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Tabley Old Hall, Chester Road, Nether Tabley, Knutsford, Chester

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 15-2018

Front Cover: Tabley Old Hall with fallen, decayed, and entangled timbers. Photo: Robert Howard

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TABLEY OLD HALL
CHESTER ROAD
NETHER TABLEY
KNUTSFORD
CHESHIRE

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SUMMARY
Dendrochronological analysis was undertaken on 18 of the 20 samples obtained from timbers associated with the now abandoned and derelict Tabley Old Hall. This analysis produced four site chronologies, TABHSQ01–TABHSQ04, accounting for 11 samples. Only the first site chronology, comprising samples from three timbers, could be dated, its 158 rings spanning AD 1179–1336. Interpretation of the sapwood gives these timbers an estimated felling date range of AD 1351–76. The three other site chronologies are undated. Two other samples were dated individually, TAB-H01 having an estimated felling date in the range AD 1667–92, whilst TAB-H12 has a felled after date of AD 1643. The five remaining measured samples are undated.

CONTRIBUTORS
Alison Arnold, Robert Howard, and Cathy Tyers

ACKNOWLEDGEMENTS
We would firstly like to thank Mr Peter Clifford, Land Agent of Knight Frank for the Crown Estate, for kindly arranging access to Tabley Old Hall. We would also like to thank Simon Taylor, Senior Investigator in the Historic England Historic Places Investigation Team, for his help in arranging sampling, his helpful advice in respect of possible timber phasing, and for supplying photographs and drawings used in this report. We would also like to thank Shahina Farid (Historic England Scientific Dating Team) for commissioning and facilitating this programme of tree-ring analysis.

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CONTENTS

INTRODUCTION

The ruinous remains of Tabley Old Hall are Grade II* listed and are part of the scheduled moated site and gatehouse on the Heritage at Risk register. The remains are located on an island, formerly a peninsula protruding into Tabley Mere, in the parish of Tabley Inferior, approximately 3.5km west-southwest of Knutsford (Figs 1a–c).

The following information is based on the National Heritage List for England (List Entry Numbers 1012354 and 1139011), Hartwell *et al* (2011) and supplemented by information from the investigation by the Historic England Historic Places Investigation team (Rimmer, Taylor and Went 2017).

Tabley Old Hall (Figs 2a/b) was thought to have been built *c* AD 1380 by John Leycester (Leicester), although the estate of Nether Tabley was acquired by the Leycester family in the thirteenth century. Tabley Old Hall originally comprised a timber-framed hall with screens passage and service wing. It was subsequently extended in the sixteenth century, probably by Adam de Leycester, with further alterations being made in the latter half of the seventeenth century, giving the house an E-shaped façade, probably by Sir Peter Leycester. The chapel is thought to be associated with Sir Peter Leycester, whilst the tower was added in the eighteenth century. Further alterations were undertaken during the nineteenth century but the early twentieth century saw the house begin to deteriorate due to severe subsidence resulting from brine extraction beneath the Cheshire plain. The house was abandoned in the 1920s and has further deteriorated to a state of collapse with only parts of the shell of the building still standing (Figs 3a/b).

SAMPLING

A dendrochronological survey was requested by Simon Taylor as part of the investigation of Tabley Old Hall by the Historic England Historic Places Investigation Team aimed at enhancing understanding and hence informing significance and future management of the site. It was hoped that the dendrochronological survey would provide independent dating evidence in relation to the potential late-fourteenth century timber framed structure embedded within the shell of the ruinous seventeenth century structure, as well as for subsequent phases of the development of the building.

The timbers were mostly long-since fallen, possibly moved from their original location, and covered by substantial quantities of building debris, masses of wild undergrowth, and shrubbery. Given the length of time these timbers have lain here, many of them were badly decayed and in some cases completely rotted. However, despite the state of collapse of the building, there were still a few timbers that survived *in situ*, or in some cases, partially so.

The dendrochronological assessment identified that there were timbers suitable for analysis. However, given the decayed nature of the *ex situ* timbers, sampling was only possible by the removal of a complete cross-sectional slice using a chainsaw. Eighteen timbers were sampled in this way. Two *in situ* timbers, deemed safely accessible, were also sampled but these were cored, as is more usual for *in situ* timbers in historic buildings. Each sample was given the code TAB-H and numbered 01–20 (Table 1). The exact original location of the *ex situ* timbers timbers is completely unknown, and in most cases, their actual function can only be surmised. The timbers were photographed as they were sampled, these being shown here as Figures 4a–d.

ANALYSIS, RESULTS AND INTERPRETATION

Each of the 20 samples thus obtained was prepared by sanding and polishing. It was seen at this time that two, TAB-H06 and TAB-H20, had less than the 40 rings deemed necessary for reliable dating here and were therefore, rejected from this programme of analysis. The annual growth ring widths of the remaining 18 samples were, however, measured, this data being given at the end of this report. The 18 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the identification of four groups of cross-matching samples.

Site chronology TABHSQ01

The first group comprises three samples, TAB-H09, TAB-H13, and TAB-H14, these cross-matching with each other as shown in Figure 5a. These three cross-matching samples were combined at their indicated offset positions to form site chronology TABHSQ01, this having an overall length of 158 rings. Site chronology TABHSQ01 was then compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1179 and the date of its last measured ring is AD 1336 (Table 2).

These three samples are clearly broadly coeval but the heartwood/sapwood boundary is found on only one sample (TAB-H13). This heartwood/sapwood boundary is dated AD 1336 which, using the 15-40 (95% confidence interval) ring sapwood estimate, gives the timber represented an estimated felling date range of AD 1351–76. However, the high level of cross-matching between all three samples suggests that these three timbers, two probable tiebeams and one timber of indeterminate function, are coeval.

Site chronology TABHSQ02

The second group also comprises three samples (TAB-H10, TAB-H17, and TAB-H18), representing a timber of indeterminate function and two timbers thought to be either main bridging beams, lintels or joists, these cross-matching with each other as shown in Figure 5b. These three samples were also combined at their indicated offset positions to form site chronology TABHSQ02, this having an overall length of 100 rings. Site chronology TABHSQ02 was also compared to the reference chronologies for oak, but there was no satisfactory cross-dating. However, despite not dating, it can be said that the three timbers represented, are clearly broadly coeval, with the timbers represented by TAB-H17 and TAB-H18 cross-matching with a *t*-value of 10.3 and probably being derived from a single tree.

Site chronology TABHSQ03

The third group also comprises three samples (TAB-H04, TAB-H07, and TAB-H08), representing a main bridging beam or lintel, a joist or lintel, and a brace or strut, these cross-matching with each other as shown in Figure 5c. These three cross-matching samples were again combined at their indicated offset positions to form site chronology TABHSQ03, this having an overall length of 86 rings. However, despite again being compared to the reference chronologies there was no satisfactory cross-dating. It is possible that the three timbers represented are coeval, though this is not certain.

Site chronology TABHSQ04

The fourth and final group comprises two samples (TAB-H15 and TAB-H16), representing a brace or strut and a timber of indeterminate function, these cross-matching with each other as shown in Figure 5d. These two samples were also combined at their indicated offset positions to form site chronology TABHSQ04, this having an overall length of 93 rings. Site chronology TABHSQ04 was also compared to the reference chronologies for oak, but again there was no satisfactory cross-matching and dating. The high level of similarity between these two ring series indicates that it is probable that the two timbers represented are coeval.

Individual ungrouped samples

The seven remaining measured but ungrouped samples were compared with the four site chronologies created, TABHSQ01–TABHSQ04, but there was no further satisfactory cross-matching. Each of these ungrouped samples was then compared individually with the full corpus of oak reference data. This indicated consistent and repeated matches for two of these samples. The 99 rings of sample TAB-H01, probably representing a bridging beam or a tiebeam, span the years AD 1554–1652

(Table 3), whilst the 65 rings of sample TAB-H12, probably representing a tiebeam, span the years AD 1564–1628 (Table 4).

These two dated timbers are clearly broadly coeval but the low level of similarity between the two ring series suggests the possibility that they may have been derived from different woodland sources and hence could potentially represent two different periods of felling activity. Sample TAB-H01 has an estimated felling date range of AD 1667–92, whilst TAB-H12 has a *terminus post quem* for felling of AD 1643.

DISCUSSION AND CONCLUSION

Tree-ring analysis at Tabley Old Hall has successfully dated five of the 18 timbers which were sampled and measured (Fig 6). The three timbers felled in the range AD 1351–76 appear likely to be associated with the primary construction of Tabley Old Hall and may suggest, albeit based on only limited evidence, that this original construction phase could have been slightly earlier than the *c* AD 1380 usually ascribed. Alternatively it is possible that the trees utilised had more sapwood rings than usual or that they were felled and stored for a short period prior to be used in the construction of original building. Two other timbers appear likely to have been felled in the latter half of the seventeenth century and were probably associated with the period of major construction activity at that time.

In some programmes of tree-ring analysis it may be possible to comment in respect of the location of the woodland source for the timbers used in a particular building or phase of construction. In this instance, however, neither the dated site chronology, nor the two individually dated samples, shows a distinct tendency to cross-match with reference chronologies concentrated in any particular locality, though there is a noticeable trend with reference chronologies from other sites in northern and western England (Tables 2, 3, and 4). This, taken with evidence from sites previously examined in the north-west region, suggests that the dated timbers are all likely to have come from relatively local, although potentially disparate, woodland sources.

The disparate nature of these woodland sources is emphasised by the undated material and the variable nature of the cross-matching of the overall assemblage, this latter being a feature noted quite frequently with sites in this general locality. The cross-matching and dating of this assemblage will also have been adversely affected by the presence of periodic bands of very narrow rings in a number of the samples, as opposed to the less sensitive growth patterns seen in the dated samples (Fig 7). These sudden growth suppression events, followed by a period of recovery, mask the general climatic signal required for successful cross-matching and dating. Such growth suppression events may be the result of localised environmental affects or alternatively anthropogenic affects such as woodland management.

Five measured samples (TAB-H02, TAB-H03, TAB-H05, TAB-H11, TAB-H19) remain both ungrouped and undated. While all these samples have sufficient rings for reliable dating purposes (Table 1), several of these (eg TAB-H03) have periodic bands of very narrow rings (Fig 8) which, as indicated above, will hamper successful analysis, whilst TAB-H11 by contrast is unusual within this assemblage of material in having much wider rings and a far more complacent growth pattern (Fig 8). It is also possible, but unproven, that these ungrouped and undated samples may represent different periods of building activity. It should however be noted that it is very common in most programmes of tree-ring analysis to find that some samples remain ungrouped and undated, often for no apparent reason.

REFERENCES

Arnold, A J, Howard R E, Laxton, R R, and Litton, C D, 2001 List 123 no 10 – Nottingham University Tree-ring Dating Laboratory results, *Vernacular Architect*, **32,** 92–8

Arnold, A J, Howard, R E, Laxton, R R, and Litton, C D, 2002 *The Urban Development of Newark-on-Trent, A Dendrochronological Approach,* Centre for Archaeol Rep, **95/2002**

Arnold, A J, Howard, R E, and Litton, C D, 2003 *Tree-ring Analysis of Timbers from Hulme Hall, Allostock, Near Northwich, Cheshire,* Centre for Archaeol Rep, **84/2003**

Arnold, A J, and Howard, R E, 2005 *Tree-ring Analysis of Timbers from the Main Guard, Pontefract Castle, Pontefract, West Yorkshire*, Centre for Archaeol Rep, **48/2005**

Arnold, A J, and Howard, R E, 2007 *Leicester's Gatehouse, Kenilworth Castle, Kenilworth, Warwickshire; Tree-ring Analysis of Timbers*, Centre for Archaeol Rep, **8/2007**

Arnold, A J, and Howard, R E, 2007 unpubl, Tree-ring Analysis of Timbers from Cromford Bridge Hall, Cromford, Derbyshire, Nottingham Tree-ring Dating Laboratory unpubl computer file *CRMBSQ03*

Arnold, A J, Howard, R E, and Litton, C D, 2008 Nottingham Tree-ring Dating Laboratory, additional dendrochronology dates, no 29, *Vernacular Architect*, **39,** 107–11

Arnold, A J, and Howard, R E, 2009 *The Manor House, Hall Green Road, West Bromwich, West Midlands, Tree-ring Analysis of Timbers*, English Heritage Res Dep Rep Ser, **49/2009**

Arnold, A J, and Howard, R E, 2014a *Tonge Hall, Tonge Hall Close, William Street, Middleton, Rochdale, Lancashire, Tree-ring Analysis of Timbers*, English Heritage Res Rep Ser, **43/2014**

Arnold, A J, and Howard, R E, 2014b *Church of St Mary, Stockport, Greater Manchester, Tree-ring Analysis of Timbers from the Vestry Roof*, English Heritage Res Rep Ser, **56/2014**

Arnold, A J, Howard, R E, and Tyers, C, 2016 *Lancaster Castle, Castle Park, Lancaster, Tree-ring Analysis of Oak and Pine timbers in the Keep and Gatehouse*, Historic England Res Rep Ser, **35/2016**

Groves, C, and Hillam, J, 1997 Tree-ring analysis and dating of timbers, in *A multi-period salt production site at Droitwich, Excavations at Upwich* (J D Hurst), CBA Res Rep, **107**, 121-6

Hartwell, C, Hyde, M, and Pevsner, N, 2011 The Buildings of England: Cheshire, 2nd edn

Howard, R E, Laxton, R R, and Litton, C D, 1990 unpubl Tree-ring Analysis of Timbers from Bewsey Old Hall, Bewsey, nr Warrington, Lancashire, Nottingham University Tree-ring Dating Laboratory unpubl computer file *BEWHSQ01*

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 List 57 no 1, Nottingham University Tree-Ring Dating Laboratory, results, *Vernacular Architect*, **25,** 36–40

Howard, R E, Laxton, R R, and Litton, C D, 1997 *Tree-ring Analysis of Timbers from Astley Castle, Warwickshire,* Centre for Archaeol Rep, **83/1997**

Howard, R E, Laxton, R R, and Litton, C D, 1998 *Tree-ring Analysis of Timbers from St Andrew's Church, Owston, Leicestershire*, Anc Mon Lab Rep, **39/1998**

Howard, R E, Laxton, R R, and, C D, 1999 List 96 no 3 Nottingham University Tree-Ring Dating Laboratory, results, *Vernacular Architect*, **30**, 90–1

Howard, R E, Laxton, R R, and Litton, C D, 2000 unpubl, Tree-ring Analysis of timbers from for Rushall Hall Barn, Rushall, Walsall, Nottingham University Tree-Ring Dating Laboratory, unpubl computer file *RSHASQ01*

Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring Analysis of Timbers from Staircase House (30A & 31 Market Place), Stockport, Greater Manchester*, Centre for Archaeol Rep, **12/2003**

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

Nayling, N, 2005 *Tree-Ring Analysis of Timbers from Baguley Hall, Greater Manchester*, Centre for Archaeol Rep, **10/2005**

Rimmer, J, Taylor, S, and Went, D, 2017 *Tabley Old Hall and Moated Site, Nether Tabley, near Knutsford, Cheshire: Architectural and Archaeological Investigation,* Historic England Res Rep Ser, **47/2017**

Tyers, I, 2004 *Dendrochronological spot-dates of samples from the Lamb Hotel (site 11000), Nantwich, Cheshire*, ARCUS Rep, **573v**

Tyers, I, 2005 *Dendrochronological spot-dates of samples from Second Wood Street (site E696), Nantwich, Cheshire*, ARCUS Rep, **573w**

TABLES

Table 1: Details of tree-ring samples from Tabley Old Hall, Chester Road, Nether Tabley, Knutsford, Cheshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
TAB-H01	Main bridging beam or possibly tiebeam	99	h/s	1554	1652	1652
TAB-H02	Main joist	58	h/s	------	------	------
TAB-H03	Lintel	73	no h/s	------	------	------
TAB-H04	Main bridging beam or lintel	75	h/s	------	------	------
TAB-H05	Lintel	167	h/s	------	------	------
TAB-H06	Tiebeam	nm	---	------	------	------
TAB-H07	Joist or lintel	76	h/s	------	------	------
TAB-H08	Brace/strut	80	h/s	------	------	------
TAB-H09	Tiebeam	119	no h/s	1179	------	1297
TAB-H10	Indeterminate	96	no h/s	------	------	------
TAB-H11	Main beam	74	no h/s	------	------	------
TAB-H12	Tiebeam	65	no h/s	1564	------	1628
TAB-H13	Indeterminate	118	h/s	1219	1336	1336
TAB-H14	Tiebeam	113	no h/s	1185	------	1297
TAB-H15	Brace/strut	56	h/s	------	------	------
TAB-H16	Indeterminate	90	no h/s	------	------	------
TAB-H17	Main beam/lintel/joist	100	no h/s	------	------	------
TAB-H18	Main beam/lintel/joist	81	no h/s	------	------	------
TAB-H19	North (RH) ground floor window lintel	68	h/s	------	------	------
TAB-H20	Wall beam, wall adjacent to front entrance	nm	---	------	------	------

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

Table 2: Results of the cross-matching of site sequence TABHSQ01 and relevant reference chronologies when the first-ring date is AD 1179 and the last-ring date is AD 1336

Reference chronology	Span of chronology	*t*-value	Reference
Baguley Hall, Greater Manchester	AD 1015 – 1390	7.8	(Nayling 2005)
Gatehouse, Kenilworth Castle, Warwickshire	AD 1092 – 1332	7.7	(Arnold and Howard 2007)
Angel Choir, Lincoln Cathedral, Lincoln	AD 904 – 1257	7.6	(Laxton and Litton 1988)
Lancaster Castle, Castle Park, Lancaster	AD 950 – 1404	7.6	(Arnold *et al* 2016)
Manor House, West Bromwich, West Midlands	AD 1107 – 1269	7.2	(Arnold and Howard 2009)
Second Wood Street, Nantwich, Cheshire	AD 932 – 1506	6.6	(Tyers 2005)
Lamb Hotel, Nantwich, Cheshire	AD 941 – 1276	6.2	(Tyers 2004)
Old Hall, Bewsey, nr Warrington, Lancashire	AD 1117 – 1362	5.8	(Howard *et al* 1990 unpubl)

Table 3: Results of the cross-matching of sample TAB-H01 and relevant reference chronologies when the first-ring date is AD 1554 and the last-ring date is AD 1652

Reference chronology	Span of chronology	*t*-value	Reference
Cromford Bridge House, Cromford, Derbyshire	AD 1550 – 1662	8.6	(Arnold and Howard 2007 unpubl)
Tonge Hall, Rochdale, Lancashire	AD 1449 – 1687	7.4	(Arnold and Howard 2014a)
Hulme Hall, Allostock, Cheshire	AD 1574 – 1689	6.2	(Arnold *et al* 2003)
Rushall Hall Barn, Rushall, Walsall, West Midlands	AD 1510 – 1672	6.2	(Howard *et al* 2000 unpubl)
Cheddleton Grange, Cheddleton, Staffordshire	AD 1551 – 1682	5.7	(Arnold *et al* 2008)
Staircase House, Stockport, Greater Manchester	AD 1489 – 1656	5.5	(Howard *et al* 2003)
Sinai House, Burton on Trent, Staffordshire	AD 1555 – 1665	5.5	(Howard *et al* 1999)
Church of St Mary, Stockport, Greater Manchester	AD 1510 – 1623	5.3	(Arnold and Howard 2014b)

Table 4: Results of the cross-matching of sample TAB-H12 and relevant reference chronologies when the first-ring date is AD 1564 and the last-ring date is AD 1628

Reference chronology	Span of chronology	*t*-value	Reference
St Andrew's Church, Owston, Leicestershire	AD 1485 – 1611	5.9	(Howard *et al* 1998)
Main Guard, Pontefract Castle, West Yorkshire	AD 1507 – 1656	5.7	(Arnold and Howard 2005)
Upwich, Droitwich, Worcestershire	AD 1454 – 1651	5.6	(Groves and Hillam 1997)
Sinai House, Burton on Trent, Staffordshire	AD 1555 – 1665	5.4	(Howard *et al* 1999)
Astley Castle, Warwickshire	AD 1495 – 1627	5.3	(Howard *et al* 1997)
5 Church Street, Newark, Nottinghamshire	AD 1403 – 1655	5.2	(Arnold *et al* 2002)
Yews Farmhouse, Styrrup, Nottinghamshire	AD 1548 – 1656	5.1	(Arnold *et al* 2001)
Moor Farm Cottage, Shardlow, Derbyshire	AD 1437 – 1616	5.1	(Howard *et al* 1994)

FIGURES

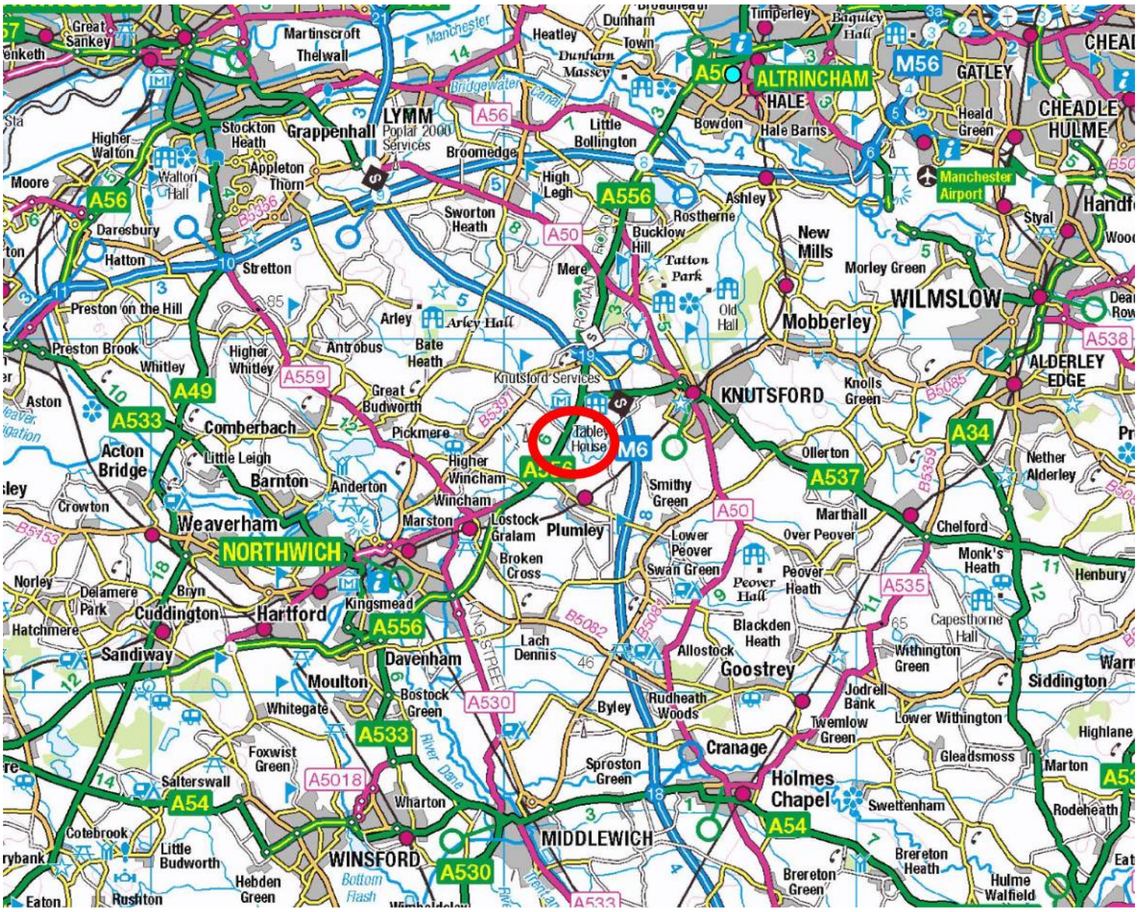


Figure 1a: Map to show the general location of Nether Tabley, Knutsford, Cheshire (red ellipse). © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

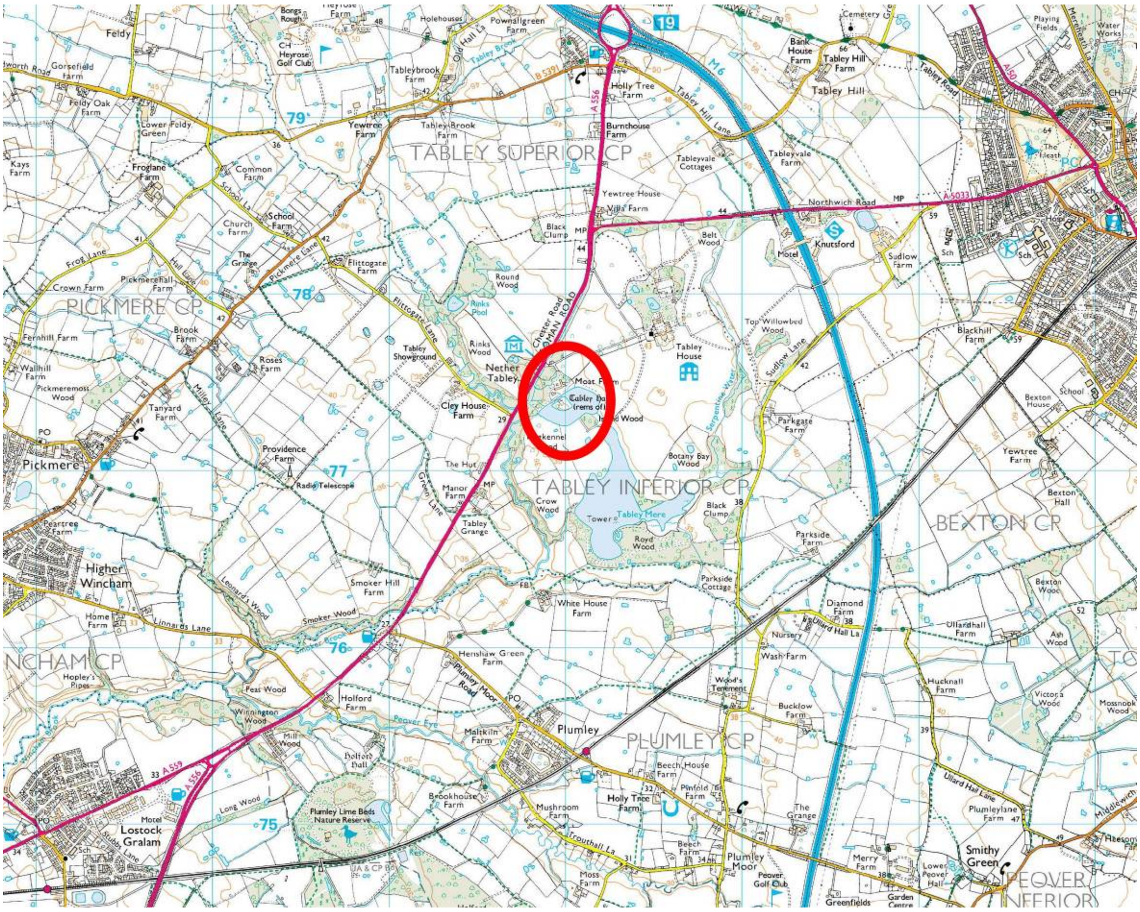


Figure 1b: Map to show the general location of Tabley Old Hall, Nether Tabley, Knutsford, Cheshire (red ellipse). © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

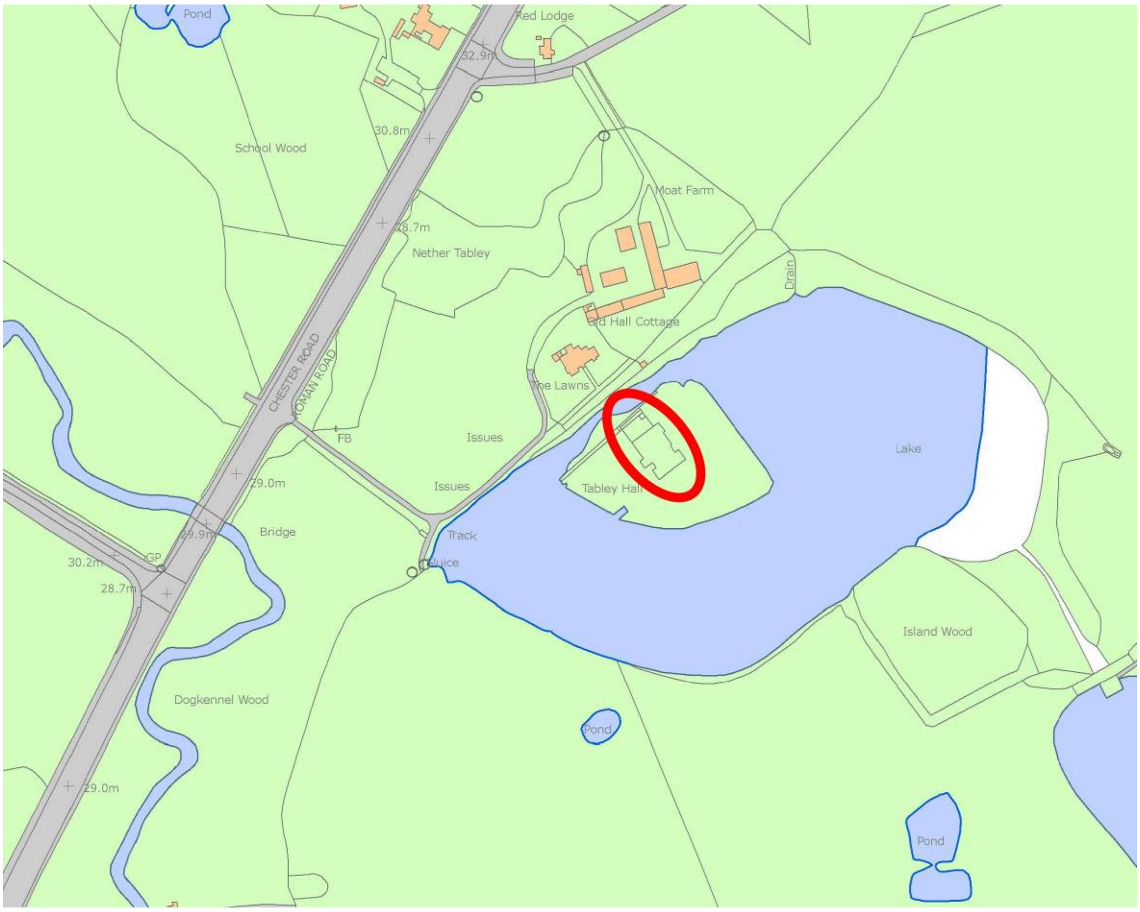


Figure 1c: Map to show the detailed location of Tabley Old Hall, Nether Tabley, Knutsford, Cheshire (red ellipse). © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2a: External view of Tabley Old Hall as it once was (© The Tabley House Collection, University of Manchester)

Figure 2b: Internal view of Tabley Old Hall as it once was (© The Tabley House Collection, University of Manchester)

Figure 3a: View of the building with its fallen, decayed, and entangled timbers as it now appears (photograph Robert Howard)

Figure 3b: Views of the fallen, decayed, and entangled timbers as it they now appear (photograph Robert Howard)

Figure 4a: Annotated photographs to help locate sampled timbers (photographs Robert Howard)

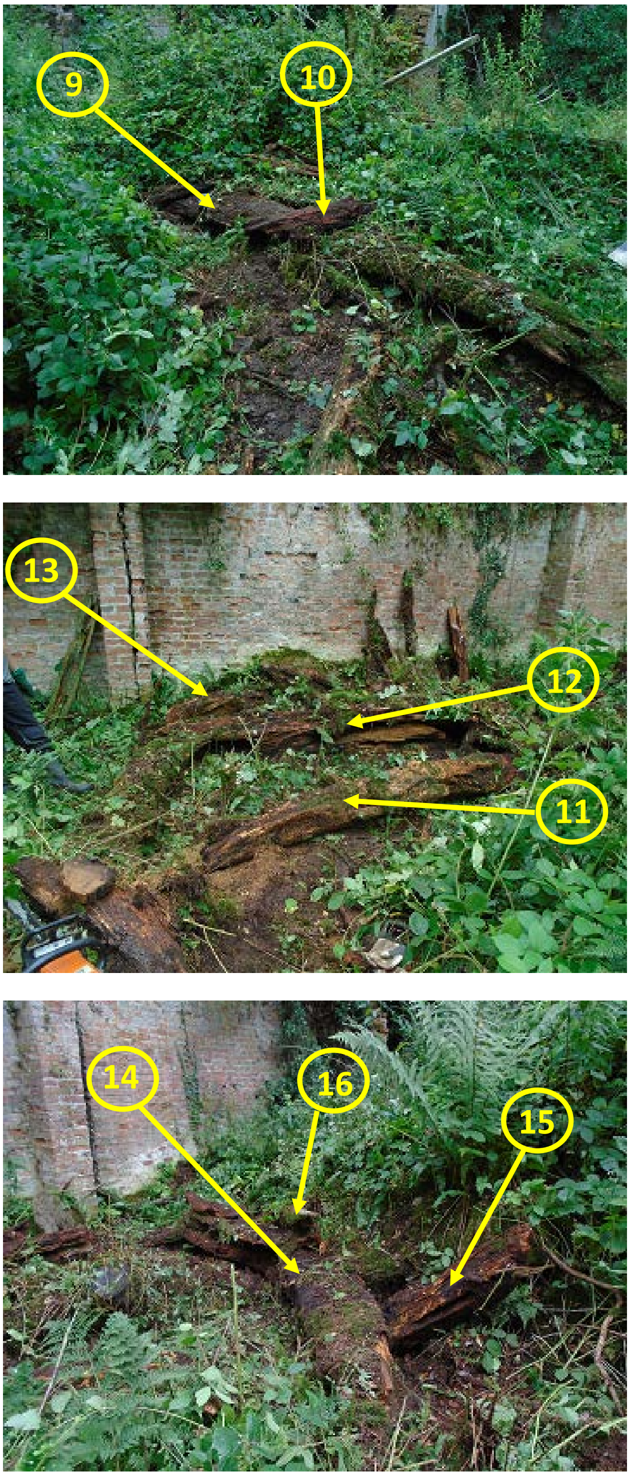
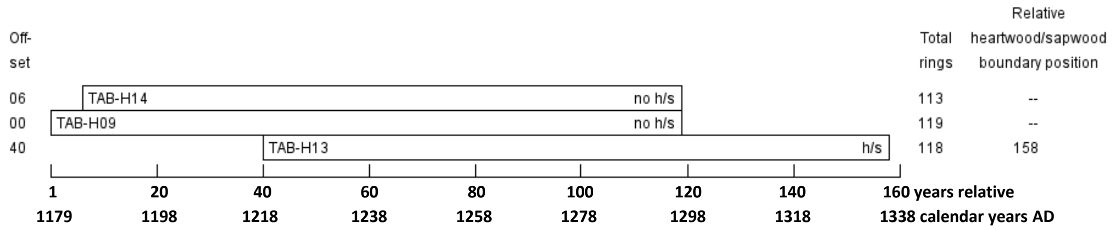


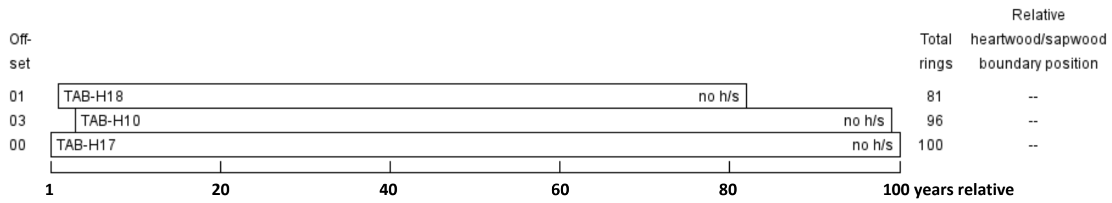
Figure 4b: Annotated photographs to help locate sampled timbers (photographs Robert Howard)

Figure 4c: Annotated photographs to help locate sampled timbers (photographs Robert Howard)

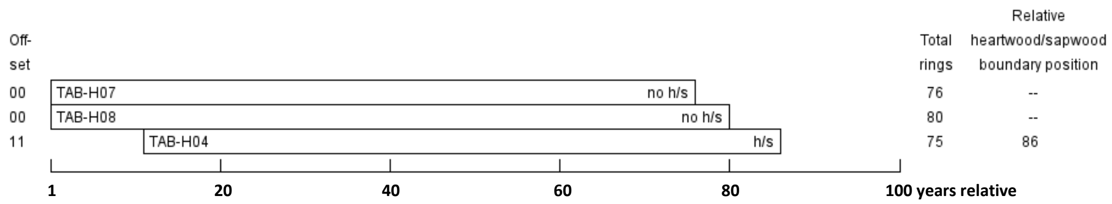
Figure 4d: Annotated photograph to help locate sampled timber (photograph Robert Howard)



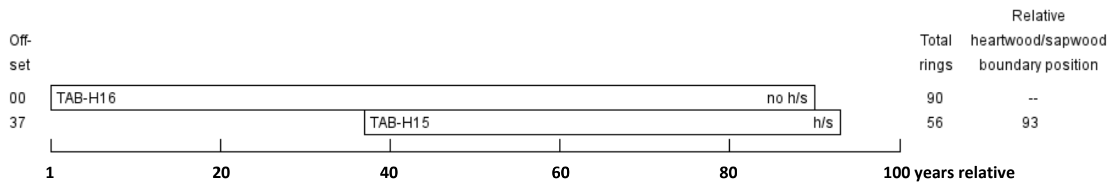
TABHSQ01



TABHSQ02



TABHSQ03



TABHSQ04

Figures 5a - 5d: Bar diagrams of cross-matching samples in site chronologies TABHSQ01 - TABHSQ04

Key: white bars = heartwood rings; h/s = heartwood/sapwood boundary

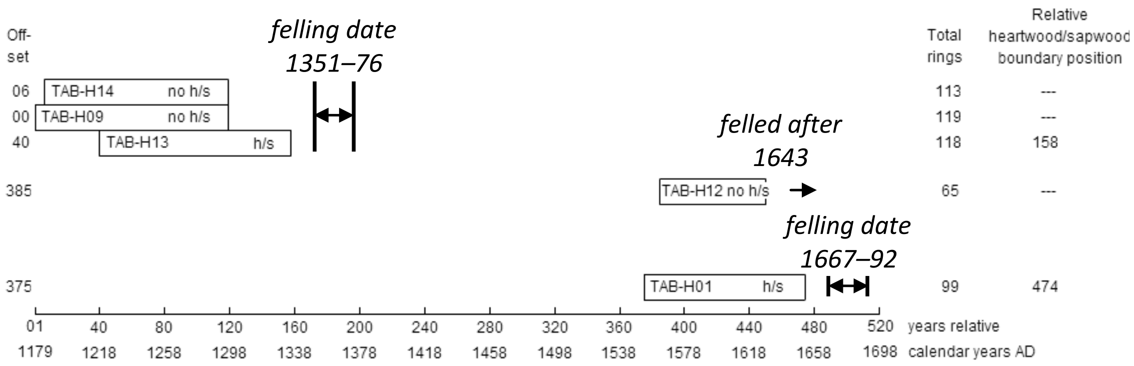


Figure 6: Bar diagram of all five dated samples showing felling date ranges

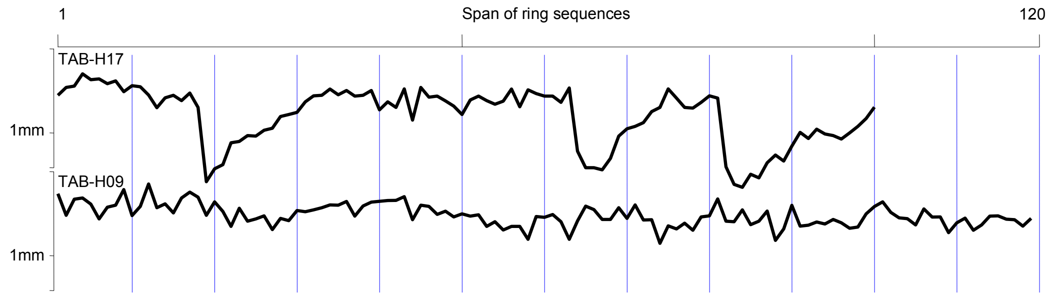


Figure 7: The ring width series for the undated sample TAB-H17, which shows three growth suppression events, and the dated sample TAB-H09, which shows no sudden changes in growth rate

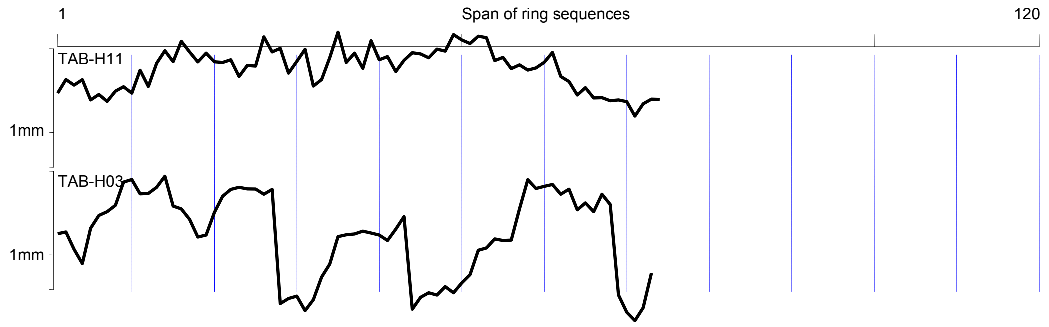


Figure 8: The ring width series for the undated and ungrouped sample TAB-H11, which shows the fast rate of growth and relative complacency, and the undated and ungrouped sample TAB-H03 which shows three growth suppression events

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

TAB-H01A 99
216 148 75 107 195 215 292 187 227 193 260 280 242 204 246 288 384 318 250 231
210 126 138 121 186 250 288 181 131 158 202 210 212 234 228 243 180 172 179 256
265 239 137 59 90 93 126 162 132 118 151 150 228 231 198 177 214 200 184 201
150 179 135 98 153 175 223 215 247 177 184 184 160 164 153 201 122 137 141 125
119 112 95 123 120 85 73 64 56 60 74 94 145 128 140 143 146 135 135
TAB-H01B 99
222 156 70 102 176 188 251 182 215 178 266 294 232 202 229 290 358 292 251 217
231 130 140 115 178 282 310 196 129 165 203 225 206 209 226 250 160 168 173 260
245 229 132 54 73 100 123 148 124 109 131 134 196 201 207 179 192 185 171 195
173 182 142 101 165 176 206 206 254 196 173 172 174 153 156 189 122 134 134 142
109 110 83 115 121 87 81 65 52 65 68 96 153 128 147 165 133 137 140
TAB-H02A 58
400 447 384 408 244 185 125 188 253 312 268 170 180 126 91 91 100 141 142 192
232 226 250 238 236 166 150 148 114 70 66 104 112 228 217 142 145 266 335 319
335 265 143 60 47 43 43 45 82 112 90 65 81 167 222 260 204 182
TAB-H02B 58
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295 254 260 227 272 176 170 172 98 77 59 84 104 201 251 184 154 234 335 284
294 221 150 59 49 42 42 46 85 112 91 64 82 167 221 264 198 187
TAB-H03A 73
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375 304 334 225 259 218 316 258 48 32 28 41 71
TAB-H03B 73
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92 93 130 150 131 153 161 140 150 165 221 198 200 106 188
TAB-H04B 75
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TAB-H05A 167
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70 76 66 103 91 89 153 185 145 67 46 39 42 57 40 37 44 54 64 64
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55 59 62 68 84 52 59 74 56 71 60 80 68 38 40 43 35 60 65 81
87 80 104 99 112 98 103 68 100 81 59 118 128 92 81 106 121 84 76 63
43 35 50 70 75 73 64 84 68 100 91 95 72 81 82 99 100 59 49 62
53 69 78 73 117 92 84
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140 112 69 70 84 110 145 125 105 128 115 109 132 71 81 76 65 60 79 78
65 78 64 107 87 93 152 181 137 81 46 34 48 57 37 39 41 51 65 73
78 51 63 46 42 47 71 96 98 89 82 86 65 50 28 28 48 62 80 73
53 53 66 73 72 70 61 77 67 62 69 67 60 46 35 37 43 59 68 80
93 77 105 105 113 98 95 67 103 84 56 97 117 101 112 94 117 82 68 68
37 34 51 64 66 78 82 85 75 77 110 99 68 82 78 96 103 50 45 62
50 64 82 83 109 92 81
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39 45 46 59 77 82 93 101 110 139 110 151 109 40 44 48 59 79 65 95
123 100 96 89 135 114 129 148 112 114 60 59 31 36 48 44
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TAB-H08A 80
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TAB-H08B 80
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TAB-H09B 119
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211 186 132 192 243 233 202 196 251 204 253 195 200 134 171 165 185 157 206 207
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TAB-H10A 96
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TAB-H10B 96
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99 135 182 100 79 88 99 140 161 171 218 183 158 179 157 159 117 170 132 182
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TAB-H11A 74
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413 324 379 439 412 406 471 451 628 568 556 637 596 389 388 297 353 336 322 378
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TAB-H11B 74
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TAB-H12A 65
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135 206 204 247 228
TAB-H12B 65
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TAB-H13A 118
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TAB-H13B 118
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TAB-H14A 113
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TAB-H14B 113
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TAB-H15B 56
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121 100 137 123 128 150 147 191 153 136
TAB-H17A 100
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TAB-H17B 100
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TAB-H18A 81
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159 228 128 271 328 242 198 167 110 160 220 232 228 156 201 200 204 218 225 218
218 232 60 51 54 50 67 100 107 87 90 111 100 100 123 144 150 112 98 128
58

TAB-H18B 81
238 215 342 205 234 209 190 219 213 218 159 147 144 173 193 192 180 57 68 74
87 107 124 149 155 171 220 250 266 261 216 237 216 192 221 200 201 240 195 167
179 221 142 275 351 234 202 144 138 148 218 223 239 156 212 210 198 228 182 219
225 229 56 54 59 56 62 85 98 102 84 111 86 108 127 143 150 111 99 126
58
TAB-H19A 68
474 569 413 521 476 630 376 508 535 303 414 277 369 230 216 166 201 254 218 263
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160 168 153 157 191 197 179 208 206 200 129 143 177 201 200 162 127 115 161 89
110 83 104 84 118 117 85 130
TAB-H19B 68
475 570 406 522 478 623 363 507 535 299 416 277 368 232 217 158 198 258 205 264
237 165 187 198 115 111 176 118 130 131 154 174 118 77 102 142 190 403 252 266
148 178 151 155 199 184 188 203 204 198 128 161 180 198 203 155 142 117 145 95
110 81 119 88 120 118 93 110

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 DatingLaboratory'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	

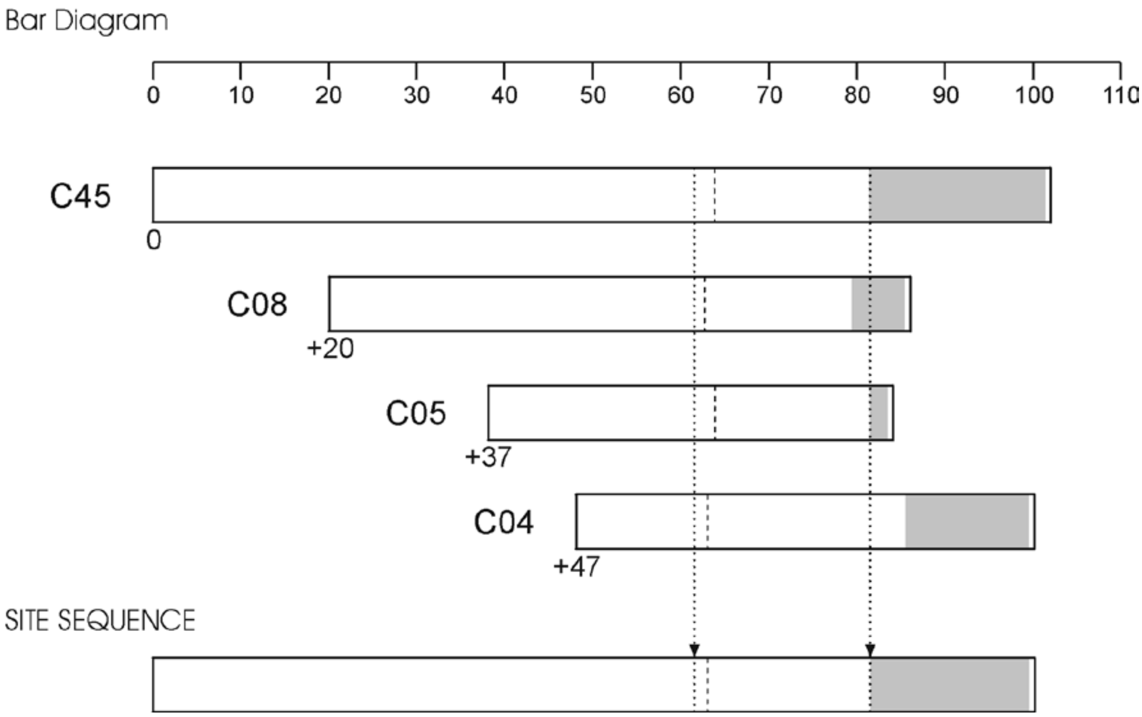


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

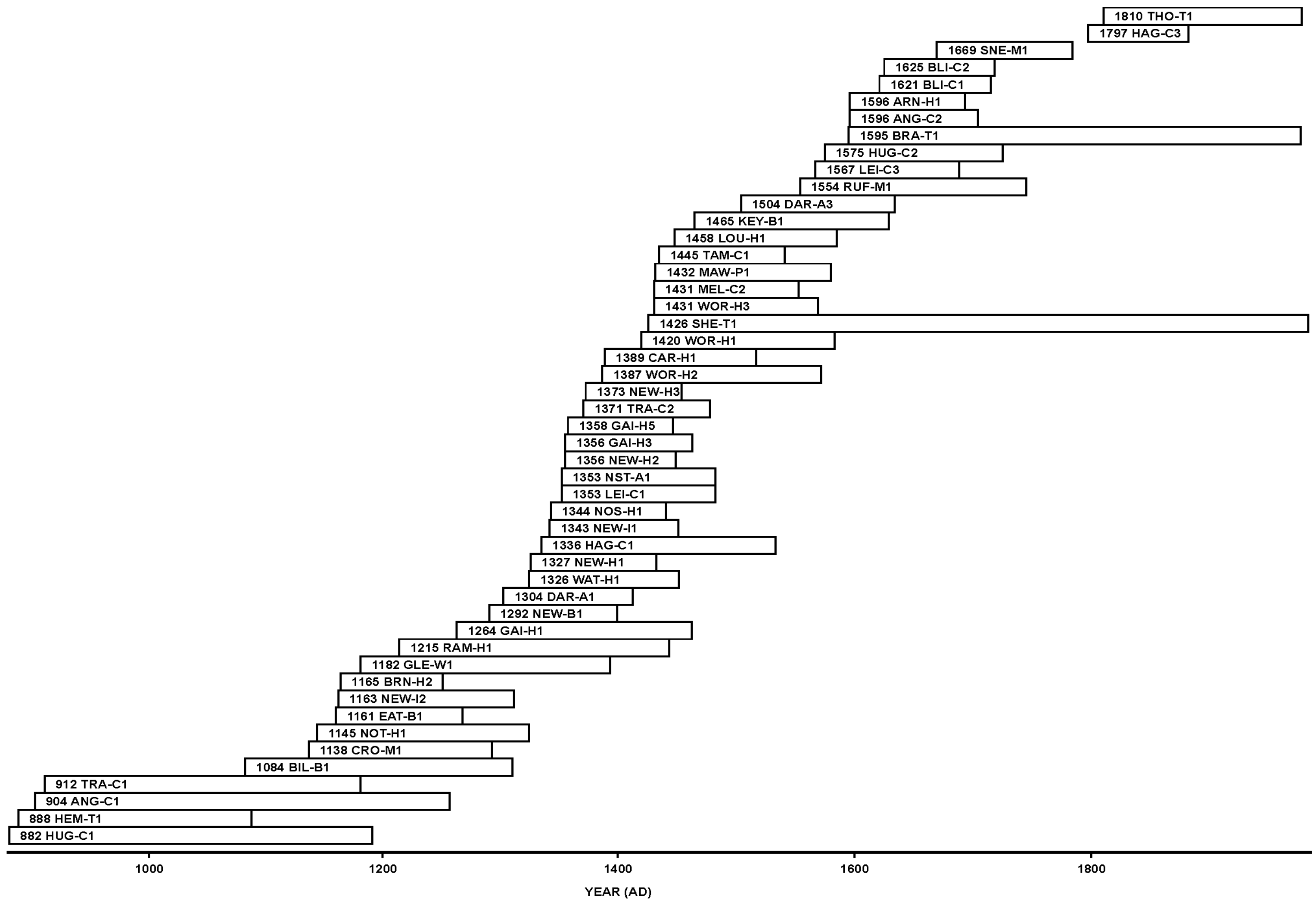
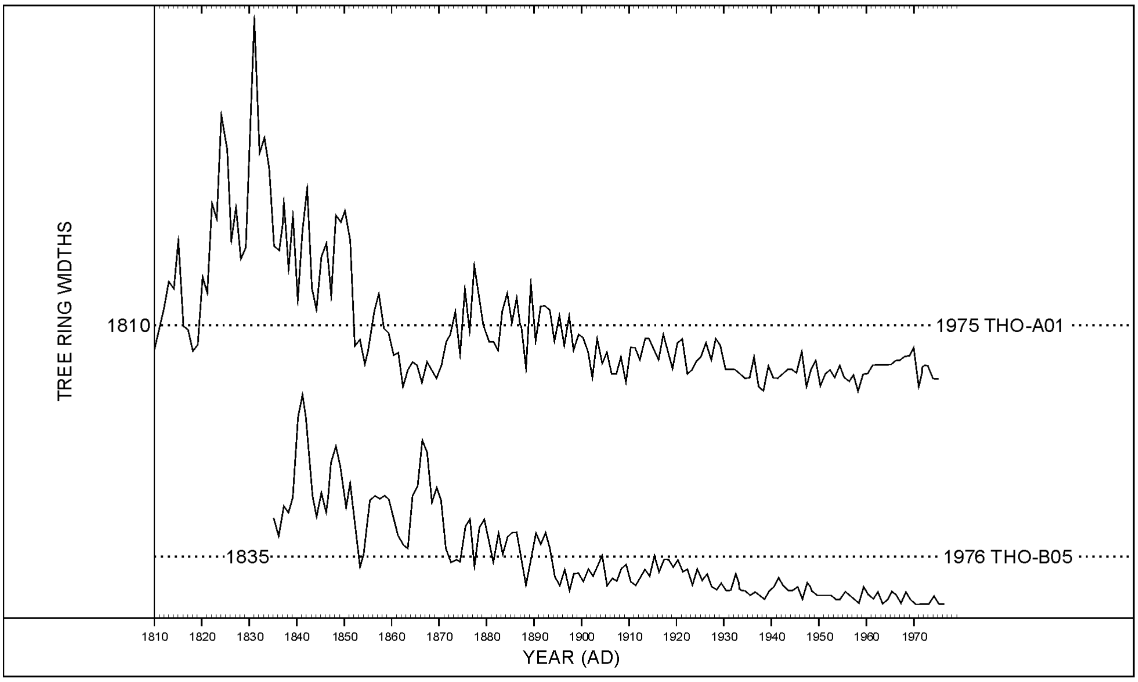


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

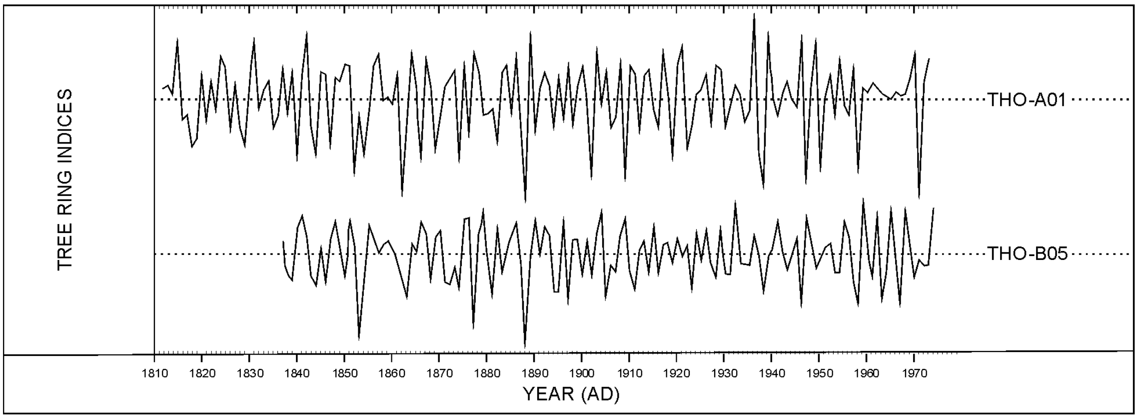


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

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.

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

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