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Home Farm Cottage
Westhorpe
Southwell
Nottinghamshire

Tree-ring Analysis of Timbers

Alison Arnold and Robert Howard

Discovery, Innovation and Science in the Historic Environment

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WESTHORPE
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SUMMARY

Dendrochronological analysis undertaken on 11 of the 16 samples obtained from timbers within Home Farm Cottage produced a single dated site chronology comprising five samples with an overall length of 192 rings. These rings were dated as spanning the years AD 1126–1317. Interpretation of the sapwood on these five samples, all from what are believed to be timbers from the primary construction, would suggest that the trees represented were cut as part of a single episode of felling at some time in the period AD 1332–57. A second site chronology comprising two samples was also be formed, but this cannot be dated. Two other samples from ground-floor ceiling joists were dated individually. One has an estimated felling date in the range AD 1573–98, the second having an estimated felling date of AD 1618–43. Two samples remain ungrouped and undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to take this opportunity to firstly thank the owner of Home Farm Cottage for her enthusiasm with this programme of tree-ring dating, and for her cooperation and help during sampling. We would also like to thank Dr Chris King, Senior Lecturer in the Department of Archaeology at the University of Nottingham, for promoting, coordinating, and leading this survey project, Matt Hurford, then of Trent & Peak Archaeology Ltd, for his valuable contribution on the possible phasing of the building, and the building survey team for the use of their drawings in this report. Finally we would like to thank Shahina Farid and Cathy Tyers (Historic England Scientific Dating Team) for supporting this programme of tree-ring dating, and for their assistance during analysis.

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INTRODUCTION

The Grade II listing description for Home Farm Cottage at Westhorpe, in Southwell (Fig 1), describes it as of mid eighteenth-century date with mid nineteenth- and twentieth-century alterations (LEN 1369940). It is of two storeys, constructed of brick with a pantile roof, and incorporates much reused timber framing. It has a plinth, dentilled eaves, single ridge, and single side wall stacks. The windows are nineteenth- and twentieth-century casements. The west front has a central two-light window flanked to the left by a similar window and to the right by a single one. Below, there is a central three-light window flanked to the left by a smaller window, both with segmental heads, and to the right by a blocked opening. To the right again, is a twentieth-century latticed wooden porch with gabled roof, covering a close-boarded door. The south gable, to the street, has two twentieth-century casements of different sizes, and above, a single three-light one.

Within, a single wall post from which springs an arch brace may be seen, along with reused spine beams and wall plates. There are also a series of joists to the ground-floor ceilings (Fig 2a/b). The house has a single purlin roof, mainly of nineteenth-century date, with reused purlin and principal rafters. The north end has a massive internal stack, and there is also a nineteenth-century kitchen range.

SAMPLING

Sampling and analysis by dendrochronology of the timbers within Home Farm Cottage was commissioned by Dr Chris King, Assistant Professor in the Department of Archaeology at the University of Nottingham, as an adjunct to the survey, recording, and interpretation of the building. The work undertaken here forms part of a larger research programme on Southwell carried out by the Southwell Community Archaeology Group. In collaboration with the University of Nottingham, Trent & Peak Archaeology, and Nottinghamshire County Council, the Archaeology Group was awarded an 'Early Fabric in Historic Towns' grant by Historic England (then English Heritage) to research and record pre-AD 1750 buildings in Southwell. As part of this project a large number of buildings are being examined, with a sub-set of them then being recorded. This project is reported in King (2019).

The recording survey at Home Farm Cottage revealed the possibility that fragments of a particularly early and unusual timber-framed building might lie buried beneath the later alterations and additions, and that it might have been aisled to its east side. Although there is evidence that during later phases of development some timbers may have been inserted or possibly reused from earlier elements of the building, the recording survey determined that the house may be divided into three basic units, unit A, B, and C (Fig 3). It is possible that these units correspond to various phases or alterations to the building. It was hoped that by sampling a selection of timbers that the date of the building, and its developmental sequence might be determined.

Thus, from the timbers available, a total of 16 oak samples was obtained by coring. Each sample was given the tree-ring code STH-B (for Southwell, site 'B'), and numbered 01–16, the sampled timbers being shown on drawings made as part of the building survey, or on an annotated photograph, these shown here as Figures 4a–d.

Details of the samples are given in Table 1, including the timber element sampled, the total number of rings each sample has, and how many of these, if any, are sapwood rings. The individual date span of each dated sample is also given.

ANALYSIS AND RESULTS

Each of the 16 samples obtained from the various timbers of Home Farm Cottage were prepared by sanding and polishing. It was seen at this time that five samples had fewer than the 50 rings here deemed necessary for reliable dating, and they were rejected from this programme of analysis. The annual growth rings widths of the remaining 11 samples were, however, measured, these measurements being given at the end of this report. These data were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process producing two groups of cross-matching samples.

The first group, forming at a minimum *t*-value of 3.5, comprises five samples, STH-B01, STH-B02, STH-B03, STH-B11, and STH-B14, the length, relative position, and overlap of these being shown in Figure 5. These five samples were combined at their indicated off-set positions to form STHBSQ01, a site chronology with an overall length of 192 rings. This site chronology was then satisfactorily dated by repeated and consistent comparison with a series of relevant reference chronologies for oak as spanning the years AD 1126–1317 (Table 2).

The second group, forming at a minimum *t*-value of 10.9, comprises two samples, STH-B08 and STH-B15, the length, relative position, and overlap of these being shown in Figure 6. These two samples were also combined at their indicated off-set positions to form STHBSQ02, a site chronology with an overall length of 64 rings. This site chronology was then also compared to the full corpus of reference material for oak, but there was no conclusive cross-matching, and these two samples must remain undated.

The two site chronologies STHBSQ01 and STHBSQ02 were then compared with the four remaining measured but ungrouped samples, STH-B04, STH-B09, STH-B12, and STH-B13, but there was no further satisfactory cross-matching. Each of the four ungrouped samples was then compared individually with the full corpus of reference material. This indicated a repeated and consistent cross-match for sample STH-B12, when its 50 rings were dated as spanning the years AD 1511–60 (Table 3) and a repeated and consistent cross-match for sample STH-B13, when its 55 rings were dated as spanning the years AD 1557–1611 (Table 4).

This analysis may be summarised as below:

Site chronology/sample	Number of samples	Number of rings	Date span AD (where dated)
STHBSQ01	5	192	1126–1317
STHBSQ02	2	64	Undated
STH-B12	1	50	1511–60
STH-B13	1	55	1557–1611
Ungrouped/undated	2	---	------
Unmeasured	5	---	------

INTERPRETATION

Site chronology STHBSQ01 (Fig 5)

None of the five samples, representing a jowled post, a wall plate, a brace, and two ceiling joists, in site chronology STHBSQ01 retains complete sapwood (the last ring produced by the tree before it was cut down), and it is thus not possible to determine precisely when any of the trees represented were cut down. One sample, however, STH-B03, retains the heartwood/sapwood boundary. This means that although it has lost all of its sapwood rings, it is *only* the sapwood rings that have been lost. Given that oak trees have fairly consistent numbers of sapwood rings, the 95% confidence interval being between a minimum of 15 and a maximum of 40 rings, it is possible to calculate a likely felling date range for the tree represented. Allowing that the heartwood/sapwood boundary on sample STH-B03 is dated to AD 1317, such a sapwood estimate would give the tree a felling date of sometime between AD 1332 at the earliest and AD 1357 at the latest.

Felling date ranges for the timbers represented by the other four samples in site chronology STHBSQ01 cannot be determined because not only are they missing all their sapwood rings, but an unknown number of heartwood rings as well. However, given that these other samples cross-match well with sample STH-B03, and with each other, it is very likely that the source trees for all the timbers were growing in the same woodland at the same time, and it would be relatively unusual that such trees would come to be used in the same structure if they had been felled at very different dates. Thus it appears likely that these timbers were also derived from trees felled at the same time in the early- to mid-fourteenth century.

Site chronology STHBSQ02 (Fig 6)

Site chronology STHBSQ02, comprising samples, STH-B08 and STH-B15 (from ceiling joists from units C and B respectively) cannot be reliably dated, and it is thus not possible to determine when either of the trees represented was felled. However, although undated, the degree of cross-matching between these two samples is again such that it is likely that the timbers are from trees growing in the same stand of woodland and were felled at the same time as each other and may possibly have actually been derived from the same tree.

Sample STH-B12

Sample STH-B12 has a last ring date of AD 1560 and retains two sapwood rings, the heartwood/sapwood boundary thus being dated to AD 1558. Allowing for the same sapwood estimate as above, 15–40 rings, this would give the timber represented, a ground-floor ceiling joist in unit B, a felling date of some point between AD 1563 at the earliest and AD 1598 at the latest.

Sample STH-B13

Sample STH-B13 has a last ring date of AD 1611 and retains eight sapwood rings, the heartwood/sapwood boundary thus being dated to AD 1603. Allowing for the same sapwood estimate as above would give the timber represented, another ground-floor ceiling joist in unit B, a felling date of some point between AD 1618 at the earliest and AD 1643 at the latest.

CONCLUSIONS

The listing for Home Farm Cottage describes it as now having the appearance of an eighteenth- or nineteenth-century building incorporating earlier timber framing. Tree-ring dating now shows that this framing is indeed likely to be primary, with this element of the structure having its origins in the early- to mid-fourteenth century. Given the conditions of the time, this probably means that it was built before the Black Death rather than after it, ie before AD 1350.

The dating of the change of the house to its present appearance is inconclusive. At least one timber dates to the later sixteenth century, while another dates to the first half of the seventeenth century. It is possible that these two timbers do represent two distinct periods of work undertaken at these dates, but it is also possible that they were salvaged and reused in still later episodes of development.

Further information placing Home Farm Cottage in its wider context within early timber-framed buildings in Southwell can be found in King (2019).

Undated samples

Four measured samples, STH-B04, STH-B08, STH-B09, and STH-B15, remain undated, although two of these, STH-B08 and STH-B15 are combined in site chronology STHBSQ02. All the undated samples would certainly appear to contain sufficient rings for reliable analysis, and do not show any particular problems such as compression or distortion of the rings which might make cross-matching and dating difficult. It is not uncommon, however, in most programmes of tree-ring analysis, to find that some samples remain undated, many of them for no apparent reason. It may, though, be possible to date these samples at some time in the future if more relevant local data is obtained from additional timbers elsewhere in the locality.

Woodland sources

As may be seen from Table 2, although site chronology STHBSQ01 has been compared with reference chronologies from all parts of Britain, a set of particularly high *t*-values indicating a high level of similarity, are found against those reference chronologies made up of material from other sites in Nottinghamshire. In particular, there is strong trend to sites in the east of the county, in the area around Southwell. This would suggest, as might be expected in the early- to mid-fourteenth century, the timbers used in the primary phase of Home Farm Cottage have not been transported very far and are from a local source.

The trees represented by samples STH-B12 and STH-B13 (Tables 3 and 4), show a wider geographical spread of cross-matches, with little suggestion of their source location. STH-B12 has a tendancy towards site chronologies from the Midlands, whereas STH-B13 has a tendancy towards Midlands and more northerly site chronologies. This, however, may be due to the samples being 'singletons' which may well be reflecting localised environmental growth conditions as opposed to the stronger climatic signal in the longer replicated site chronology, STHBSQ01, as well as being affected by the temporal and geographical variation within the reference chronology database.

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TABLES

Table 1: Details of tree-ring samples from Home Farm Cottage, Westhorpe, Southwell, Nottinghamshire

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
STH-B01	Unit B - first Floor, east wall plate on jowled post	67	no h/s	1221	------	1287
STH-B02	Unit B/C - east jowled wall post rising to first floor	124	no h/s	1126	------	1249
STH-B03	Unit B/C - brace from east jowled wall post	141	h/s	1177	1317	1317
STH-B04	Unit C - east wall plate (to aisle?)	46	h/s	------	------	------
STH-B05	Unit A - horizontal plate/beam to pantry	nm	---	------	------	------
STH-B06	Unit C – reused east ground-floor-ceiling beam/plate	nm	---	------	------	------
STH-B07	Unit C – ground floor ceiling beam	nm	---	------	------	------
STH-B08	Unit C – ground floor ceiling common joist 3	62	no h/s	------	------	------
STH-B09	Unit C – ground floor ceiling common joist 6	60	18	------	------	------
STH-B10	Unit C – ground floor ceiling common joist 8	nm	---	------	------	------
STH-B11	Unit C – ground floor ceiling common joist 9	94	no h/s	1205	------	1298
STH-B12	Unit B – ground floor ceiling common joist 1	50	2	1511	1558	1560
STH-B13	Unit B – ground floor ceiling common joist 4	55	8	1557	1603	1611
STH-B14	Unit B – ground floor ceiling common joist 9	130	no h/s	1149	------	1278
STH-B15	Unit B – ground floor ceiling common joist 10	64	no h/s	------	------	------
STH-B16	Unit B – main ground floor ceiling beam	nm	---	------	------	------

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

Table 2: Results of the cross-matching of site sequence STHBSQ01 and relevant reference chronologies when the first-ring date is AD 1126 and the last-ring date is AD 1317

Reference chronology	Span of chronology	*t*-value	Reference
'Severns', Castle Road, Nottingham	AD 1030 – 1334	13.7	Howard *et al* 1996b
22/4 Kirkgate, Newark, Nottinghamshire	AD 1209 – 1338	12.7	Arnold *et al* 2002
The Hollies, Bathley, Nottinghamshire	AD 1150 – 1295	12.4	Alcock *et al* 1991
40-44 Castlegate, Newark, Nottinghamshire	AD 1169 – 1330	11.0	Arnold *et al* 2002
40-44 Cartergate, Newark, Nottinghamshire	AD 1134 – 1330	10.7	Arnold *et al* 2002
Bingham, Nottinghamshire (working mean)	AD 1149 – 1313	10.6	Arnold and Howard 2013 unpubl
Southview Cottage, Norwell, Nottinghamshire	AD 1132 – 1306	10.5	Hurford *et al* 2010
Vicars Court, Lincoln, Lincolnshire	AD 1090 – 1286	9.3	Hillam and Groves 1996
5 King Street, Melton Mowbray, Leicestershire	AD 1237 – 1330	7.8	Arnold *et al* 2008
Jews House, Lincoln, Lincolnshire	AD 1162 – 1297	7.4	Groves 1994

Table 3: Results of the cross-matching of sample STH-B12 and relevant reference chronologies when the first-ring date is AD 1511 and the last-ring date is AD 1560

Reference chronology	Span of chronology	*t*-value	Reference
26 Westgate Street, Gloucester, Gloucestershire	AD 1399 – 1622	9.8	Howard *et al* 1998
Oakham Castle, Oakham, Rutland	AD 1383 – 1620	9.6	Arnold and Howard 2013a
Preston Manor, Preston, Rutland	AD 1471 – 1631	8.8	Arnold and Howard 2014a unpubl
Kingsbury Hall, Kingsbury, Warwickshire	AD 1391 – 1564	8.4	Arnold and Howard 2006
4-5 St Johns Alley, Devizes, Wiltshire	AD 1447 – 1647	8.2	Haddon-Reece *et al* 1990
Coates' Barn, Main Street, Cosby, Leicestershire	AD 1426 – 1562	7.9	Alcock *et al* 1991
St Michael & St Mary's, Melbourne, Derbyshire	AD 1509 – 1638	7.4	Laxton *et al* 1984
Church of St Andrew, Welham, Leicestershire	AD 1443 – 1633	7.4	Arnold *et al* 2005a
Holy Cross Church, Epperstone, Nottinghamshire	AD 1477 – 1647	7.4	Arnold *et al* 2003 unpubl
Town Hall, Alcester, Worcestershire	AD 1375 – 1625	6.8	Arnold and Howard 2014b unpubl

Table 4: Results of the cross-matching of sample STH-B13 and relevant reference chronologies when the first-ring date is AD 1557 and the last-ring date is AD 1611

Reference chronology	Span of chronology	*t*-value	Reference
Manor House, Sutton in Ashfield, Nottinghamshire	AD 1441 – 1656	7.9	Howard *et al* 1996a
Fair Flats Farm, Bradfield, South Yorkshire	AD 1492 – 1633	7.7	Howard *et al* 1994
5 Church Street, Newark, Nottinghamshire	AD 1403 – 1655	7.4	Arnold *et al* 2002
Nether Alderley Mill, Cheshire	AD 1531 – 1596	6.7	Arnold and Howard 2012 unpubl
All Saints Church, Fenton, Lincolnshire	AD 1434 – 1617	6.6	Arnold *et al* 2005b
104 Kirkgate, Leeds, West Yorkshire	AD 1329 – 1628	6.2	Arnold *et al* 2020
Auckland Castle, Bishop Auckland, County Durham	AD 1425 – 1698	5.9	Arnold and Howard 2013b
Sutton Scarsdale Manor, Nottinghamshire	AD 1513 – 1644	5.8	Howard *et al* 1995 unpubl
Tonge Hall, Rochdale, Lancashire	AD 1449 – 1687	5.8	Arnold and Howard 2014
Ledston Hall, Ledston, West Yorkshire	AD 1424 – 1668	5.7	Arnold *et al* 2015

FIGURES

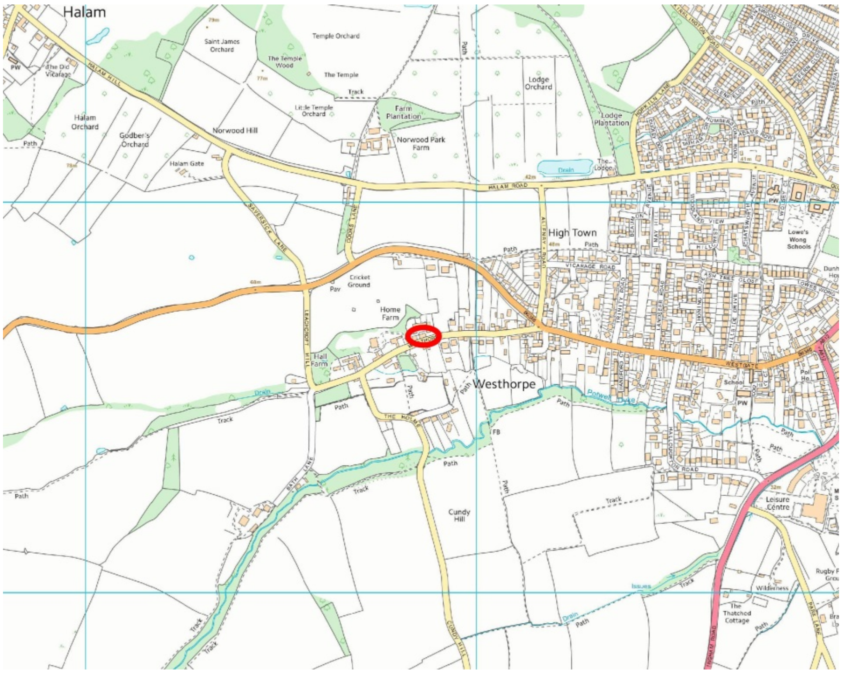


Figure 1a/b: Location of Home Farm Cottage marked in red. Scale (top) 1:10000 (bottom) 1:2000. © Crown Copyright and database right 2020. All rights reserved. Ordnance Survey Licence number 100024900. © British Crown and SeaZone Solutions Ltd 2020. All rights reserved. Licence number 102006.006. © Historic England

Figure 2a/b: Views, looking north-east, of the timbers to the ground-floor front room at Home Farm Cottage; wall-post and brace (top) and ceiling beams (bottom)(photographs Robert Howard)

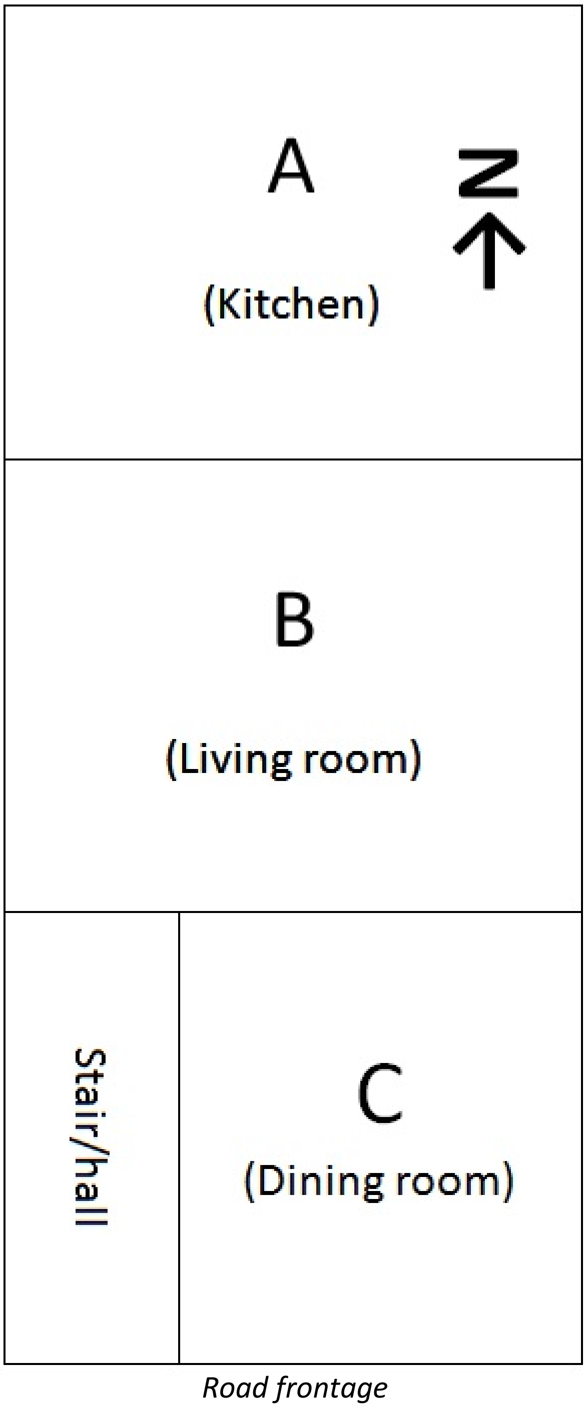


Figure 3: Simple plan to show layout and arrangements of the units to Home Farm Cottage as determined by the building survey team. It is possible that these units correspond to various phases or alterations of the building (after building survey team)

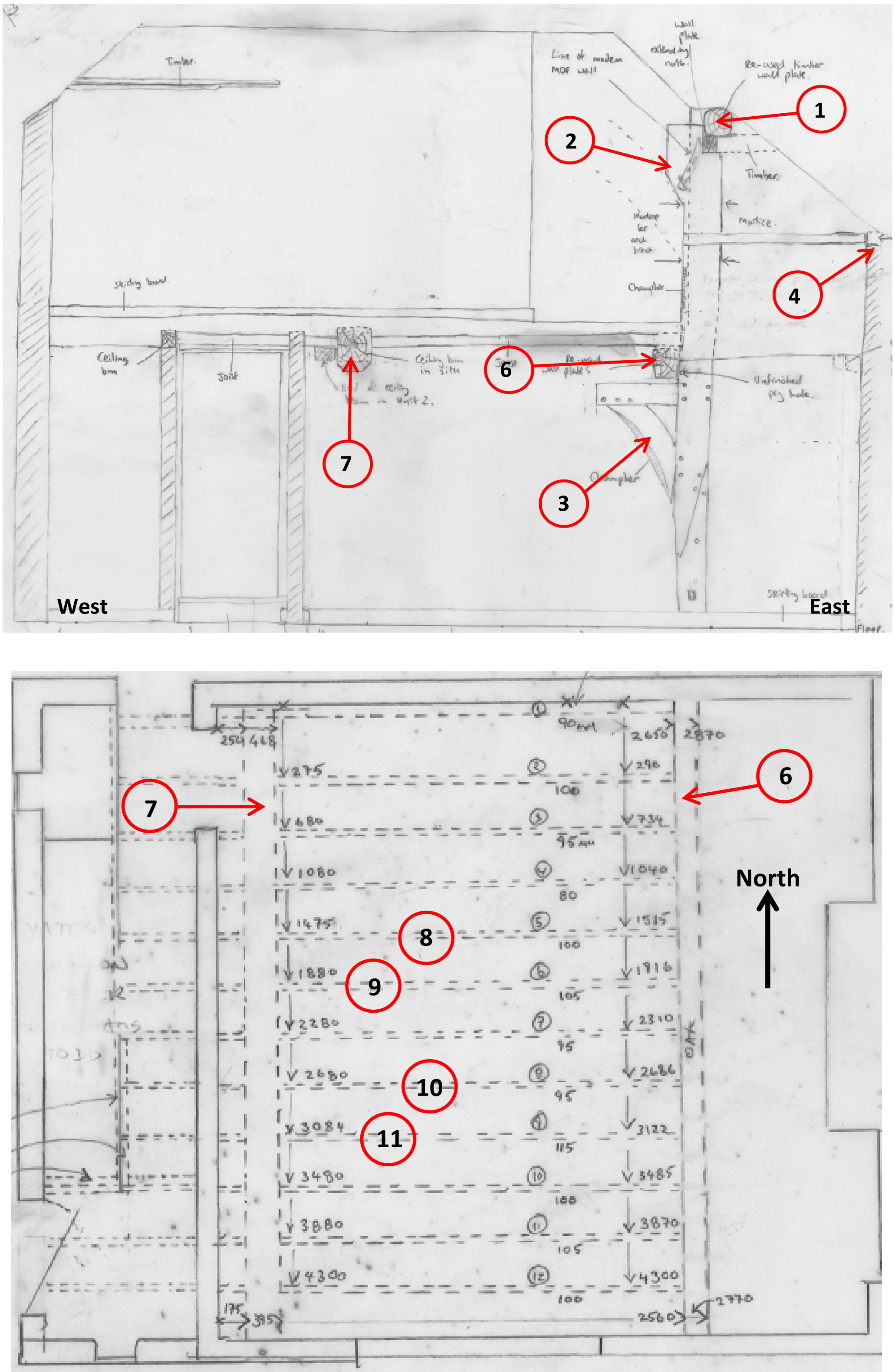


Figure 4a/b: Drawing of south face of north wall of unit C (top), and plan of unit C (bottom), to help locate sampled timbers (after building survey team)

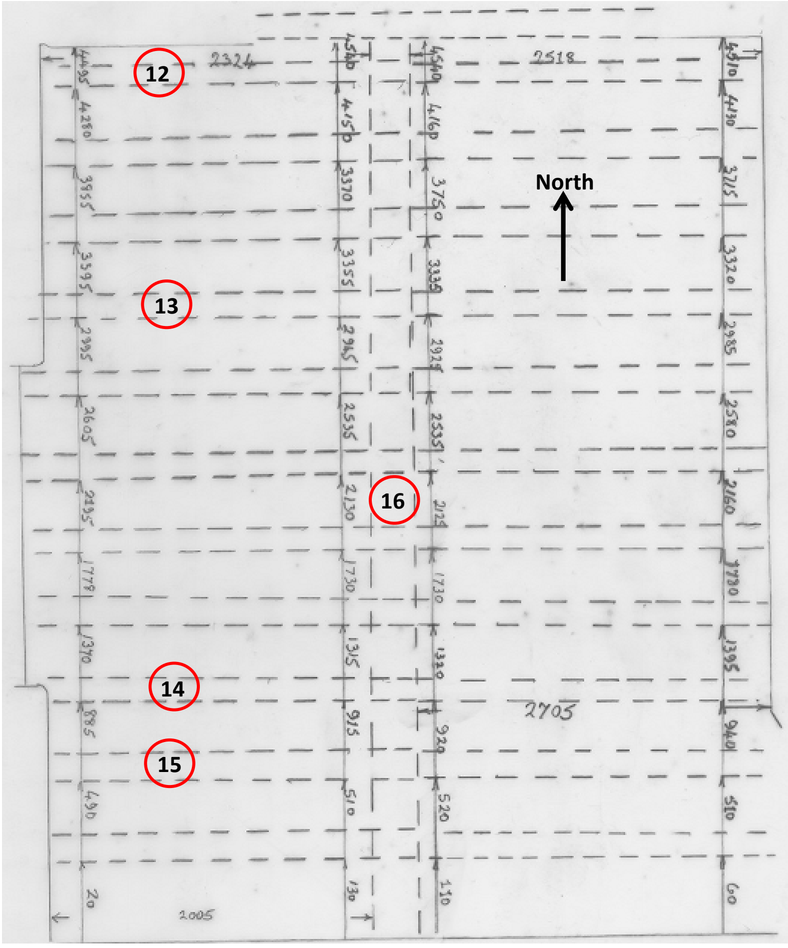
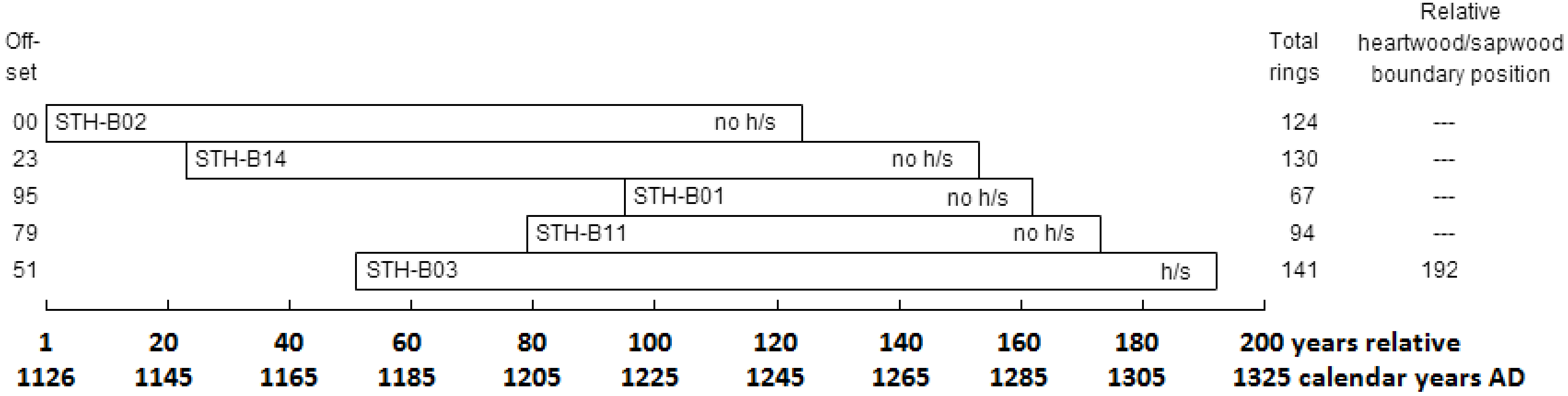
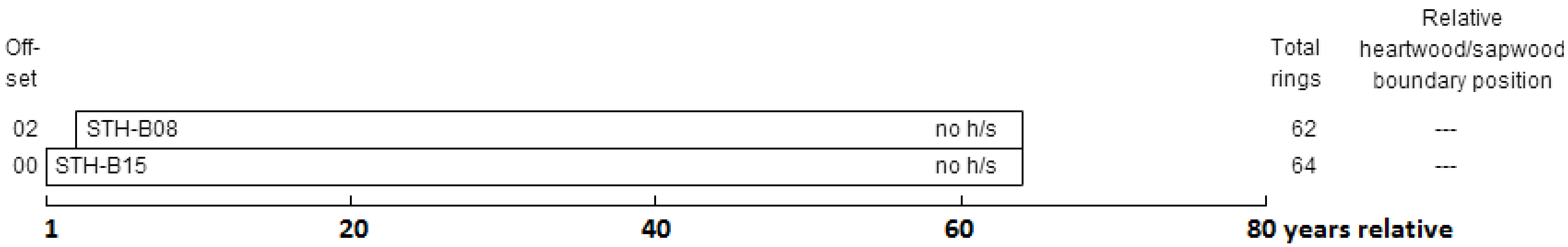


Figure 4c/d: Plan of unit B (top) (after building survey team) and annotated photograph of unit A looking south (bottom) (photograph Robert Howard) to help locate sampled timbers



h/s = heartwood/sapwood boundary

Figure 5: Bar diagram of the samples in site chronology STHBSQ01



no h/s = the sample does not retain the heartwood/sapwood boundary

Figure 6: Bar diagram of the samples in site chronology STHBSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

STH-B01A 67
75 108 92 246 159 144 83 69 107 135 111 87 89 117 171 132 241 200 172 131
93 53 67 114 130 137 87 89 60 89 151 107 128 131 114 96 122 85 114 118
87 129 139 98 103 98 115 128 129 156 165 134 160 164 131 118 97 115 109 125
152 206 220 129 115 132 156

STH-B02A 124
109 87 72 56 68 101 80 92 94 106 92 87 118 151 154 162 110 113 88 110
134 139 155 134 117 93 87 78 116 111 123 132 107 143 123 134 102 142 139 127
136 132 141 121 95 110 81 96 85 110 133 128 86 123 80 97 133 115 100 79
78 99 79 85 100 90 88 103 103 107 107 107 95 129 103 96 84 101 106 101
103 82 98 124 128 154 120 103 82 89 106 115 89 118 128 109 89 85 126 142
128 100 100 121 125 137 129 81 96 135 107 157 101 151 87 75 73 98 109 111
100 105 74 113

STH-B03A 141
91 127 182 85 141 219 175 159 85 84 79 74 73 214 228 212 247 187 187 210
183 256 340 169 146 130 167 98 125 104 161 227 228 332 279 252 217 189 168 201
184 128 205 142 93 93 95 131 176 134 110 82 85 144 139 124 73 68 97 84
140 129 129 117 68 60 81 76 106 115 78 48 43 59 73 82 87 89 79 71
75 73 51 45 46 67 76 62 40 59 59 98 101 56 77 75 64 60 54 67
55 34 29 53 60 65 82 63 63 53 48 37 58 81 87 90 78 53 49 41
48 53 68 75 93 81 54 53 52 53 75 73 94 103 100 81 74 69 81 98
142

STH-B04A 46
122 191 112 38 62 87 133 294 173 167 211 235 173 196 210 144 151 105 134 137
89 118 84 89 83 96 58 85 72 109 183 203 215 109 139 144 171 106 160 142
164 203 164 169 158 206

STH-B08A 62
466 455 370 379 311 334 355 369 409 309 306 300 229 366 275 394 215 270 227 278
175 169 176 198 226 181 185 289 273 205 274 220 171 239 109 126 125 131 135 88
93 100 110 144 136 123 187 118 117 68 107 115 182 96 74 104 145 84 96 75
87 134

STH-B09A 60
324 301 310 279 368 308 284 216 275 376 405 415 443 515 443 312 219 309 172 175
229 254 248 189 181 128 173 140 196 226 178 161 80 68 81 98 103 100 72 60
98 87 90 114 104 109 95 78 104 106 106 118 74 126 92 103 86 75 107 99

STH-B11A 94
106 67 77 101 123 191 191 145 133 140 96 97 76 80 78 107 119 81 100 117
146 95 58 110 116 146 163 148 86 149 145 144 134 119 161 105 82 92 113 117
128 73 71 63 60 75 79 86 94 91 98 78 49 40 67 82 81 114 99 77
73 54 51 67 72 96 139 114 92 71 85 88 97 77 75 110 143 82 64 47
69 71 60 70 85 110 111 149 120 114 125 67 60 62

STH-B12A 50
302 265 257 264 250 209 147 153 184 110 153 155 116 96 58 107 112 146 112 127
228 127 85 75 109 132 125 156 236 203 247 167 155 184 154 151 118 222 299 196
260 170 187 251 290 123 95 118 185 175

STH-B13A 55
147 120 202 155 178 179 192 217 205 203 169 155 178 226 282 228 271 275 249 117
130 126 254 339 307 231 246 247 255 250 405 218 279 170 121 137 212 198 245 243
223 287 296 192 207 184 282 265 195 218 234 237 220 239 268

STH-B14A 130
267 190 64 60 114 93 83 142 265 264 219 205 98 148 100 157 228 254 203 300
241 163 107 120 184 150 111 118 67 75 102 68 114 128 92 50 71 98 129 75
38 35 41 51 75 118 85 89 61 44 61 32 39 35 65 42 53 47 52 43
60 75 119 100 118 117 66 78 46 52 84 175 147 90 93 115 173 83 40 113
91 157 153 135 53 87 110 101 123 103 174 84 64 57 75 108 86 70 53 72
92 85 192 138 126 103 96 114 56 53 93 121 114 224 237 198 132 78 50 66
78 117 200 205 175 100 84 81 119 133

STH-B15A 64
382 380 461 521 444 450 434 378 436 350 352 304 274 213 190 325 293 407 218 259
229 242 164 146 170 189 257 184 154 207 207 168 214 195 153 181 101 137 159 161
177 98 121 131 151 178 132 154 170 126 112 89 121 125 119 94 81 103 141 116
103 95 90 162

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

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

rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

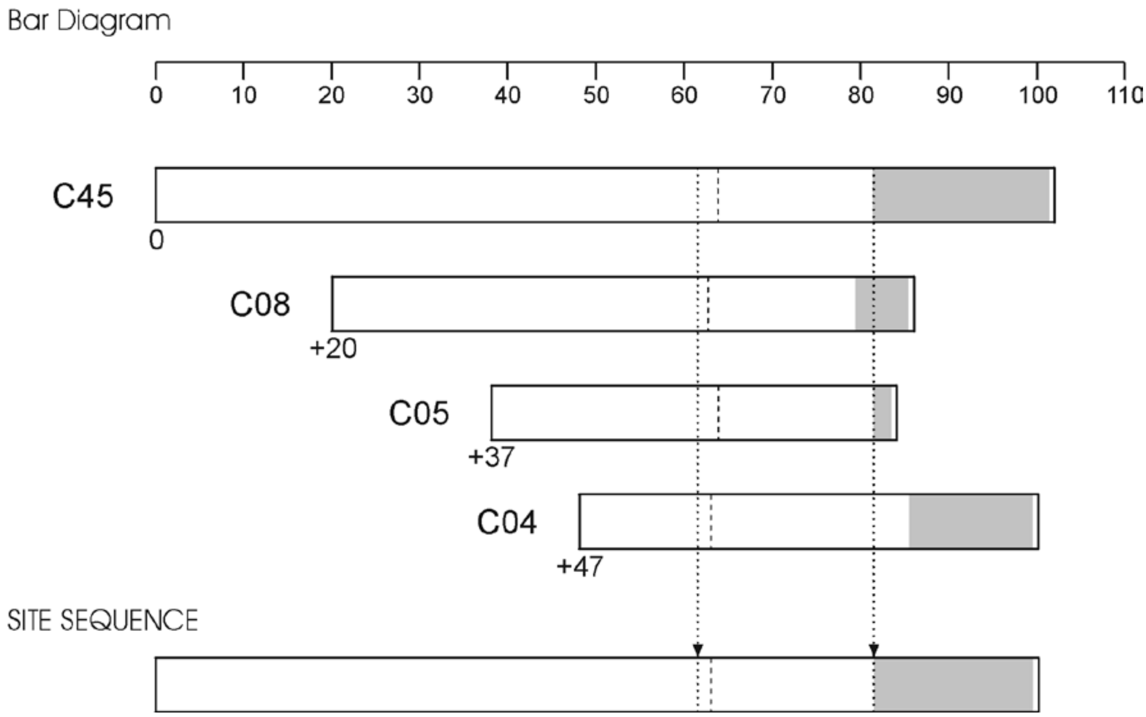


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

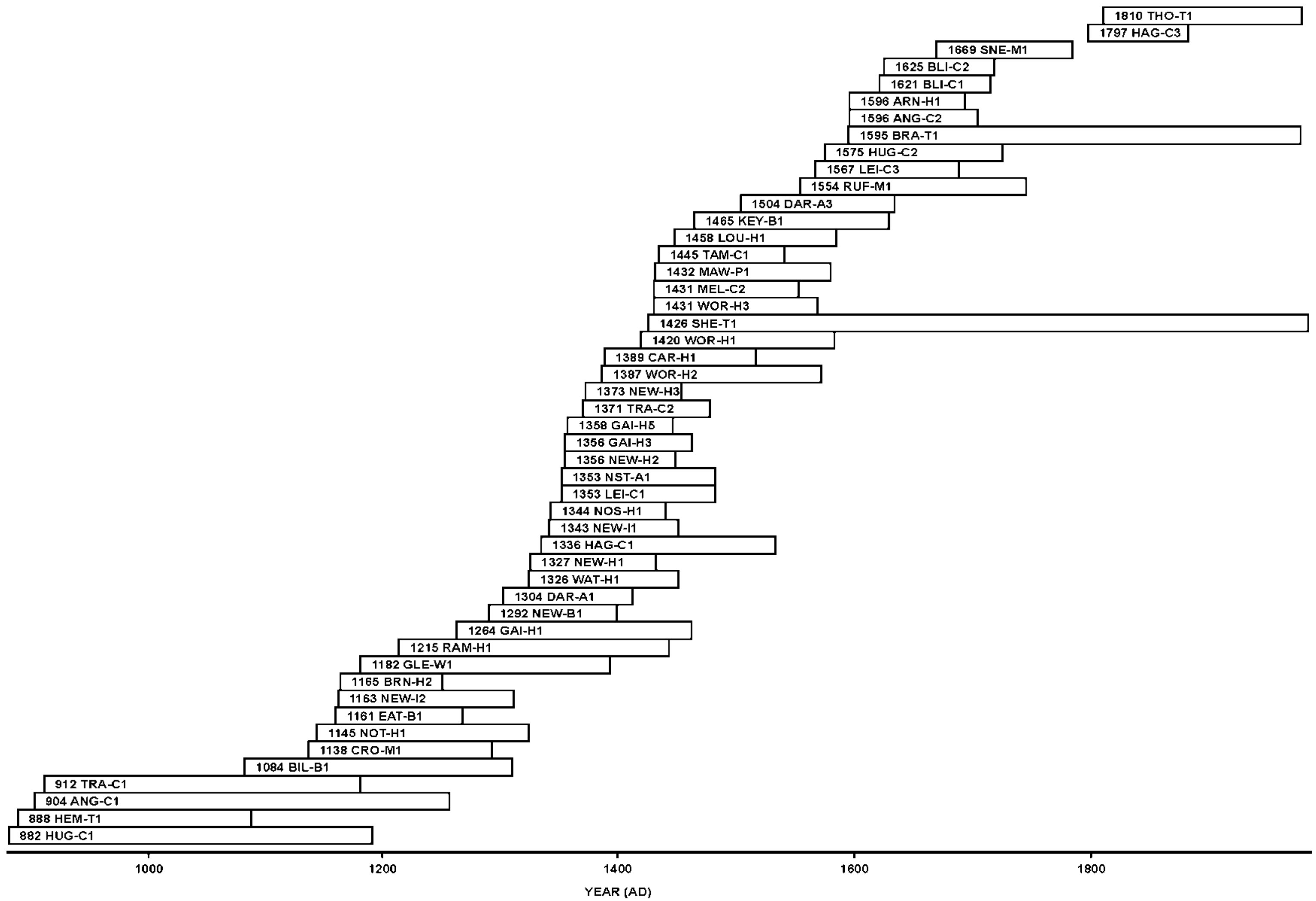
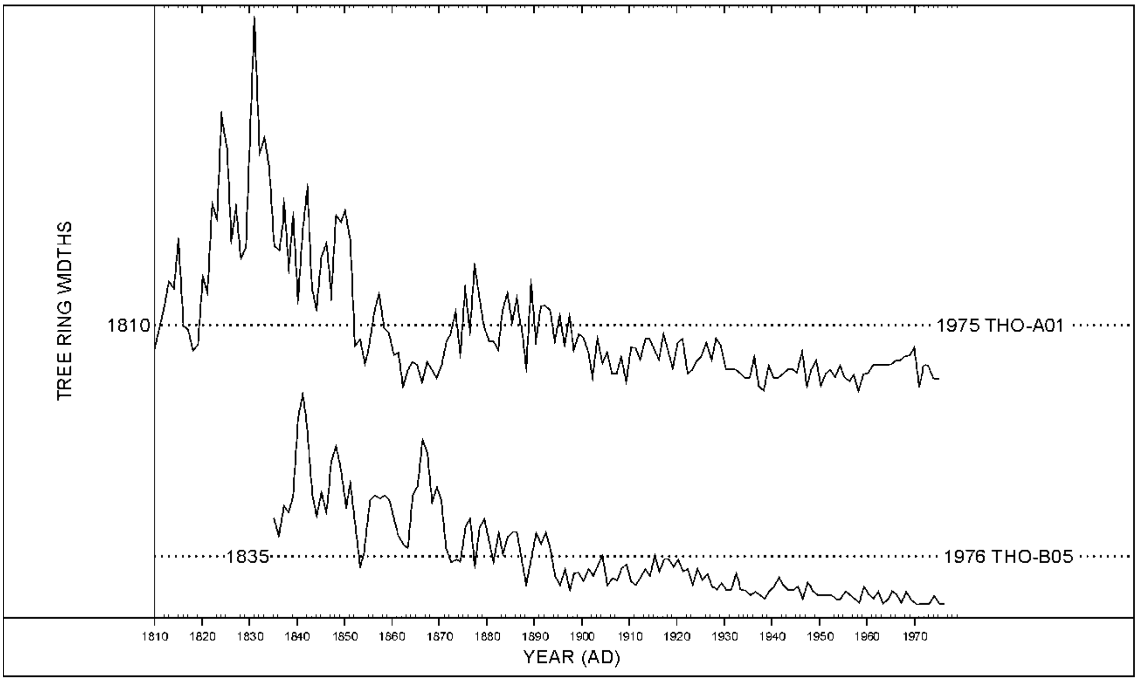


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

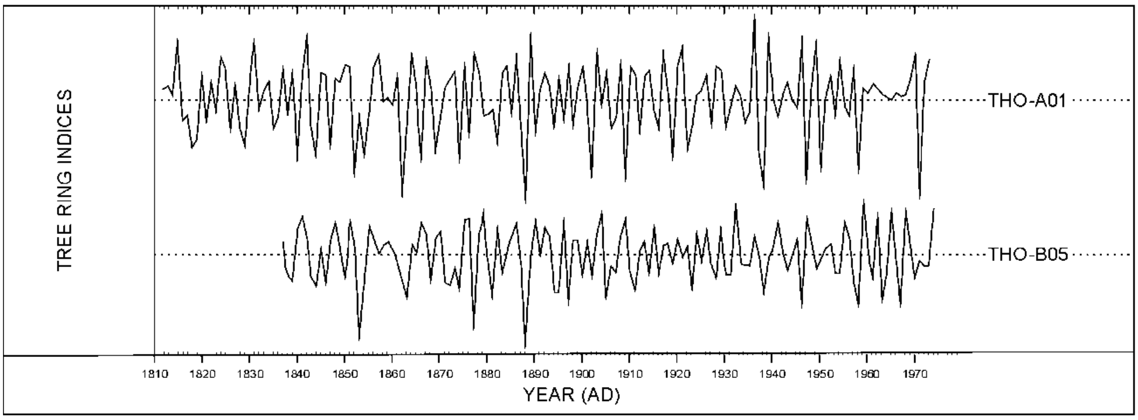


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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