

# 7-12 CHURCH STREET, DRONFIELD, DERBYSHIRE TREE-RING ANALYSIS OF TIMBERS

## SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard



*This report has been prepared for use on the internet and the images within it have been down-sampled to optimise downloading and printing speeds.*

*Please note that as a result of this down-sampling the images are not of the highest quality and some of the fine detail may be lost. Any person wishing to obtain a high resolution copy of this report should refer to the ordering information on the following page.*

Research Report Series 55-2014

7-12 CHURCH STREET,  
DRONFIELD,  
DERBYSHIRE

## TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: SK 35318 78377

© English Heritage

ISSN 1749-8775 (Print)  
ISSN 2046-9802 (Online)

*The Research Report Series incorporates reports by the expert teams within the Investigation & Analysis Division of the Heritage Protection Department of English Heritage, alongside contributions from other parts of the organisation. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series, the Architectural Investigation Report Series, and the Research Department Report Series.*

*Many of the Research Reports are of an interim nature and serve to make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers must consult the author before citing these reports in any publication. Opinions expressed in Research Reports are those of the author(s) and are not necessarily those of English Heritage.*

*Requests for further hard copies, after the initial print run, can be made by emailing:*

*Res.reports@english-heritage.org.uk*

*or by writing to:*

*English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD*

*Please note that a charge will be made to cover printing and postage.*

## **SUMMARY**

Dendrochronological analysis was undertaken on 13 of the 15 core samples obtained from the five cruck trusses of this barn. This analysis produced two site chronologies. The first site chronology, comprising nine samples from trusses A, B, C, and D, has an overall length of 214 rings, dated as spanning the years AD 1313–1526. Interpretation of the sapwood on these samples would suggest that some of the timbers of trusses A and B were felled in the late AD 1450s or early AD 1460s, while some of the timbers of trusses C and D have an estimated felling date range of AD 1537–62. The second site chronology, comprising two samples from truss A, has an overall length of 110 rings but cannot be dated. Two further measured samples remain ungrouped and undated.

## **CONTRIBUTORS**

Alison Arnold and Robert Howard

## **ACKNOWLEDGEMENTS**

The Nottingham Tree-ring Dating Laboratory would like to thank David Renwick, Project Manager of the Church Street development, and the many contractors on site at the time of sampling, for their considerable help and cooperation during assessment and coring. We would also like to thank Professor David Hey for the background information to the site used in the introduction below and Elden Minns and Co Ltd, Chartered Architects and Surveyors, for the use of their survey plans and drawings. Finally we would like to thank Shahina Farid and Cathy Tyers (English Heritage Scientific Dating Team) for commissioning this programme of tree-ring dating and their assistance during the production of this report.

## **ARCHIVE LOCATION**

Derbyshire Historic Environment Record  
Environmental Services Department  
Shand House  
Dale Road South  
Matlock  
Derbyshire DE4 3RY

## **DATE OF INVESTIGATION**

2013

## **CONTACT DETAILS**

Alison Arnold and Robert Howard  
Nottingham Tree-ring Dating Laboratory  
20 Hillcrest Grove  
Sherwood  
Nottingham NG5 1FT  
0115 960 3833  
roberthoward@tree-ringdating.co.uk  
alisonarnold@tree-ringdating.co.uk

## CONTENTS

Introduction .....	1
Sampling .....	1
Analysis and Results .....	2
Interpretation .....	3
Discussion and Conclusion .....	4
Bibliography .....	6
Tables .....	7
Figures .....	9
Data of Measured Samples .....	16
Appendix: Tree-Ring Dating .....	20
The Principles of Tree-Ring Dating .....	20
The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory .....	20
1. Inspecting the Building and Sampling the Timbers .....	20
2. Measuring Ring Widths .....	25
3. Cross-Matching and Dating the Samples .....	25
4. Estimating the Felling Date .....	26
5. Estimating the Date of Construction .....	27
6. Master Chronological Sequences .....	28
7. Ring-Width Indices .....	28
References .....	32

## INTRODUCTION

The grade II listed 7–12 Church Street is a range of former shop units near the centre of Dronfield (Fig 1), these being built of coursed rubble coal measures sandstone with stone and Welsh slate roofing. The site was the subject of a programme of archaeological survey and recording by West Yorkshire Archaeological Services (2013) and Professor David Hey (unpublished) has undertaken a substantial amount of documentary research on the building and its surroundings which forms the basis of the background information below.

These units had been converted to commercial use from what are believed to be a series of early seventeenth-century outbuildings belonging to a now lost farmhouse, Buttermere Farm, which stood just to the west of the barn where there is now a small car park. These outbuildings contain five full-height cruck trusses (Figs 2 and 3), the trusses supporting a single purlin roof which also retains some windbraces. There is also a two-bay, three-storey unit at the east end of the range, but this appears to contain only relatively modern softwood timbers. There is no indication that these buildings were ever used as domestic accommodation, although all of them have been subject to alterations undertaken in the eighteenth, nineteenth, and twentieth centuries.

The ridge-pieces, purlins, and wall-plates of the barn extend beyond the extant five trusses suggesting the original building may have been longer, and it is possible that there were once further trusses at either end before the present gable walls replaced them. There is also a possibility that the front and rear stone-built outer walls themselves replace original timber-framing.

It is also believed, on the basis of structural and carpentry evidence that the barn may have been built in two stages, possibly to adapt to the slope of the ground, although the order of construction cannot be determined. The two trusses at the western end (here designated trusses A and B) are at a lower level than the three trusses, C, D, and E, to the eastern end. In addition, the tie-beams of trusses A and B are halved into the eastern faces of the cruck blades, whereas the other tiebeams are halved into the west faces. The distance between trusses B and C is shorter than in the other bays, suggesting there may have been a division or break here, and truss C is the only one to bear carpenters' marks, which are chiselled into the northern cruck blade and into the tie-beam and collar in the form of Roman numerals.

## SAMPLING

Sampling and analysis by dendrochronology of the timbers to the main single-storey range of 7–12 Church Street were requested by Bob Hawkins, English Heritage Designation Adviser. This programme of analysis was undertaken to provide independent dating evidence for the original construction of the building and the date of any reused timbers, or any timbers subsequently inserted. It was hoped that this information would inform

repairs and conservation plans for the building which is currently undergoing conversion to domestic accommodation.

Thus, from the timbers available, a total of 15 samples was obtained by coring. Each sample was given the code DRN-C (for Dronfield, site 'C') and numbered 01–15 (Table 1). These samples were distributed as equally as possible within the building, taking into account the suitability of the timbers for tree-ring analysis. In this respect it should perhaps be noted that the barn presented timbers with variable numbers of rings. The timbers of truss E, and the east end in general, were derived from slightly faster grown trees and thus had lower numbers of rings. Consequently many of the timbers in this area were unsuitable for tree-ring analysis.

The locations of these samples were recorded at the time of sampling on a drawing made by Elden Minns and Co Ltd Chartered Architects and Surveyors, and provided by English Heritage. These drawings are reproduced here in Figure 2 and Figures 4a–e. Details of the samples are given in Table 1. In this Table, as in the drawings, the trusses have been identified as A to E from west to east following the schema of the Elden Minns' plans, with individual timbers then being further identified on a north–south basis as appropriate.

## ANALYSIS AND RESULTS

Each of the 15 samples obtained from the five cruck trusses was prepared by sanding and polishing. It was seen at this time that two samples, from the collars of trusses C and D, had too few rings for reliable dating, and so they were rejected from this programme of analysis. The annual growth ring widths of the remaining 13 samples were, however, measured, the data of these measurements being given at the end of this report. The data of the 13 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing two groups of cross-matching samples to be formed.

The analysis initially resulted in the production of one sub-group of five samples from trusses A and B and a second sub-group of four samples from trusses C and D. Both sub-groups dated independently very well and in spite of the short period of overlap between them (Fig 5) they also cross-matched well. Because of the satisfactory independent dating of each sub-group, the nine constituent samples were combined at their indicated offset positions to form a single site chronology DRNCSQ01, this having an overall length of 214 rings. Site chronology DRNCSQ01 was then compared to an extensive corpus of reference material for oak. This indicated a consistent and repeated match with a number of reference chronologies when the date of its first ring is AD 1313 and the date of its last measured ring is AD 1526. The evidence for this dating is given in Table 2.

The second group comprises two samples, these cross-matching with each other as shown in Figure 6. The two samples were combined at their indicated offset positions to form DRNCSQ02, this site chronology having an overall length of 110 rings. Site chronology DRNCSQ02 was also compared to an extensive corpus of reference material

for oak, but there was no conclusive cross-matching at any position and it must, at least for the moment, remain undated.

Site chronologies DRNCSQ01 and DRNCSQ02 were then compared to the two remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. The two ungrouped samples were then compared individually to the full corpus of reference data, but again there was no satisfactory cross-matching and these two must, therefore, also remain undated. This analysis is summarised in Table 3.

## INTERPRETATION

Analysis by dendrochronology of the timbers of 7–12 Church Street has produced two site chronologies. The first site chronology comprises nine of the 13 samples measured, its 214 rings dated as spanning the years AD 1313–1526. However, although these nine samples have formed a single site chronology, interpretation of the sapwood on them indicates that, as may be seen from Table 1 and Figure 5, timbers of two distinct phases of felling are to be found in the single-storey range; there being in the order of 80–100 years difference between them.

### *Earlier felling phase – trusses A and B*

This phase of felling is represented by samples DRN-C01, C04, C05, C06, and C07, all these samples being from the timbers associated with trusses A and B. Two of these samples, DRN-C04 and C05, have last measured ring dates of AD 1454 and AD 1451 respectively. Both these samples are derived from timbers which have complete sapwood on them, meaning that they both have the last ring produced by the source tree before it was felled. However, because of the soft and fragile nature of this part of the timber, small amounts of sapwood, between 5–10mm, were lost from the samples in coring (denoted by lower case 'c' in Table 1 and Fig 5). In such circumstances it is possible, based on the growth characteristics, to estimate how many sapwood rings the lost portions might have contained. In both these cases the loss suggested that the two timbers represented were felled in the late AD 1450s or early AD 1460s.

The relative position of the heartwood/sapwood boundary on the other three samples of this earlier group DRN-C01, C06, and C07 (Table 1; Fig 5), is such that it is highly likely that the timbers they represent were also felled at about the same time, and that all five timbers were cut as part of a single episode of felling in the late AD 1450s or early AD 1460s.

### *Later felling phase – trusses C and D*

This phase of felling is represented by samples DRN-C09, C10, C11, and C12 representing all four cruck blades of trusses C and D. None of these samples retain complete sapwood, or are from timbers with complete sapwood on them, and it is thus not possible to provide an exact felling date. The four samples do, however, retain some



sapwood or at least the heartwood/sapwood boundary, this being at a very similar relative position and date on all four samples (Table 1; Fig 5), and indicative of a single phase of felling.

The average date of the heartwood/sapwood boundary on these four later samples is AD 1522. Adding to this the likely 95% probability limits for the amount of sapwood these timbers might have had, 15–40 rings, would give them an estimated felling date range of AD 1537–62.

#### *Undated site chronology DRNCSQ02*

The second site chronology DRNCSQ02, comprises samples DRN-C02 and DRN-C03, and is 110 rings long. This site chronology cannot be conclusively dated. Both samples are from the timbers of truss A; the south blade and collar respectively. There is some disturbance to the growth rings of both samples, although it is not particularly pronounced, which may have affected the ability of these two samples to date. It therefore remains a possibility that these two samples represent a different felling date to the other two identified, but clearly this cannot be proven dendrochronologically and any such supposition would rely solely on structural evidence.

#### *Undated samples*

Two final measured samples, DRN-C08 and C15, remain ungrouped and undated. As may be noted from Table 1, both these have few rings and hence were considered borderline as to their suitability for successful dating.

## DISCUSSION AND CONCLUSION

Two phases of felling have been identified from the dated timbers of the single-storey range: an earlier phase dating to the late AD 1450s or early AD 1460s, and a later phase having an estimated felling date range of AD 1537–62. Given that these phases also represent discreet groups of timbers, with the earlier date found only amongst the timbers associated with trusses A and B, and the later date only amongst the timbers of trusses C and D, it is likely that these represent the approximate construction dates for these portions of the building.

As such, the tree-ring dating shows that although the building in its present stone-built form may date to the early seventeenth century, it actually has its origin nearer to the middle part of the fifteenth century, with a further phase of construction in the mid-sixteenth century. Thus this single-storey range appears to be of somewhat greater antiquity than is indicated in the list description. The results obtained in this analysis also support the structural interpretation that this single-storey range was built in two stages.

The overall cross-matching between the five samples from the earlier phase would suggest that although these timbers were probably derived from a single woodland

source, although the individual trees were not growing particularly close to each other and are possibly from different stands of woodland. The overall cross-matching between the four samples from the later phase, however, would suggest that these timbers were probably derived from a single woodland, with these trees being closely adjacent to each other.

It is likely that the woodland sources for both earlier and later dated timbers was relatively local for, although compared with reference data for all parts of England, the highest levels of similarity between the site chronology and the reference chronologies are found predominantly with sites in Derbyshire (with three other sites in Dronfield producing notably high *t*-values) and the surrounding counties.

The lack of timbers suitable for analysis from truss E, and hence the difference in growth characteristics compared with those associated with the other trusses, could signify that they represent an additional felling phase but this cannot be proven.

## BIBLIOGRAPHY

Arnold, A J, and Howard, R E, 2007 *Tree-ring analysis of timbers from All Hallows' Church, Kirkburton, West Yorkshire*, EH Res Dept Rep Ser, **49/2007**

Arnold, A J, and Howard, R E, 2008 *Primrose Hill House and Barn, Meadowsweet Avenue, Kings Norton, Birmingham; Tree-Ring Analysis of Timbers*, EH Res Dept Rep Ser, **41/2008**

Arnold, A J, and Howard, R E, 2014 *Dronfield Hall Barn, 19 High Street, Dronfield, Derbyshire; Tree-Ring Analysis of Timbers*, EH Res Dept Rep Ser, **18/2014**

Arnold, A J, and Howard, R E, unpubl Dronfield Woodhouse Hall, Carr Lane, Dronfield Woodhouse, Derbyshire; Tree-ring analysis of timbers – Nottingham Tree-ring Dating Laboratory unpubl computer file *DRNBSQ01*

Hey, D, unpubl *Medieval Dronfield*

Hillam, J, 1984 *Tree-ring analysis of timbers from Elland Old Hall, West Yorkshire*, Anc Mon Lab Rep, **4165**

Howard, R E, Laxton, R R, Litton, C D, Morrison, A, Sewell, J, and Hook, R, 1994 List 58 no 11 – Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1992– 93, *Vernacular Architect*, **25**, 41–3

Tyers, I, 2003 *Tree-Ring Analysis of Oak Timbers from a Building on the Lea Road Foundry Site, Church Street, Dronfield, Derbyshire*, Centre for Archaeol Rep, **75/2003**

West Yorkshire Archaeological Services, 2013 *7–12 Church Street, Dronfield* Report No **2654**

## TABLES

*Table 1: Details of tree-ring samples from 7–12 Church Street, Dronfield, Derbyshire*

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
DRN-C01	North blade, truss A	122	h/s	1313	1434	1434
DRN-C02	South blade, truss A	98	h/s	-----	-----	-----
DRN-C03	Collar, truss A	90	h/s	-----	-----	-----
DRN-C04	North purlin, truss A - B	100	15c	1355	1439	1454
DRN-C05	South purlin, truss A - B	70	11c	1382	1440	1451
DRN-C06	North blade, truss B	107	h/s	1315	1421	1421
DRN-C07	South blade, truss B	84	h/s	1347	1430	1430
DRN-C08	Collar, truss B	42	18C	-----	-----	-----
DRN-C09	North blade, truss C	105	h/s	1416	1520	1520
DRN-C10	South blade, truss C	108	h/s	1417	1524	1524
DRN-C11	Collar, truss C	nm	---	-----	-----	-----
DRN-C12	North blade, truss D	86	8	1441	1518	1526
DRN-C13	South blade, truss D	92	h/s	1434	1525	1525
DRN-C14	Collar, truss D	nm	---	-----	-----	-----
DRN-C15	North blade, truss E	44	23c	-----	-----	-----

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

C = complete sapwood is retained on the sample. Where dated, this is the felling date of the tree represented

c = complete sapwood is found on the timber but all or part has been lost from the sample in coring

nm = sample not measured

*Table 2: Results of the cross-matching of site sequence DRNCSQ01 and relevant reference chronologies when the first-ring date is AD 1313 and the last-ring date is AD 1526*

Reference chronology	Span of chronology	<i>t</i> -value	Reference
All Hallows Church, Kirkburton, West Yorkshire	AD 1306–1633	11.1	( Arnold and Howard 2007 )
Dronfield Hall Barn, Dronfield, Derbyshire	AD 1313–1526	10.5	( Arnold and Howard 2014 )
Primrose Hill, Kings Norton, Birmingham	AD 1354–1593	10.5	( Arnold and Howard 2008 )
Lea Road Foundry Site, Church Street, Dronfield, Derbyshire	AD 1344–1526	9.7	( Tyers 2003 )
Elland Old Hall, Calderdale, West Yorkshire	AD 1372–1574	9.7	( Hillam 1984 )
Ughill Manor, Bradfield, South Yorkshire	AD 1349–1504	9.6	( Howard <i>et al</i> 1994 )
Dronfield Woodhouse Hall, Dronfield Woodhouse, Derbyshire	AD 1342–1533	9.6	( Arnold and Howard unpubl )

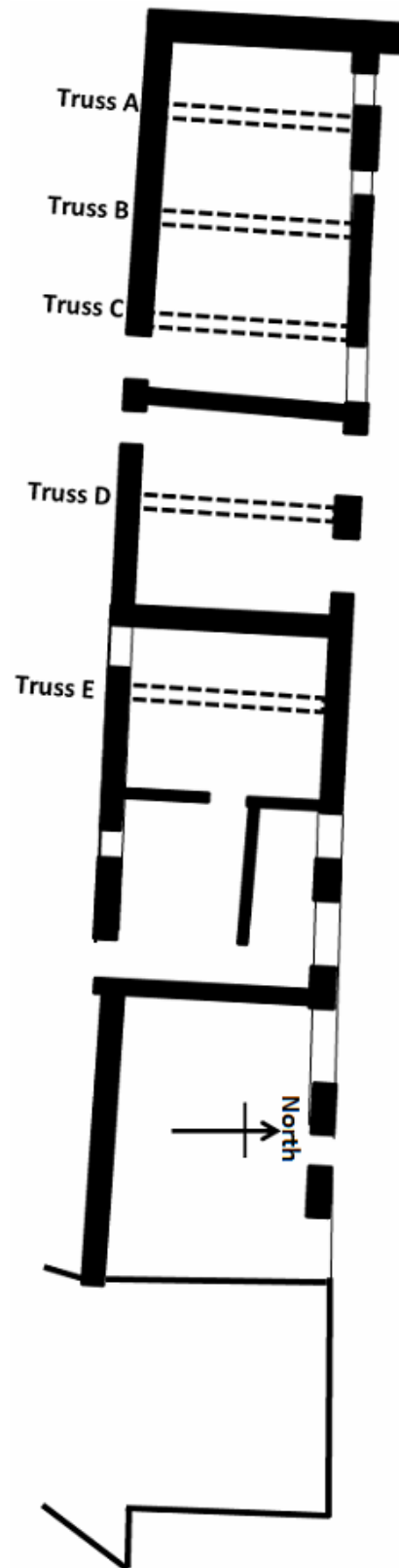
*Table 3: Summary of tree-ring analysis from 7–12 Church Street, Dronfield*

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
DRNCSQ01	9	214	1313–1526
DRNCSQ02	2	110	undated
Ungrouped	2	---	undated
Unmeasured	2	---	-----

## FIGURES



Figure 1: Map to show the location of Dronfield (top) and 7–12 Church Street (bottom) © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

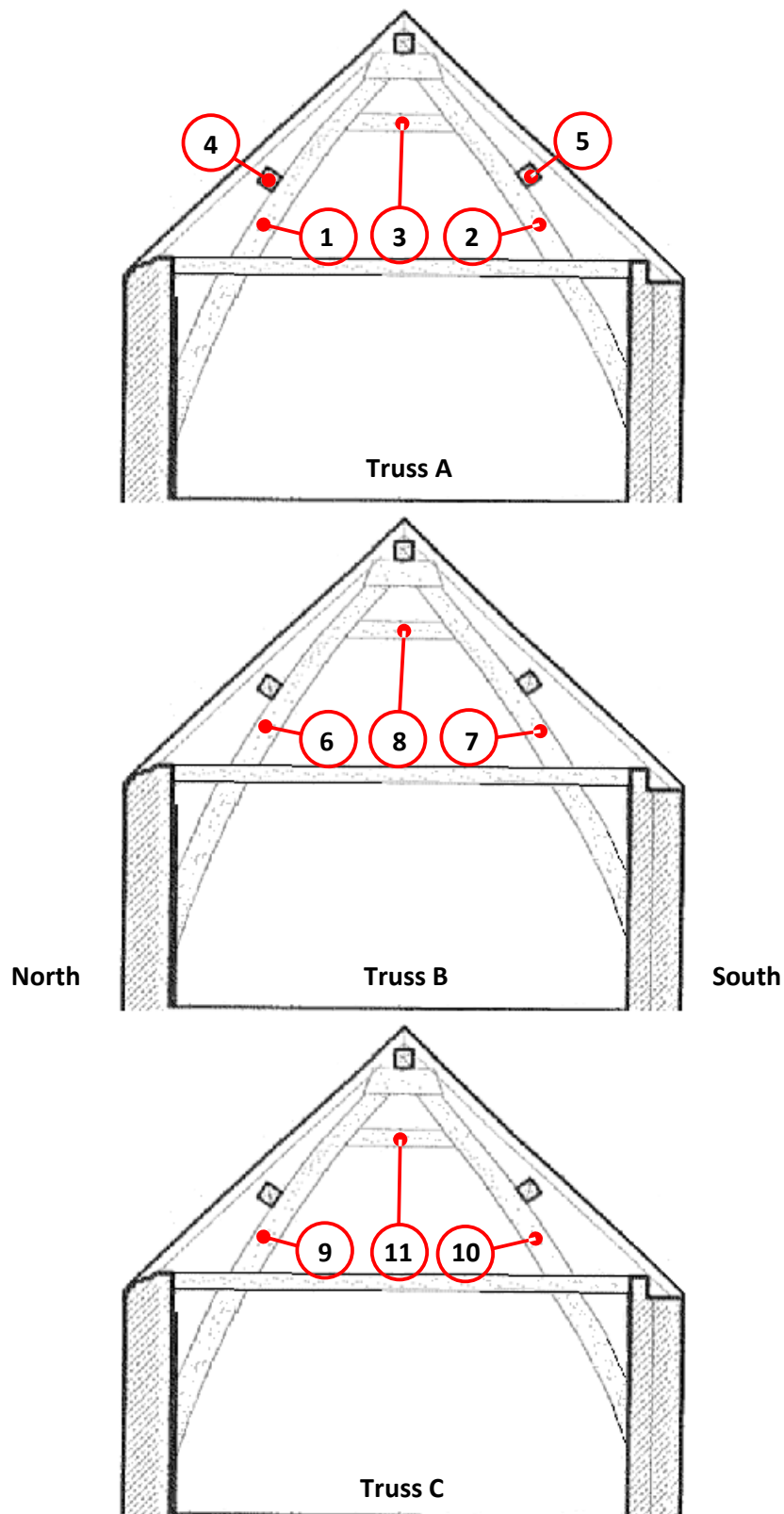


*Figure 2: Simplified ground floor plan of 7-12 Church Street to show layout of the building and the position of the cruck truss (after Elden Minns & Co Ltd, Surveyors)*

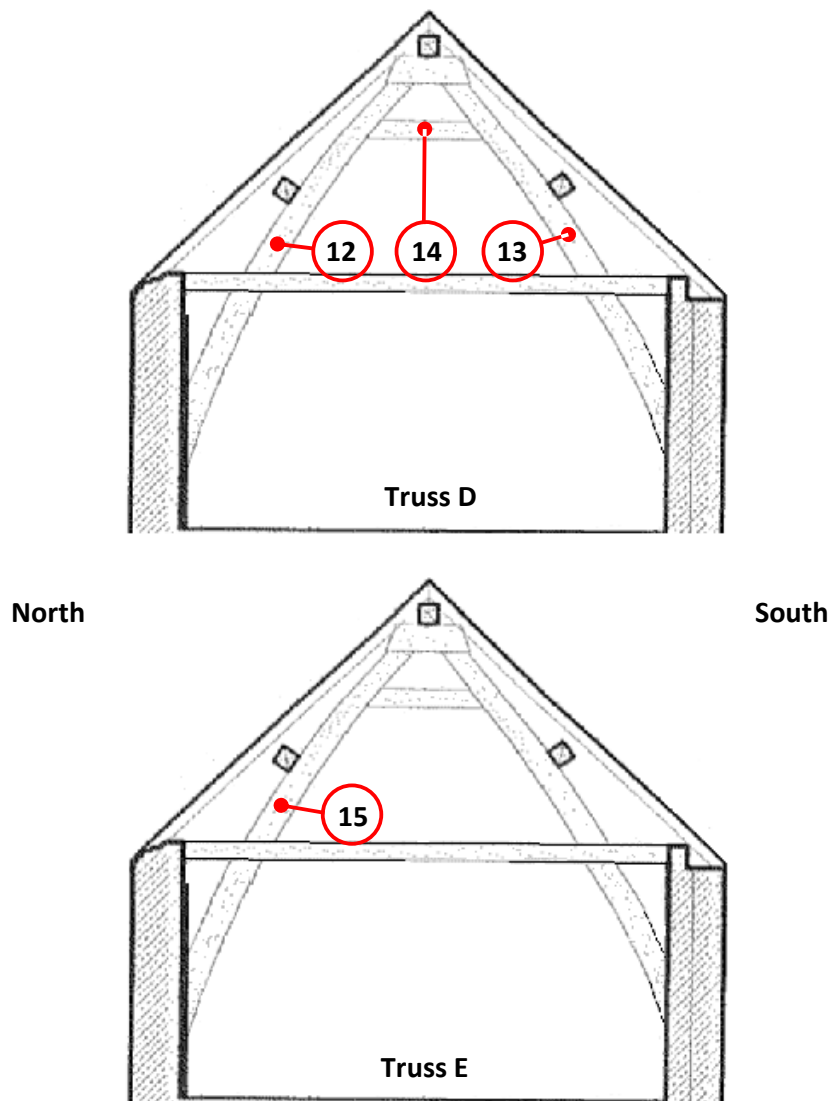


*Figure 3: Views of trusses A, B, and C (top), truss D (middle), and truss E (bottom) (photographs Robert Howard)*

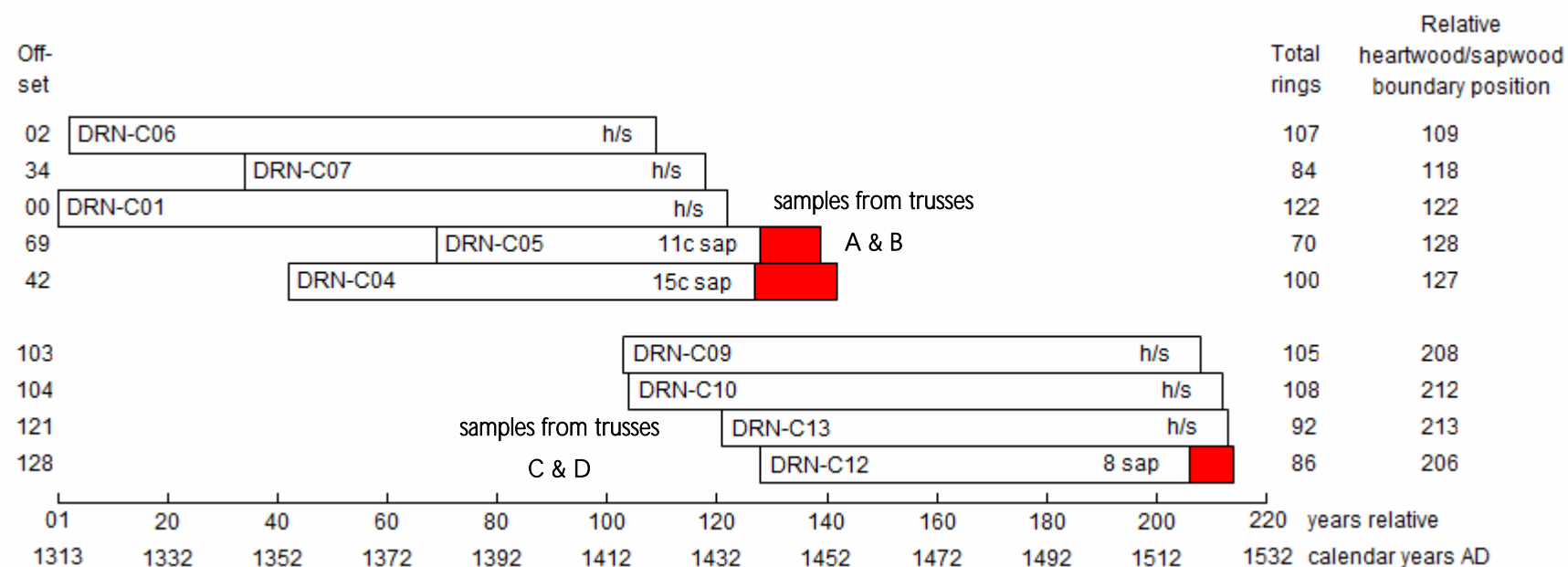




*Figure 4a-c: Representative drawings of the trusses to locate the sampled timbers (after Elden Minns & Co Ltd, Surveyors)*

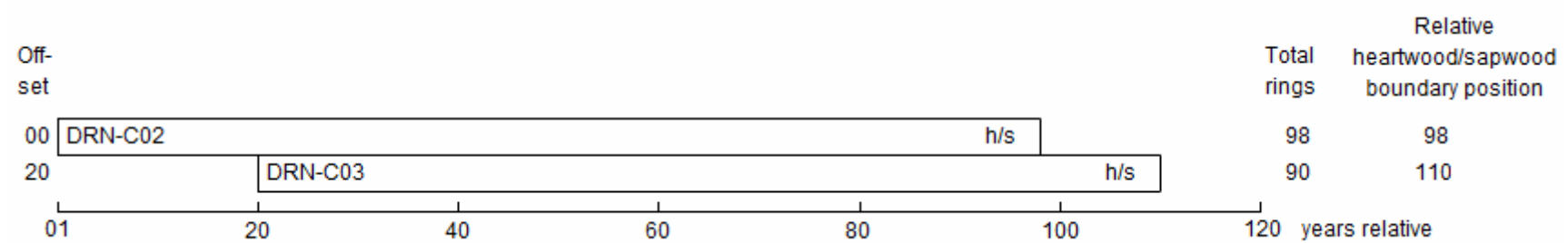


*Figure 4d-e: Representative drawings of the trusses to locate the sampled timbers (after Elden Minns & Co Ltd, Surveyors)*



White bars = heartwood rings, shaded bars = sapwood rings; h/s = heartwood/sapwood boundary; c = complete sapwood is found on the timber but all or part has been lost from the sample in coring

Figure 5: Bar diagram of the samples in site chronology DRNCSQ01



White bars = heartwood rings, h/s = heartwood/sapwood boundary

*Figure 6: Bar diagram of the samples in site chronology DRNCSQ02*

## DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

### DRN-C01A 122

111 105 151 187 230 98 131 92 98 128 242 202 234 136 218 160 159 237 185 226  
221 220 254 181 253 258 157 171 203 171 221 194 239 192 182 185 178 151 209 171  
176 189 148 131 101 127 98 70 84 171 157 178 135 148 113 116 126 106 103 139  
75 123 57 70 96 103 129 59 71 71 79 90 101 153 179 126 109 85 73 170  
190 164 84 114 117 140 121 145 105 122 136 178 153 173 145 155 107 81 82 111  
110 120 115 143 175 137 91 131 102 90 187 125 175 124 72 81 111 119 128 147  
88 118

### DRN-C01B 122

113 128 179 200 221 91 134 87 105 123 245 203 239 132 225 179 145 248 189 207  
221 231 239 182 246 239 157 177 189 178 221 207 242 202 154 189 190 145 195 189  
156 192 143 127 103 108 110 73 81 179 150 153 114 143 110 109 129 108 106 148  
73 127 75 68 95 102 135 73 79 89 70 93 93 149 145 121 117 85 76 162  
204 156 89 129 132 128 128 134 101 118 114 163 146 166 143 150 105 84 82 95  
125 117 106 134 175 159 75 146 101 103 191 134 171 100 60 78 92 112 121 159  
88 123

### DRN-C02A 98

147 274 248 292 359 300 373 378 395 328 387 375 368 314 337 247 245 308 282 241  
213 269 264 204 209 184 120 95 84 73 89 75 137 126 88 83 100 82 96 104  
84 52 103 120 104 96 159 143 84 73 73 79 66 86 73 79 132 128 56 59  
67 75 66 80 57 75 53 82 50 123 93 78 128 154 135 160 151 158 231 215  
162 206 156 127 158 113 130 128 82 90 166 143 116 161 165 157 154 138

### DRN-C02B 98

141 276 242 289 363 299 356 380 387 328 396 371 333 312 332 248 259 342 266 225  
213 276 262 227 233 214 136 90 75 78 85 78 125 132 89 80 97 93 95 95  
85 56 104 115 107 95 150 148 90 69 72 71 67 95 76 71 128 120 57 67  
71 68 65 81 64 64 64 67 76 108 92 67 137 155 138 153 154 145 253 212  
165 197 157 123 158 106 128 135 80 84 174 143 125 159 157 159 150 144

### DRN-C03A 90

250 175 194 228 202 183 167 157 142 117 132 92 96 90 94 85 87 82 77 57  
32 41 58 82 101 100 98 108 89 99 80 91 92 97 91 121 181 110 70 85  
114 116 108 168 207 250 196 219 170 225 162 148 165 129 109 146 112 118 137 115  
87 99 75 56 62 59 53 81 70 65 95 85 87 89 72 93 75 96 103 105  
117 112 92 110 105 91 123 114 104 137

### DRN-C03B 90

252 191 206 242 206 174 169 165 116 96 125 91 91 85 82 80 76 97 70 54  
31 39 74 96 116 117 95 123 96 110 67 79 95 103 94 107 167 102 71 78  
121 104 120 161 191 232 176 192 164 228 166 154 167 143 112 139 141 98 143 115  
100 100 67 57 61 62 60 81 70 66 94 91 81 80 85 82 81 90 90 92  
118 114 91 116 104 92 127 114 93 134

### DRN-C04A 100

266 287 160 204 323 184 157 212 162 142 159 160 148 125 159 162 110 120 124 145  
97 116 157 127 144 78 93 98 96 132 104 123 132 111 120 105 110 93 85 87  
95 85 82 95 64 92 75 99 109 121 112 107 100 84 90 98 81 102 64 63  
53 35 51 43 59 56 73 73 103 78 97 76 92 132 135 132 140 168 110 146  
154 153 132 131 106 148 175 121 159 176 161 104 141 145 135 154 170 140 148 166

### DRN-C04B 100

277 295 164 203 326 175 156 214 184 146 161 171 139 128 160 152 116 118 129 141  
103 118 151 128 132 73 110 98 91 129 100 123 133 114 113 102 100 92 83 87  
101 92 87 86 81 86 88 99 121 126 98 118 95 85 83 101 78 104 61 63  
39 42 42 54 46 66 86 71 105 75 96 79 100 128 137 137 153 162 109 151  
160 153 132 129 112 142 182 117 165 178 154 100 149 142 143 148 175 139 148 165

DRN-C05A 70

128 113 198 167 456 222 104 95 104 104 112 86 100 91 83 82 94 103 135 107  
80 98 132 114 132 96 84 85 90 75 100 99 89 89 84 85 115 75 110 103  
88 96 95 97 82 76 78 86 78 81 81 66 85 91 64 67 82 60 92 130  
95 115 153 145 115 101 109 151 122 185

DRN-C05B 70

130 115 194 166 455 226 100 101 105 92 112 96 98 96 83 93 89 98 132 107  
92 91 126 115 144 88 82 82 93 68 99 99 82 92 82 85 118 71 116 101  
82 101 90 96 77 76 88 78 74 75 96 66 79 88 62 73 76 71 80 132  
116 114 141 130 114 100 110 141 123 185

DRN-C06A 107

475 478 526 437 347 396 514 474 543 350 275 193 358 207 167 250 128 230 263 213  
224 178 215 209 225 198 204 174 179 137 196 142 175 200 199 132 151 145 112 96  
126 156 137 153 78 67 81 117 168 157 150 135 83 110 124 104 89 112 100 114  
89 80 57 78 115 74 81 71 59 52 54 83 112 78 93 68 116 100 100 95  
110 121 98 123 78 90 84 115 98 111 90 131 84 84 96 96 93 105 101 90  
96 110 109 71 54 115 153

DRN-C06B 107

470 425 509 424 424 393 532 463 507 418 267 199 343 221 176 240 123 225 258 217  
221 182 211 215 234 196 207 172 177 139 200 140 187 205 198 131 153 153 106 91  
126 153 139 160 78 62 73 120 164 160 139 129 78 104 132 100 90 117 82 129  
78 81 69 72 93 76 81 68 51 58 55 80 123 87 88 65 128 103 105 90  
99 132 102 106 82 98 88 119 104 98 108 131 98 79 86 112 93 100 103 84  
93 116 106 65 66 117 153

DRN-C07A 84

79 72 67 88 189 217 289 371 324 307 198 362 330 200 203 495 283 331 311 369  
204 221 293 268 224 341 264 321 156 250 242 229 295 179 176 231 203 317 233 342  
281 217 223 153 207 164 187 140 198 220 161 186 174 243 182 287 194 253 181 196  
111 129 212 128 116 207 109 138 143 140 152 200 75 243 200 124 206 148 238 169  
173 156 196 209

DRN-C07B 84

77 68 59 102 182 212 294 376 322 313 193 362 323 205 208 494 287 319 298 379  
207 232 305 260 214 341 275 323 156 253 260 218 300 185 176 219 203 318 239 339  
285 214 223 146 209 159 191 135 189 224 153 181 178 242 190 278 196 268 174 203  
114 137 201 140 133 209 104 131 146 138 153 195 78 240 208 125 205 154 233 173  
171 169 193 206

DRN-C08A 42

369 395 424 383 485 468 378 282 295 243 200 210 187 167 185 178 164 103 162 135  
153 350 482 463 335 292 185 360 282 331 195 248 270 338 178 145 145 299 330 267  
250 410

DRN-C08B 42

373 415 467 432 489 444 352 282 294 262 200 206 183 153 188 167 171 129 143 145  
160 346 496 458 343 271 250 307 292 278 244 256 251 353 178 145 143 307 337 270  
257 398

DRN-C09A 105

595 614 412 314 665 491 350 625 446 559 512 450 396 343 313 328 389 260 229 206  
226 170 209 150 220 207 168 190 246 222 187 242 213 245 223 200 209 185 181 235  
255 212 141 171 243 221 200 184 206 209 205 200 262 203 215 174 170 193 171 306

230 190 175 191 203 284 204 256 240 187 168 248 184 146 162 150 154 139 149 156  
264 150 178 177 114 115 134 128 122 141 160 117 151 168 246 238 181 98 129 141  
128 141 138 150 127

DRN-C09B 105

617 614 397 325 682 505 355 625 453 571 517 478 360 326 292 337 393 253 231 229  
198 165 204 140 217 210 168 195 273 221 182 237 214 243 226 195 218 171 203 221  
233 200 142 181 206 231 177 204 209 199 209 201 273 203 195 178 190 189 211 278  
225 184 187 184 215 268 203 256 241 197 188 234 190 141 161 162 146 132 160 154  
262 161 150 184 112 104 133 121 132 159 131 112 128 174 206 239 167 102 128 133  
140 140 132 159 131

DRN-C10A 108

513 387 293 383 434 327 460 362 363 332 415 486 450 285 323 335 245 226 253 307  
237 304 122 203 126 160 214 214 233 175 207 198 328 292 298 198 189 189 240 351  
256 257 248 276 300 234 237 252 212 221 260 289 265 309 254 246 264 176 321 218  
257 221 180 179 259 259 284 243 261 203 287 271 192 229 175 178 169 222 265 290  
241 231 284 202 202 184 171 148 203 223 225 259 325 261 250 284 228 185 137 238  
179 212 233 180 268 255 181 310

DRN-C10B 108

532 409 290 349 442 320 468 359 356 327 422 500 431 289 316 342 253 220 264 310  
245 281 132 212 135 131 213 217 220 179 195 201 345 293 270 217 195 201 229 339  
265 253 244 277 309 227 237 250 203 228 242 292 281 295 263 252 250 189 316 228  
232 216 181 187 256 240 268 262 240 196 278 268 196 221 174 187 162 216 263 311  
245 243 288 197 203 195 169 162 191 219 225 252 331 275 257 289 222 184 159 216  
175 210 237 180 275 234 195 319

DRN-C12A 86

279 230 318 310 305 213 188 164 346 260 294 245 196 210 236 262 316 217 303 314  
405 316 253 267 229 278 318 340 348 410 278 317 240 235 332 254 365 306 234 243  
210 203 317 309 270 191 334 375 228 321 196 302 296 300 281 325 206 186 292 211  
209 212 192 176 267 276 168 192 256 281 200 181 178 148 170 240 187 184 174 160  
240 167 137 201 190 252

DRN-C12B 86

272 239 311 307 310 200 185 170 350 256 298 246 197 210 221 289 304 229 285 336  
379 322 244 260 210 269 332 326 356 409 281 318 259 241 340 242 350 306 230 280  
201 200 321 301 269 200 328 370 231 318 203 301 303 295 271 329 208 182 300 198  
216 214 217 154 239 283 182 178 258 274 207 176 179 146 174 231 193 178 176 164  
229 149 159 194 185 243

DRN-C13A 92

501 497 432 374 316 186 295 300 181 228 314 217 171 196 275 323 295 307 271 239  
232 339 368 365 273 207 289 267 237 264 226 207 251 229 275 260 290 304 231 228  
176 370 332 257 248 240 215 331 255 342 300 230 256 374 225 209 245 254 225 266  
204 228 317 237 280 347 265 187 190 168 175 200 230 190 238 276 250 153 184 218  
262 258 260 221 190 209 209 206 184 142 158 226

DRN-C13B 92

497 499 456 367 330 198 283 307 176 230 321 221 161 203 269 330 303 296 264 235  
232 322 359 365 259 225 301 254 260 262 220 207 246 226 268 253 306 293 245 233  
184 370 329 254 255 251 215 343 252 334 312 222 257 366 237 201 253 259 227 259  
201 220 326 227 289 339 263 189 196 168 175 200 233 206 218 271 259 140 196 223  
256 262 259 218 186 198 206 217 181 157 159 217

DRN-C15A 44

432 378 321 352 349 314 242 235 284 284 265 242 207 242 278 235 114 63 42 68  
107 96 78 122 117 86 107 103 132 103 110 110 107 126 146 94 92 103 149 114  
151 109 267 225

DRN-C15B 44

423 372 318 359 347 309 220 266 275 300 261 248 204 251 268 237 94 63 49 82  
106 135 95 128 121 80 99 103 128 92 106 112 92 164 129 96 100 103 154 118  
142 135 254 228



## 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 Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (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 complement of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

**5. Estimating the Date of Construction.** As m 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.



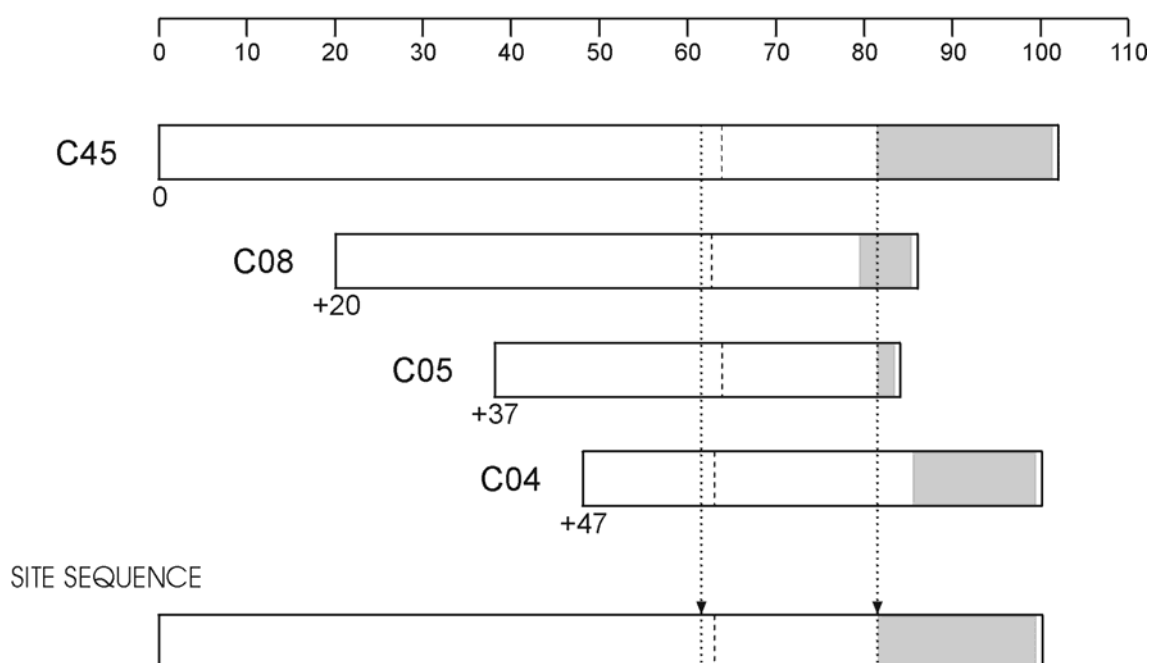
**6. Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and 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.

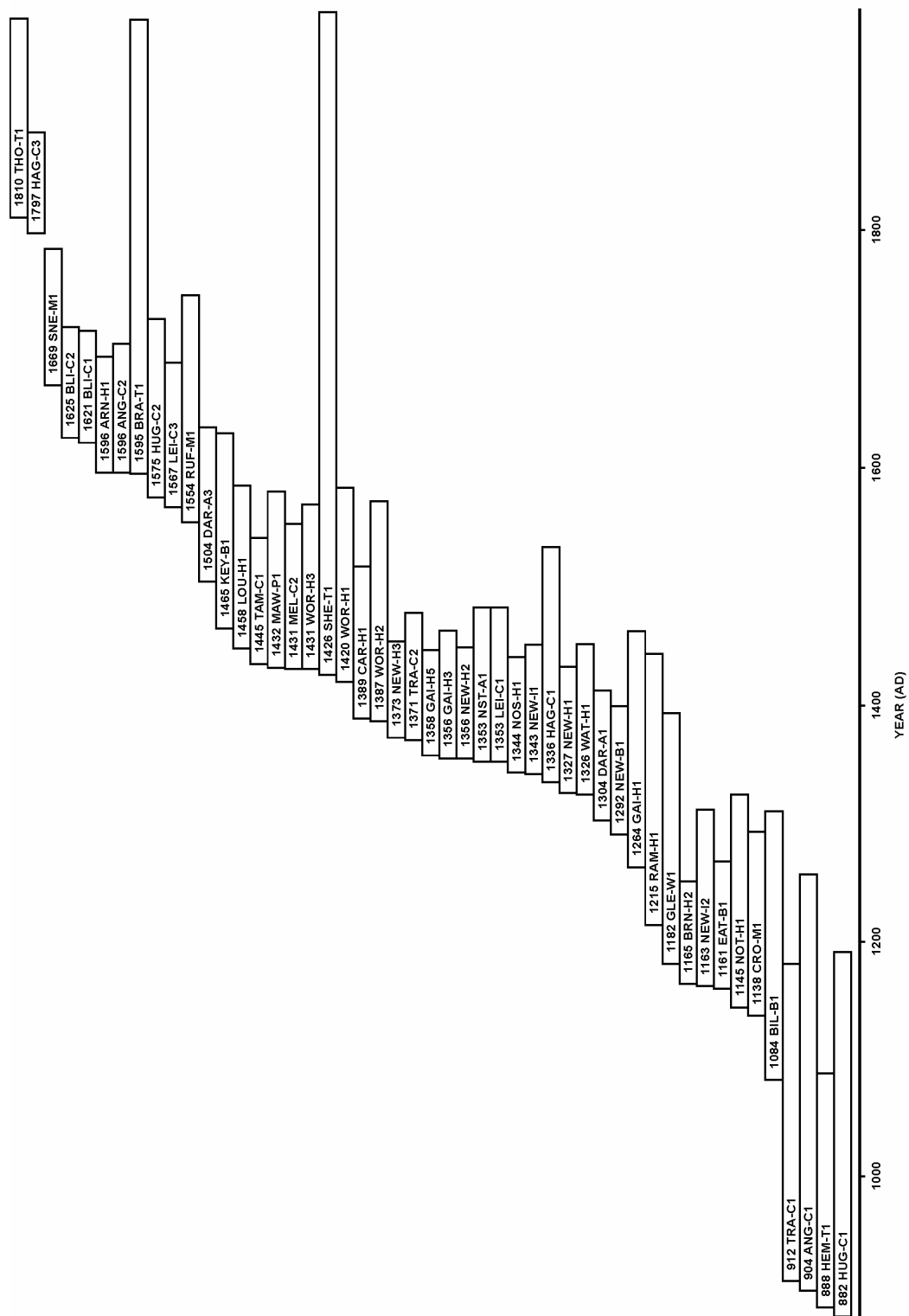
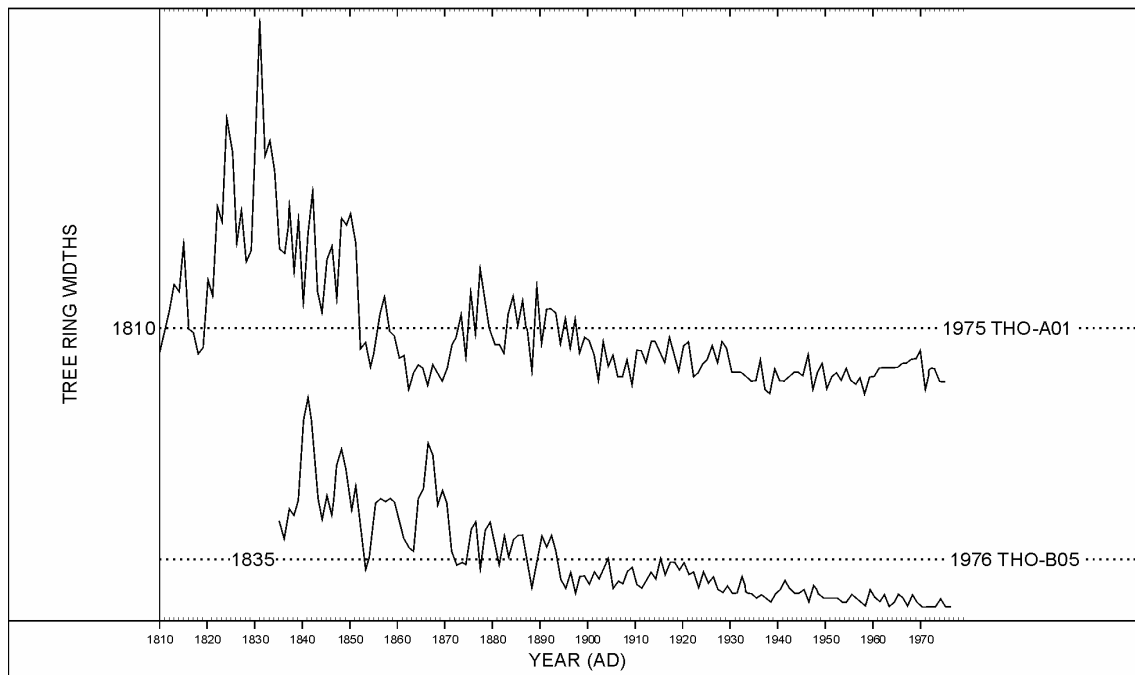
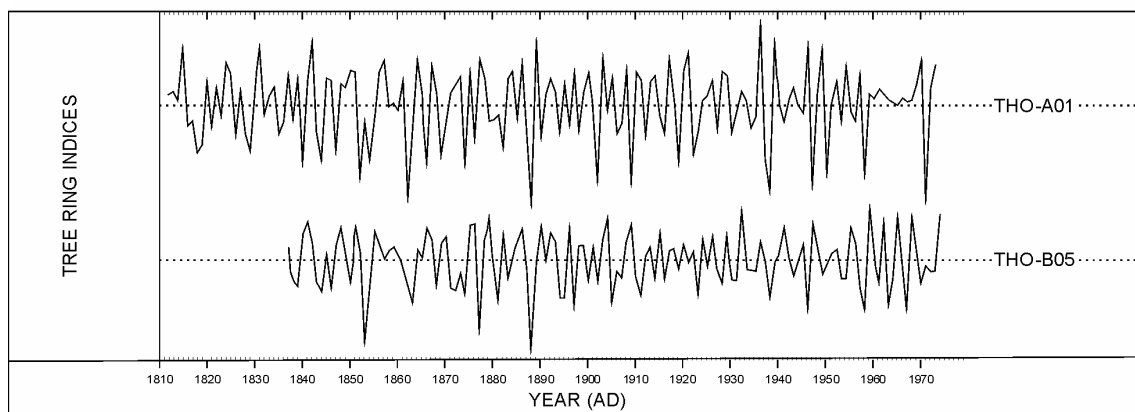


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(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

## References

- Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, **33**, 7–14
- English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London
- Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165–85
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **15–26**
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 17 - Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in the East Midlands, *Vernacular Architect*, **23**, 51–6.
- Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, **8**, 381–90
- Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25–35
- Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III
- Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90–8
- Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7
- Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*, **18**, 29–40
- Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, **28**, 40–56
- Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London
- Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



## ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for the protection and sustainable management of the resource, and to promote the widest access, appreciation and enjoyment of our heritage. Much of this work is conceived and implemented in the context of the National Heritage Protection Plan. For more information on the NHPP please go to <http://www.english-heritage.org.uk/professional/protection/national-heritage-protection-plan/>.

The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

- \* Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
- \* Assessment (including Archaeological and Architectural Investigation, the Blue Plaques Team and the Survey of London)
- \* Imaging and Visualisation (including Technical Survey, Graphics and Photography)
- \* Remote Sensing (including Mapping, Photogrammetry and Geophysics)

The Heritage Protection Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support community engagement and build this in to our projects and programmes wherever possible.

We make the results of our work available through the Research Report Series, and through journal publications and monographs. Our newsletter *Research News*, which appears twice a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on [www.english-heritage.org.uk/researchreports](http://www.english-heritage.org.uk/researchreports)

*For further information visit [www.english-heritage.org.uk](http://www.english-heritage.org.uk)*

