Brampton Manor Barn, Old Road, Chesterfield, Derbyshire

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard and Cathy Tyers

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SUMMARY

Dendrochronological analysis was undertaken on timbers from the roof, floor frame, and a partition resulting in the construction of three site sequences. Site sequence BRMNSQ01 contains six samples from roof timbers and spans the period AD 1487–1577. Interpretation of the surviving sapwood suggests felling of these timbers occurred in AD 1581–1606, possibly AD 1590–1606, with construction of the barn likely to have followed shortly after felling. Site sequence BRMNSQ02 contains nine samples, a mixture of joists from the floor frame and studs from the partition and spans the period AD 1661–1740. Felling of these timbers is likely to have occurred in AD 1741–60 and indicates that these modifications are coeval. The third site sequence, BRMNSQ03, is undated as are a series of unmatched individual timber series.

CONTRIBUTORS

Alison Arnold, Robert Howard and Cathy Tyers

ACKNOWLEDGEMENTS

Simon White, the owners' agent, and Craig Lynch, the tenant of the building, are thanked for facilitating access. Thanks are also due to Beki Burns (Historic England Scientific Dating Team) for commissioning and facilitating this programme of tree-ring analysis.

ARCHIVE LOCATION

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

DATE OF INVESTIGATION

2016

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INTRODUCTION

Brampton Manor Barn is located about 2km west of the centre of Chesterfield (Figs 1– 3), adjacent to the Manor House which is thought to have been built by two brothers, Robert and John Watkinson, between AD 1585 and AD 1599 (www.s40local.co.uk/the-manor).

The barn, considered a rare survival for the area, is a Grade II listed building and a Scheduled Monument and has been on the Heritage at Risk Register since 2002 due to continued slow decay. It is constructed from stone rubble with some ashlar dressings and a slate roof. It consists of three bays (Fig 4), separated by four cruck trusses, with each truss consisting of blades, tiebeams, and collars (Fig 5). Braces spring from the blades to the single set of purlins.

Bays 1 and 2 are separated by a substantial oak-framed and boarded partition (Fig 6), whilst bays 2 and 3 are divided by a brick partition. Bay 2 is open to the roof, whereas bays 1 and 3 are floored; in the case of bay 1 the floor frame is exposed and consists of a central main beam which supports joists to the east and west (Fig 7).

SAMPLING

A dendrochronological survey was requested by Amanda White, Historic England Heritage at Risk Surveyor, to provide independent dating evidence in order to aid understanding and significance of the structure and hence inform advice with respect to a programme of repair and future care.

Thirty-one core samples were taken from timbers of the roof, the exposed floor frame in bay 1, and the timber partition between bays 1 and 2, in accordance with the conditions of the Scheduled Monuments Consent Class 6 Certification (S00149280). Each sample was given the code BRM-N and numbered 01–31. Further details relating to the samples can be found in Table 1 and the location of all samples has been marked on Figures 8 and 9. The barn is aligned north-east to south-west and thus a site north has been imposed with truss 1 at the north end and truss 4 at the south end. Floor joists were also numbered from north to south, whilst the studs of the partition were numbered from east to west.

ANALYSIS AND RESULTS

Six of the samples, one of the cruck blades, three joists from the floor frame, and two studs from the partition, had too few rings for reliable analysis and so were rejected prior to measurement. The remaining 25 core samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These measurements were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 17 samples matching to form three groups.

Six of the roof samples were combined at the relevant offset positions to form BRMNSQ01, a site sequence of 91 rings (Fig 10). The intra-site matching of the components of this site sequence is poor overall (Table 2) but was confirmed by comparison of the individual samples or matched pairs of samples with a range of reference chronologies (Table 3). The resultant site sequence, BRMNSQ01, was found to match a series of relevant reference chronologies consistently at a first-ring date of AD 1487 and a last-ring date of AD 1577. The evidence for this dating is given in Table 4.

Nine samples, from five joists and four studs, matched and were combined at the relevant offset positions to form BRMNSQ02, a site sequence of 80 rings (Fig 11). This site sequence was also compared against a series of relevant reference chronologies where it was found to span the period AD 1661–1740 (Table 5).

Finally, the samples from two other joists matched and were combined to form BRMNSQ03, a site sequence of 64 rings (Fig 12). Attempts to date this site sequence and the remaining ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

Analysis has resulted in the successful dating of 15 timbers from the roof, the floor frame, and the partition wall (Fig 13). Felling date ranges have been calculated using the estimate that 95% of mature oak trees from this area have between 15 and 40 sapwood rings.

Roof

The six dated samples associated with the roof comprise four elements from truss 2, a collar from truss 3, and a purlin in bay 2. Five of these samples have some sapwood or at least the heartwood/sapwood boundary ring. The dates of the heartwood/sapwood boundary rings are broadly contemporary, varying by only eight years, and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1566, allowing an estimated felling date to be calculated for the five timbers represented to the range AD 1581–1606.

The sixth dated sample does not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for it. However, with a last-measured heartwood ring date of AD 1574 it would be estimated that it was felled after AD 1589. This *terminus post quem* for felling falls within the felling date range calculated for the rest of the roof samples making it possible that this timber was felled at the same time. There is no evidence to suggest that this wind-brace was a later insertion or modification and thus, assuming that all six of the dated timbers belong to a single felling, it would be possible to refine the estimated felling date range to AD 1590–1606. However, it is also possible that the tree represented by sample BRM-N07 fell outside of the usual 95% confidence range for sapwood rings and had less than the lower limit of the 15-40 range.

Floor frame and Partition

Five of the samples taken from the joists of the floor frame and four from studs in the partition have been successfully dated. Of these, seven have the heartwood/sapwood boundary ring. The dates of these are broadly contemporary, varying by only five years, and are again suggestive of a single felling. The average heartwood/sapwood boundary ring date for these seven samples is AD 1720, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1741–60. This allows for sample BRM-N31 having a last-measured ring date of AD 1740 with incomplete sapwood.

The other two dated samples, both joists, do not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for them. However, with last measured ring dates of AD 1709 (BRM-N14) and AD 1717 (BRM-N18) this would be estimated to be at the earliest AD 1725 and AD 1733, respectively. Therefore, it is possible that these timbers are coeval with the rest of the dated timber from the floor frame and partition, and indeed the overall level of cross-matching within this group of dated timbers suggests that this is the case.

DISCUSSION

Tree-ring analysis has dated a number of the roof timbers to a felling date range of AD 1581–1606, possibly AD 1590–1606, suggesting a construction date in the later sixteenth or very early seventeenth century shortly after felling. This coincides with the suggested construction date of between AD 1585 and AD 1599 assigned to the adjacent Manor House itself and points to the two buildings being broadly contemporary and likely to have been built as part of the same construction programme.

The floor frame in bay 1 and the timber partition separating bays 1 and 2 have now been shown to be coeval, with the timbers utilised in both of these elements being dated to a felling date range of AD 1741–60. This suggests alterations being undertaken on the barn in the mid-eighteenth century, approximately 150 years after the initial construction. If during a future programme of repair work the boards associated with the partition are temporarily removed in order to facilitate repairs, then it is recommended that they are subject to dendrochronological analysis which could be undertaken through direct measurement of the exposed cross-sectional surfaces. This would provide the opportunity, if successful, of ascertaining whether the boards are coeval with the timber-framing of the partition or whether they were later replacements.

The level of cross-matching between the components of BRMNSQ01 suggests that the source of the timbers used in the initial construction of the barn may have been somewhat more disparate than those used in the later alterations. With the interesting exception of Wheelrights Shop in Kent, both site sequences (BRMNSQ01 and BRMNSQ02) match most highly against reference chronologies in the Midlands and Yorkshire (Tables 4 and 5), suggesting the sources for the timbers utilised for both the original construction and the later alterations were relatively local.

Only one potential same-tree match was noted during the analysis. This was between samples from two joists (BRM-N16 and BRM-N19) which matched each other at t = 10.7, a value high enough to suggest that both timbers may have been derived from the same-tree

It is unfortunate that site sequence BRMNSQ03 containing samples from two additional floor joists could not be dated. However, with heartwood/sapwood boundary rings only five years apart it is likely that both timbers represented were felled at the same time as each other (Fig 12).

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TABLES

Table 1: Details of samples taken from Brampton Manor Barn, Chesterfield, Derbyshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof						
BRM-N01	East blade, truss 1	62	h/s	----	----	----
BRM-N02	West blade, truss 1	40	01	----	----	----
BRM-N03	West blade, truss 2	84	h/s	1487	1570	1570
BRM-N04	Collar, truss 2	64	h/s	1504	1567	1567
BRM-N05	North windbrace, west blade, truss 2	62	h/s	1505	1566	1566
BRM-N06	South windbrace, west blade, truss 2	56	21	----	----	----
BRM-N07	South windbrace, east blade, truss 2	54	--	1521	----	1574
BRM-N08	East purlin, bay 2	79	15	1499	1562	1577
BRM-N09	West blade, truss 3	61	16	----	----	----
BRM-N10	Collar, truss 3	54	09	1522	1566	1575
BRM-N11	West purlin, bay 3	49	10	----	----	----
BRM-N12	East blade, truss 4	NM	--	----	----	----
Floor frame						
BRM-N13	Main beam	60	04	----	----	----
BRM-N14	Joist 4, east	47	--	1663	----	1709
BRM-N15	Joist 5, east	NM	--	----	----	----
BRM-N16	Joist 7, east	49	h/s	1672	1720	1720
BRM-N17	Joist 9, east	57	h/s	----	----	----
BRM-N18	Joist 1, west	52	--	1666	----	1717
BRM-N19	Joist 2, west	57	06	1672	1722	1728
BRM-N20	Joist 3, west	45	04	1680	1720	1724
BRM-N21	Joist 4, west	NM	--	----	----	----
BRM-N22	Joist 9. West	56	02	----	----	----
BRM-N23	Joist 12, west	NM	--	----	----	----

Table 1: (cont)

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Partition						
BRM-N24	Bottom rail	56	10	----	----	----
BRM-N25	Centre post	59	11	----	----	----
BRM-N26	Stud 1	NM	--	----	----	----
BRM-N27	Stud 2	NM	--	----	----	----
BRM-N28	Stud 3	72	17	1668	1722	1739
BRM-N29	Stud 4	57	17	1683	1722	1739
BRM-N30	Stud 5	71	14	1661	1717	1731
BRM-N31	Stud 6	44	21	1697	1719	1740

KEY:
NM = not measured;
h/s = the heartwood/sapwood boundary is the last measured ring

Table 2: Matrix to show the t-values produced between the individual components of site sequence BRMNSQ01; the higher the t-value the greater the similarity between the ring sequences; – indicates t-value of less than 3.0

	BRM-N03	BRM-N04	BRM-N05	BRM-N07	BRM-N08	BRM-N10
BRM-N03	***					
BRM-N04	3.8	***				
BRM-N05	–	–	***			
BRM-N07	3.0	3.4	4.8	***		
BRM-N08	3.1	3.0	–	3.0	***	
BRM-N10	–	6.1	–	–	–	***

Table 3: Results of the cross-matching of the individual series or matched pairs of series and relevant reference chronologies

Sample/Series (Date)	Reference chronology	*t*-value	Span of chronology	Reference
BRM-N03	Hardwick Hall (West Lodge), Hardwick, Derbyshire	6.3	AD 1397–1625	Howard *et al* 2002
(AD 1487–1570)	Sinai Park, Burton, Staffordshire	5.9	AD 1227–1750	Tyers 1997
	Object: Mermaid Door	5.9	AD 1464–1640	Tyers 1992
	Bishops House, Sheffield, South Yorkshire	5.8	AD 1359–1591	Morgan 1977
BRM-N08	Alcester Town Hall, Alcester, Warwickshire	6.3	AD 1374–1625	Arnold and Howard 2014
(AD 1499–1577)	Bede House Chapel, Newark-upon-Trent, Nottinghamshire	6.1	AD 1411–1554	Arnold *et al* 2002
	Knole, Sevenoaks, Kent	5.9	AD 1431–1605	Miles and Bridge 2010
	St Peter's Church (bellframe), Aston Flamville, Leicestershire	5.5	AD 1475–1620	Arnold *et al* 2005
BRM-N04/BRM-N10	Bishops House, Sheffield, South Yorkshire	6.6	AD 1359–1591	Morgan 1977
(AD 1504–1575)	Frith Hall, Brampton, Derbyshire	6.4	AD 1480–1602	Howard *et al* 1993
	Unthank Hall, Holmesfield, Derbyshire	5.0	AD 1359–1589	Howard *et al* 1993
	Cartledge Hall, Holmesfield, Derbyshire	5.0	AD 1456–1568	Howard *et al* 1993
BRM-N05/BRM-N07	North Lees Hall, Outseats, Derbyshire	6.0	AD 1468–1578	Howard *et al* 1994
(AD 1505–1574)	Grange Farm, Norton, Sheffield, South Yorkshire	5.8	AD 1436–1599	Arnold and Howard 2007
	Sutton Scarsdale Manor Barn, Chesterfield, Derbyshire	5.7	AD 1520–1632	Howard *et al* 1997
	Pontefract Castle, Pontefract, West Yorkshire	5.6	AD 1507–1656	Arnold and Howard 2005

Table 4: Results of the cross-matching of site sequence BRMNSQ01 and relevant reference chronologies when the first-ring date is AD 1487 and the last-measured ring date is AD 1577

Reference chronology	*t*-value	Span of chronology	Reference
Cartledge Hall, Holmesfield, Derbyshire	7.9	AD 1459–1581	Howard *et al* 1993
Grange Farm, Norton, Sheffield, South Yorkshire	6.9	AD 1436–1599	Arnold and Howard 2007
Hardwick Hall (West Lodge), Hardwick, Derbyshire	6.4	AD 1397–1625	Howard *et al* 2002
Pontefract Castle, Pontefract, West Yorkshire	6.2	AD 1507–1656	Arnold and Howard 2005
Bramall Hall, Bramall, Stockport, Greater Manchester	6.0	AD 1359–1590	Arnold and Howard 2013
Alcester Town Hall, Alcester, Warwickshire	6.0	AD 1374–1625	Arnold and Howard 2014
Unthank Hall, Holmesfield, Derbyshire	6.0	AD 1359–1589	Howard *et al* 1993

Table 5: Results of the cross-matching of site sequence BRMNSQ02 and relevant reference chronologies when the first-ring date is AD 1661 and the last-measured ring date is AD 1740

Reference chronology	*t*-value	Span of chronology	Reference
Church Farm, Bringhurst, Leicestershire	7.9	AD 1664–1781	Groves *et al* 2004
Wheelright’s Shop, Chatham Docks, Kent	7.8	AD 1615–1780	Bridge 1998
Coates’ Barn, Main Street, Cosby, Leicestershire	7.2	AD 1642–1734	Alcock *et al* 1991
Kibworth Harcourt Mill, Leicestershire	7.2	AD 1582–1773	Arnold *et al* 2004
Bolsover Castle (Riding School), Bolsover, Derbyshire	6.9	AD 1494–1744	Howard *et al* 2005
Stoneleigh Abbey, Stoneleigh, Warwickshire	6.9	AD 1646–1813	Howard *et al* 2000
The Keep, Bolsover Castle, Bolsover, Derbyshire	6.7	AD 1532–1749	Arnold *et al* 2003

FIGURES

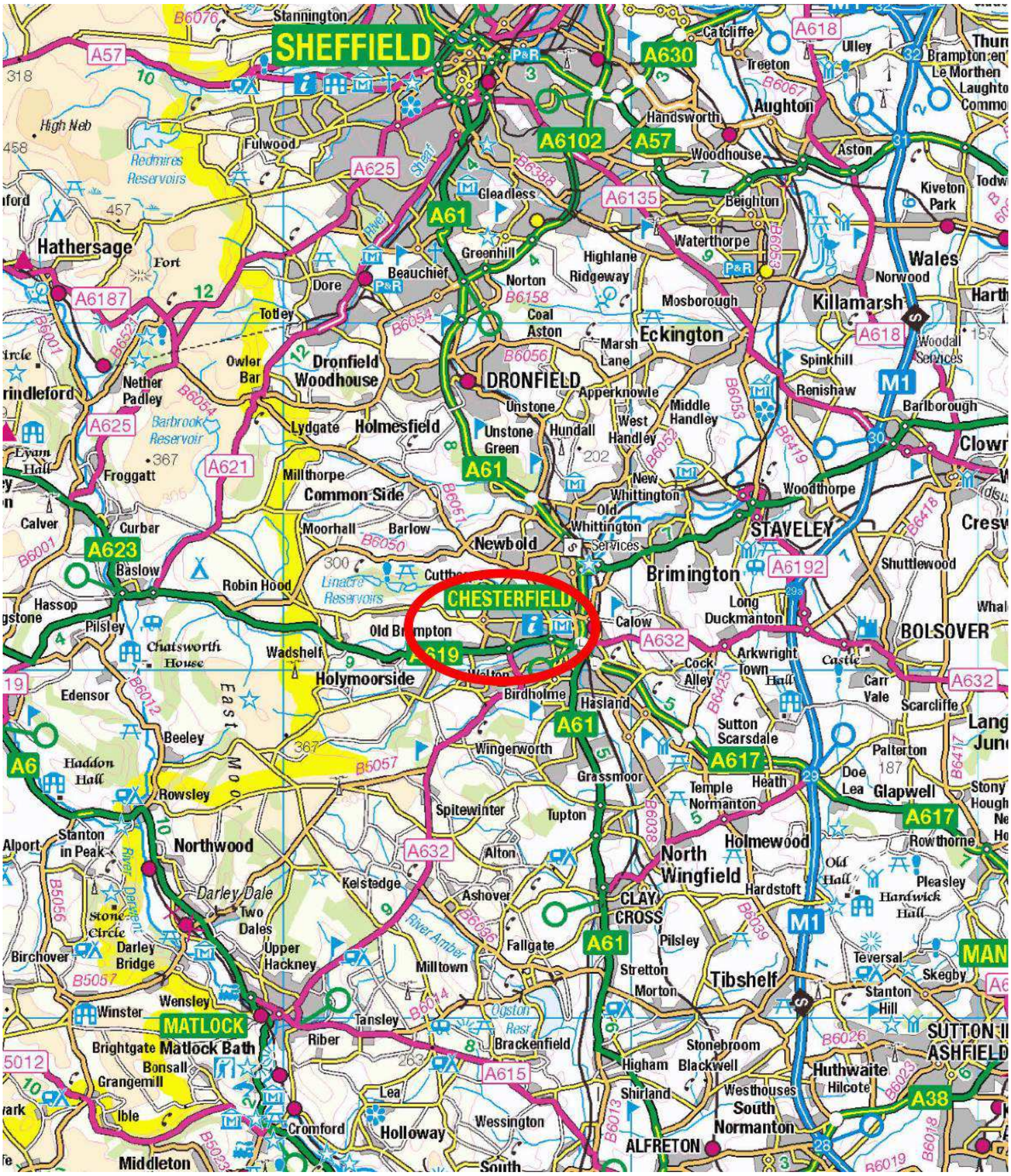

Figure 1: Map to show the general location of Brampton Manor Barn (circled). ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

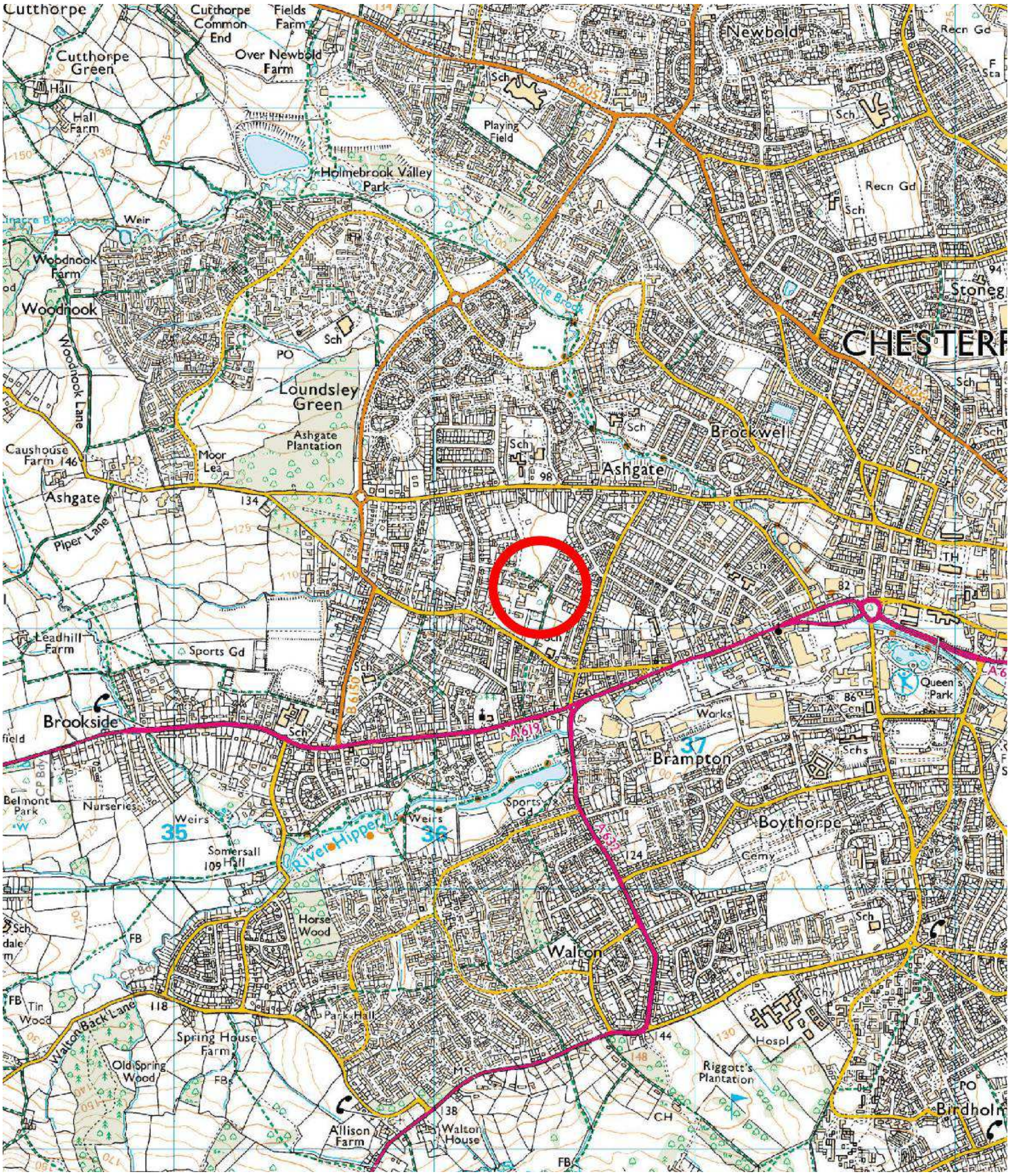

Figure 2: Map to show the location of Brampton Manor Barn (circled) within Chesterfield. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

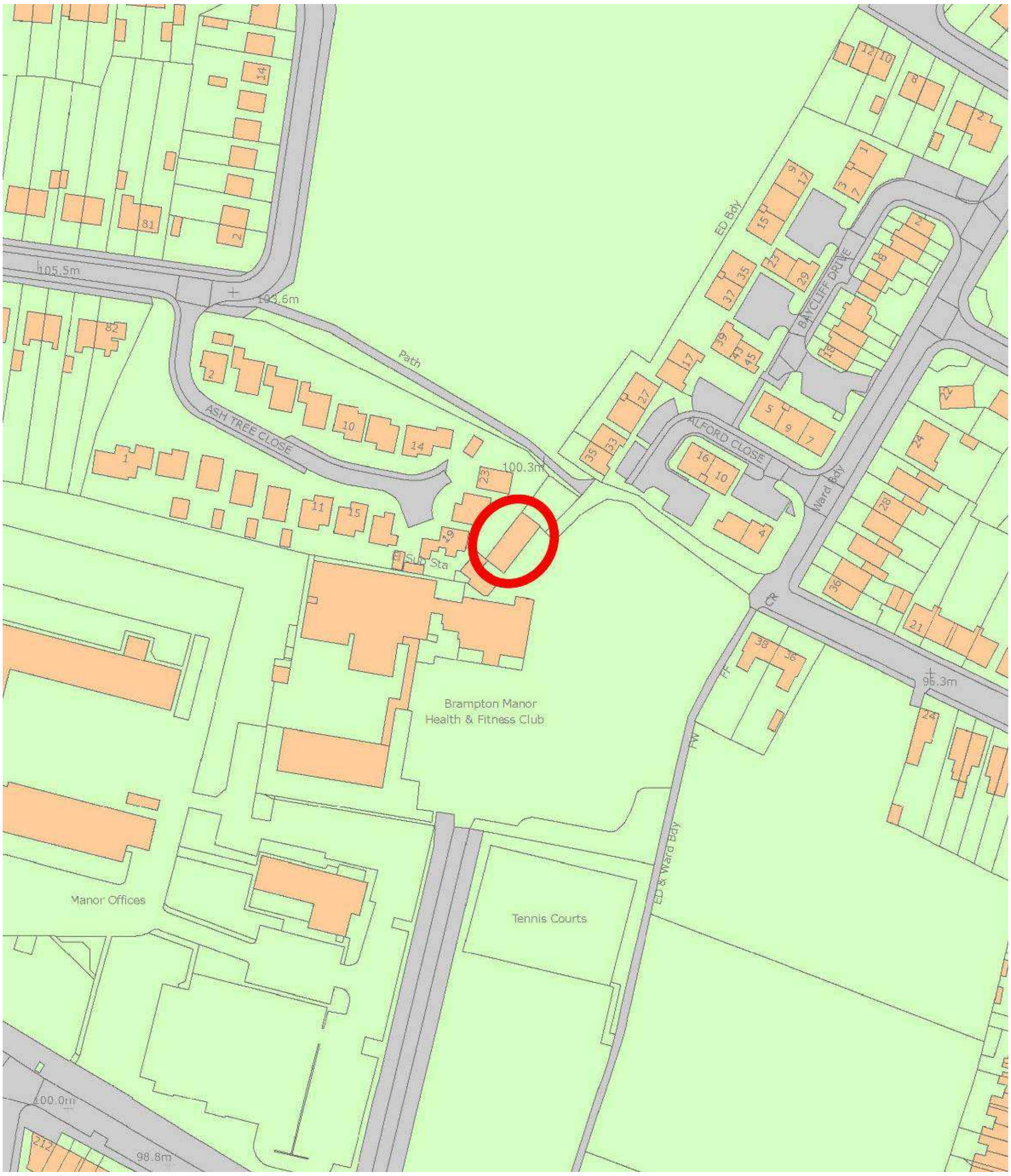

Figure 3: Map showing the detailed location of Brampton Manor Barn (circled). ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

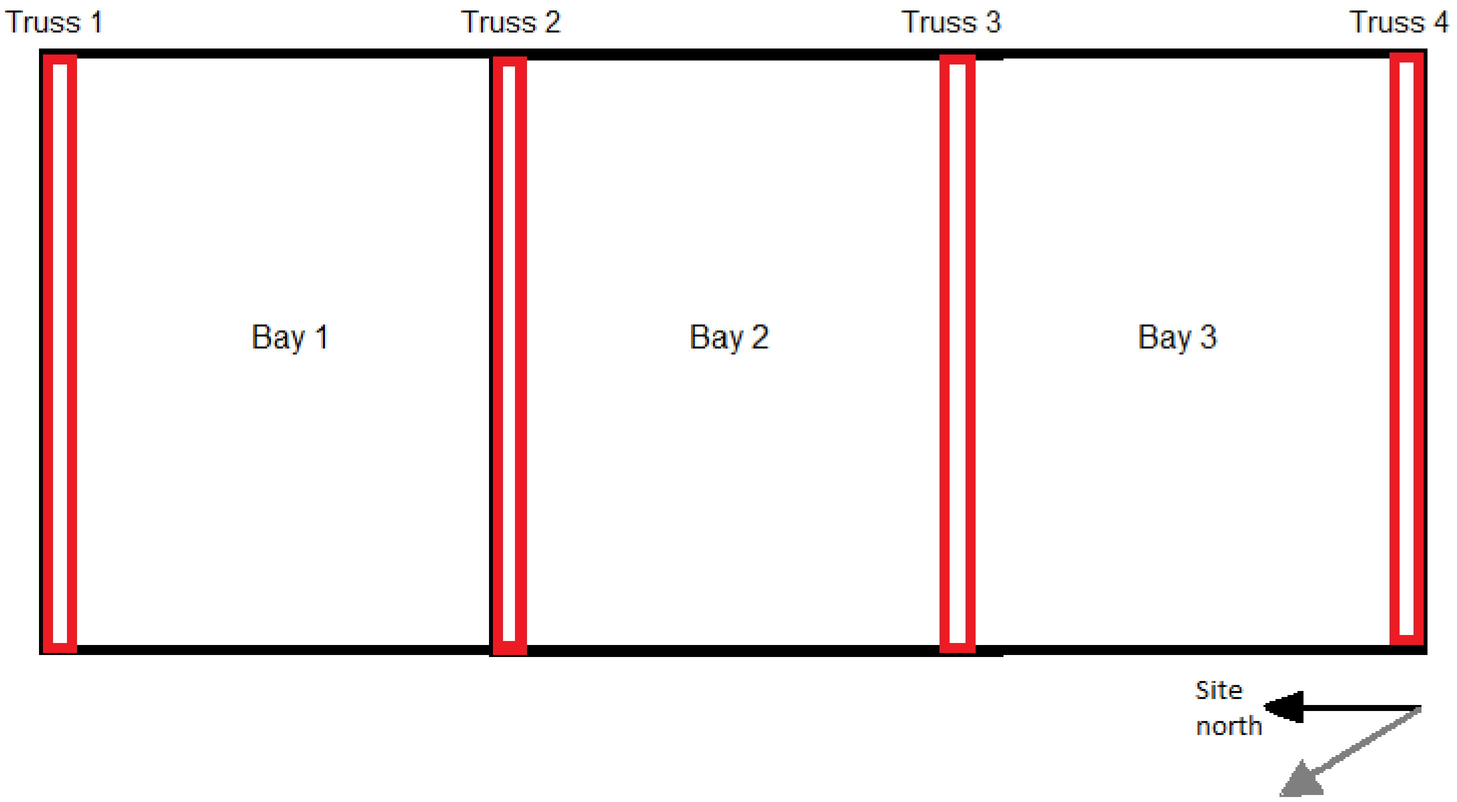

Figure 4: Sketch plan showing the approximate position of trusses

Figure 5: The roof, with truss 2 in the foreground, photograph taken from the north (Robert Howard)

Figure 6: Timber partition separating bays 1 and 2, photograph taken from the south (Alison Arnold)

Figure 7: Floor frame in bay 1, photograph taken from the south-east (Alison Arnold):

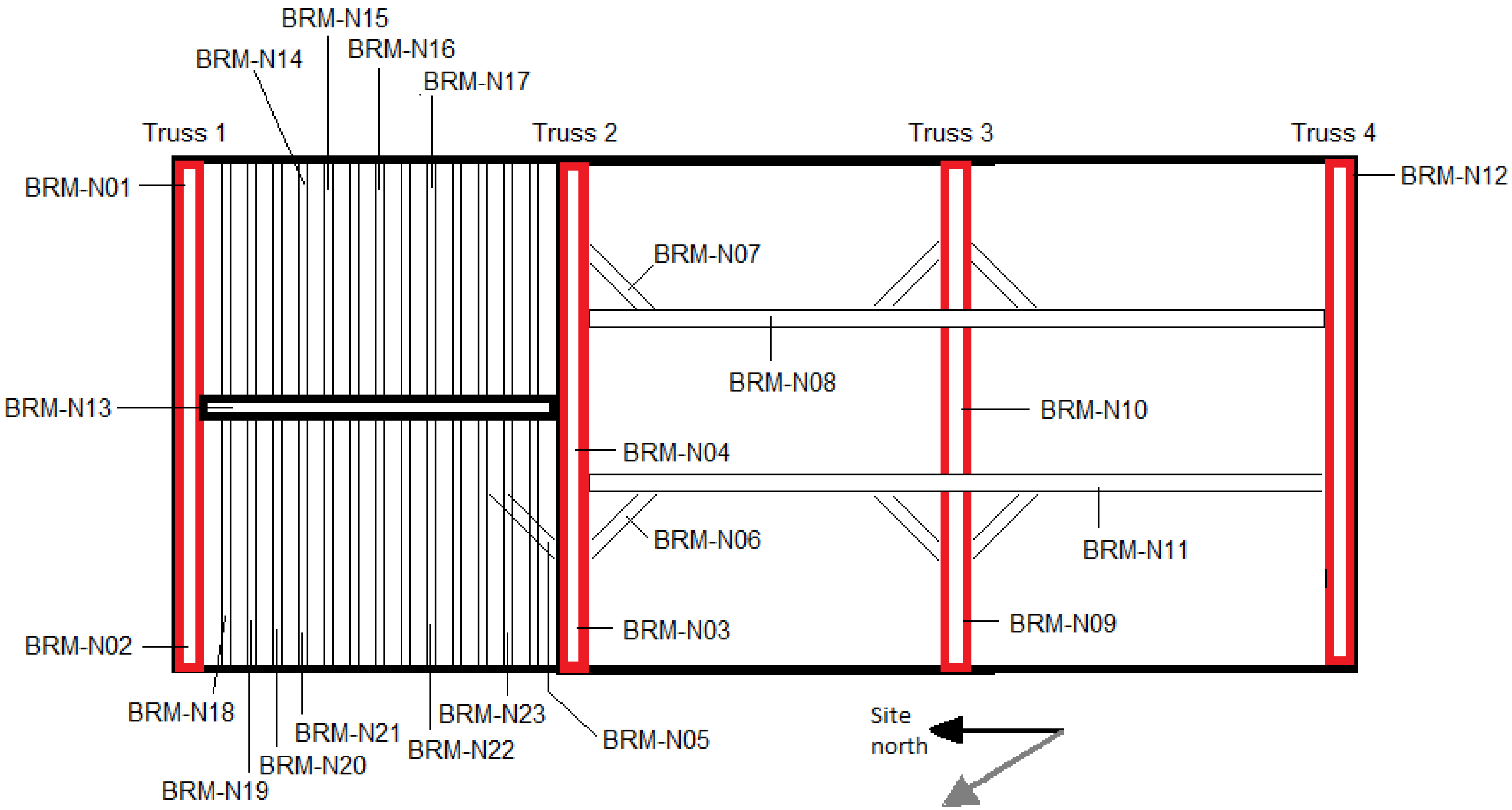

Figure 8: Sketch plan of the barn showing the approximate position of sampled timbers BRM-N01–23

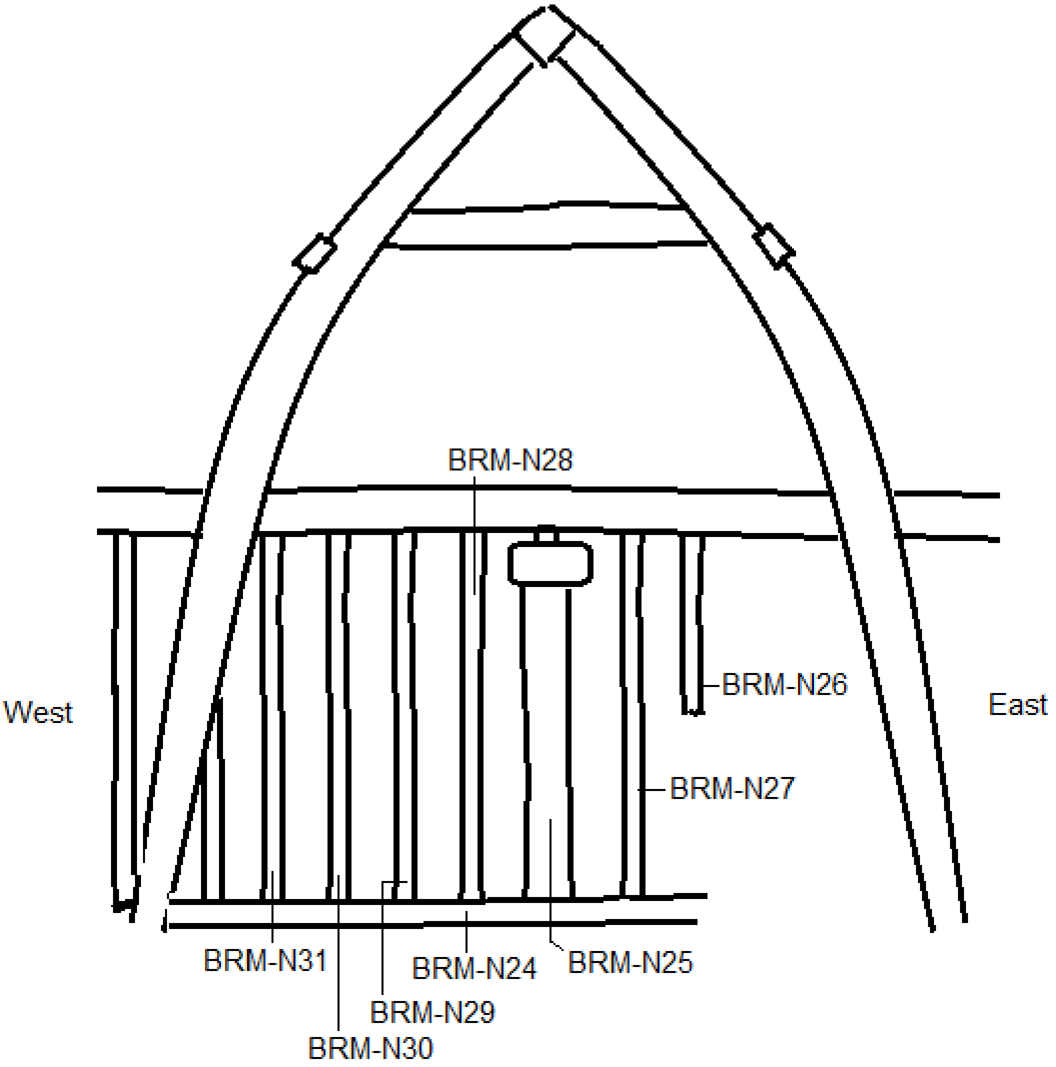

Figure 9: Sketch of the partition wall, showing the location of sampled timbers BRM-N24–31

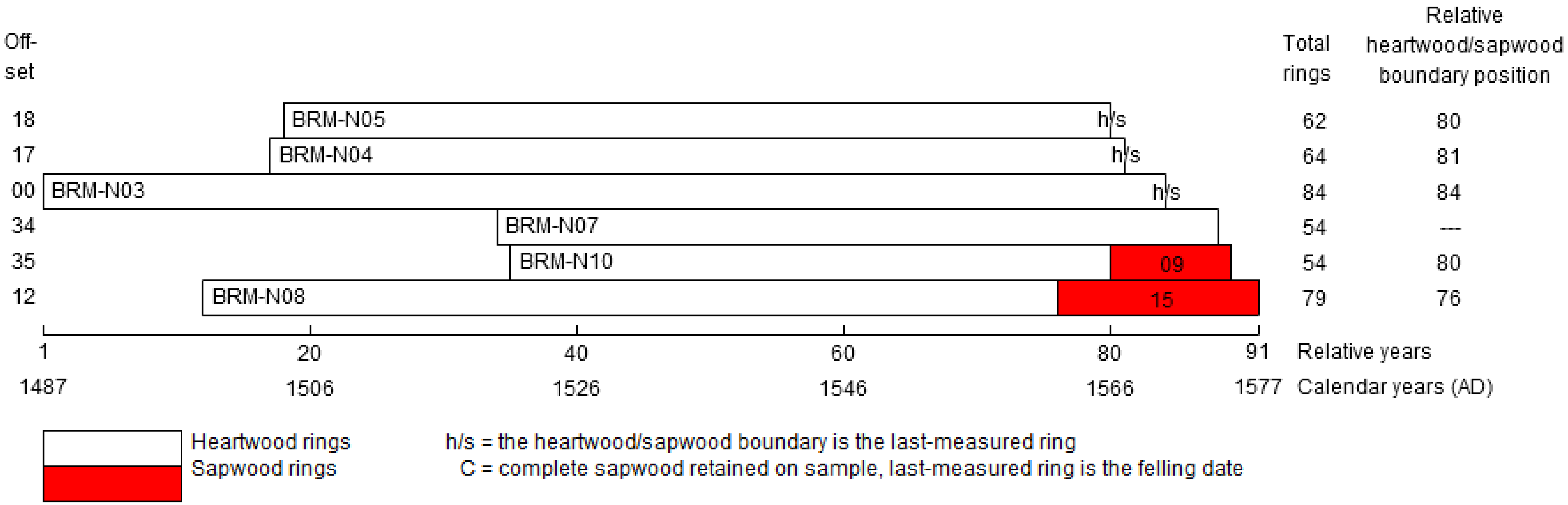

Figure 10: Bar diagram to show the relative position of samples in site sequence BRMNSQ01

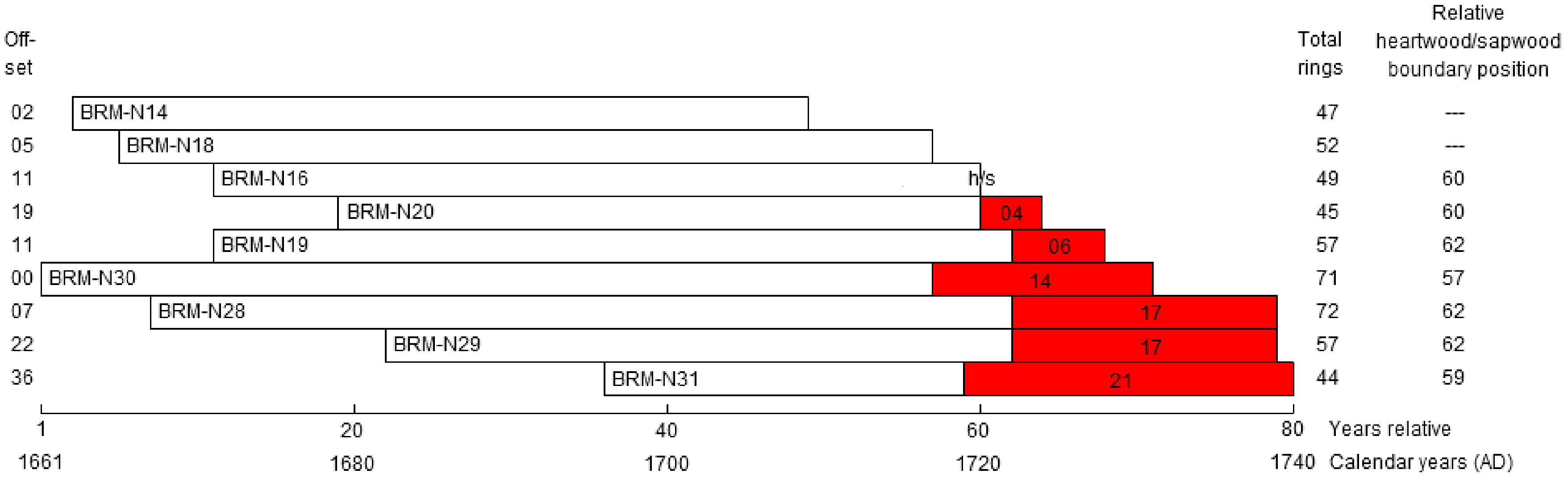

Figure 11: Bar diagram to show the relative position of samples in site sequence BRMNSQ02

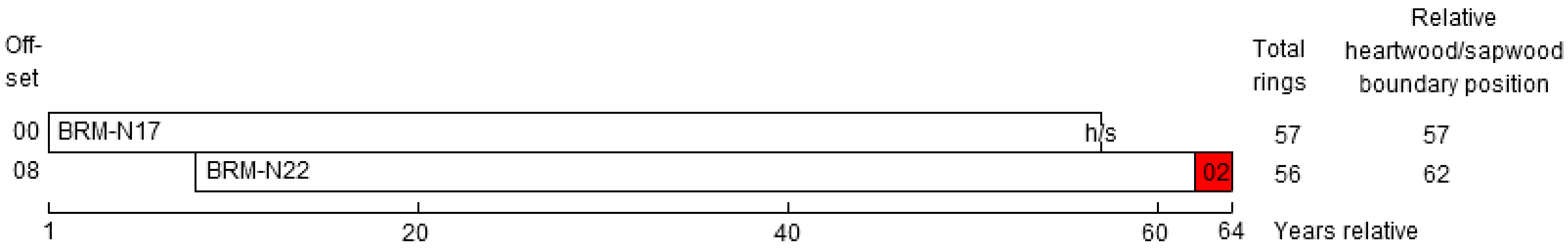

Figure 12: Bar diagram to show the relative position of samples in undated site sequence BRMNSQ03

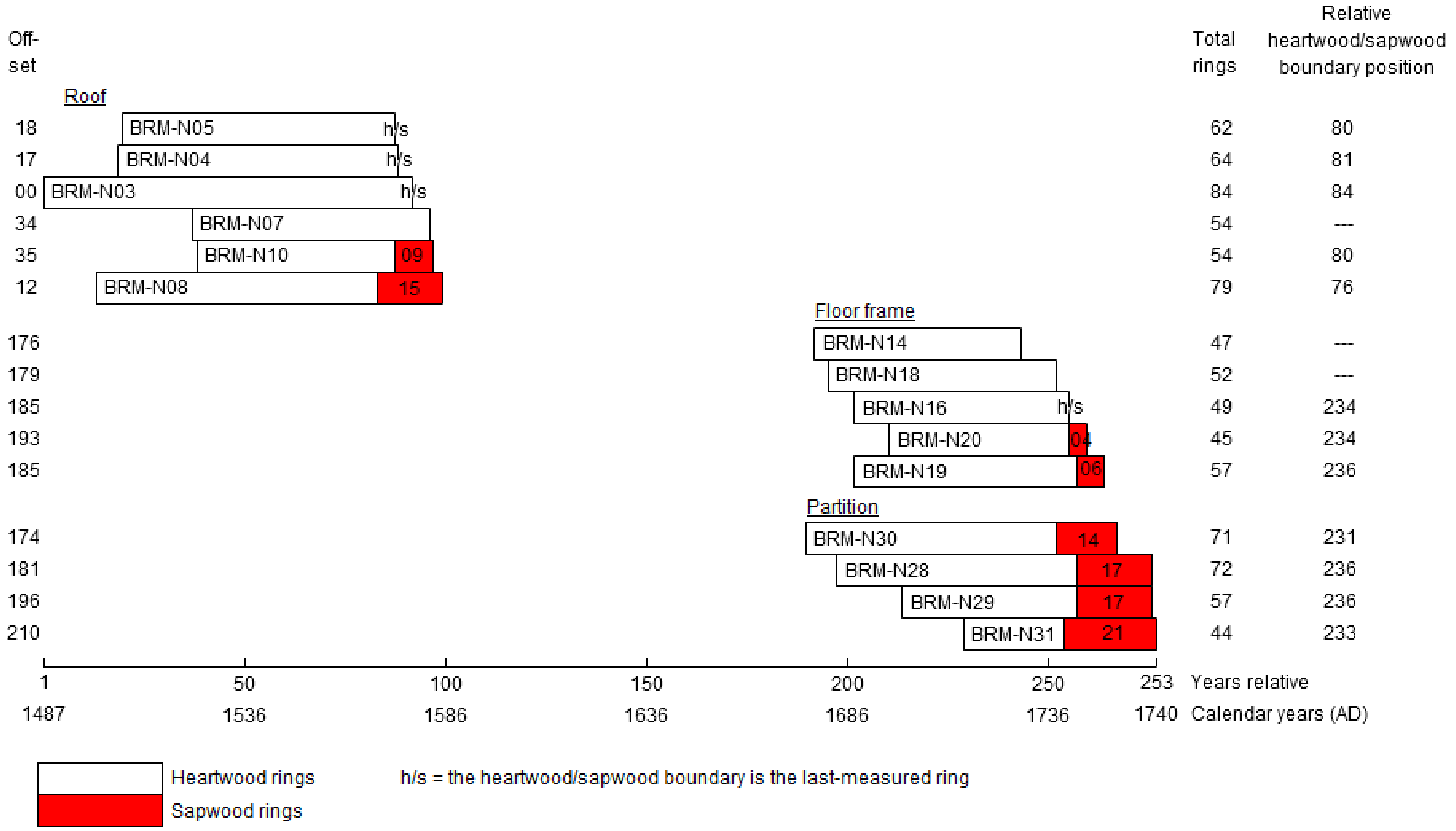

Figure 13: Bar diagram of dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

```
BRM-N01A 62
177 254 276 269 254 273 248 291 281 310 263 376 318 357 436 437 325 401 409 345
465 405 364 290 167 186 266 485 484 387 387 439 425 481 502 610 414 147 194 287
239 338 327 324 473 254 301 429 298 300 305 418 149 122 139 131 161 152 243 134
158 156
BRM-N01B 62
195 250 292 276 246 264 242 279 270 295 255 371 316 364 440 436 329 403 416 347
461 401 362 297 166 195 270 481 477 407 399 435 400 494 501 618 409 134 199 288
239 336 326 324 477 252 301 427 297 302 306 416 152 124 137 131 171 150 240 138
157 140
BRM-N02A 40
316 297 234 247 152 156 189 160 178 261 309 164 200 282 360 238 218 198 143 156
140 107  87  89 135 274 409 523 474 361 272 275 288 309 395 371 396 353 329 339
BRM-N02B 40
297 304 372 232 138 171 201 169 184 267 307 147 189 270 357 267 227 191 142 156
133 104  86  91 134 274 410 508 432 360 276 286 289 310 387 372 391 360 339 302
BRM-N03A 84
296 292 255 193 145 166  74  53 169 201 157 190 392 373 224 265 362 296 319 278
152 214 337 343 407 256 259 223 220 280 259 387 330 303 331 421 292 332 195 452
303 330 245 245 368 311 291 310 298 434 375 282 271 323 214 288 319 266 357 221
172 290 255 302 245 260 216 228 224 173 136 135 260 233 242 207 331 310 227  91
 62  94 107 114
BRM-N03B 84
290 293 255 208 132 189  94  63 171 228 161 202 391 375 227 266 358 329 351 308
182 216 339 343 400 285 292 235 231 278 255 371 351 297 335 417 285 323 197 455
305 335 250 250 355 309 291 311 304 434 370 297 279 328 217 290 318 269 357 218
176 285 261 299 249 260 215 226 227 177 136 134 264 232 245 206 331 298 241  88
 76  86 105 112
BRM-N04A 64
465 324 260 250 259 362 315 357 346 401 468 327 359 400 464 460 362 451 415 346
388 349 394 317 365 429 287 370 364 275 298 321 290 314 312 261 342 276 257 244
161 212 198 168 247 279 207 248 191 128 191 179 134  97 109 132 191 171 186 201
210 132 118 113
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465 323 255 253 254 364 328 352 346 399 482 330 354 397 466 464 358 452 417 338
401 360 376 310 369 419 286 372 378 285 294 319 279 334 312 270 351 269 260 235
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213 125 122 114
BRM-N05A 62
122 167 168 180 284 211 180 238 389 177 309 160 344 325 235 133 156 138 129 139
 99 105 133 122 118 121 145 157 151 192 161 288 255 427 191 182 178 142 117 156
201 138 152 167 107  78  71  72  59  76  91  71  56  53 156 141 134 105 118  98
 60 103
BRM-N05B 62
117 105 154 208 284 213 219 239 379 178 300 161 325 319 270 134 161 135 133 138
 98 101 119 117 114 112 128 158 148 193 163 283 264 434 195 177 186 148 116 155
206 132 164 154 127  78  69  76  66  68 102  72  51  63 157 146 118 108 108  97
 71  96
BRM-N06A 56
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186 317 357 366 285 237 259 253 254 253 256 275 271 245 279 256 262 286 267 221
162 237 174 163 235 139 105  78  73  74  66  64  68  85 107 119 140  94 102 125
114  62  51  68  58  88  93  75  78 115 125 114 140 110  94  50
BRM-N06B 56
182 323 359 365 286 242 272 243 261 266 264 269 270 241 281 255 262 283 266 220
165 235 176 152 226 151  95  88  67  78  67  64  70  86 108 121 141  93 100 126
116  63  51  70  67  98  85  99  79 127 130 112 143 109  91  57
BRM-N07A 54
290 217 260 269 243 230 237 244 182 158 233 288 233 230 264 278 238 236 200 273
312 252 317 265 305 209 227 235 190 223 288 169 167 168 183 144 102  98 538 720
834 754 634 584 478 382 373 365 536 623 740 490 415 376
BRM-N07B 54
223 221 269 240 236 236 246 248 203 161 218 293 226 238 280 268 257 245 207 273
314 261 323 279 312 211 220 248 186 207 305 192 175 153 207 149 103  98 555 677
806 752 644 564 467 372 368 360 535 606 723 492 406 367
BRM-N08A 79
298 264 270 281 285 261 323 306 281 280 352 252 262 236 218 214 231 246 247 284
298 245 312 293 276 247 264 288 331 322 301 136 145 114 117 104 118 123 115 152
182 202 327 190 237 254 333 186 110 135 150 140 144 168 165 200 206 189 143 120
152 172 180 175 179 178 150 110  81  69  83  95 103 115 108 141 150 126 133
BRM-N08B 79
299 263 277 278 288 243 316 307 293 292 354 248 263 236 221 221 214 248 252 279
303 255 315 303 284 262 277 287 339 314 302 123 137 106 118  99 126 136 123 156
204 230 336 184 223 257 327 199 123 151 145 143 136 162 164 203 191 185 145 125
156 171 174 192 187 164 163 110  78  69  78  93 104 109 109 132 134 131 136
BRM-N09A 61
454 360 465 401 520 503 418 509 337 570 467 457 295 428 318 385 430 499 469 350
338 293 192 180 145 113 101  85  77  61  52  71  95  80  91  81 107 106  76  90
103 105 121 149 113 136  87 131  81  54 126  86 111 109  81 105  72  89  91 111
 83
BRM-N09B 61
477 369 484 421 527 518 429 515 335 586 465 461 299 433 304 410 428 511 475 363
338 292 210 208 159 128 103  77  95  58  61  65 100  83  88  84 105  99  74  92
100 105 121 145 116 135  85 129  86  51 128  82 104 118  78  95  74  90  87 109
 99
BRM-N10A 54
157 169 220 265 244 183 202 337 241 295 314 243 249 237 360 419 378 268 421 300
258 312 269 277 272 202 262 285 166 209 196 168 236 207 111  82  86  73  86  88
122 110 143  59  63  64  87 103 107  73  79 109  98  68
BRM-N10B 54
159 166 229 265 243 184 206 333 246 289 314 238 247 240 361 406 386 270 420 301
253 303 280 288 264 202 255 285 184 214 191 170 236 203 104  77 101  83  89  87
123 112 135  58  69  66  84  97 104  75  81 104 100  70
BRM-N11A 49
299 484 465 399 234 209 291 364 395 386 324 254 444 395 318 275 333 200 230 287
388 278 227 207 235 266 162 225 155 192 199 201 128 185 186 147 104 105 204 185
130 165 126 154 163 158 151 213 152
BRM-N11B 49
305 499 460 406 235 196 302 317 393 383 337 266 437 402 311 268 326 195 230 290
385 283 232 222 230 267 153 225 154 193 187 188 135 178 184 134 110 116 200 184
134 165 119 157 166 168 168 156 196
BRM-N13A 60
195  98 138 134 111 136 364 219 348 478 222 440 485 408 301 405 420 490 499 394
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355 132 154 175 156 146 126 155 112  91 130 168 252 330 297 411 365 333 156 190
218 317 195 163 149 189 154 176 127 155 166 225 217 268 195 250 300 245 173 163
BRM-N13B 60
195  98 146 133 115 135 363 216 366 461 217 446 485 404 298 421 438 500 505 390
349 131 164 186 175 143 125 160 118  97 136 157 245 345 301 439 379 328 155 189
217 316 198 158 150 184 162 167 126 157 171 220 221 271 185 270 304 206 162 164
BRM-N14A 47
315 387 114 149 269 401 290 258 212 174  79 116  86  78  81  69  78 123  97 374
181 136  66 111 237 166 135  72 196 132 199 165 170 122  86  97  66  63  80 120
176 220 140 204 188 330 294
BRM-N14B 47
459 380 266 195 319 365 259 215 194 161  75 108  81  84 173 211 295 226 142 387
176 128  55 113 243 175 128  70 189 132 206 168 178 135  82  99  68  57  84 125
186 215 147 196 192 327 301
BRM-N16A 49
557 442 286 253 235 416 364 346 280 229 348 197 219  95  98 206 281 254 123 231
193 219 166 148 124  97 166 110 112 159 205 221 252 177 215 227 256 246 174 264
294 303 198 193 232 333 343 216 298
BRM-N16B 49
642 442 294 256 271 424 360 350 281 229 360 184 197  95 101 206 258 216 117 228
190 193 156 129 102  97 147 104 108 158 214 236 260 175 213 229 258 248 195 237
295 305 198 195 227 328 354 212 298
BRM-N17A 57
343 247 138 115 199 230 236 267 234 166 130 107  86  66 104 128 241 260 265 427
261 321 151 137 159 188 199 137 133  99 104 101  84  86  66  74  47  38  33  25
 24  33  43  78  64  79  48  54  58 109 114 156  99  78  86 101  71
BRM-N17B 57
361 241  98 126 191 210 250 269 214 199 130 112  81  75  95 131 208 230 252 387
257 318 152 142 151 184 191 145 149 107 108  99  85  84  65  73  48  39  32  25
 31  30  45  75  62  79  51  46  62 108 118 147 102  78  84 103  69
BRM-N18A 52
230 310 215 163 183 331 168 133 138  91 104 141 193 249 199 153 339 180 156 190
217 209 195 222 172 147 115 179 193 199 180 158 127  95  57  88 111 154 187 142
154 149 169 212 123 152 188 214 179 168 180 188
BRM-N18B 52
217 309 214 167 185 351 166 139 146  81 106 146 187 247 200 154 329 186 170 203
239 206 210 213 169 152 125 162 213 207 185 167 129  92  53  85 121 150 190 121
131 139 158 222 130 142 203 214 183 160 177 182
BRM-N19A 57
370 571 309 191 170 252 262 250 231 184 256 171 184 104 103 186 189 209 125 165
125 146 134 132 112  73 102  74  82 121 175 218 256 156 207 212 252 287 146 235
262 326 202 179 216 286 252 182 266 297 278 157 155 156 146 193 157
BRM-N19B 57
353 574 365 190 168 249 262 246 232 187 252 170 177 109 103 183 185 213 127 163
130 141 134 131 114  76 106  79  78 139 177 215 248 156 193 212 248 279 161 230
273 326 214 182 217 278 248 164 262 301 280 154 156 152 151 192 157
BRM-N20A 45
486 401 461 282 290 268 372 354 371 367 245 269 230 273 261 273 278 212 200 152
102  89  96 142 158 109 141 141 152 194 137 175 176 237 174 162 189 200 175 121
 98 113 137 123 149
BRM-N20B 45
491 400 479 285 291 287 355 360 368 371 253 272 237 271 268 277 277 221 195 151
 60  87  92 142 162 109 148 141 157 196 135 176 181 238 178 160 194 208 185 129
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106 110 149 114 167
BRM-N22A  56
369 262 206 187 142  90 165 300 319 408 357 413 274 310 139 157 139 208 250 157
193 124 153 151 106  92  72  66  38  34  32  27  48  48  71 108  99 107  74
 79  76 172 199 145 104  95  90  73  94 145  87  73  66  67  86 119
BRM-N22B 56
350 254 208 188 142  84 185 294 323 413 351 421 273 304 134 149 144 201 259 159
185 130 150 156 110  76  68  63  44  35  34  30  33  47  73  84  83 102  65
 66  77 160 202 134 107  90  92  75 112 142  97  65  60  73  94 126
BRM-N24A 56
249 265 519 499 424 454 200 239 396 300 413 271 260 287 488 341 373 275 332 320
344 257 270 342 326 374 427 423 273 129 160 160 117 122 139 140 215 221 195 161
202 112 165 177 144 127 113  88 127 136 124  96  96  81  77  78
BRM-N24B 56
285 245 537 486 427 454 198 248 342 312 403 281 255 305 497 338 373 273 346 331
338 276 265 363 308 412 466 419 258 127 168 173 126 131 136 148 231 217 202 137
207 100 175 173 144 136 103  80 139 138 120 103  95  79  72 102
BRM-N25A 59
361 363 300 231 394 450 403 260 346 130 199 259 218 280 257 263 138 221 285 217
176 200 138 192 188 230 171 130 191 199 254 170 286 192 298 289 284 221 407 262
287 323 243 195 277 239 353 357 308 410 297 440 388 204 239 277 298 183 223
BRM-N25B 59
332 303 286 273 390 455 345 268 361 126 200 261 229 292 257 260 136 211 259 214
189 208 141 214 193 229 169 130 190 208 249 170 288 194 298 282 286 224 399 271
288 313 246 208 278 236 348 364 297 457 318 465 343 204 236 266 308 197 218
BRM-N28A 72
129 107 124 118 103 113  71  70  75 109  86  85 107  76 118 110 116  98 113  95
112 122  85  96  91 109 123 103 114 120 150 109  78 108 106  98 101  67  74  60
 75  75  59  74 106 114  96 115 154 172 145 165 173 166 154 127 126 137 171 168
172 184 168 154 156 179 197 181 185 129 127 147
BRM-N28B 72
143 115 125 117  94 110  79  68  62 113  77  87 111  67 124 114 112 100 102 101
112 122  84  96  95  98 125 100 115 120 147 115  77 102 108 100 101  61  72  62
 71  75  60  69 108 115  90 112 152 171 150 156 167 166 144 130 129 141 173 162
173 182 170 148 159 171 203 172 199 122 119 149
BRM-N29A 57
179 196 259 221 158 165 239 210 228 196 150 166 181 230 146 162 128  79  94  74
 83 108  61  77  57  67  82  73  89 125 144 142 165 157 170 138 140 133 170 186
183 213 193 152 181 170 192 233 241 250 240 324 334 232 186 224 218
BRM-N29B 57
184 203 256 217 162 164 243 218 218 197 147 169 180 216 165 160 126  76  93  66
 91 104  64  70  63  73  84  68  86 126 145 146 159 163 168 135 149 131 179 185
189 219 215 148 181 170 202 230 242 252 238 329 338 236 179 230 207
BRM-N30A 71
218 339 343 296 267 249 190 158 134 111 144 117 116 136 110  95 123 135 145 195
155 198 256 240 199 200 151 144 158 127 127 101 108 137 106 124 139 111  74  73
 73  63 101  98  69  78  75 110 132  80  90 128 150  94 156 162 183 136 156 151
178 169 145 137 146 140 141 145 153 172 156
BRM-N30B 71
232 338 346 295 270 236 204 137 123 101 126 123 126 116 109  85 131 118 123 191
156 167 213 212 173 189 136 146 157 121 125 105 116 135  99 119 140 112  70  62
 86  63 102  91  68  81  74 104 131  84  91 143 179 111 148 162 183 135 157 150
178 167 150 130 143 152 138 150 153 168 156
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BRM-N31A 44
191 223 148 132 129 110 124 119  73  90  77  83  84  79  78 136 167 124 118 143
148 126 131 165 184 171 172 158 168 146 140 148 148 164 174 157 182 228 174 125
102 107  89 111
BRM-N31B 44
190 230 167 129 123 113 133 113  73  90  81  72  91  75  82 135 164 129 111 145
149 120 141 142 179 173 165 160 167 147 129 134 161 197 185 179 176 234 174 122
114  98 108 112
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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

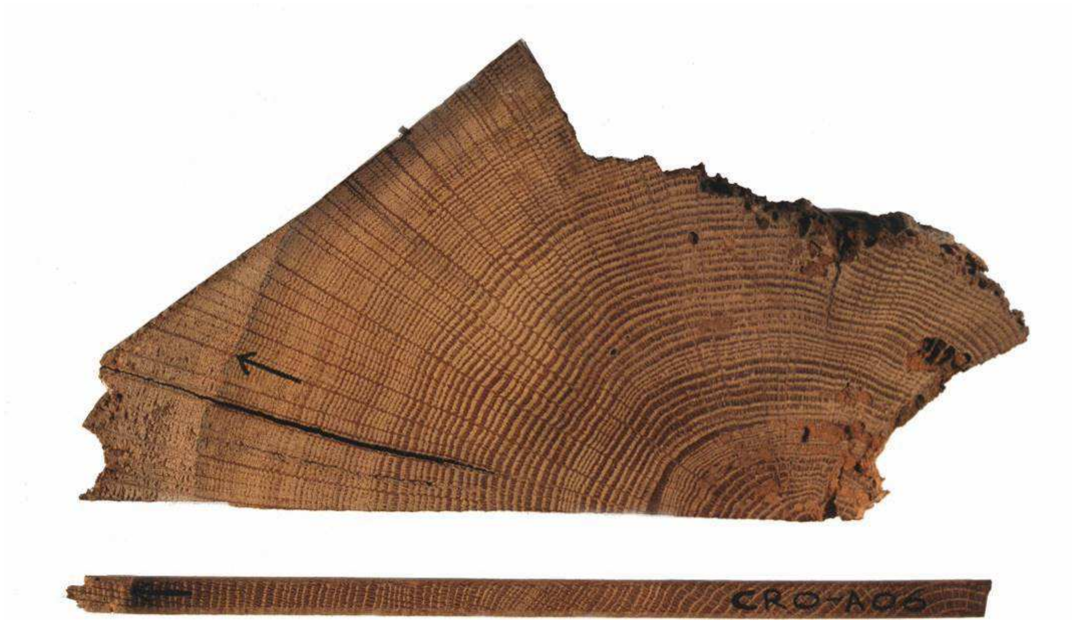


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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 Figure A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

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

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

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

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

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

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form

they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

Bar Diagram

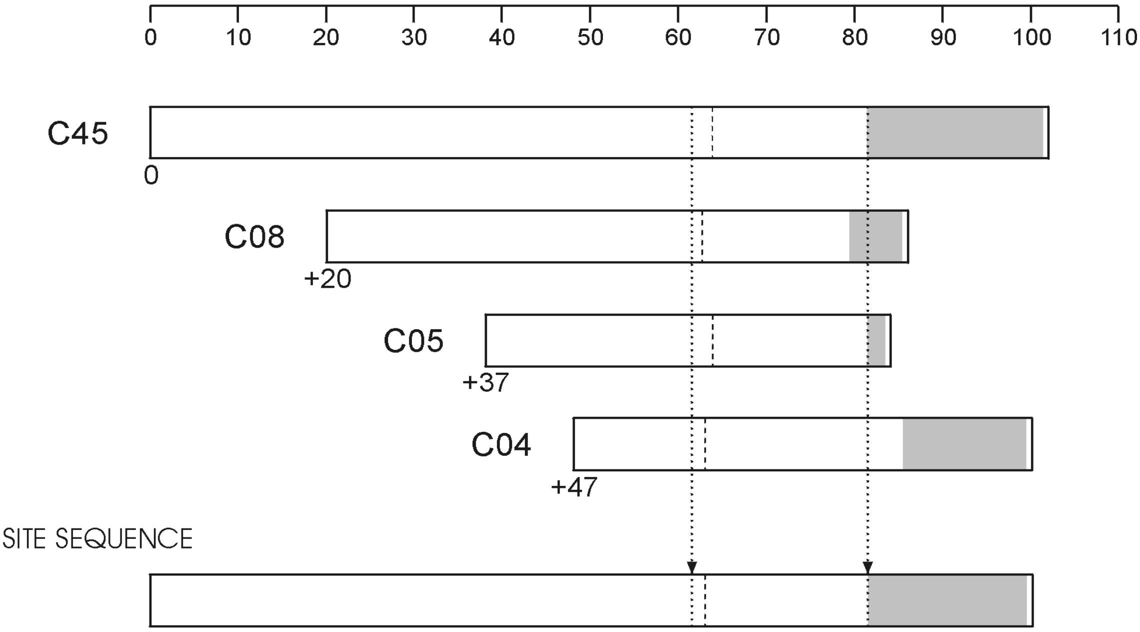


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

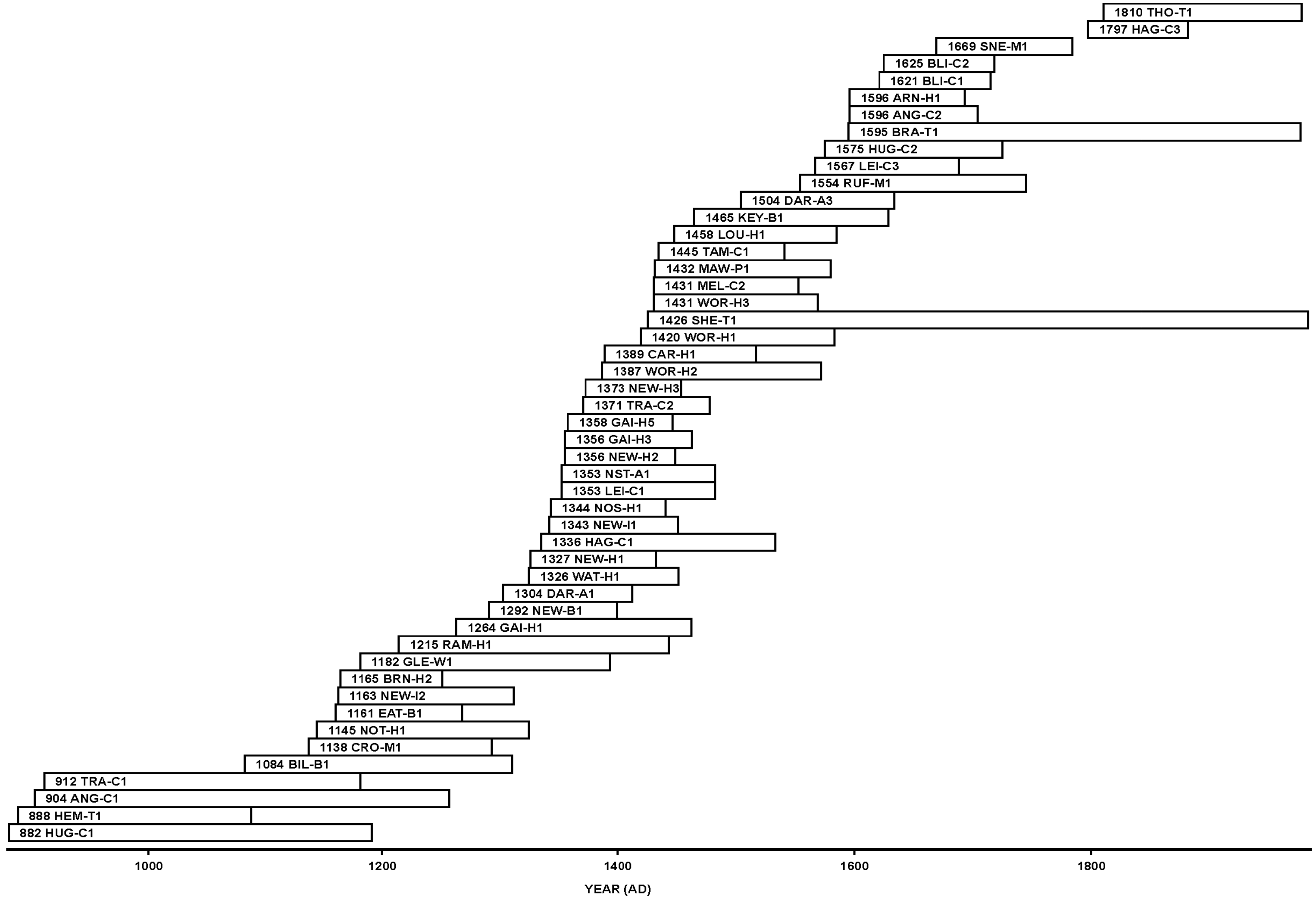
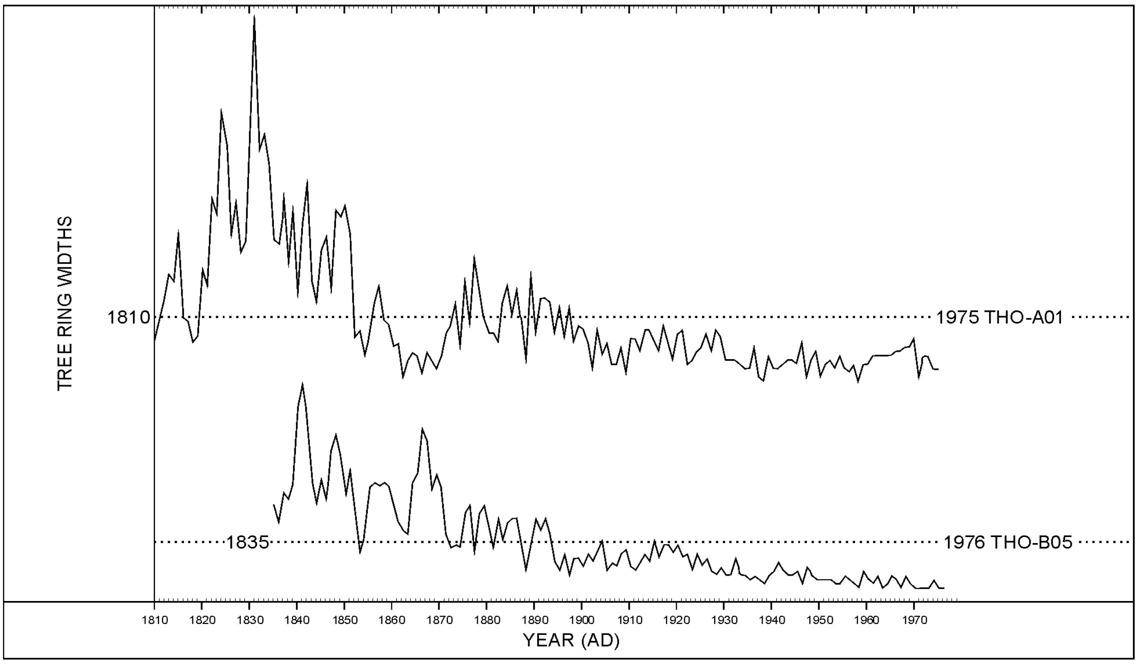


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

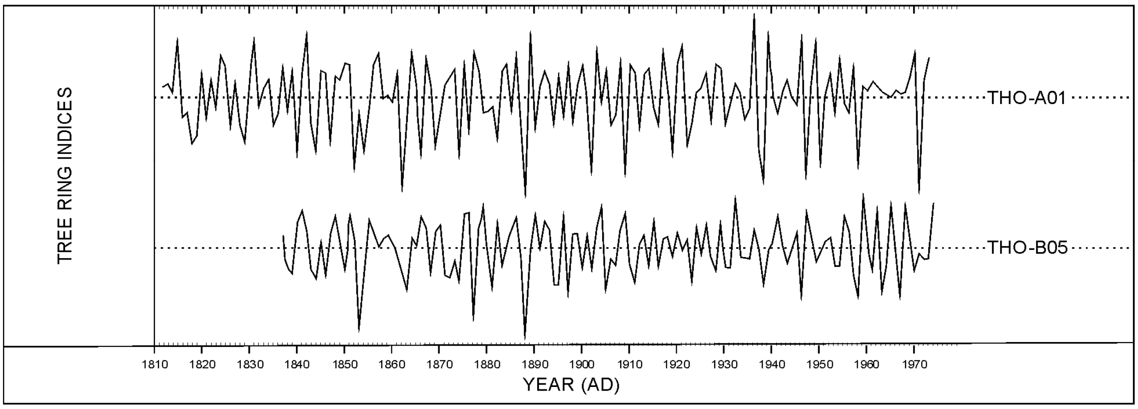


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely.

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