RESEARCH REPORT SERIES no. 65-2014

MANOR FARMHOUSE, SOUTH WRAXALL, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Cathy Tyers, Matt Hurford and Martin Bridge

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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NGR: ST 83453 65603

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)

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SUMMARY

Dendrochronological analysis was undertaken on 10 of the 18 samples taken from the hall range and cross-wing roofs at Manor Farmhouse. This resulted in the production of a single site sequence, SWMFSQ01, which comprises six samples with an overall length of 126 rings dating to the years AD 1151–1276. A single sample, SWM-F12, with an overall length of 66 rings was dated to AD 1234–99. The results suggest that the three dated samples from the hall range roof were all probably felled in AD 1300–19, whilst the four dated samples from the cross-wing roof were all probably felled in AD 1291–1316, thus these two roofs appear broadly coeval.

CONTRIBUTORS

Cathy Tyers, Matt Hurford, and Martin Bridge

ACKNOWLEDGEMENTS

We would like to thank Mr Louden, the manager of the South Wraxall Estate for giving permission to undertake the work and the tenants Mr and Mrs Bly for their support of the project. Thanks are also due to Avis Lloyd for arranging access and for supplying additional background material on the building. The dendrochronological work was funded by the English Heritage Scientific Dating Team and coordinated by Peter Marshall.

ARCHIVE LOCATION

Wiltshire and Swindon HER
Wiltshire Archaeological Service
The Wiltshire and Swindon History Centre
Cocklebury Road
Chippenham SN15 3QN

DATE OF INVESTIGATION

2009–10

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INTRODUCTION

In 2009 the Wiltshire Buildings Record (WBR) successfully obtained support through the English Heritage Historic Environment Enabling Programme for their project 'Wiltshire cruck buildings and other archaic roof types'. The detailed aims and objectives of the project are set out in the Project Design (Lloyd 2009). The overall aim was to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This would then facilitate detailed comparison with other counties allowing Wiltshire to be placed in a regional context. Investigation of these late medieval buildings (*c* AD 1200–*c* AD 1550) combined building survey, historical research, and dendrochronological analysis.

A series of 25 buildings identified by the WBR as having the potential to contribute to the aims and objectives of the project was assessed for dendrochronological suitability during 2009. In order to maximise the potential for dating, these detailed dendrochronological assessments and the WBR assessments of the significance of each building informed the final selection of buildings subsequently subjected to detailed study.

A single final Project Report produced by Lloyd (2012) summarises the overall results. However, each building included in the project has an associated individual report on the structural analysis produced by the WBR, whilst the primary archive of the dendrochronological analysis is the English Heritage Research Report Series.

A brief introduction to dendrochronology can be found in the Appendix. However further details can be found in the guidelines published by English Heritage (1998), which are also available on the English Heritage website (http://www.english-heritage.org.uk/publications/dendrochronology-guidelines/).

Manor Farmhouse

This Grade 1 listed building is located just to the north of the village of South Wraxall, to the north-east of the Manor House (Figs 1 and 2). The following information is summarised from the WBR report (2012) and the listed building entry (http://lbonline.english-heritage.org.uk).

Manor Farmhouse is believed to be on the site of the chapel of St Audoen (St Ouen), which is thought to have included a *hospitium*. It was part of the Manor of Bradford and held by the Cluniac priory at Monkton Farleigh. The extant ranges form a T-shaped plan, with the hall range orientated on an east-west axis and the cross-wing on a north-south axis (Fig 3). Both ranges are built of limestone rubble with stone quoins and buttresses, under a limestone slate roof, and are thought to be broadly coeval even though they have different roof types (see below). Stylistically there are features in both ranges that suggest a very early fourteenth-century construction date, although the foundation document for the *hospitium* is dated 1267.

The cross-wing roof comprises three crown post trusses with collar purlin (Fig 4). The crown posts are unmoulded, square, and slender and rise from a tiebeam to the crown plate. There is only two-way bracing to the crown plate and crown post. The braces are roughly chamfered. The hall range roof consists of three arch-braced trusses with cranked tiebeams and curved wind bracing to the lower tier of purlins (Fig 5). The roof timbers are clearly smoke-blackened in this range.

SAMPLING

Dendrochronological sampling and analysis of oak (*Quercus* spp) timbers associated with the primary roofs of the hall range and cross-wing was commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of these elements and hence inform the overall objectives of the 'Wiltshire cruck buildings and other archaic roof types' project. The dendrochronological study also formed a key component of the English Heritage-funded training programme for the second author, although the reporting was not completed within the duration of the training programme.

Sampling was undertaken by trainee Matt Hurford and supervised by Martin Bridge. A total of 18 oak timbers were sampled by coring, ten from the cross-wing roof and eight from the hall range roof. Each sample was given the code SWM-F (for South Wraxall Manor Farmhouse) and numbered 01–18. The sampling encompassed as wide a range of elements as possible, whilst focussing on those timbers with the best dendrochronological potential. Thus, no samples were taken from bay 2 of the cross-wing as the timbers all appeared to be derived from fast-grown trees and were considered highly unlikely to provide samples with sufficient numbers of rings for reliable dendrochronological analysis. The majority of the timbers in the hall range roof, including all the arch braces, common rafters, and the upper purlins, were also fast grown and hence considered unsuitable for dendrochronological analysis. In addition sampling was hampered in the hall range by an unsafe floor in the south area of bay 1.

The crown-post trusses in the cross-wing were numbered 1–3 from north to south following the medieval carpenters marks found on the crown posts, whereas those in the hall range were labelled A–C from the east to the west. The location of the samples was noted and marked on sketch drawings made at the time of coring. No formal plans or drawings subsequently became available so these sketches have formed the basis of the sample location drawings (Figs 6–11). Further details relating to the samples can be found in Table 1. In this table the timbers have been located and numbered following the scheme on the drawings provided.

ANALYSIS AND RESULTS

Each of the 18 samples obtained was prepared by sanding and polishing. The overall borderline nature of the material was highlighted at this point as eight of the samples had too few rings for reliable dating, and were therefore rejected from this programme of analysis. The annual growth rings of the remaining 10 samples were measured, the data of these measurements being given at the end of this report. The measurement and analysis was undertaken using a combination of the Litton/Zainodin grouping procedure (see Appendix) and software written by Tyers (2004). Tyers (ibid) facilitates cross-matching and dating through a process of qualified statistical comparison and visual comparison. It uses a variant of the Belfast CROS programme (Baillie and Pilcher 1973).

Initial analysis resulted in a group of five samples being formed (Table 2). During this analytical process a possible match to this group of five samples was noted for SWM-F14. This was confirmed by the dating evidence obtained for this individual sample when it was compared to an extensive range of reference chronologies for oak (Table 3). SWM-F14 was therefore combined with the five other grouped series at the indicated offsets to form site chronology SWMFSQ01, this having an overall length of 126 rings (Fig 12). The dating evidence for site chronology SWMFSQ01 when the date of the first ring is AD 1151 and the date of its last ring is AD 1276 is presented in Table 4.

Site chronology SWMFSQ01 was also compared with the remaining four ungrouped samples but there was no further satisfactory cross-matching. The four ungrouped samples were then compared individually with the reference chronologies, this indicating repeated cross-matching and dating for one of them, SWM-F12, when its 66 rings span AD 1234–99 (Table 5).

This analysis can be summarised as follows:

Site chronology/sample	Number of samples	Number of rings	Date span (where dated)
SWMFSQ01	6	126	AD 1151–1276
SWM-F12	1	66	AD 1234–99
	3	---	ungrouped
	8	---	unmeasured

INTERPRETATION

For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings within this project is the Nottingham Tree-Ring Dating Laboratory estimate of 15–40 (95% confidence rings). This is used to calculate felling date ranges for samples with incomplete sapwood or felled-after dates for samples which are heartwood only.

Cross-wing

The four dated timbers from the cross-wing roof comprise three common rafters and a crown post (Fig 12; Table 1). One of the samples, SWM-F07, retains the heartwood/sapwood boundary and has a felling date range of AD 1291–1316. The remaining three samples have no trace of sapwood but appear broadly coeval. It seems likely that these three timbers may also have been felled in the late-thirteenth or early fourteenth century.

Hall range

The three dated timbers from the hall range are all principal rafters (Fig 12; Table 1). One of these, SWM-F12, has retained some sapwood and hence an estimated felling date range of AD 1300–19 can be obtained. There is no trace of sapwood on the remaining two samples and it was noted during sampling that these timbers appeared to have been heavily trimmed. Thus, whilst it cannot be proven, it appears likely that these two timbers are coeval with SWM-F12 and hence also probably felled in the early fourteenth century.

DISCUSSION AND CONCLUSION

Although there are relatively few timbers dated from either roof, the dendrochronological evidence suggests that the hall range and cross-wing roofs are broadly coeval. The timbers from the cross-wing roof suggest a late thirteenth- or early fourteenth-century construction date, whilst those from the hall range roof suggest an early fourteenth-century date, assuming that the dated timbers are associated with the primary construction. In the absence of bark edge and the lack of any same-tree links between timbers in the two roofs, it is not possible to determine whether they are likely to be of precisely the same date. Whilst restricted in the extent of dated timbers, the dendrochronological results do support the early fourteenth-century date suggested on stylistic evidence.

Site chronology SWMFSQ01and the individually dated sample, SWM-F12, generally produce the highest *t*-values, and thus show the greatest degree of similarity, with reference chronologies from the surrounding areas (Tables 4 and 5) suggesting that it is likely that these timbers are probably of local origin. However, the lack of similarity between SWMFSQ01 and SWM-F12 suggests that there may be more than one source of woodland utilised which is perhaps unsurprising bearing in mind the monastic associations. The unsuitability of much of the timber within both ranges for dendrochronological analysis appears likely to be due to a combination of the use of relatively fast-grown young trees and heavy trimming during conversion into the appropriate timber element.

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TABLES

Table 1: Details of tree-ring samples from Manor Farmhouse, South Wraxall, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Cross-wing roof								
SWM-F01	Bay 1, east common rafter 1	57	--	2.36	120x120	----	----	----
SWM-F02	Bay 1, east common rafter 3	nm	--	--	140x???	----	----	----
SWM-F03	Truss 1, tie beam	nm	--	--	200x170	----	----	----
SWM-F04	Truss 2, tie beam	nm	--	--	200x200	----	----	----
SWM-F05	Bay 3, west common rafter 1	60	--	1.63	120x120	1179	----	1238
SWM-F06	Bay 3, collar 04	50	h/s	1.94	80x100	----	----	----
SWM-F07	Bay 3, west common rafter 5	57	h/s	1.91	90x130	1220	1276	1276
SWM-F08	Truss 3, crown post	70	--	1.33	130x170	1196	----	1265
SWM-F09	Bay 4, west common rafter 4	63	--	1.90	110x120	1199	----	1261
SWM-F10	Bay 4, east common rafter 3	nm	--	--	110x120	----	----	----
Hall range roof								
SWM-F11	Bay 1, north lower purlin	55	--	2.91	220x220	----	----	----
SWM-F12	Truss A, north principal	66	20	1.99	120x190	1234	1279	1299
SWM-F13	Bay 2, north west windbrace	nm	--	--	140x200	----	----	----
SWM-F14	Truss B, north principal	77	--	1.55	220x300	1151	----	1227
SWM-F15	Bay 3, north east windbrace	nm	--	--	130x250	----	----	----
SWM-F16	Truss B, south principal	83	--	1.84	220x310	1170	----	1252
SWM-F17	Bay 3, south lower purlin	nm	--	--	220x224	----	----	----
SWM-F18	Truss C, north principal	nm	--	--	130x200	----	----	----

nm = not measured

h/s = the heartwood/sapwood boundary ring is the last ring on the sample

??? = the second dimension is not known as part of the timber lay behind modern wooden boards

Table 2: Cross-matching between the samples in site sequence SWMFSQ01; \ indicates an overlap of less than 30 years; - indicates t-values less than 3.00

	swm-f07	swm-f08	swm-f09	swm-f16	swm-f14
swm-f05	\	4.18	7.60	6.12	-
swm-f07		4.35	5.76	6.00	\
swm-f08			4.05	3.64	-
swm-f09				4.64	\
swm-f16					6.42

Table 3: Results of the cross-matching of site sequence SWM-F14 and relevant reference chronologies when the first-ring date is AD 1151 and the last-ring date is AD 1227

Reference chronology	t-value	Span of chronology	Reference
Place House, Bluecoat Yard, Ware, Hertfordshire	6.1	AD 1179–1316	Howard *et al* 1997
Garnivals Week, Milverton, Somerset	5.7	AD 1166–1286	Miles and Worthington 1997
Reading Waterfront, Berkshire	5.6	AD 1168–1407	Groves *et al* 1997
Doulting Barn, Somerset	5.5	AD 1154–1287	Miles and Worthington 2000
Spire and Tower, Salisbury Cathedral, Wiltshire	5.4	AD 1053–1241	Miles *et al* 2004
Manor Farmhouse, Meare, Somerset	5.4	AD 1156–1314	Bridge 2002
Tudor House, Steventon, Oxfordshire	5.0	AD 1164–1284	Miles and Bridge 2010
Court Farm Barn, Winterbourne, Gloucestershire	4.8	AD 1177–1341	Miles 2001

Table 4: Results of the cross-matching of site sequence SWMFSQ01 and relevant reference chronologies when the first-ring date is AD 1151 and the last-ring date is AD 1276

Reference chronology	*t*-value	Span of chronology	Reference
Manor Barn, Avebury, Wiltshire	6.6	AD 1072–1278	Tyers 1999
Spire and Tower, Salisbury Cathedral, Wiltshire	6.5	AD 1053–1241	Miles *et al* 2004
124 High Street, Burford, Oxfordshire	6.1	AD 1202–1400	Miles *et al* 2006a
No 18, Wilsford, Wiltshire	5.8	AD 1182–1308	Miles and Worthington 2002
East Lynch Cottage, Selworthy, Somerset	5.8	AD 1157–1314	Miles and Worthington 1999
Tudor House, Steventon, Oxfordshire	5.7	AD 1164–1284	Miles and Bridge 2010
Polesworth Abbey Gatehouse, Warwickshire	5.0	AD 1095–1342	Arnold and Howard 2007
Shrewsbury Abbey precincts, Shropshire	5.0	AD 1174–1268	Groves 1988

Table 5: Results of the cross-matching of sample SWM-F12 and relevant reference chronologies when the first-ring date is AD 1234 and the last-ring date is AD 1299

Reference chronology	*t*-value	Span of chronology	Reference
Bury Barton, Lapford, Devon	6.3	AD 1132–1323	Groves 2005
Sandwell Priory, West Midlands	6.3	AD 1161–1323	Howard *et al* 1986
Thorne, Clannaborough, Devon	6.0	AD 1200–1319	Groves 2005
Rudge, Morchard Bishop, Devon	5.7	AD 1124–1315	Groves 2005
Burghope Manor, Wiltshire	5.6	AD 1191–1316	Miles *et al* 2006b
The Queen's Head, Crowmarsh Gifford, Oxfordshire	5.5	AD 1203–1341	Haddon-Reece *et al* 1989
King John's Hunting Lodge, Lacock, Wiltshire	5.5	AD 1148–1318	Hurford *et al* 2010
Manor Farmhouse, Meare, Somerset	5.3	AD 1156–1314	Bridge 2002

FIGURES

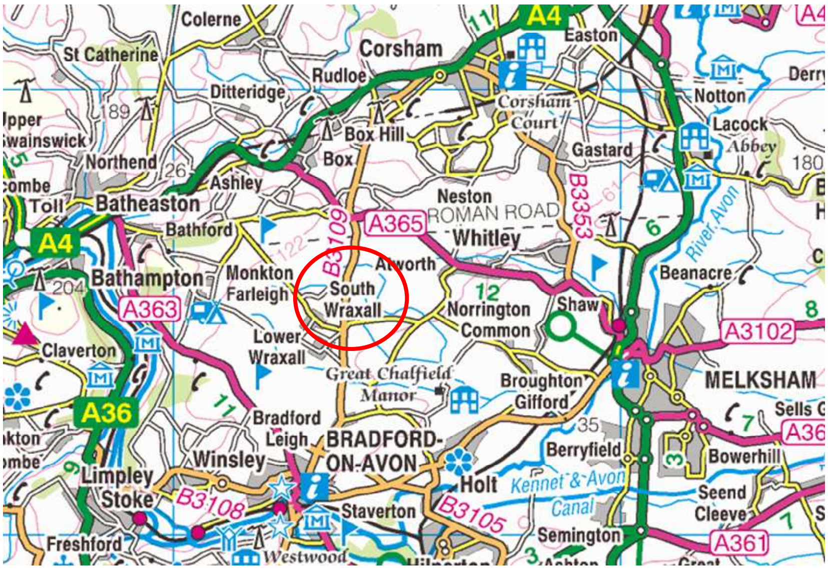

Figure 1: Map to show the location of South Wraxall, Wiltshire. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: Map to show the location of Manor Farmhouse within the farmyard at Manor Farm, South Wraxall. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: General view of the south elevation of Manor Farmhouse. Hall range to the left and cross-wing to the right (photo Matt Hurford)

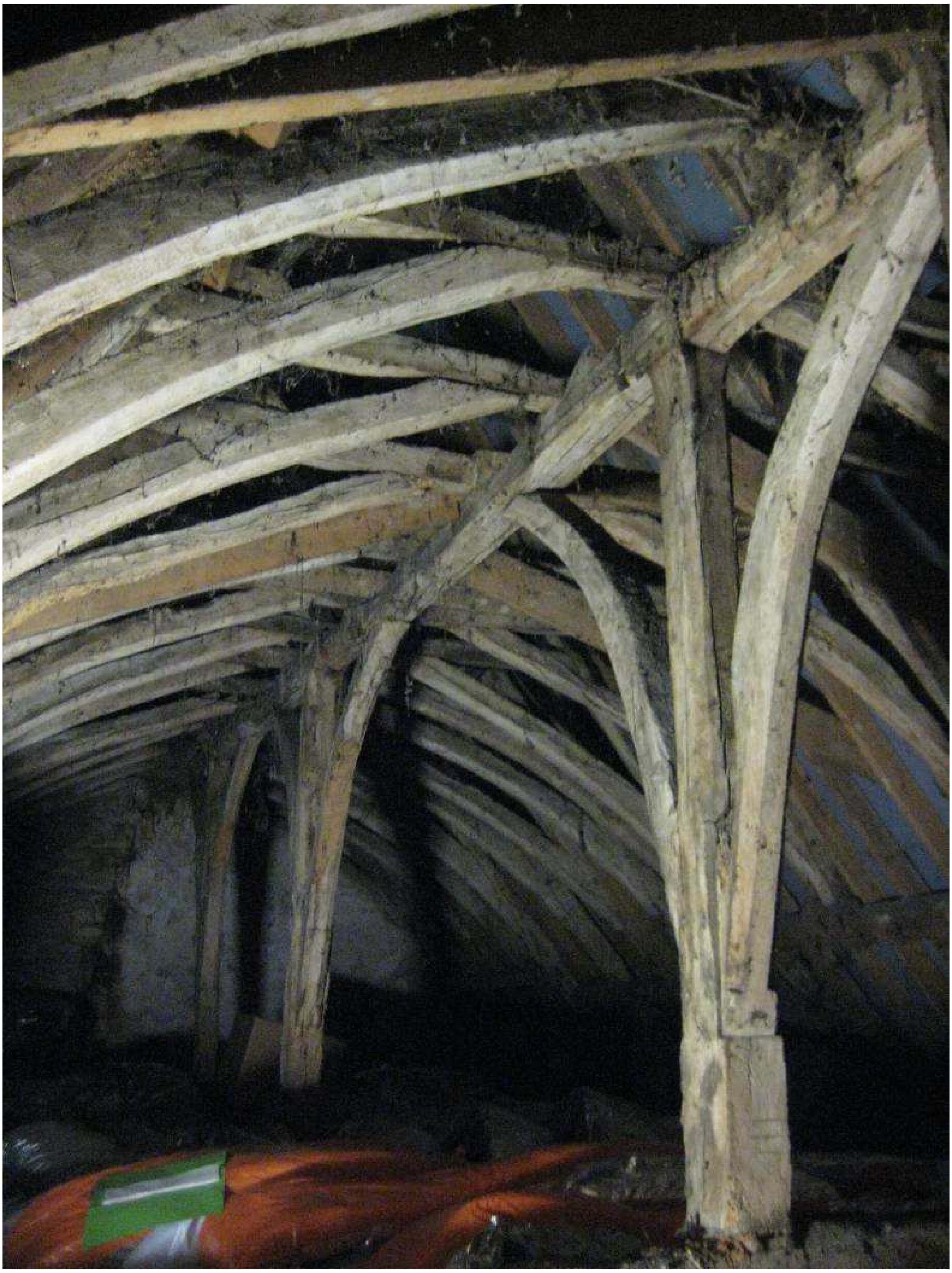

Figure 4: General view of the cross-wing roof viewed looking north-east (photo Matt Hurford)

Figure 5: The hall range roof, truss B viewed looking south-east (photo Matt Hurford)

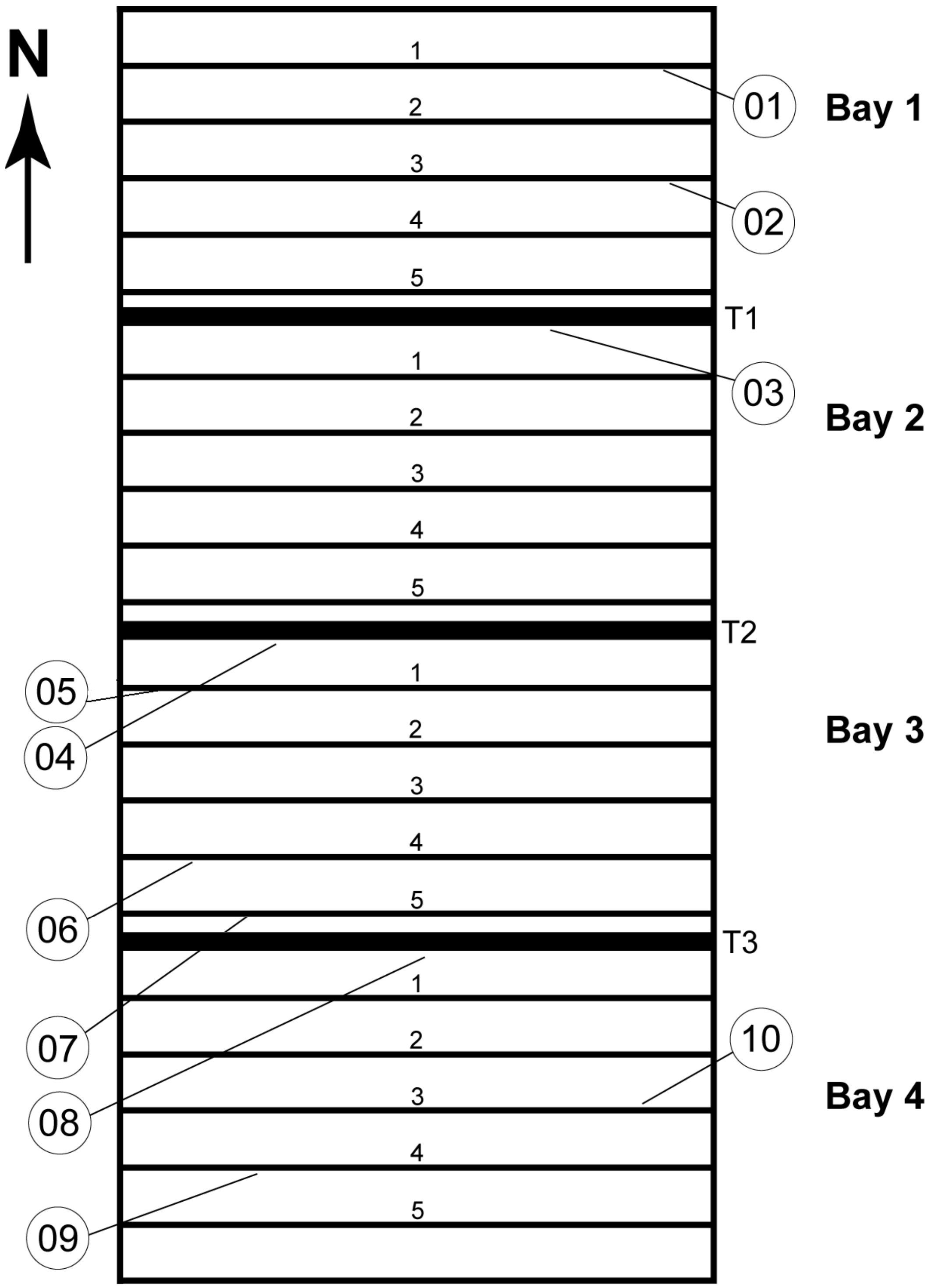

Figure 6: Sketch plan of the cross-wing roof showing the sample locations

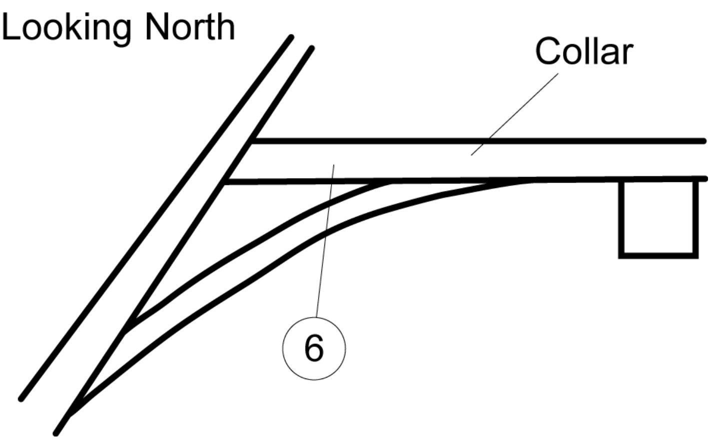

Figure 7: Sketch showing the location of sample SWM-F06 from the collar 4 in bay 3 in the cross-wing roof

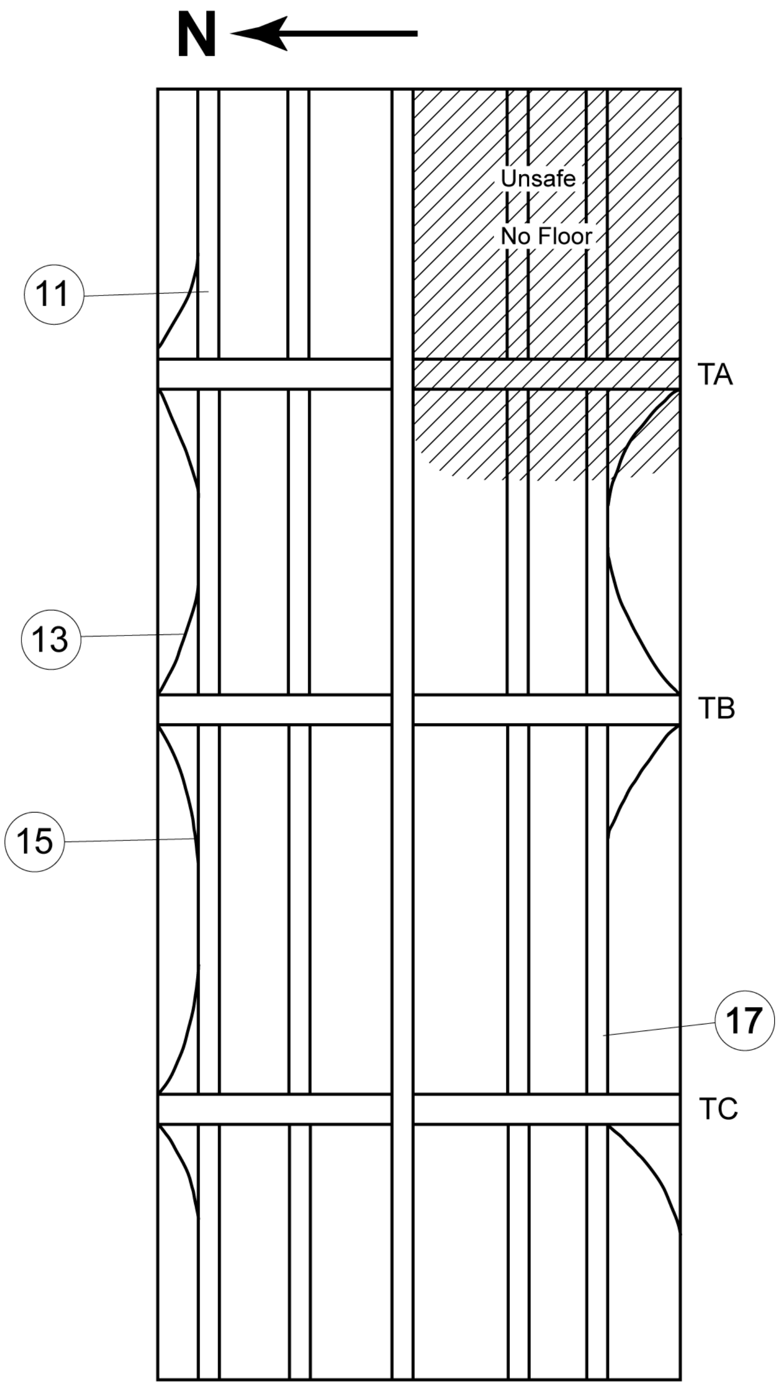

Figure 8: Sketch plan of the hall range roof showing some of the sample locations

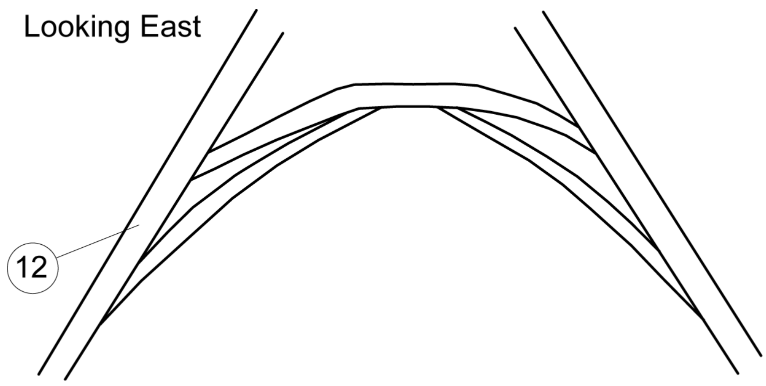

Figure 9: Sketch showing the location of sample SWM-F12 from truss A in the hall range roof

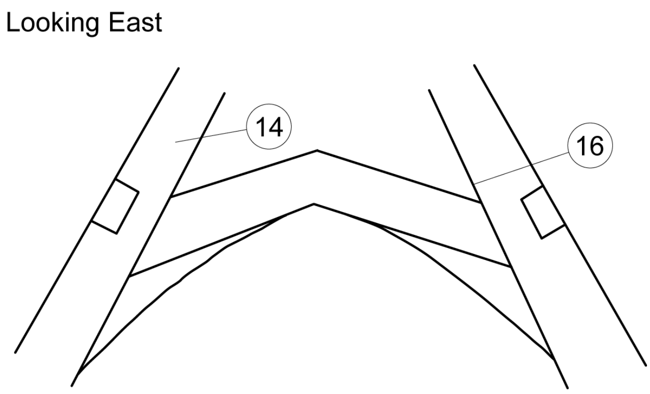

Figure 10: Sketch showing the location of samples SWM-F14 and SWM-F16 from truss B in the hall range roof

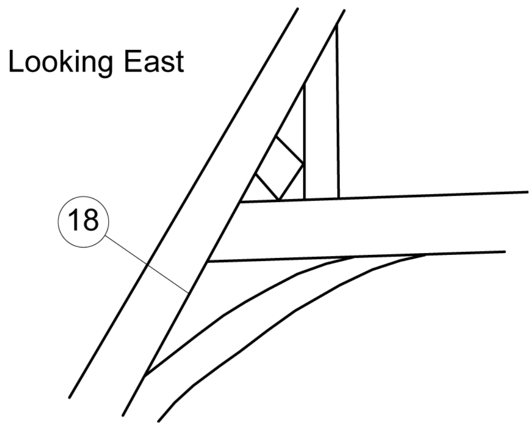

Figure 11: Sketch showing the location of sample SWM-F18 from truss C in the hall range roof

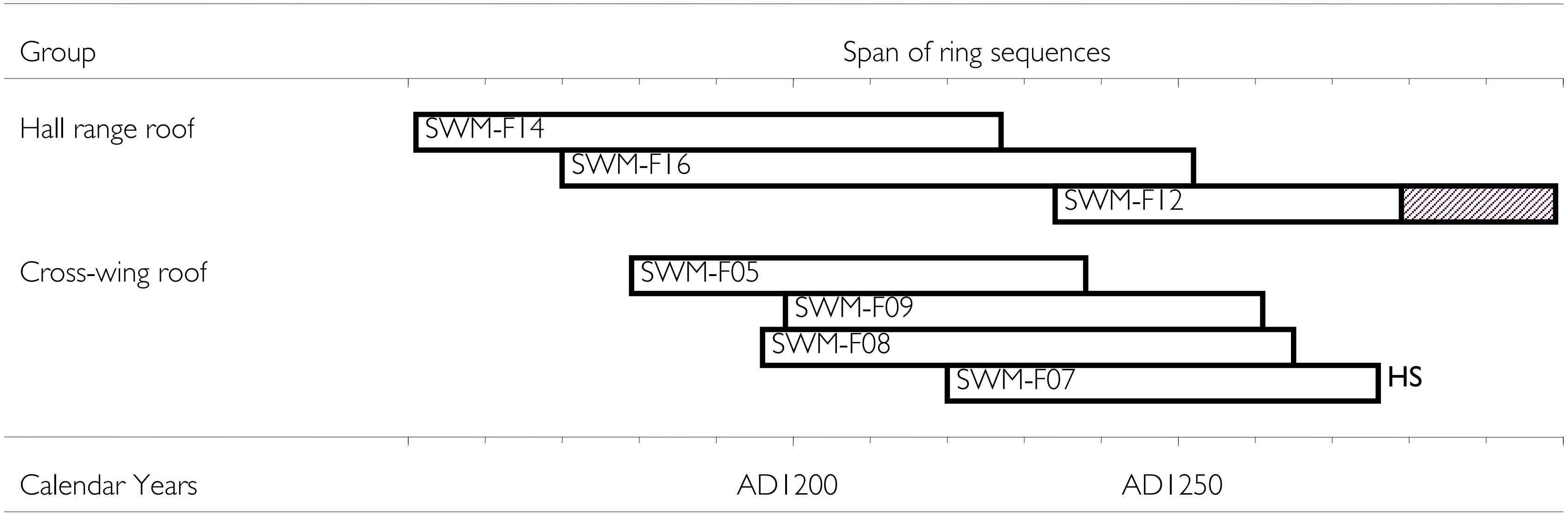

Figure 12: Bar diagram of samples in site chronology SWMFSQ01 and the individually dated sample SWM-F12. White bar = heartwood rings; hatched bar = sapwood rings; HS = the last ring of the sample is at the heartwood/sapwood boundary

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

SWM-F01A 57
431 645 483 397 237 257 284 219 258 251 324 176 180 239 236 353 371 254 507 449
336 428 350 230 418 393 287 297 225 292 402 266 154 247 246 170 156 201 178 143
147 143 164 114 129 105 128 67 35 36 37 44 35 71 67 55 74
SWM-F01B 57
449 636 483 403 241 259 278 227 260 253 327 177 178 235 238 345 372 264 511 452
348 436 371 234 419 407 281 293 223 292 400 267 156 241 239 166 156 206 173 136
140 142 164 105 131 97 126 68 38 32 39 43 36 67 72 56 69
SWM-F05A 60
101 104 84 107 78 117 133 229 318 280 254 172 155 94 100 141 211 206 127 118
117 114 76 63 82 73 106 144 100 147 131 150 130 136 118 134 141 165 95 97
87 127 247 243 148 140 229 370 316 434 404 278 193 155 135 164 179 137 161 127
SWM-F05B 60
101 103 85 108 79 118 136 235 313 286 251 165 156 99 111 140 205 204 134 124
117 104 69 60 91 71 110 139 100 155 135 149 148 130 108 137 146 164 100 92
92 128 237 232 148 156 246 367 330 401 466 306 193 151 132 163 190 137 157 126
SWM-F06A 50
244 154 117 139 193 160 271 257 183 132 181 152 177 217 176 256 267 226 276 261
228 68 62 45 87 102 87 151 186 191 160 145 191 300 266 309 271 278 335 296
260 197 194 178 229 205 159 169 157 178
SWM-F06B 50
247 153 105 147 189 165 271 254 182 145 183 149 180 211 177 262 264 229 275 257
226 68 62 46 83 95 93 152 182 193 159 143 192 301 264 306 274 272 333 297
259 196 198 180 226 207 162 166 156 178
SWM-F07A 57
267 382 348 200 181 361 501 329 473 463 234 156 155 159 158 171 157 203 144 141
86 89 78 72 89 99 132 135 92 80 110 156 121 98 113 161 107 126 136 195
230 179 252 211 183 151 119 164 248 239 185 210 239 250 174 159 317
SWM-F07B 57
257 381 353 204 179 370 506 329 443 461 237 158 151 147 152 160 162 199 153 134
79 91 78 71 89 102 129 132 96 81 93 144 120 113 108 157 109 123 138 189
230 182 246 215 186 150 118 165 250 238 184 206 239 256 171 162 302
SWM-F08A 70
219 215 164 351 284 214 146 183 193 272 198 176 501 354 339 280 178 123 173 149
118 124 60 126 144 194 166 92 89 107 126 108 137 126 89 84 67 57 59 70
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241 314 369 365 281 183 288 312 236 347 337 198 117 95 110 174 166 162 158 160
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SWM-F09B 63
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241 317 373 362 321 184 266 280 220 299 324 201 115 98 109 178 173 154 175 177
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SWM-F11A 55
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195 198 138 176 232 239 264 192 236 313 255 207 312 320 262 258 255 319 213 319
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207 375 269 212 312 296 291 284 272 245 161 84 86 83 131
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144 160 118 145 158 174 207 116 86 82 78 55 77 51 83 154 166 94 94 114
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142 159 126 137 156 169 223 109 88 77 94 54 73 59 79 152 157 102 93 111
166 95 113 134 109 172
SWM-F14A 77
627 493 423 432 465 442 395 318 219 188 129 162 164 178 119 88 155 216 233 195
138 140 116 159 215 244 240 134 216 161 152 200 130 95 196 204 196 64 56 58
56 45 52 40 50 56 62 38 48 64 81 72 72 52 82 56 65 76 91 80
86 89 83 94 101 142 120 83 68 176 149 177 117 64 124 138 129
SWM-F14B 77
623 506 411 434 465 446 408 316 225 187 139 163 163 175 131 78 153 223 231 193
140 142 116 160 220 244 238 140 204 168 159 202 125 93 190 204 193 65 60 54
59 38 56 38 54 53 66 34 41 78 79 69 75 52 72 68 61 82 83 86
78 90 84 97 98 132 126 76 77 177 163 185 121 68 114 145 136
SWM-F16A 83
293 230 188 125 160 211 223 217 153 233 133 97 111 63 73 122 136 158 150 200
185 107 102 95 146 193 178 138 82 95 174 141 177 258 142 211 127 169 185 192
198 156 188 152 203 214 280 228 120 162 239 302 356 181 140 221 275 169 190 242
201 64 97 77 125 157 137 207 222 134 211 184 176 143 211 212 287 363 204 193
307 425 418
SWM-F16B 83
297 225 189 122 166 215 212 213 149 232 126 99 112 63 70 121 139 160 147 200
165 102 107 106 132 202 170 132 85 94 171 143 176 247 148 220 131 169 182 193
204 146 192 147 204 215 278 235 116 169 243 298 350 186 136 225 274 159 188 257
197 73 89 77 122 159 136 207 205 133 212 184 187 153 206 222 279 339 207 171
309 425 402

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

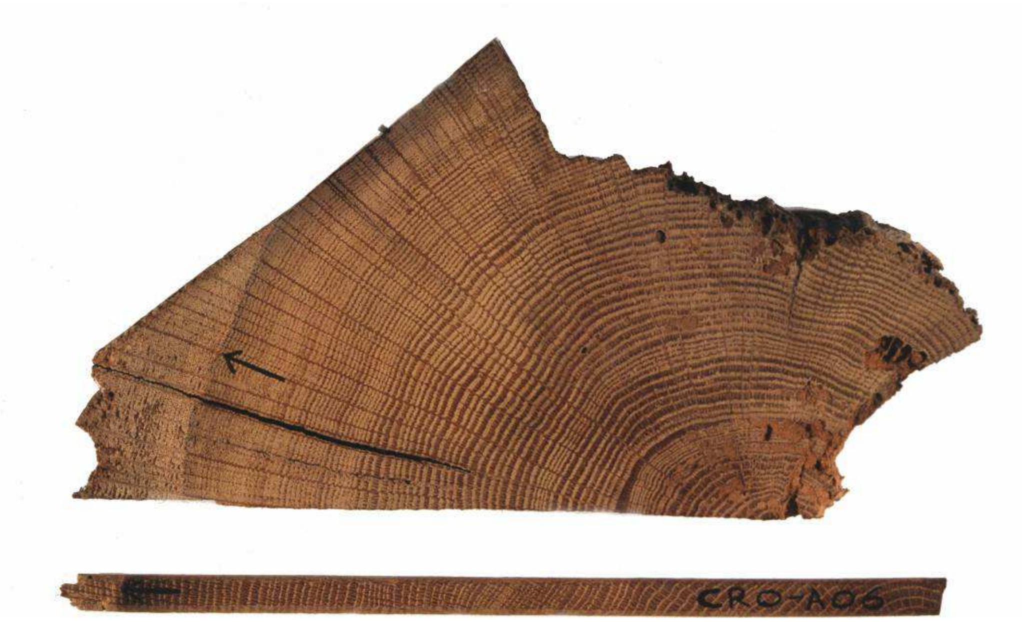


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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	

Bar Diagram

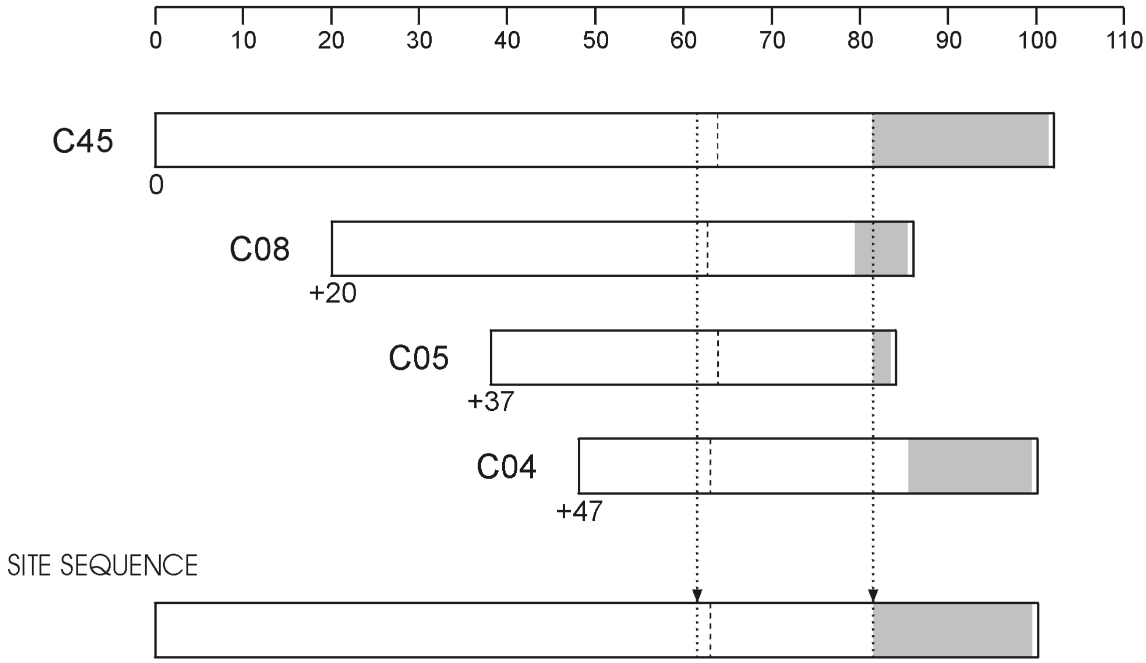


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

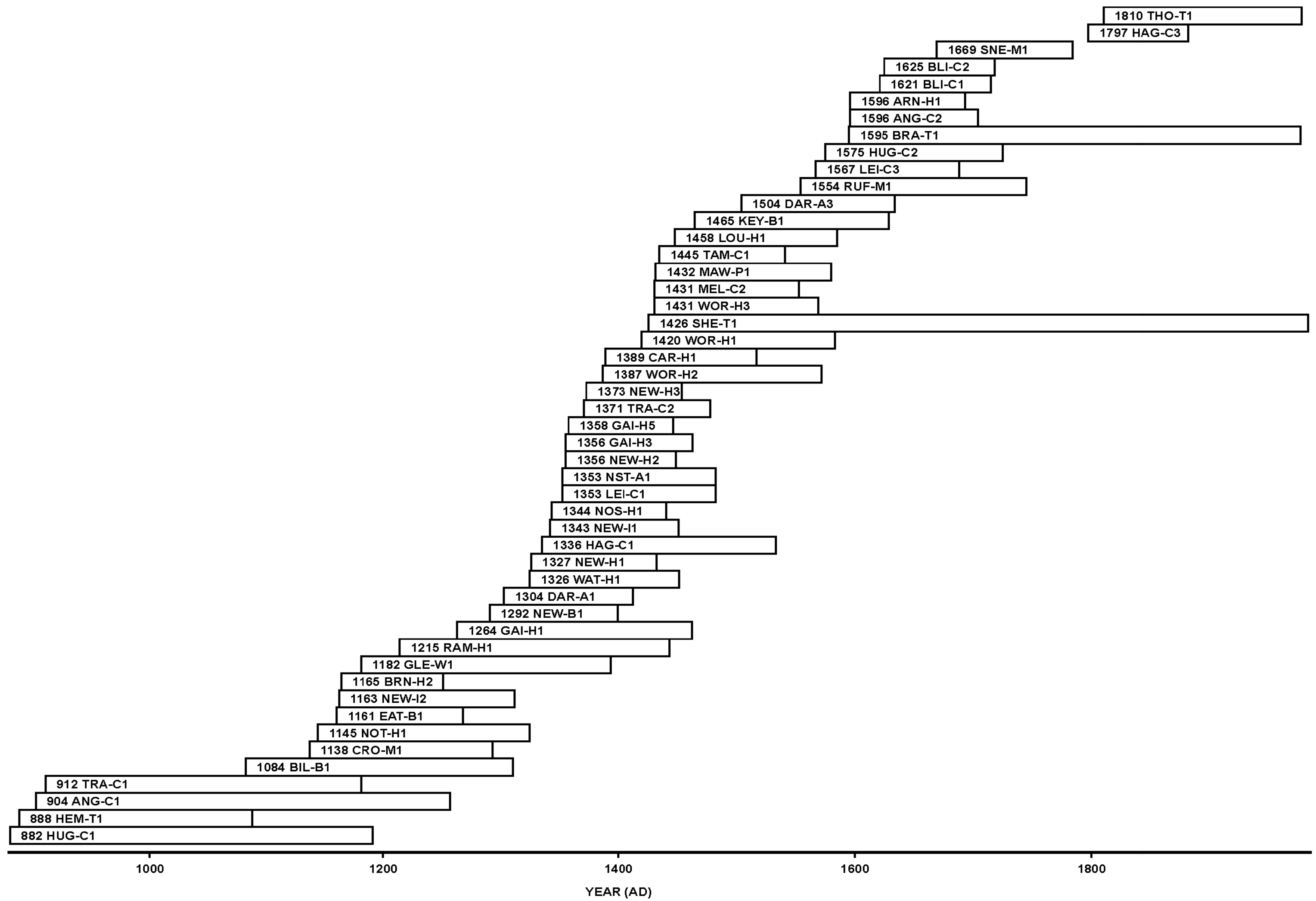
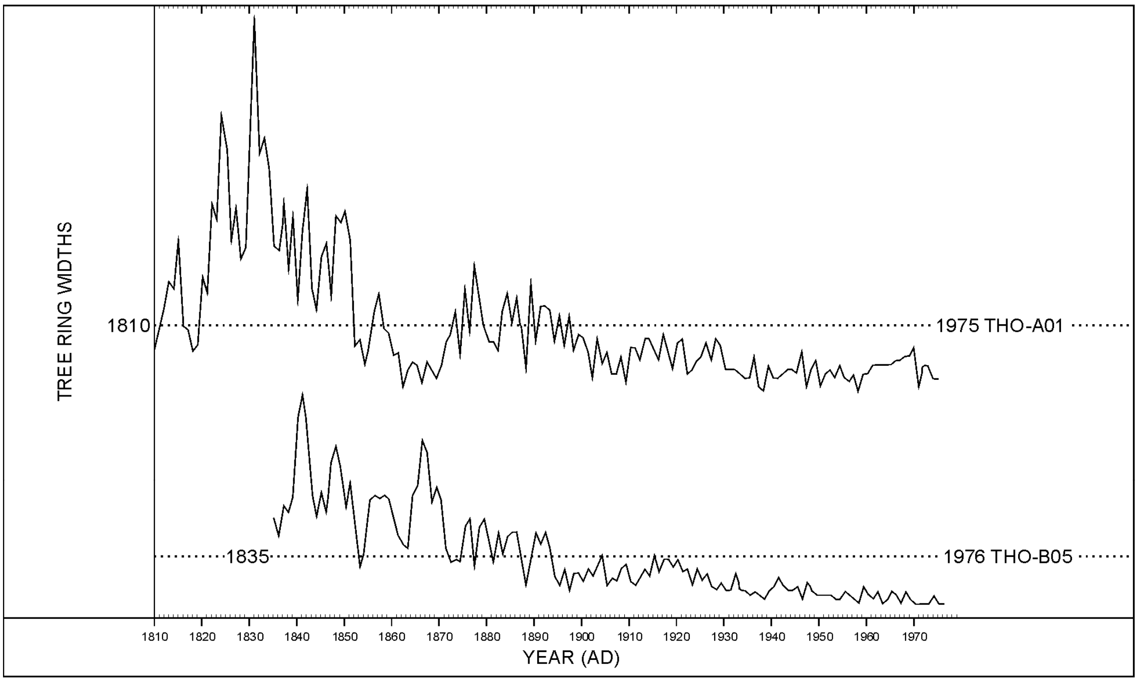


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

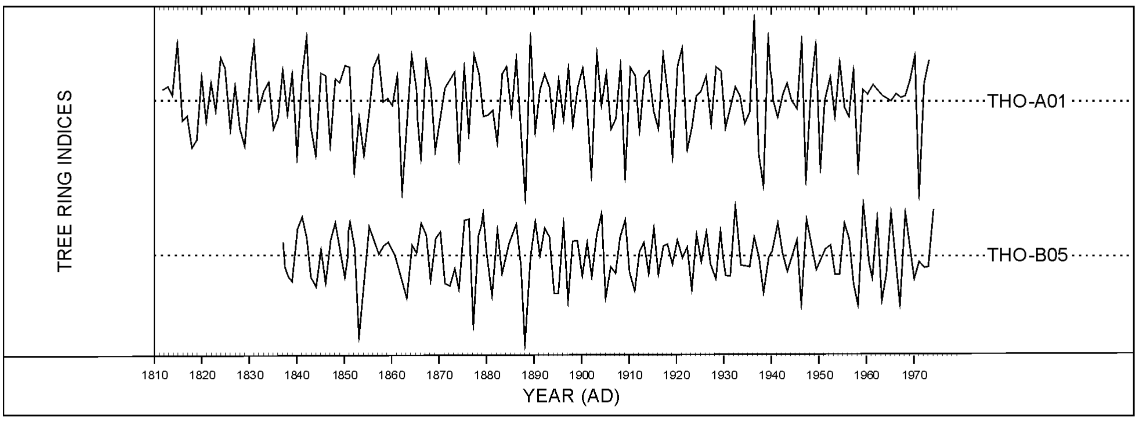


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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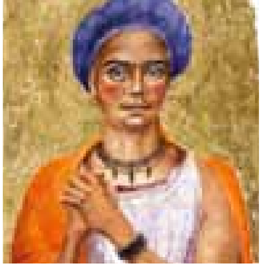


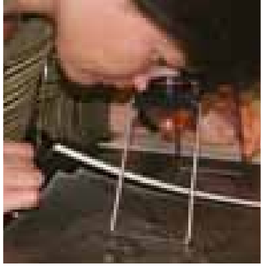


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ENGLISH HERITAGE

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)