of these six samples, with a series of values in excess of t=10, the maximum being t=16.3. Such values would suggest that some joists may in fact have been derived from a single tree, or at least from a group of trees growing very close to each other in the same copse or stand of woodland. As such, it is more likely than not that such a group of trees would be felled at the same time as each other. Thus again, it appears likely that all the dated timbers to the inserted ceiling in the south bay of the former open hall were felled in, or at least about, spring AD 1556.

DISCUSSION AND CONCLUSION

Tree-ring analysis of timbers from Kings Farm has thus successfully dated 17 of the 23 timbers from which samples were measured. This analysis suggests that the extant cruck trusses and associated timbers, along with the ground-floor ceiling joists in the northernmost bay, which were all believed to primary, are indeed so, these all being derived from trees felled in, or about, spring AD 1461.

In addition, this analysis indicates that the hall, or at least its south bay (high end), which was believed to have originally been open was potentially ceiled in the mid-sixteenth century, the dated oak joists from this ceiling being derived from trees felled in, or about, the spring of AD 1556, although this is with the proviso that the main spine beam from this ceiling has not been dated.

Woodland sources

The overall level of cross-matching between the dated fifteenth-century timbers, including one possible same-tree match (WTL-A10/WTL-A11 gives a *t*=11.1), suggests that this is a coherent set of timbers derived from a group of trees obtained from the same woodland. The smaller group of sixteenth-century timbers, as indicated above, match very strongly with all but two of the *t*-values between pairs of series in excess of 5 and seven of the *t*-values in excess of 10 and thus may only represent a very small number of trees. The fifteenth-century trees employed are relatively fast grown in comparison to the sixteenth-century trees with the earlier trees probably generally less than about 70–80 years old when felled, as opposed to the later trees which appear to be in the region of 150–200+ years old when felled.

In some programmes of tree-ring analysis it is possible to suggest the region or general locality from which the timbers used in a particular building might have been sourced. This is usually intimated by any site chronology created during analysis, although having been compared with reference material from all over England, tending to match more closely with reference chronologies from some particular region or area. However, as may be seen in Table 1 for site chronology WTLASQ01, the reference chronologies listed show a very wide geographical dispersion, and no particular regional trend, apart from broadly southern England, can be discerned. Site chronology WTLASQ02 also matches most strongly with reference chronologies from a wide geographical area (Table 2), though with a more westerly distribution and with the highest levels of similarity seen with buildings from the Clarendon Park Estate some 5 km to the south-west of West Winterslow.

Undated samples

As may be seen in Table 1, six measured samples remain undated. However, although some other very short samples have been dated in this programme of analysis, the remaining undated samples tend to be very short, the longest undated samples, WTL-A17 and WTL-A20, having 53 and 60 rings respectively. Neither of these samples show any features such as distortion or compression which might cause problems with cross-matching. It is possible that the undated timbers grew somewhere for which there is currently insufficient reference data available to provide secure cross-matching. However, for whatever reason, it is a very common, if inexplicable, feature of tree-ring analysis to find that some samples will not date. This undated material will be reviewed periodically as further reference chronologies become available and these timbers may, in due course, also be dated.

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TABLES

Table 1: Details of tree-ring samples from Kings Farm, Winterslow, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Cruck trusses					
WTL-A01	Truss 1, west cruck blade	47	no h/s	------	------	------
WTL-A02	Ridge beam, truss 1 – 2	31	no h/s	------	------	------
WTL-A03	Truss 2, east cruck blade (upper portion)	54	11	1404	1446	1457
WTL-A04	Truss 2, east cruck blade (lower portion)	49	17C	1412	1443	1460
WTL-A05	Truss 2, west cruck blade (upper portion)	43	2	1404	1444	1446
WTL-A06	Truss 3, east cruck blade (upper portion)	35	14	1423	1443	1457
WTL-A07	Truss 3, east cruck blade (lower portion)	40	3	1406	1442	1445
WTL-A08	Truss 3, west cruck blade (lower portion)	nm	---	------	------	------
WTL-A09	West purlin, truss 3 - 4	53	10	1405	1447	1457
WTL-A10	Truss 4, east cruck blade (upper portion)	36	11	1424	1448	1459
WTL-A11	Truss 4, west cruck blade (upper portion)	41	5	1418	1453	1458
	Ceiling to former open hall					
WTL-A12	East joist 1	152	27C	1404	1528	1555
WTL-A13	East joist 2	83	no h/s	1336	------	1418
WTL-A14	East joist 3	146	h/s	1386	1531	1531
WTL-A15	East joist 4	91	no h/s	1362	------	1452
WTL-A16	East joist 5	93	no h/s	1399	------	1491
WTL-A17	East joist 7	53	10	------	------	------
WTL-A18	East joist 8	128	no h/s	1391	------	1518
WTL-A19	West joist 5	nm	---	------	------	------
WTL-A20	Main north – south spine beam	60	no h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Primary ground floor ceiling joists					
WTL-A21	Joist 2	52	12	1401	1440	1452
WTL-A22	Joist 3	55	14C	1406	1446	1460
WTL-A23	Joist 4	66	27C	1395	1433	1460
WTL-A24	Joist 5	38	10	------	------	------
WTL-A25	Joist 6	37	12	------	------	------

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

Table 2: Results of the cross-matching of site sequence WTLASQ01 and relevant reference chronologies when the first-ring date is AD 1395 and the last-ring date is AD 1460

Reference chronology	Span of chronology	*t*-value	Reference
Fulham Palace, London	AD 1356–1494	7.4	Bridge and Miles 2004
Winchester College panels, Hampshire	AD 1403–1537	7.3	Lewis 1995
Wreck: Mary Rose refit	AD 1372–1535	7.2	Bridge and Dobbs 1996
Windsor Castle, Berkshire	AD 1192–1613	7.1	Tyers *et al* 1997
Purcombe Farmhouse, Marshwood, Dorset	AD 1379–1504	6.6	Bridge 2014
Holy Trinity Church, North Tidworth, Wiltshire	AD 1363–1512	6.4	Bridge 2009
St Thomas Tower, Tower of London	AD 1349–1511	6.0	Tyers and Hibberd 1993
White Tower, Tower of London	AD 1260–1489	5.5	Miles 2007
St Andrew's Church, Ford, West Sussex	AD 1286–1511	5.4	Bridge 2000
Eastleigh Manor, Westleigh, Devon	AD 1405–1474	5.2	Miles 1994

Table 3: Results of the cross-matching of site sequence WTLASQ02 and relevant reference chronologies when the first-ring date is AD 1336 and the last-ring date is AD 1555

Reference chronology	Span of chronology	*t*-value	Reference
Queen Manor Farm Granary, Clarendon Park, Wiltshire	AD 1337–1602	10.7	Tyers 1999
The Old Mansion, Clarendon Park, Wiltshire	AD 1315–1625	10.0	Tyers 1999
Queen Manor Farmhouse, Clarendon, Wiltshire	AD 1347–1537	8.5	Tyers 1999
Trerice, Kestle Mill, Cornwall	AD 1394–1562	6.9	Hurford *et al* 2009
100 Minories, London	AD 1313–1567	6.6	Tyers 2017
Wednesbury Forge, Sandwell, West Midlands	AD 1322–1616	6.6	Tyers 2007
Stoneleigh Abbey, Stoneleigh, Warwickshire	AD 1398–1658	6.4	Howard *et al* 2000
Priory School, Reigate, Surrey	AD 1384–1545	6.3	Bridge 2003
Manor House, Avebury, Wiltshire	AD 1393–1596	6.1	Arnold and Howard 2011 unpubl
Middleton Hall, Middleton, Warwickshire	AD 1390–1646	5.9	Arnold *et al* 2006

FIGURES

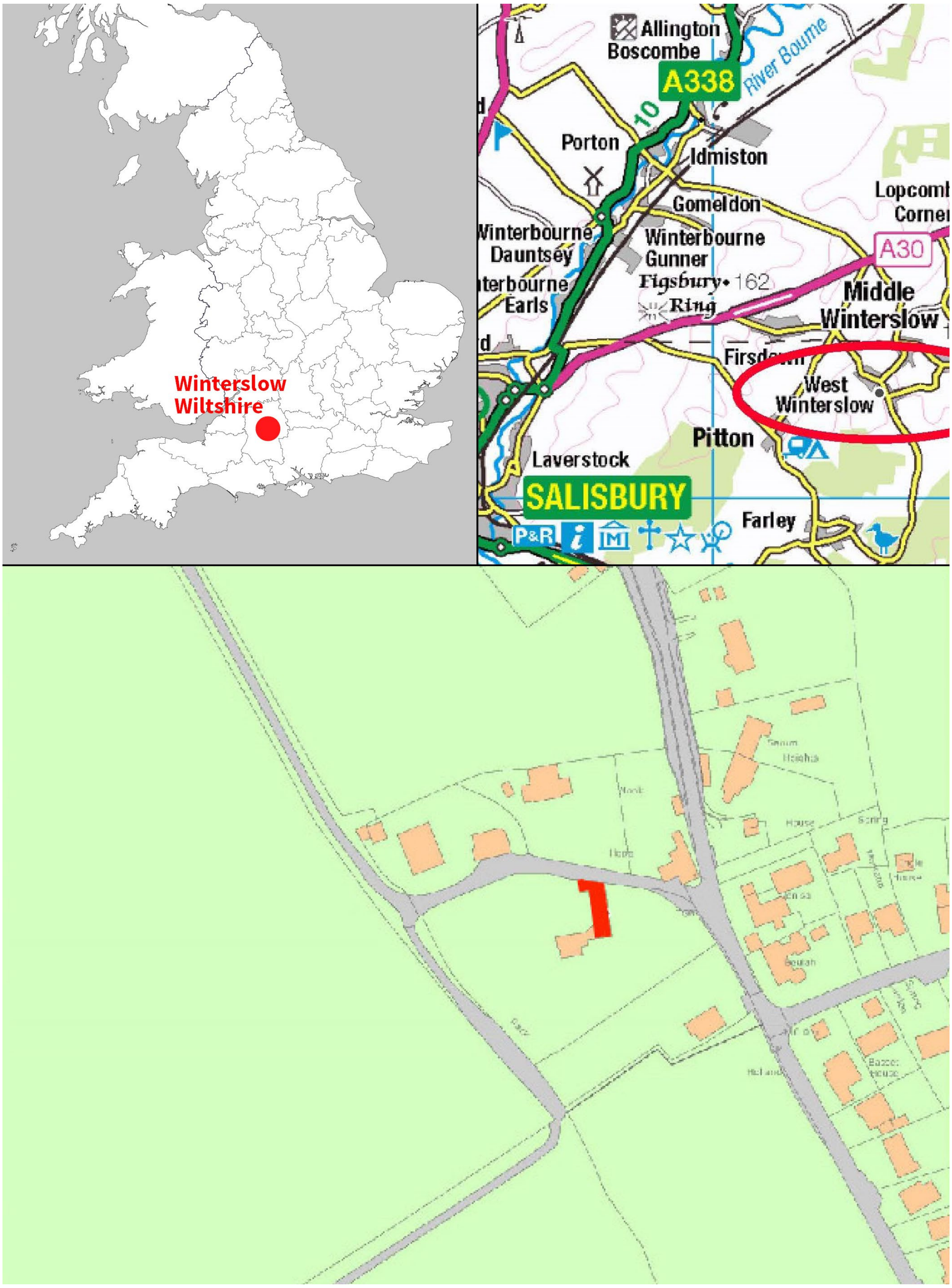


Figure 1: Maps to show the location of Kings Farm in West Winterslow, Wiltshire, marked in red. Scale: top right 1:105,000, bottom 1:1,600 © Crown Copyright and database right 2022. All rights reserved. Ordnance Survey Licence number 100024900.

Figure 2a: Cruck truss 2 showing north face (note how each blade is made up of an upper and lower piece) (photograph Robert Howard)

Figure 2b: Upper section of cruck truss 4 showing north face (photograph Robert Howard)

Figure 2c: Primary ground-floor ceiling joists (photograph Robert Howard)

Figure 2d: Inserted ceiling to former open hall (photograph Robert Howard)

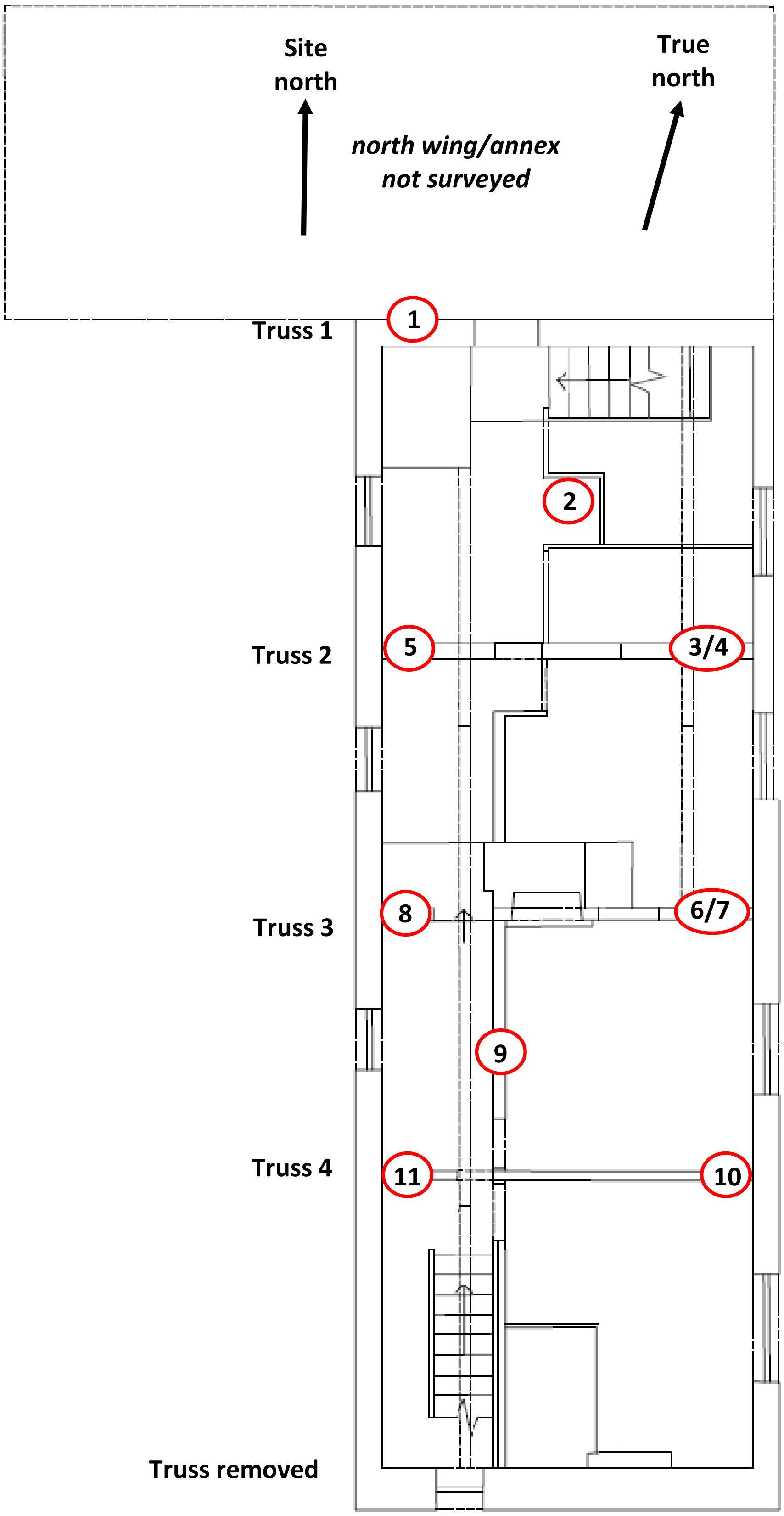


Figure 3a: Plan at first-floor level to show the locations of the sampled timbers (after Rebecca Lane 2021)

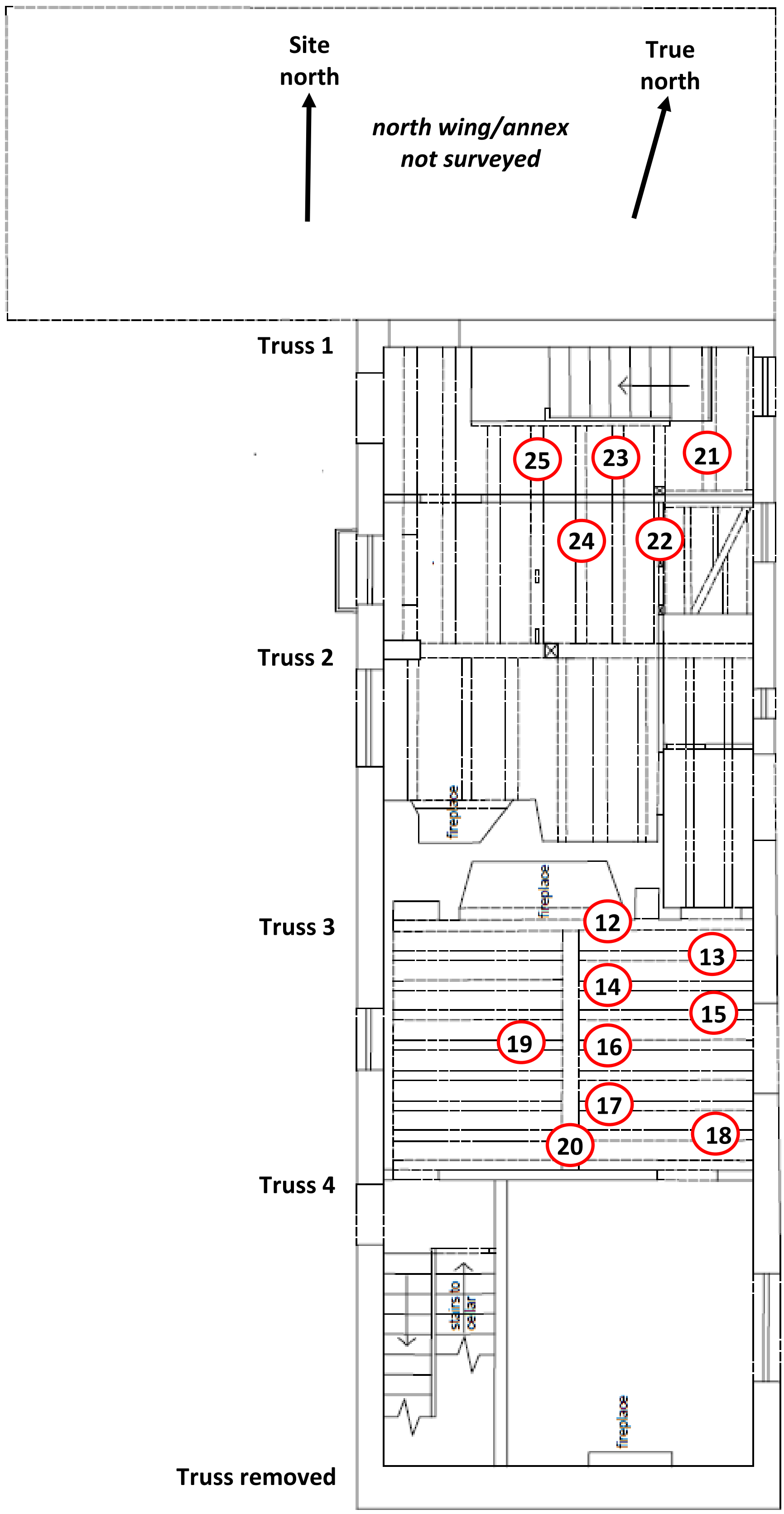


Figure 3b: Plan at ground-floor level to show the locations of the sampled timbers (after Rebecca Lane 2021)

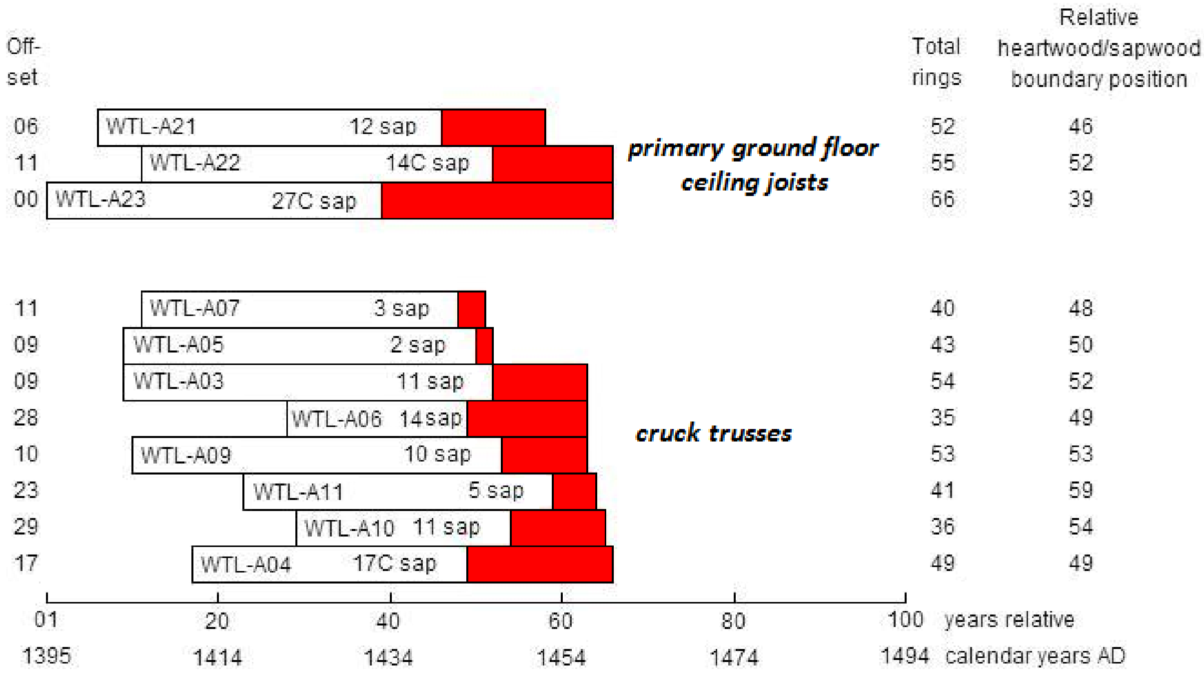


Figure 4: Bar diagram of the dated samples in site chronology WTLASQ01

White bars = heartwood rings; red bars = sapwood rings;
C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the tree

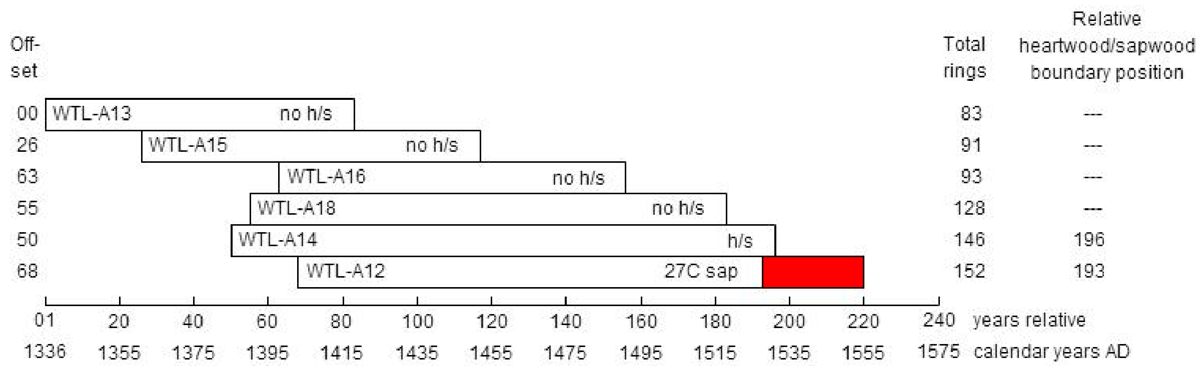


Figure 5: Bar diagram of the dated samples in site chronology WTLASQ02

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

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

WTL-A01A 47
415 392 567 677 485 464 537 407 268 501 561 211 258 100 128 110 185 188 210 321
167 143 112 209 278 356 357 228 246 301 338 228 193 345 99 211 276 329 320 250
181 231 300 234 181 209 316

WTL-A01B 47
399 387 547 677 544 443 589 409 266 527 550 223 259 112 117 101 182 212 221 345
169 144 110 213 275 364 360 264 209 296 356 231 225 345 135 195 278 306 323 255
177 264 303 254 178 200 300

WTL-A02A 31
496 843 836 932 930 596 270 352 453 592 624 608 575 504 607 481 603 389 343 381
305 311 403 640 403 473 510 598 492 481 438

WTL-A02B 31
509 837 806 927 923 586 256 368 464 579 634 648 540 492 634 490 594 371 344 392
318 309 410 651 403 499 537 606 510 476 439

WTL-A03A 54
258 318 381 288 350 346 330 346 290 286 291 240 232 250 286 207 312 254 224 282
239 239 251 143 190 223 165 160 192 184 196 187 179 190 228 148 223 312 254 371
314 262 214 218 188 326 334 343 306 420 269 291 256 256

WTL-A03B 54
263 322 401 291 341 343 328 346 303 271 263 225 215 260 249 225 302 237 214 273
228 204 245 179 198 201 165 170 187 192 196 206 171 199 212 154 219 304 284 345
320 248 203 247 193 306 341 312 343 412 330 219 315 312

WTL-A04A 49
643 473 439 276 207 332 543 305 700 364 330 426 593 614 449 381 312 367 212 206
389 249 191 234 315 517 664 341 470 312 437 364 404 323 234 409 175 253 243 611
350 250 362 323 350 263 292 260 254

WTL-A04B 49
623 463 425 273 194 348 530 325 719 378 346 410 586 624 447 376 310 371 241 208
385 253 199 231 296 525 671 332 490 286 434 373 399 334 257 403 184 258 235 605
328 252 341 328 378 271 265 256 242

WTL-A05A 43
289 324 412 339 418 456 434 452 437 389 314 216 304 332 374 266 352 276 310 378
273 276 274 195 218 200 170 196 187 162 168 147 134 143 223 146 193 238 264 313
289 215 190

WTL-A05B 43
303 325 346 334 399 455 348 449 428 375 332 208 307 335 373 275 338 280 303 387
267 287 251 197 207 193 159 203 200 152 162 148 141 142 232 144 189 248 259 323
290 213 178

WTL-A06A 35
172 252 321 186 126 115 125 112 162 268 287 340 268 185 248 213 186 128 200 240
260 310 227 215 209 137 195 218 207 234 242 318 273 247 259

WTL-A06B 35
95 221 317 173 136 107 130 118 194 293 249 332 269 167 255 280 197 108 221 245
272 268 210 216 215 153 197 208 212 232 254 306 260 230 261

WTL-A07A 40
250 380 528 421 314 428 423 337 377 267 260 294 384 292 496 300 303 458 478 420
429 353 448 312 278 334 454 295 300 404 387 448 350 214 229 292 403 309 312 254

WTL-A07B 40
285 374 519 400 323 432 423 353 373 278 254 307 374 286 495 306 296 492 498 420
423 378 429 311 287 317 440 290 301 393 379 463 331 222 207 345 391 285 300 274

WTL-A09A 53
112 124 280 185 218 125 102 272 233 202 176 173 276 376 289 457 363 268 360 350
360 381 322 375 303 219 343 362 271 235 184 157 201 281 159 237 256 225 229 236
235 162 206 187 221 332 331 281 210 283 216 240 295

WTL-A09B 53
114 123 292 193 225 99 101 271 230 225 160 160 280 378 296 453 373 244 377 343
354 369 307 385 297 204 332 329 267 232 162 187 181 289 159 248 259 243 228 273
218 160 220 173 251 335 335 257 234 242 213 240 315

WTL-A10A 36
323 540 196 142 231 217 154 233 366 234 358 399 404 422 420 242 319 553 503 643
449 365 334 375 324 496 309 392 362 334 452 304 318 312 303 347

WTL-A10B 36
339 560 212 168 187 235 160 214 384 241 368 414 382 425 418 266 333 518 485 566
462 382 339 365 298 511 321 399 367 319 462 325 317 315 296 346

WTL-A11A 41
141 147 198 219 174 325 421 426 202 128 148 182 157 201 309 214 359 438 361 583
422 226 246 426 428 549 487 384 359 348 237 435 329 364 427 379 506 318 356 419
428

WTL-A11B 41
168 132 197 219 175 308 427 406 201 107 151 201 155 182 317 207 371 445 357 571
432 257 257 444 408 581 504 392 340 340 223 470 357 421 421 370 490 334 345 403
460

WTL-A12A 152
179 184 131 86 104 133 87 93 90 114 73 91 81 49 103 102 96 105 128 180
170 168 81 82 146 126 112 114 85 107 76 91 93 142 148 59 62 99 146 150
168 89 71 70 80 108 125 111 81 96 158 157 110 89 128 98 89 92 92 178
146 129 146 142 119 98 90 72 95 103 95 92 65 65 68 81 71 95 59 58
50 42 67 79 59 51 85 90 85 79 84 134 142 123 56 85 81 75 56 89
81 70 48 53 79 71 46 83 88 78 75 52 64 50 103 64 46 60 74 58
70 50 79 79 109 69 77 107 84 73 56 71 82 101 120 145 110 96 69 70
43 62 67 60 73 91 87 80 110 134 89 132

WTL-A12B 152
185 175 140 89 104 126 87 95 92 113 72 90 80 48 97 108 100 107 130 176
195 166 87 73 142 137 135 105 93 97 89 89 68 156 142 65 58 108 150 152
171 80 78 70 89 107 117 107 90 77 152 160 123 104 121 89 98 95 92 190
132 129 156 140 126 101 98 73 104 111 86 92 70 65 68 75 60 102 64 63
50 38 65 87 50 57 94 82 100 85 84 148 145 129 59 92 79 78 68 78
81 51 54 43 78 83 35 89 93 70 85 50 60 67 92 76 45 60 67 78
68 57 67 84 106 86 69 109 81 76 65 70 82 101 112 155 107 98 73 73
40 68 59 62 71 96 87 88 110 136 102 134

WTL-A13A 83
187 185 215 178 186 235 301 267 285 314 121 77 97 244 362 370 307 268 234 307
293 258 230 198 183 196 192 341 376 270 207 204 173 179 173 165 167 133 110 134
125 141 180 200 171 150 156 142 93 173 104 100 125 134 96 137 102 92 146 142
146 108 91 92 112 103 141 139 168 165 97 86 96 212 118 81 103 94 73 137
79 103 170

WTL-A13B 83
174 195 211 177 189 210 291 272 276 308 137 66 80 241 342 421 364 250 253 314
281 272 257 207 187 202 163 331 368 250 181 206 172 176 175 159 173 135 118 126
121 146 173 181 187 159 140 153 79 187 121 114 125 137 96 145 87 92 149 135
150 111 89 99 104 98 154 140 157 159 106 78 100 220 97 84 98 96 71 134
87 101 183

WTL-A14A 146
123 110 112 97 94 112 112 109 220 269 232 163 122 144 167 126 156 216 212 169
139 89 100 213 96 143 100 124 78 168 99 120 166 190 142 129 202 229 191 150
94 77 185 141 79 90 84 87 85 105 80 115 112 62 75 123 131 175 128 109
70 65 88 122 123 132 85 79 142 121 148 87 76 60 73 68 75 123 96 112
136 143 167 84 90 92 116 118 92 87 104 70 89 101 120 139 81 73 81 79
92 110 94 90 121 139 130 106 100 162 153 125 72 95 85 106 76 122 118 88
71 52 97 81 52 100 102 94 93 60 63 71 86 75 59 60 76 73 82 70
78 86 106 87 72 137

WTL-A14B 146
120 109 108 109 89 104 121 106 217 275 236 157 125 144 169 126 152 222 204 168
142 89 109 205 94 136 103 121 88 174 88 122 166 192 132 138 203 233 192 143
81 92 184 128 92 89 92 92 73 96 84 121 110 56 76 110 142 155 150 106
73 75 70 121 128 132 76 81 134 132 151 84 67 69 68 70 76 115 92 123
142 159 165 82 86 91 117 116 91 98 90 73 85 100 120 151 73 79 79 78
95 110 98 86 120 135 121 101 112 159 156 112 81 98 85 102 78 118 125 81
75 57 95 77 65 103 77 90 98 70 59 71 90 78 60 58 79 61 87 65
85 93 90 77 78 143

WTL-A15A 91
348 444 585 399 259 249 186 187 171 129 187 191 230 182 230 301 286 299 319 325
275 257 121 171 119 131 118 141 117 110 121 128 189 210 195 134 117 125 190 176
146 167 165 131 104 91 107 131 91 98 82 89 69 133 66 110 140 156 89 115
168 157 115 101 65 85 153 106 102 78 100 85 60 90 101 143 125 69 91 86
111 133 125 81 77 69 70 103 94 109 98

WTL-A15B 91
354 434 584 388 261 247 198 173 155 140 170 196 217 196 228 314 291 289 319 313

290 307 122 173 106 135 120 131 124 118 118 129 193 214 189 142 117 132 171 182
142 170 156 139 99 95 101 140 78 104 83 83 75 123 71 115 142 143 82 129
162 156 115 96 71 81 159 126 101 76 90 84 72 91 103 131 127 75 78 87
102 128 137 82 74 68 80 93 103 110 107

WTL-A16A 93
107 99 117 107 157 184 166 121 72 93 116 75 92 76 92 75 128 51 67 117
136 108 93 147 271 206 167 64 67 135 117 99 109 107 117 87 119 87 162 183
68 67 121 185 163 158 89 74 84 96 106 138 136 97 78 167 170 134 98 112
74 106 82 103 244 143 140 167 173 173 128 115 106 151 143 110 110 84 82 98
114 114 145 90 71 92 59 85 110 98 78 178 124

WTL-A16B 93
96 102 110 112 162 184 164 135 85 85 113 75 87 77 86 83 125 54 52 106
129 132 91 149 241 198 164 64 79 125 126 94 92 86 105 89 117 85 178 154
63 64 123 196 153 169 85 79 82 110 125 138 150 93 85 161 182 134 98 121
117 95 106 87 259 151 140 175 157 173 128 112 100 135 151 120 116 75 81 104
128 128 134 92 78 117 65 87 131 89 85 162 152

WTL-A17A 53
342 407 354 441 560 471 577 492 350 457 354 312 368 371 323 328 376 283 191 403
515 331 203 376 289 194 147 235 245 315 264 151 251 207 131 132 178 210 306 210
197 312 253 175 212 225 402 209 264 345 165 171 266

WTL-A17B 53
343 411 362 452 548 474 573 487 353 478 346 306 365 376 293 334 365 289 207 459
549 323 221 385 273 207 150 246 250 312 253 151 262 235 123 126 160 212 292 204
203 325 264 179 243 209 403 209 276 339 159 184 245

WTL-A18A 128
138 105 129 127 201 200 117 106 96 103 101 143 148 164 148 119 75 80 159 58
82 69 76 65 107 91 101 114 128 157 113 115 152 126 129 53 59 129 82 76
106 78 85 73 75 75 102 113 53 40 109 128 112 126 71 65 62 83 83 97
82 74 59 91 137 128 114 128 85 92 123 98 203 144 135 175 157 171 145 155
104 145 132 86 95 101 75 75 87 110 107 75 58 80 53 71 112 81 67 109
82 87 79 71 106 118 84 51 78 85 71 67 76 62 51 59 46 79 48 51
73 74 58 64 42 51 35 56

WTL-A18B 128
134 101 120 130 201 213 126 107 100 117 112 134 160 161 149 121 68 83 148 56
79 73 69 59 119 83 94 128 125 165 100 124 141 119 142 46 70 110 97 77
111 95 89 80 67 77 111 114 52 46 120 148 121 136 75 64 62 76 82 97
95 64 62 93 138 135 104 128 78 105 112 92 206 137 134 181 157 165 128 175
101 142 129 90 101 101 66 79 98 104 108 85 53 85 46 75 111 72 70 109
84 88 75 70 120 103 80 62 82 78 67 63 76 60 59 48 46 82 50 46
82 70 68 62 40 42 44 50

WTL-A20A 60
316 293 272 171 196 227 374 359 234 251 216 185 153 178 182 183 249 159 178 207
255 269 289 242 261 211 180 123 287 185 170 147 189 137 131 145 178 307 310 334
217 186 185 134 139 151 226 269 167 185 120 121 148 193 164 157 139 165 248 290

WTL-A20B 60
289 289 272 179 192 242 346 356 250 237 228 184 152 184 188 194 259 171 176 196
250 264 283 241 271 207 185 119 290 178 170 149 190 134 140 137 196 295 306 323
227 182 182 139 134 134 226 225 170 177 125 136 115 208 148 175 140 146 234 314

WTL-A21A 52
336 206 166 181 219 277 218 192 173 171 212 232 159 162 119 101 116 136 95 188
114 98 143 160 113 94 84 71 86 52 83 123 83 87 58 56 110 235 140 116
185 225 240 195 200 187 215 106 203 206 215 151

WTL-A21B 52
322 202 176 184 209 267 189 202 162 182 214 210 167 171 108 98 128 140 98 188
117 94 146 152 125 97 80 80 82 57 74 121 91 78 71 53 105 227 160 175
183 216 233 225 189 190 207 117 190 209 223 228

WTL-A22A 55
320 343 378 441 406 443 496 346 397 335 248 250 257 164 423 266 223 253 339 308
146 179 234 198 120 169 225 149 126 109 115 168 320 192 265 356 250 281 253 204
182 178 195 248 381 345 268 257 192 258 245 173 200 206 155

WTL-A22B 55
335 348 406 485 398 443 503 350 392 339 237 239 263 164 421 276 222 246 349 277
211 184 234 235 109 145 229 126 135 112 109 170 323 176 241 331 261 287 228 212
125 179 194 255 381 363 242 223 236 231 250 209 196 171 175

WTL-A23A 66
185 154 127 299 309 414 371 271 239 281 248 301 239 192 172 178 240 234 205 211
210 180 166 167 135 225 202 174 225 295 360 293 217 269 237 175 195 257 166 175
160 107 126 198 121 65 103 104 103 126 88 90 90 75 68 75 75 64 62 60
42 51 50 67 43 54

WTL-A23B 66
170 162 131 288 309 414 397 287 237 266 259 319 232 210 177 167 237 235 204 208
206 182 161 171 137 225 177 179 244 275 385 293 217 265 237 176 203 247 177 168
162 107 132 181 131 67 104 111 102 126 95 90 84 75 65 75 78 64 67 55
51 45 51 62 50 46

WTL-A24A 38
256 186 166 232 80 117 195 184 209 400 398 405 431 396 368 269 509 456 518 527
509 432 393 470 476 406 378 310 297 375 285 297 359 365 375 310 278 389

WTL-A24B 38
247 166 188 217 117 117 170 170 195 383 417 414 405 414 380 265 507 457 525 537
502 421 396 472 495 395 410 298 268 374 289 310 326 381 384 304 276 391

WTL-A25A 36
202 272 288 262 238 229 375 510 534 226 179 251 179 246 307 286 285 214 210 235
122 119 91 146 192 153 209 167 150 184 140 169 151 129 122 217

WTL-A25B 37
188 280 294 254 242 219 383 514 527 219 191 259 164 232 318 288 286 210 231 227
122 113 96 151 201 145 203 178 143 166 139 164 157 117 160 170 103

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

1. *Inspecting the Building and Sampling the Timbers.*

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

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

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

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

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

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

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

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

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

2. Measuring Ring Widths.

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

3. Cross-Matching and Dating the Samples.

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for

C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

4. Estimating the Felling Date.

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

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

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

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

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

5. Estimating the Date of Construction.

There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after

(Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. Master Chronological Sequences.

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

7. Ring-Width Indices.

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

t-value/offset Matrix

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

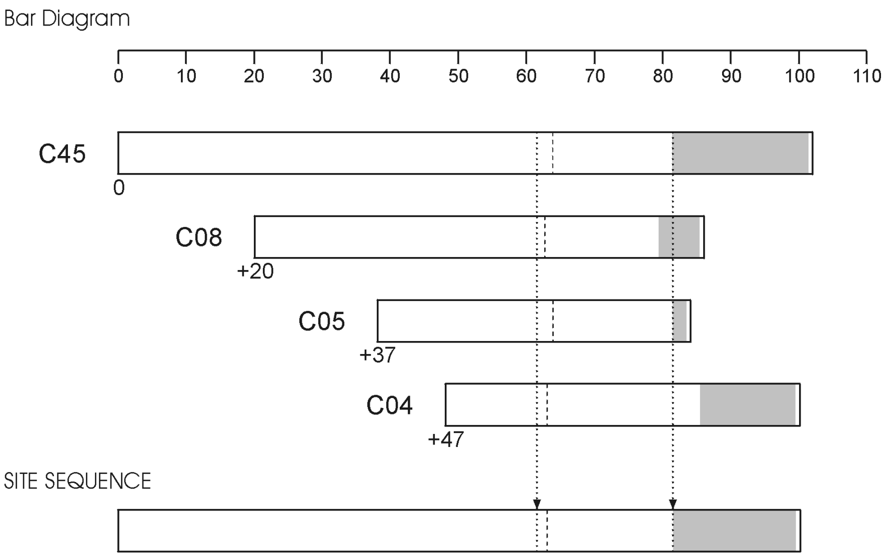


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

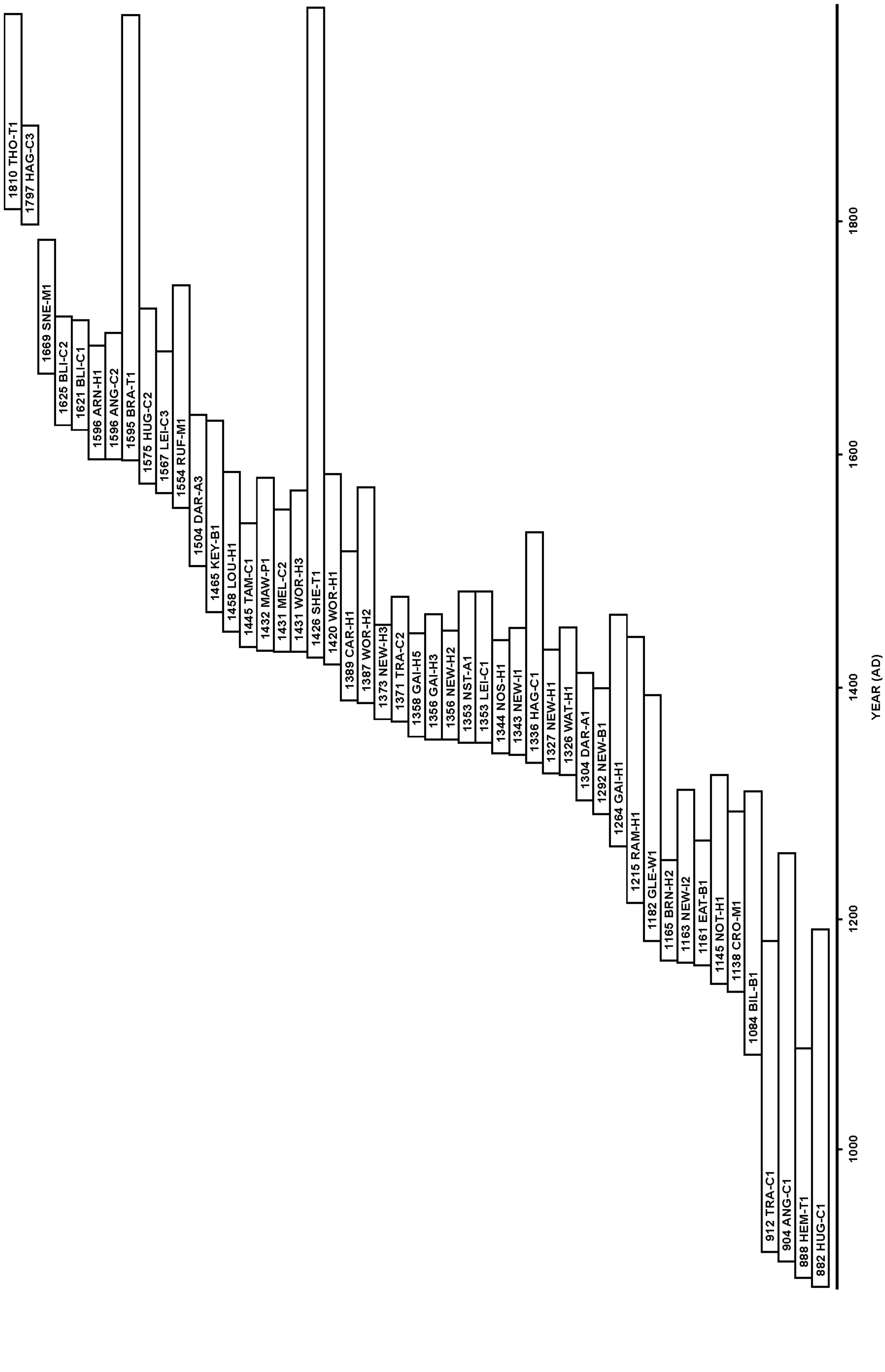
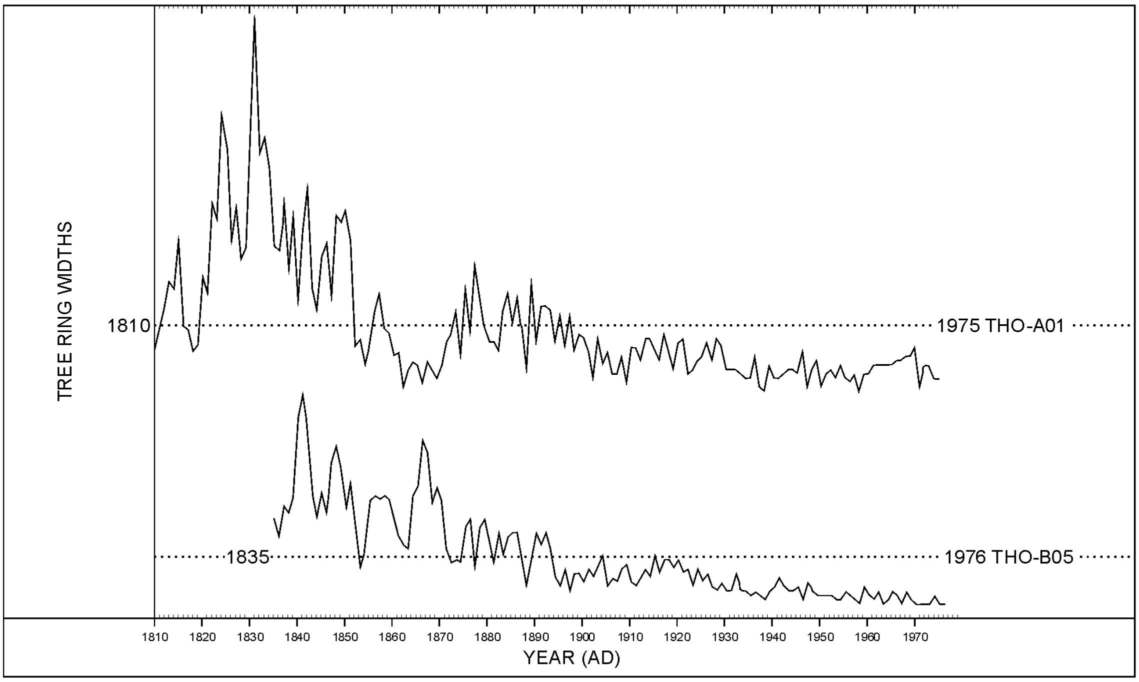


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

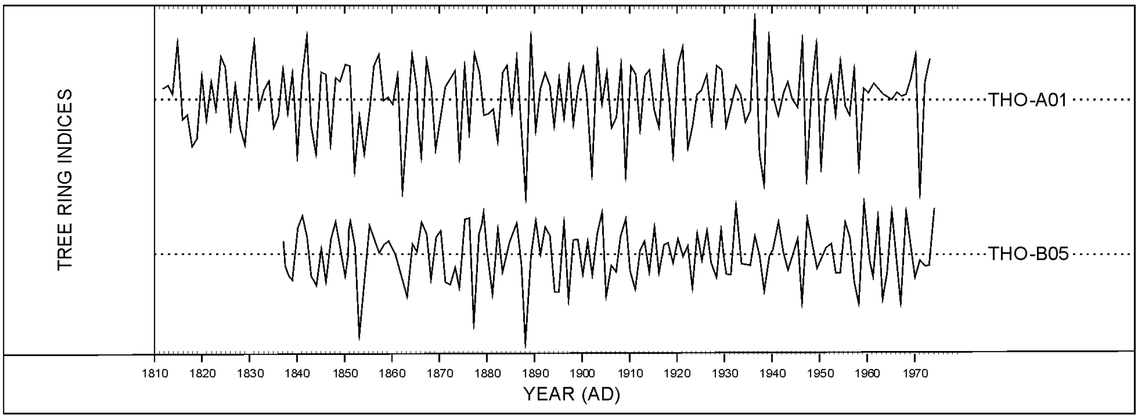


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

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

The growth trends have been removed completely

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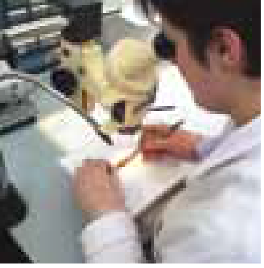
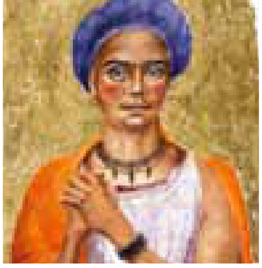


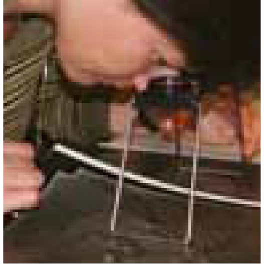


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