RESEARCH DEPARTMENT REPORT SERIES no. 72-2010 ISSN 1749-8775

ST FIRMIN CHURCH, THURLBY, LINCOLNSHIRE
TREE-RING ANALYSIS OF TIMBERS OF THE BELLFRAME AND TOWER

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 72-2010

ST FIRMIN CHURCH, THURLBY, LINCOLNSHIRE

TREE-RING ANALYSIS OF TIMBERS OF THE BELLFRAME AND TOWER

Alison Arnold and Robert Howard

NGR: TF 10503 16800

© English Heritage

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.
Many of these are interim reports which 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 Department 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

Samples were taken from the dismantled bellframe and supporting beams, and from *in-situ* tower timbers. All 12 bellframe samples grouped and were combined to form THUBSQ01, a site sequence of 194 rings. This was found to span the period AD 1599–1792, with the timbers represented all probably being felled in AD 1792.
Only one of the supporting beams could be dated, to a felling of AD 1455. Little can be deduced from a single sample as it is unclear whether it is reused, primary, or inserted.
Three of the lower *in-situ* timbers, all corbels, grouped to form a site sequence, THUBSQ03, which has a last-measured ring date of AD 1547. These samples have *termini post quos* of AD 1540, AD 1555, and AD 1562.
Two further site sequences are undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank the Captain of the Bells, Terry Madison, for arranging access to the tower timbers and Roger Osborne for agreeing to slices being taken from the dismantled bellframe. George Dawson kindly met with the Laboratory personnel on site to discuss the bellframe and sourced sketch drawings which had been produced some years ago when the bellframe was still *in-situ*. Thanks are also given to the Scientific Dating Section at English Heritage and Cathy Tyers of the Sheffield University Dendrochronology Laboratory for their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

Lincolnshire Historic Environment Record
Planning and Conservation Group
Lincolnshire County Council
City Hall
Beaumont Fee
Lincoln LN1 1DN

DATE OF INVESTIGATION

2009–10

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

The parish church of St Firmin is located in the Lincolnshire village of Thurlby (Figs 1 and 2; TF 10503 16800). It is thought to have had its origins in the eleventh century, with work being undertaken in the twelfth, thirteenth, fourteenth, and fifteenth centuries, as well as being restored in AD 1856. It consists of a three-stage tower with fourteenth-century spire, clerestoried nave, chancel, aisles, transepts, north and south chapels, and porches (www.lbonline.english-heritage.org.uk).

Bellframe and supporting beams

The bellframe was removed from the tower in late 2009 in order for a new metal frame to be installed. The timbers of the frame and the six supporting beams upon which it had sat were given to a local farmer, Roger Osborne, and when seen by the Laboratory were residing on a trailer.

From sketches found by George Dawson and from looking at the timbers it is possible to reconstruct the original form of the frame. It had five bells, hung in four pits: three parallel pits orientated north-south and a transverse pit across the north end of the other pits (Fig 3). The main trusses consisted of sill, long head, and braces which ran from sill to head. This frame sat upon six longitudinal beams which spanned the tower east-west (Fig 4).

In-situ timbers

These can be divided into lower and upper timbers (Fig 4). The lower timbers consist of six north-south beams, two of which are supported on posts and corbels and have braces from beam to post (Fig 5). The upper timbers consist of two east-west beams, supported on posts and with a brace running between the post and the beam. One of these trusses is against the north wall and one against the south wall (Fig 6).

SAMPLING

Sampling was requested by Graham Pledger, bellframe advisor for English Heritage, to provide a precise date for the construction of the *ex-situ* bellframe and associated support beams. In addition it was hoped that the analysis of the timbers still *in-situ* in the tower would allow a greater understanding of their historical context and potential purpose.

A total of 30 timbers was sampled. Each sample was given the code THU-B (for Thurlby Church) and numbered 01–30. Sixteen of these samples are slices taken from the bellframe (THU-B01–12) and supporting beams (THU-B13–16). The other 14 samples are cores taken from the *in-situ* timbers (THU-B17–30). The location of core samples was noted at the time of sampling and has been marked on Figures 7–11. Those components of the dismantled bellframe which were sampled and an example of one of the supporting beams were photographed (Figs 12–17). Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

All 30 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

Bellframe and supporting beams

All 12 samples taken from the timbers of the bellframe matched each other at a value of t=4.5. These 12 samples were combined at the relevant offset positions to form THUBSQ01, a site sequence of 194 rings (Fig 18). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently and securely at a first-ring date of AD 1599 and a last-measured ring date of AD 1792. The evidence for this dating is given in Table 2. One of these samples (THU-B08) has complete sapwood and the last-measured ring date of AD 1792, the felling date of the timber represented. A further five dated samples have the heartwood/sapwood boundary ring, which in all cases is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1766, which allows an estimated felling date to be calculated for the five timbers represented to the range AD 1788–1806 (this allows for sample THU-B09 having a last-measured ring date of AD 1787 with incomplete sapwood), consistent with a felling of AD 1792. The other six dated samples do not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated, except to say with last-measured heartwood ring dates ranging from AD 1708 (THU-B03) to AD 1767 (THU-B04), it is also possible these were felled in AD 1792.

Two samples taken from the supporting beams matched each other and were combined at the relevant offset positions to form THUBSQ02, a site sequence of 69 rings (Fig 19). Attempts to date this site sequence by comparing it against the reference material were unsuccessful and it remains undated.

A third sample (THU-B14) was compared individually against the reference material where it was found to span the period AD 1389–1455. The evidence for this dating is given by the t-values in Table 3. This sample has complete sapwood, demonstrating the timber represented was felled in AD 1455.

The fourth sample, THU-B13, is too short to be individually dated securely.

In-situ timbers

Three of the samples taken from the lower timbers matched each other and were combined at the relevant offset positions to form THUBSQ03, a site sequence of 90 rings (Fig 20). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently and securely at a first-ring date of AD 1458 and a last-measured ring date of AD 1547. The evidence for this dating is given by the *t*-values in Table 4. None of these samples has the heartwood/sapwood boundary ring date and, therefore, it is not possible to calculate an estimated felling date for the timbers represented, except to say, that with last-measured ring dates of AD 1525 (THU-B19), AD 1540 (THU-B26), and AD 1547 (THU-B24), these would be estimated to be AD 1541, AD 1556, and AD 1563 at the earliest, respectively.

Eight other samples, from both the upper and lower timbers, matched each other and were combined at the relevant offset positions to form THUBSQ04, a site sequence of 76 rings (Fig 21). Attempts to date this site sequence by comparing it against the relevant reference material were unsuccessful and it remains undated.

All felling date ranges have been calculated using the estimate that mature oak trees in this area have between 15 and 40 sapwood rings.

DISCUSSION

Prior to tree-ring analysis being undertaken the bellframe was believed, on documentary sources, to date to AD 1713, the date of two of its bells. However, the dendrochronological research has demonstrated that it was constructed from timber felled in AD 1792, making it about 80 years older. Notes attached to the drawings found by George Dawson list the dates of the five bells. In addition to the two dated to AD 1713, there are a further two dated to AD 1908, and one dated to AD 1790. It now seems likely that the bellframe was constructed just after the casting of this last bell.

Only one of the supporting beams has been successfully dated, to a felling of AD 1455. Unfortunately, as a single dated timber that is not an integral part of an extant structure there is little that can be deduced from its dating. This beam could be primary or reused and may have been a later insertion into the supporting framework. As well as the interpretation, the dating of individual samples can be problematic, especially when the tree-ring sequence is relatively short, as in this case. However, it matches well and consistently at AD 1455 and is considered a secure date.

Only three of the *in-situ* timbers have been successfully dated, within site sequence THUBSQ03. The three lower timbers, all corbels, have *termini post quos* for felling of AD 1540, AD 1555, and AD 1562. All three samples show periods of severe growth retardation, which may explain the slightly lower matches against the reference material than might be hoped for. Having said this, the site sequence does match consistently and at a level deemed secure against the reference chronologies.

It is unfortunate that site sequence THUBSQ04, containing eight of the *in-situ* timbers, from both the upper and lower structures, could not be dated. This is most likely due to the short ring-width sequences of many of these samples, with the overall site sequence only being 76 rings. From studying the relative heartwood/sapwood boundary positions, it is possible to say that all the lower timbers represented were most likely felled at the same time. Unfortunately, none of the upper timbers retained the heartwood/sapwood boundary and so it is not possible to say whether both the upper and lower structures are contemporary or even that all upper timbers were felled at the same time.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, and Litton, C D, 2003a *Tree-ring analysis of timbers from Clothall Bury Farmhouse, near Baldock, Wallingford Parish, Hertfordshire*, Centre for Archaeol Rep, 87/2003

Arnold, A J, Howard, R E, and Litton, C D, 2003b *Tree-ring analysis of timbers from the roofs of the Lady Chapel, north and south aisle, and the Choir south aisle, Worcester Cathedral, Worcester*, Centre for Archaeol Rep, 96/2003

Arnold, A J, Howard, R E, and Litton, C D, 2005 *Tree-ring analysis of timbers from the Gazebo, Shifnal Manor, Shifnal, near Telford, Shropshire*, Centre for Archaeol Rep, 60/2005

Arnold, A J, Howard, R E, and Litton, C D, 2008 Nottingham Tree-ring Dating Laboratory: additional dendrochronology dates, *Vernacular Architect*, 39, 107–11

Bridge, M C, 2001 Tree-ring dates from University College London: List 115, *Vernacular Architect*, 32, 70–4

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1989 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, 20, 39–41

Groves, C, Locatelli, C, and Howard, R E, 2004 *Tree-ring analysis of oak timbers from Church Farm, Bringhurst, Leicestershire*, Centre for Archaeol Rep, 56/2004

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1993 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, 24, 40–2

Howard, R E, Laxton, R R, and Litton, C D, 1997 Nottingham University Tree-Ring Dating Laboratory Results: general list, *Vernacular Architect*, 28, 124–27

Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring analysis of timbers from The Dower House, Fawsley Park, Fawsley, nr Daventry, Northamptonshire*, Anc Mon Lab Rep, 29/1999

Howard, R E, 2003 unpubl Working site master for Little Morton Hall, Cheshire; unpubl computer file *LMHASQ03*, NTRDL

Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring analysis of timbers from Combermere Abbey, Whitchurch, Cheshire*, Anc Mon Lab Rep, 83/2003

Hurford, M, Arnold, A J, Howard, R E, and Tyers, C, 2008 *Flores House, High Street, Oakham, Rutland*, *tree-ring analysis of timbers*, Engl Heritage Res Dep Rep Ser, 94/2008

Hurford, M, Arnold, A J, Howard, R E, and Tyers, C, 2010 *Auld Cottage, Main Street, Norwell, Nottinghamshire*, *tree-ring analysis of timbers*, Engl Heritage Res Dep Rep Ser, 43/2010

Laxton, R R, Litton, C D, Simpson, W G, and Whitley, J P, 1982 Tree-ring dates for some East Midlands Buildings: Table 1, no 2, *Trans Thoroton Soc Notts*, 86, 76–7

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

Tyers, I, 1990 Tree-ring dates from Museum of London: List 37, *Vernacular Architect*, 21, 45–6

TABLES

Table 1. Details of tree-ring samples from the bellframe and bell tower at Thurlby Church, Thurlby, Lincolnshire

Sample Number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Bellframe						
THU-B01	Top sill	108	22	1679	1764	1786
THU-B02	Bottom sill	149	--	1616	----	1764
THU-B03	Unidentified	99	--	1610	----	1708
THU-B04	Top sill	70	--	1698	----	1767
THU-B05	Bottom sill	107	--	1650	----	1756
THU-B06	Unidentified	154	--	1599	----	1752
THU-B07	Bottom sill	89	--	1644	----	1732
THU-B08	Bottom sill	156	22C	1637	1770	1792
THU-B09	Top sill	138	13	1650	1774	1787
THU-B10	Top sill	88	10	1688	1765	1775
THU-B11	Brace	104	06	1666	1763	1769
THU-B12	Brace	123	18	1659	1763	1781
Supporting beams						
THU-B13	Beam	48	--	----	----	----
THU-B14	Beam	67	17C	1389	1438	1455
THU-B15	Beam	69	--	----	----	----
THU-B16	Beam	49	--	----	----	----

Table 1 (contd)

Sample Number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
In-situ timbers – lower						
THU-B17	North-south beam (easternmost)	55	12	----	----	----
THU-B18	North-south beam (westernmost)	53	07	----	----	----
THU-B19	East truss, north corbel	68	--	1458	----	1525
THU-B20	West truss, north post	41	h/s	----	----	----
THU-B21	East truss, north post	55	15	----	----	----
THU-B22	East truss, north brace	45	04	----	----	----
THU-B23	West truss, north brace	70	25C	----	----	----
THU-B24	East truss, south corbel	88	--	1460	----	1547
THU-B25	East truss, south post	68	18	----	----	----
THU-B26	West truss, south corbel	54	--	1487	----	1540
In-situ timbers – upper						
THU-B27	North truss, east post	44	--	----	----	----
THU-B28	South truss, west post	46	--	----	----	----
THU-B29	South truss, east post	48	--	----	----	----
THU-B30	North truss, east brace	46	--	----	----	----

*h/s = the heartwood/sapwood boundary ring is the last measured ring on the sample
C = complete sapwood retained on the sample

Table 2: Results of the cross-matching of site sequence THUBSQ01 and relevant reference chronologies when the first ring date is AD 1599 and the last-ring date is AD 1792

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	9.4	AD 882–1981	Laxton and Litton 1988
Church Farm, Bringhurst, Leicestershire	10.9	AD 1664–1781	Groves *et al* 2004
Thaxted Church, Essex	8.7	AD 1644–1813	Tyers 1990
Bradgate Trees, Leicestershire	7.8	AD 1595–1975	Laxton and Litton 1988
Clothall Bury Farmhouse, Hertfordshire	7.8	AD 1636–1753	Arnold *et al* 2003a
Green's Mill, Sneinton, Nottinghamshire	7.6	AD 1664–1787	Laxton *et al* 1982
Worcester Cathedral, Worcestershire	7.6	AD 1484–1772	Arnold *et al* 2003b

Table 3: Results of the cross-matching of sample THU-B14 and relevant reference chronologies when the first-ring date is AD 1389 and the last-measured ring date is AD 1455

Reference chronology	*t*-value	Span of chronology	Reference
Little Morton Hall, Cheshire	7.2	AD 1377–1462	Howard 2003 unpubl
Thaxted Church, Essex	5.8	AD 1345–1526	Tyers 1990
Nevill Holt, Leicestershire	5.5	AD 1274–1534	Arnold *et al* 2008
Combermere, Cheshire	5.3	AD 1363–1564	Howard *et al* 2003
Dog and Duck, Shardlow, Derbyshire	5.3	AD 1380–1455	Howard *et al* 1993
23 Church Street, Eckington, Derbyshire	5.3	AD 1381–1474	Esling *et al* 1989
Auld Cottage, Norwell, Nottinghamshire	5.2	AD 1335–1512	Hurford *et al* 2010

Table 4: Results of the cross-matching of site sequence THUBSQ03 and relevant reference chronologies when the first-ring date is AD 1458 and the last-ring date is AD 1547

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	4.8	AD 882–1981	Laxton and Litton 1988
Otley Hall (structural), nr Ipswich, Suffolk	5.7	AD 1415–1587	Bridge 2001
Shifnal Manor Gazebo, Shropshire	5.4	AD 1455–1628	Arnold *et al* 2005
Dower House, Fawsley, Northamptonshire	5.0	AD 1427–1575	Howard *et al* 1999
Lowdham Old Hall (barn), Lowdham, Nottinghamshire	5.0	AD 1422–1527	Howard *et al* 1997
Flores House, Oakham, Rutland	5.0	AD 1408–1591	Hurford *et al* 2008
Auld Cottage, Norwell, Nottinghamshire	5.0	AD 1335–1512	Hurford *et al* 2010

© ENGLISH HERITAGE

FIGURES

Figure 1: Map to show the general location of Thurlby

© Crown Copyright and database right 2013. All rights reserved. Ordnance Survey Licence number 100024900

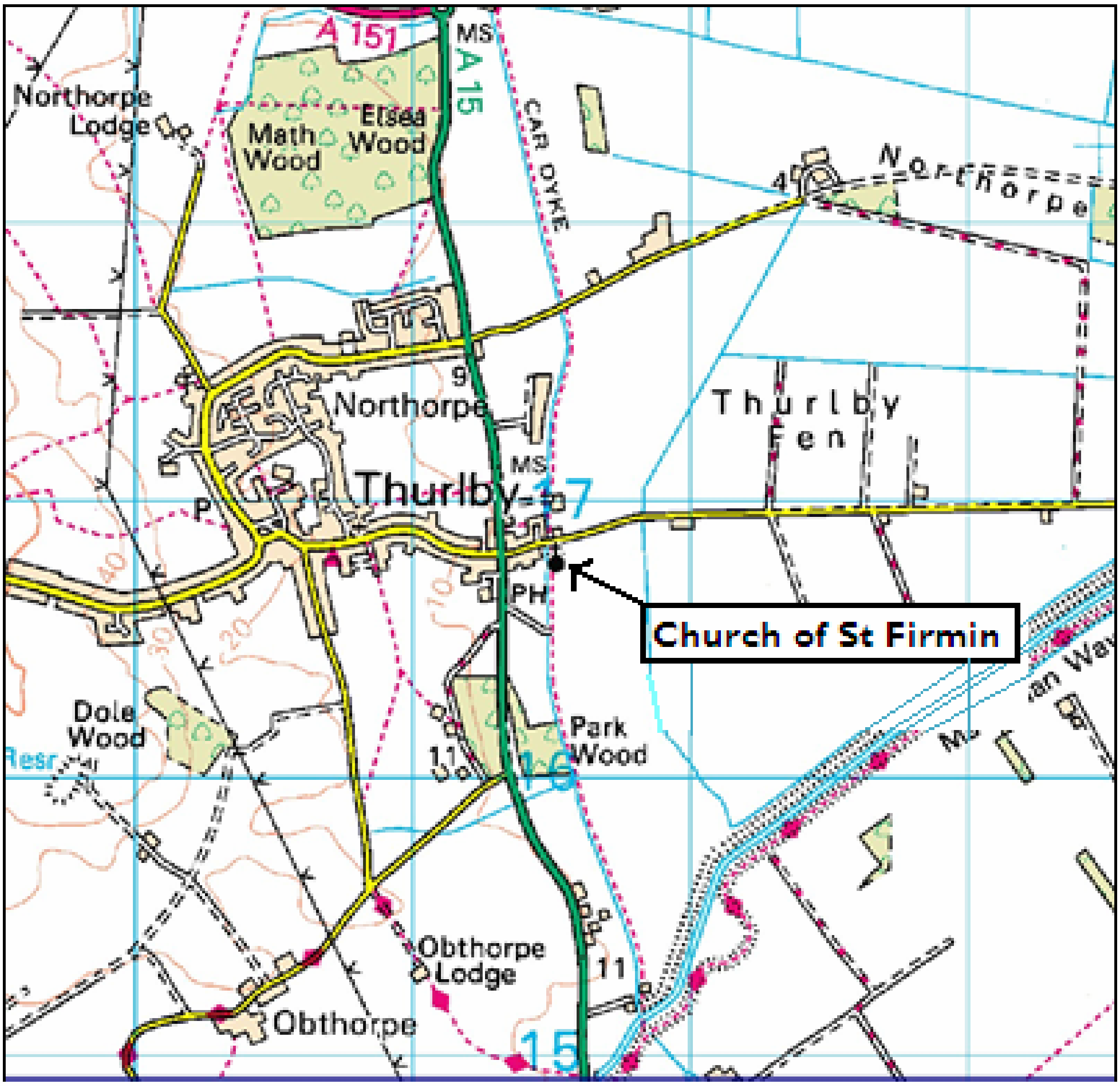


Figure 2: Map to show the location of St Firmin

© Crown Copyright and database right 2013. All rights reserved. Ordnance Survey Licence number 100024900

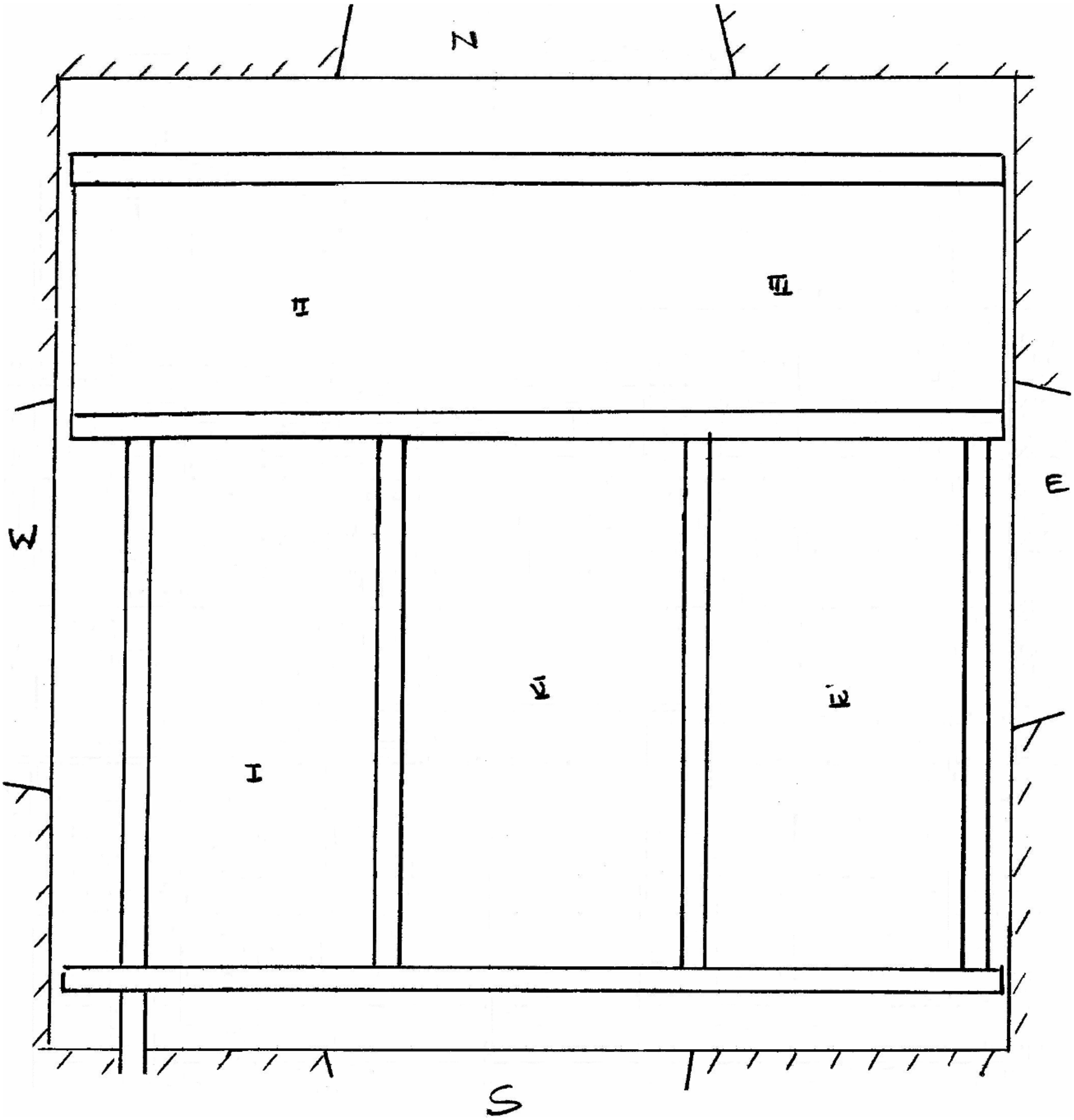


Figure 3: Thurlby Church; tower plan (provided by George Dawson)

© ENGLISH HERITAGE

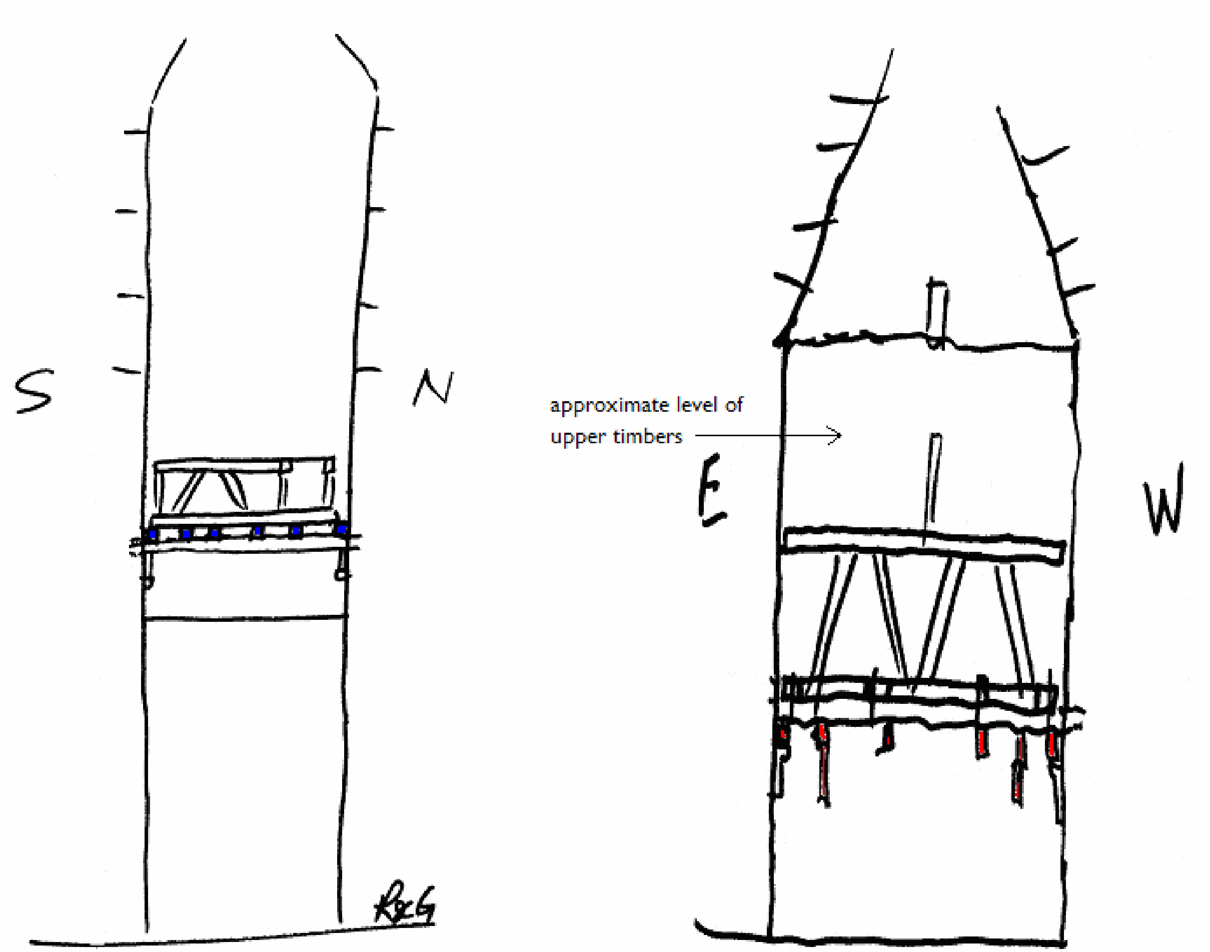


Figure 4: Sketch drawings which show the bellframe design, six supporting beams in blue on the drawing to the left, and lower in-situ timbers in red and approximate level of upper in-situ timbers marked on the drawing to the right (provided by George Dawson)

Figure 5: Lower in-situ timbers (east truss, north side)

© ENGLISH HERITAGE

Figure 6: Upper in-situ timbers (south truss, west side)

© ENGLISH HERITAGE

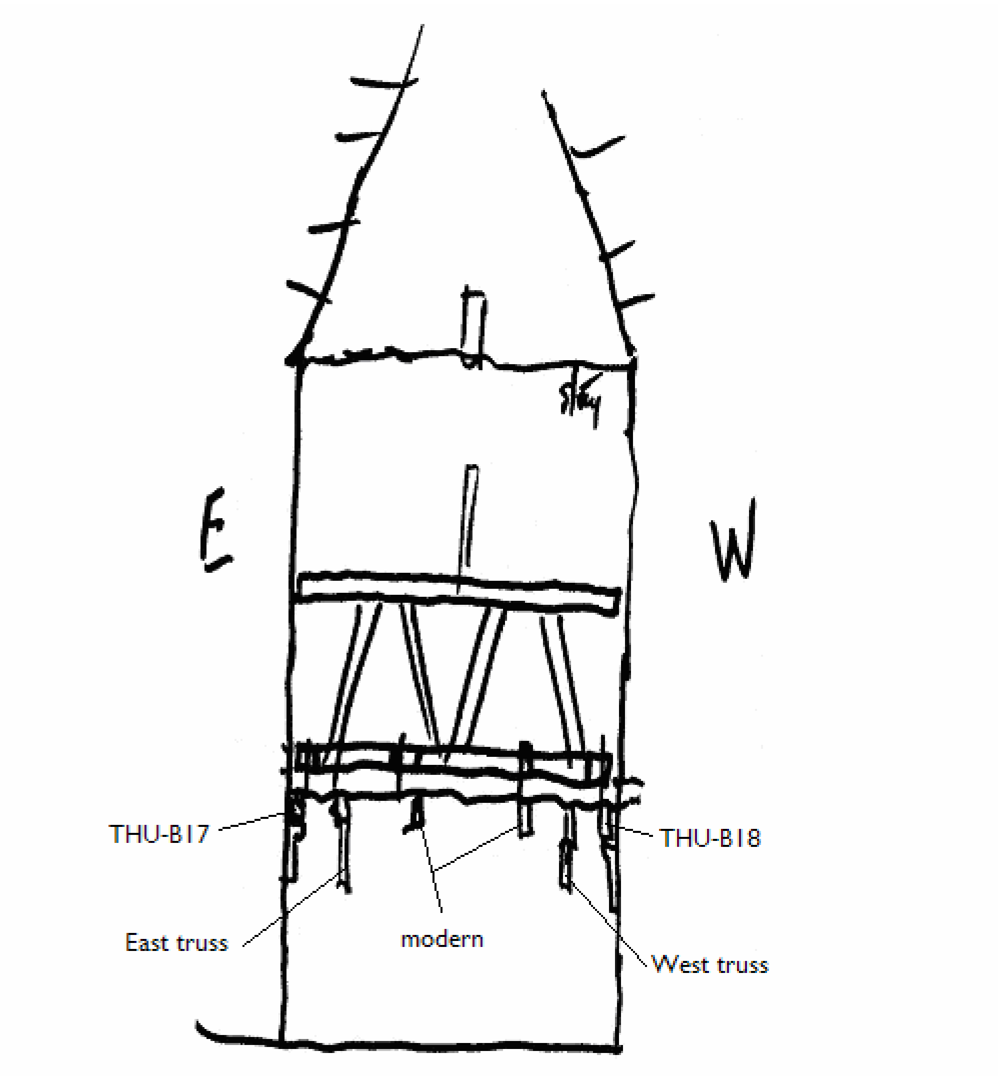


Figure 7: Sketch drawing showing the location of samples THU-B17 and THU-B18 and the position of the east and west truss

Figure 8: Lower in-situ timbers; sketch of east truss, showing the location of samples THU-B19, THU-B21-2, and THU-B24-5

Figure 9: Lower in-situ timbers; sketch of west truss, showing the location of samples THU-B20, THU-B23, and THU-B26

© ENGLISH HERITAGE

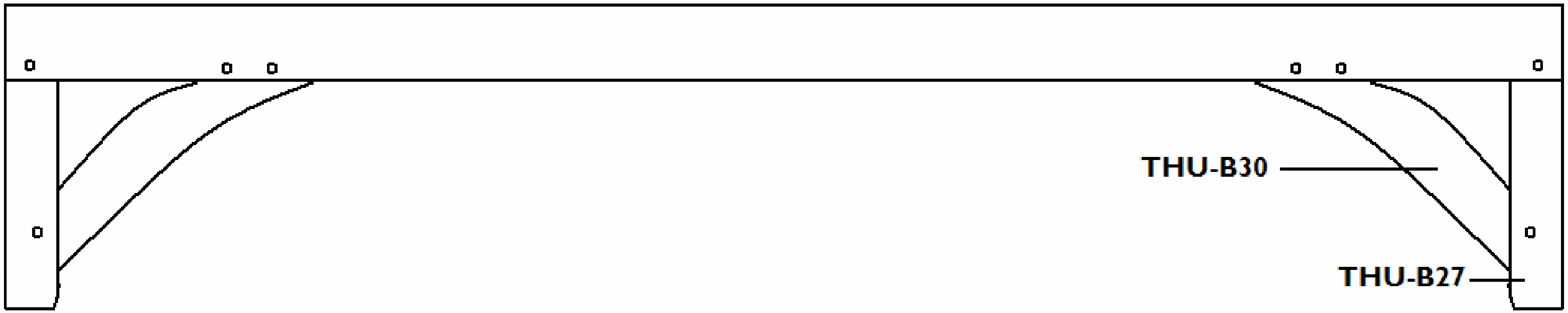


Figure 10: Upper in-situ timbers; sketch of north truss, showing the location of samples THU-B27 and THU-B30

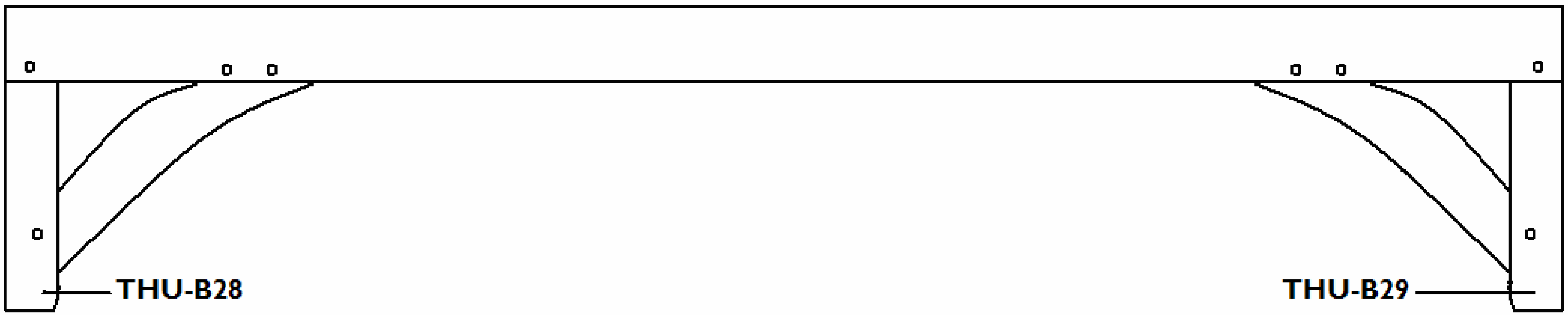


Figure 11: Upper in-situ timbers; sketch of south truss, showing the location of samples THU-B28 and THU-B29

© ENGLISH HERITAGE

Figure 12: Samples THU-B01 and THU-B11

© ENGLISH HERITAGE

Figure 13: Sample THU-B02

Figure 14: Samples THU-B03, THU-B04, THU-B09, and THU-B10

© ENGLISH HERITAGE

Figure 15: Samples THU-B05, THU-B06, and THU-B07

© ENGLISH HERITAGE

Figure 16: Samples THU-B08 and THU-B12

Figure 17: One of the supporting beams

© ENGLISH HERITAGE

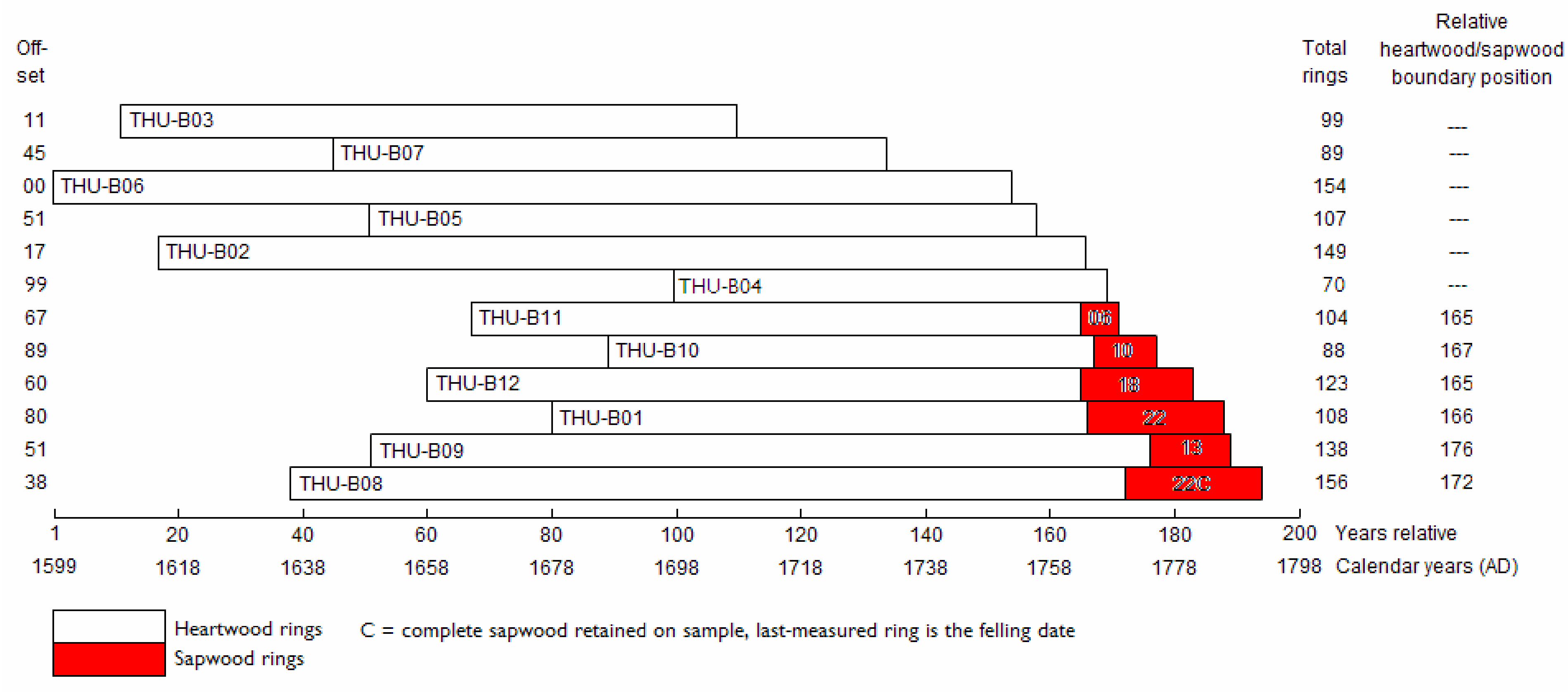


Figure 18: Bar diagram of samples in site sequence THUBSQ01

© ENGLISH HERITAGE

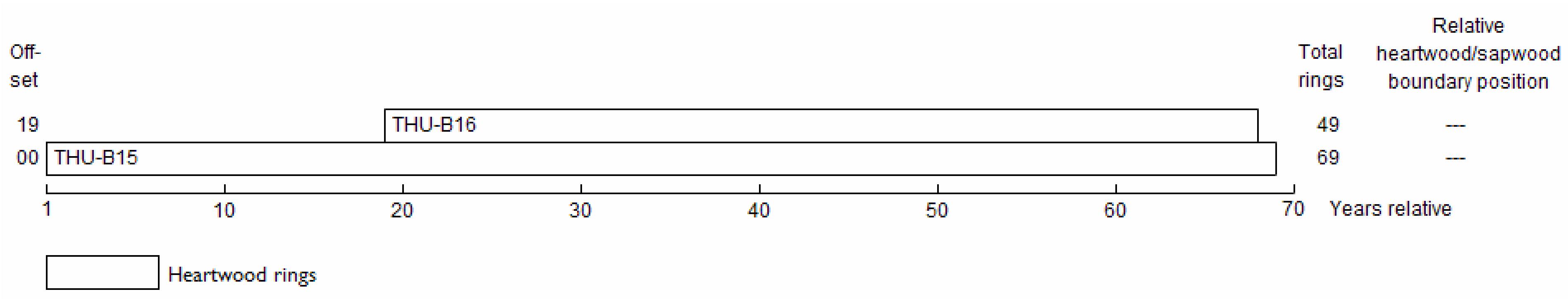


Figure 19: Bar diagram of samples in undated site sequence THUBSQ02

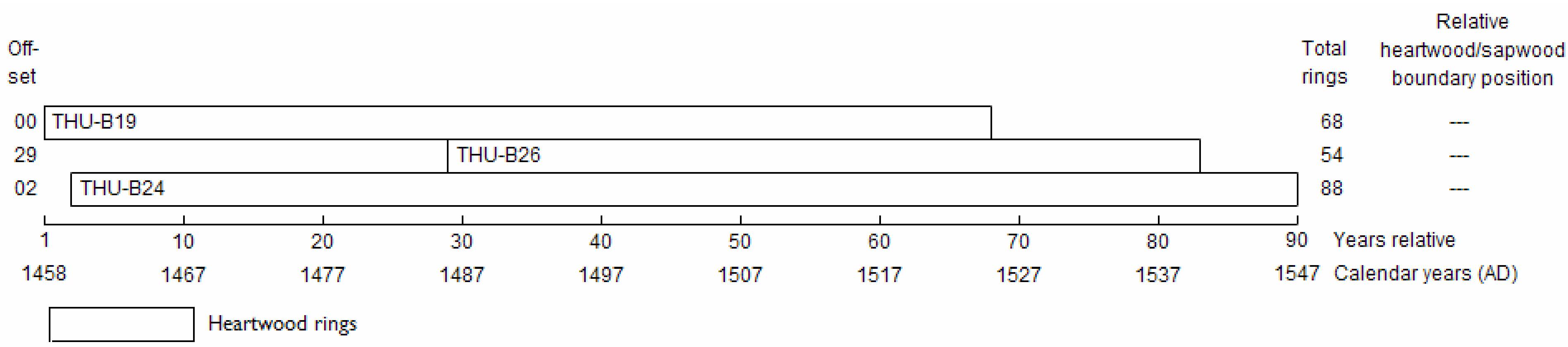


Figure 20: Bar diagram of samples in site sequence THUBSQ03

© ENGLISH HERITAGE

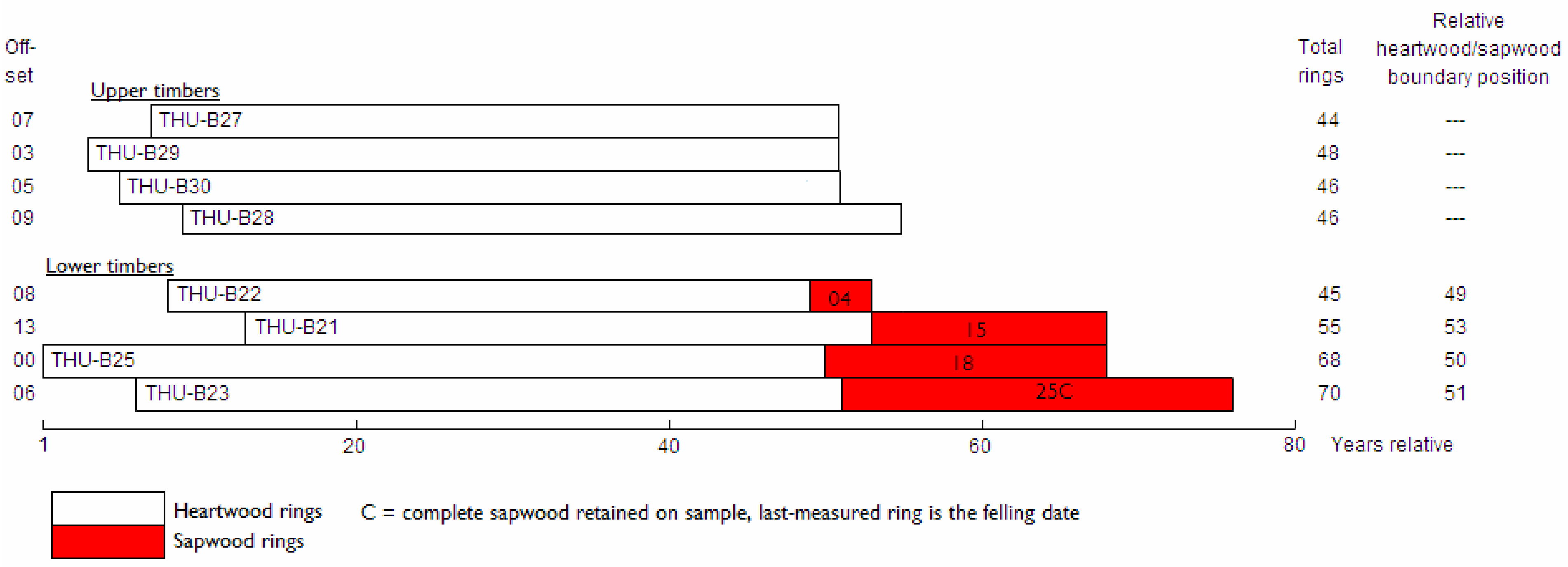


Figure 21: Bar diagram of samples in site sequence THUBSQ04

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

THU-B01A 108
158 167 107 101 78 67 92 164 189 196 146 116 107 158 163 167 86 141 160 221
162 224 204 132 182 231 185 241 191 200 156 92 172 193 214 156 218 211 247 178
138 227 236 236 192 279 282 245 307 238 258 187 222 204 177 153 231 149 106 181
220 176 126 147 127 141 164 179 215 133 129 135 171 159 166 187 179 146 124 152
158 161 187 151 146 140 88 110 75 65 99 140 109 118 147 171 140 135 144 154
121 107 108 112 93 100 85 82
THU-B01B 108
173 175 96 119 70 79 82 145 173 186 140 125 100 160 166 157 109 116 182 240
189 185 176 153 188 212 165 231 176 215 152 103 168 190 219 159 222 213 250 186
154 237 258 230 185 288 284 250 296 238 237 209 211 214 174 142 219 147 104 191
214 180 136 144 125 159 164 170 211 168 129 154 182 163 168 194 174 145 126 151
160 166 184 152 155 137 82 116 92 75 102 147 112 114 156 153 165 116 139 168
128 106 114 108 83 106 82 109
THU-B02A 149
149 188 132 270 300 283 239 200 139 134 103 120 283 229 67 46 129 124 73 81
228 136 158 131 125 137 56 180 190 173 198 176 224 129 119 149 69 130 164 144
182 69 138 100 198 118 182 101 125 131 48 130 178 148 181 102 209 135 103 100
161 181 140 243 154 134 214 166 103 59 172 213 182 126 66 120 105 189 113 112
171 232 169 143 80 109 59 132 138 110 163 107 165 117 107 97 136 194 89 169
163 126 85 126 140 187 89 74 171 103 129 153 116 102 175 140 119 111 69 280
203 65 97 124 56 83 79 91 117 99 201 119 153 130 122 129 116 495 163 194
121 147 96 168 113 129 98 268 162
THU-B02B 149
156 178 145 263 329 256 213 174 120 125 72 115 277 233 62 47 120 134 67 92
221 140 164 132 118 147 55 191 210 190 198 171 228 113 126 131 75 113 153 150
168 68 135 97 179 129 185 92 128 132 59 117 170 148 183 103 211 145 104 88
166 190 125 250 142 142 209 167 108 55 174 216 175 129 58 127 101 186 117 115
179 217 165 145 75 112 61 128 140 113 162 109 168 120 98 95 139 196 90 174
159 127 86 123 143 190 88 81 176 112 139 150 113 110 173 133 133 103 71 291
215 55 104 116 65 88 75 85 125 105 198 125 161 123 122 137 107 478 151 192
134 132 84 168 121 128 93 268 170
THU-B03A 99
173 276 195 197 156 215 191 179 178 125 134 68 129 214 93 132 146 158 196 217
157 175 179 219 164 284 440 276 365 202 235 258 160 181 222 227 311 203 298 145
219 258 163 182 216 217 251 189 268 342 360 298 429 188 184 157 347 299 529 232
454 296 514 376 205 161 312 373 286 393 269 336 613 417 184 163 370 283 343 188
160 240 138 324 135 216 231 235 297 370 186 133 200 260 471 205 252 266 364
THU-B03B 99
240 274 210 199 152 190 168 170 155 123 134 68 132 193 92 110 137 150 164 187
160 164 181 211 171 274 446 302 359 203 223 247 159 172 215 233 321 201 293 146
216 272 163 185 200 221 264 205 265 323 356 284 419 164 190 144 336 303 522 265
476 291 505 387 211 159 331 368 291 402 241 327 601 419 200 171 387 289 341 189
160 250 151 313 128 213 223 234 276 348 189 127 203 264 459 199 245 273 371

THU-B04A 70
62 72 154 215 193 234 340 282 393 322 280 151 114 182 313 389 281 331 439 334
201 272 332 428 479 394 445 304 509 432 345 399 245 374 495 373 288 210 289 147
193 254 201 169 153 150 165 133 171 173 116 141 166 196 127 175 139 138 75 112
173 147 108 128 161 149 182 172 163 169
THU-B04B 70
66 66 153 213 191 243 321 279 420 293 282 182 103 180 287 363 249 310 441 323
197 277 325 425 477 408 449 303 518 417 366 410 243 380 501 366 296 209 297 135
194 246 207 162 160 153 166 123 201 157 113 138 166 189 134 174 140 132 79 121
158 148 116 127 147 150 183 168 166 185
THU-B05A 107
189 125 77 111 133 272 169 127 132 119 193 183 97 127 81 160 215 247 298 247
284 299 222 195 127 65 100 136 165 220 276 313 380 298 231 125 229 271 316 222
100 86 101 103 93 82 49 81 156 178 125 170 90 248 307 258 326 310 254 147
132 165 236 381 265 311 284 261 138 126 186 221 274 231 284 246 272 296 266 178
134 166 117 98 88 204 149 113 157 271 174 117 144 92 107 129 173 192 173 203
245 243 181 193 182 160 155
THU-B05B 107
177 122 81 116 137 280 221 180 144 113 186 189 88 134 65 161 203 263 317 279
315 286 218 171 94 74 69 143 172 205 267 301 370 310 262 101 255 253 304 218
109 94 96 98 86 88 56 88 154 167 135 174 100 267 310 241 345 304 241 160
136 159 227 386 260 318 273 268 140 128 184 226 263 238 280 242 262 296 255 186
133 162 128 91 107 210 142 112 150 276 172 104 141 106 97 135 168 194 190 217
248 211 184 214 151 157 156
THU-B06A 154
170 144 275 275 357 212 180 204 198 208 285 272 276 293 363 360 389 382 341 317
299 294 229 210 238 234 272 277 294 281 329 205 187 221 223 187 148 220 216 319
264 145 41 38 32 36 50 104 104 126 88 82 86 65 100 106 113 129 141 115
130 242 155 125 117 88 123 94 141 182 147 180 111 213 146 104 93 115 159 136
158 139 105 149 110 99 45 113 80 114 69 56 49 58 107 64 46 49 91 89
66 43 106 72 91 115 93 122 82 104 88 71 79 119 172 96 188 156 130 97
103 156 188 155 122 170 135 157 187 141 148 146 126 141 98 85 156 115 67 120
115 116 79 68 95 83 117 147 124 127 94 109 94 126
THU-B06B 154
158 171 284 271 349 213 181 211 203 201 287 254 282 257 355 375 396 394 345 336
312 293 215 207 234 235 259 272 292 302 325 206 179 221 231 192 140 229 214 340
263 134 44 49 38 28 53 102 101 101 86 86 93 66 102 103 117 119 132 111
135 232 162 129 112 92 118 93 150 179 147 194 110 197 142 102 101 110 152 140
164 151 98 141 120 84 56 113 83 104 76 53 50 61 100 63 40 49 94 81
71 47 102 76 89 116 86 119 93 98 95 61 94 112 174 98 187 156 141 92
108 151 187 151 123 153 135 170 183 142 163 144 115 138 95 86 170 114 64 114
122 109 86 74 89 84 123 135 122 129 86 113 93 115
THU-B07A 89
152 100 120 154 145 136 158 115 108 126 178 304 267 175 168 184 289 232 156 152
116 227 329 287 381 309 293 321 343 253 111 79 120 264 338 282 256 351 430 221
211 126 189 189 296 158 117 128 132 200 154 87 67 146 181 210 147 220 120 227
336 212 190 237 136 114 79 95 161 232 210 178 196 166 125 118 208 201 303 248
422 311 294 314 303 294 237 233 208

THU-B07B 89
136 118 129 139 133 148 164 98 97 124 183 313 276 176 169 182 295 238 172 159
136 202 320 286 386 288 350 321 294 181 108 77 91 266 313 285 240 332 388 212
205 137 154 148 233 163 128 159 168 198 177 105 59 123 186 194 162 243 137 276
319 227 232 257 156 107 85 96 174 234 207 160 172 152 105 130 209 208 267 299
342 298 308 314 346 295 225 233 221
THU-B08A 156
115 210 238 226 91 83 162 184 178 181 153 198 137 142 133 81 117 94 239 131
77 144 100 140 177 168 166 64 71 49 73 139 159 168 232 190 235 156 82 93
152 161 172 179 92 200 177 174 126 214 173 245 198 140 124 128 154 121 68 103
112 164 138 159 153 119 176 214 144 174 150 152 108 109 144 175 232 167 223 192
221 165 114 187 221 206 174 271 225 216 242 253 194 185 206 225 131 122 284 186
104 170 228 171 118 148 121 189 191 278 263 174 149 173 227 245 194 242 199 203
147 154 170 156 201 178 160 168 95 99 78 65 91 121 82 102 110 165 129 128
159 164 168 134 129 182 102 120 81 104 59 81 130 140 125 130
THU-B08B 156
100 210 250 220 92 88 165 185 170 182 160 192 129 133 107 90 112 109 215 141
69 145 111 142 179 156 141 75 61 58 62 135 148 163 224 188 245 157 83 88
152 160 173 176 98 204 178 165 113 213 181 248 202 139 126 127 155 122 80 88
124 175 150 146 156 123 169 214 145 177 162 160 99 101 137 185 233 153 214 206
203 160 119 199 210 214 151 254 242 195 240 241 184 188 213 215 163 128 287 158
104 147 196 171 113 134 127 192 185 251 284 173 150 174 215 233 224 266 206 197
142 153 188 143 204 167 163 170 86 110 87 60 105 127 89 95 115 164 141 136
140 193 167 134 134 194 109 125 84 102 62 87 134 143 129 122
THU-B09A 138
72 65 68 76 46 69 55 49 67 104 211 171 117 175 168 97 91 100 160 134
95 157 147 97 63 41 107 167 175 174 205 113 215 147 52 36 61 98 150 103
53 121 124 207 133 170 236 259 287 228 243 270 203 454 307 170 298 255 267 263
155 245 285 274 138 172 130 130 76 76 130 155 165 119 147 135 113 137 114 114
104 97 125 89 106 91 74 73 107 122 127 82 69 55 78 77 114 81 93 125
113 119 122 103 110 99 97 97 100 109 110 114 70 135 112 85 70 96 113 101
100 94 111 121 122 80 102 103 94 78 76 95 100 99 70 75 68 79
THU-B09B 138
93 72 61 68 55 67 49 58 67 109 210 170 118 162 168 101 90 96 151 137
86 163 152 97 60 36 105 169 170 174 203 125 210 154 43 37 60 94 156 111
61 103 117 205 135 152 196 219 224 190 219 243 213 458 330 148 298 250 278 269
151 252 286 280 140 138 135 134 78 72 124 154 172 129 162 139 103 143 114 123
106 112 117 86 98 111 77 77 93 126 120 77 74 60 72 77 114 85 90 121
111 126 116 105 99 96 97 99 102 106 108 114 80 125 106 87 65 101 114 93
104 102 107 124 112 98 104 101 88 79 90 93 102 107 71 77 76 98
THU-B10A 76
224 164 129 192 124 165 142 155 175 203 191 213 167 120 148 179 281 147 197 177
213 106 123 128 206 209 152 178 156 121 126 118 166 189 187 114 165 76 157 148
117 133 149 114 110 148 149 171 77 86 152 173 86 115 95 170 128 147 147 107
106 78 108 132 185 106 85 116 99 121 143 122 99 108 90 121
THU-B10B 83
158 106 115 166 158 143 162 137 123 142 139 196 126 163 168 199 102 126 144 216
203 155 181 180 122 123 150 179 165 209 122 139 113 160 185 142 143 125 120 136
149 184 279 148 121 180 191 153 140 154 158 172 172 148 154 152 125 132 143 213
130 114 132 137 129 146 132 96 138 88 218 207 120 147 138 206 172 120 110 170
199 189 183

THU-B11A 104
138 180 332 209 292 235 299 195 133 103 173 201 179 189 154 217 296 246 117 140
229 183 240 115 151 184 116 216 124 198 212 216 227 262 117 108 82 140 178 93
117 143 203 114 103 142 212 220 197 162 138 99 83 108 188 180 180 113 113 61
134 106 129 146 145 122 130 187 126 142 76 82 126 158 87 101 112 165 142 120
164 127 144 107 128 177 159 118 100 168 102 136 187 136 118 156 93 227 162 76
139 89 178 135
THU-B11B 104
190 158 302 211 303 228 300 198 143 103 176 196 180 186 143 209 258 242 108 133
212 178 216 112 143 180 125 220 119 189 204 181 223 239 131 105 86 142 178 113
112 149 200 117 105 134 222 219 193 168 142 91 94 97 177 196 174 101 130 53
130 118 123 140 151 121 140 180 123 124 77 70 104 137 75 106 94 145 138 128
160 144 131 97 142 175 153 107 106 166 101 120 167 135 125 136 90 218 171 71
149 93 182 145
THU-B12A 123
190 237 188 227 116 120 94 139 139 219 159 148 178 239 194 117 125 166 179 136
153 107 150 224 208 97 110 182 160 161 93 104 123 99 131 97 104 136 155 149
160 100 109 81 117 163 71 108 109 150 99 79 113 153 123 127 119 124 79 79
94 139 153 142 92 132 52 109 140 88 133 127 110 112 158 105 111 57 73 108
119 76 95 66 129 102 90 126 83 115 74 128 136 153 85 99 126 94 111 127
115 106 128 90 165 136 68 146 65 146 100 98 95 127 126 136 127 114 89 115
112 94 96
THU-B12B 123
199 247 193 216 83 124 100 142 139 236 170 193 172 223 200 141 119 177 185 144
175 108 166 212 205 93 111 186 165 159 88 106 123 94 148 94 122 142 157 155
171 104 98 84 128 152 77 102 116 148 91 83 116 145 142 121 108 123 72 91
85 137 141 147 89 127 46 120 120 108 123 134 102 103 150 95 128 60 80 102
131 70 90 69 133 99 91 125 84 113 76 126 133 155 86 101 134 84 110 127
112 110 132 86 159 142 65 153 58 145 99 102 95 127 122 134 130 113 72 120
118 124 101
THU-B13A 48
254 420 277 273 338 342 321 508 376 212 236 230 556 572 536 601 556 590 683 641
596 442 542 536 429 312 380 422 304 265 386 288 216 148 239 290 342 444 378 323
266 353 379 371 343 321 445 358
THU-B13B 48
281 422 298 252 347 332 322 390 384 221 234 228 553 572 508 613 566 584 578 627
597 410 554 535 439 289 379 413 302 262 371 274 207 143 179 259 327 373 383 354
291 393 394 368 353 304 430 335
THU-B14A 67
247 248 402 341 360 236 463 686 498 550 387 400 478 468 519 522 505 441 347 626
502 494 438 607 525 562 451 492 277 211 113 180 137 119 229 257 281 318 666 782
536 472 569 693 408 172 127 141 156 117 85 113 164 131 274 200 177 168 145 176
181 121 186 141 118 157 116
THU-B14B 67
236 243 381 346 342 236 451 693 482 607 465 486 530 489 519 541 500 440 344 621
502 509 427 612 543 564 454 490 278 241 135 217 147 136 204 292 321 303 634 865
539 469 564 715 411 165 115 165 175 111 109 122 164 129 272 202 182 156 161 195
187 117 183 155 104 161 105

THU-B15A 69
303 203 302 390 314 191 311 255 455 406 360 418 392 511 498 398 332 352 302 525
312 434 398 481 532 398 362 386 234 387 292 414 375 315 419 372 268 367 378 315
305 284 347 419 358 301 289 304 154 141 144 124 214 237 194 282 192 310 227 154
179 195 122 125 173 130 123 199 322
THU-B15B 69
310 196 308 386 322 182 311 257 453 402 358 418 394 512 497 415 322 349 290 527
303 447 397 487 521 404 361 382 257 405 319 409 397 344 414 361 295 352 359 322
312 277 353 420 362 288 308 303 161 143 170 129 234 251 179 271 213 311 239 132
189 190 125 135 183 131 121 204 305
THU-B16A 49
427 557 758 752 629 682 610 682 635 369 716 630 550 746 505 529 714 545 563 523
405 404 389 532 460 539 473 594 454 315 219 256 229 387 401 247 468 376 312 228
202 208 432 265 313 449 359 278 239
THU-B16B 49
441 552 749 794 600 684 643 687 663 400 698 640 564 722 487 534 746 605 554 592
410 419 384 522 462 589 522 614 462 316 213 299 215 386 364 268 472 370 267 239
202 204 397 293 330 425 337 274 270
THU-B17A 55
257 315 366 327 340 272 229 270 280 359 376 455 398 326 267 257 213 234 221 238
334 274 361 366 338 382 372 358 416 301 224 268 305 338 322 297 322 308 363 299
241 235 242 250 225 183 206 206 118 75 116 130 118 101 99
THU-B17B 55
286 322 363 271 340 288 238 260 301 363 379 438 425 327 259 265 216 228 222 241
331 267 362 385 339 380 374 358 422 301 217 276 299 340 308 299 322 306 363 301
242 235 233 243 212 198 207 211 121 80 97 138 122 101 114
THU-B18A 53
53 56 120 73 121 152 198 119 102 118 128 160 216 248 197 237 312 295 284 332
238 238 262 244 336 331 277 344 267 267 246 176 189 158 191 306 302 277 222 223
210 202 269 247 242 313 242 212 269 304 230 140 134
THU-B18B 53
59 56 115 66 123 97 187 116 114 114 134 157 219 252 204 227 325 296 283 332
242 245 255 254 340 354 292 345 275 262 251 174 168 167 183 300 319 279 218 235
219 196 259 260 236 313 235 212 265 315 228 145 136
THU-B19A 68
343 487 697 569 443 443 339 388 353 218 109 68 86 139 220 208 311 342 228 269
223 315 349 530 393 263 248 417 318 601 219 221 283 123 169 105 197 256 317 248
208 254 364 349 433 301 281 294 290 271 291 525 412 413 422 190 106 64 73 81
131 176 137 123 184 250 338 321
THU-B19B 68
346 473 729 603 462 436 336 384 346 228 101 74 80 134 216 213 308 333 241 264
227 315 348 530 386 253 245 407 339 608 217 222 274 137 174 105 203 241 314 255
214 252 368 357 427 304 278 301 292 251 290 509 419 412 406 191 111 57 85 78
130 176 137 126 181 256 351 293
THU-B20A 41
114 167 96 72 86 57 60 112 211 205 248 181 142 193 151 271 169 129 153 178
227 279 236 246 231 383 530 202 277 286 301 255 287 296 247 303 255 232 180 211
230
THU-B20B 41
135 167 93 76 86 56 65 121 198 193 233 198 134 193 164 223 182 121 161 178
218 277 228 243 230 392 524 214 281 296 277 253 287 290 257 301 252 227 194 211
227
THU-B21A 55

206 279 307 219 187 238 178 216 204 217 253 263 189 183 146 257 488 472 457 287
466 345 290 253 208 246 286 184 366 303 266 209 248 244 208 374 276 302 293 215
279 160 135 107 139 112 85 66 63 112 100 87 69 72 85
THU-B21B 55
210 275 291 212 193 249 165 219 198 221 265 251 191 180 147 256 510 461 459 289
462 345 289 248 210 246 302 190 364 295 271 206 243 251 202 377 286 299 282 201
283 159 134 107 141 104 89 65 66 100 96 96 76 59 99
THU-B22A 45
337 370 553 409 371 221 224 260 162 196 225 200 290 281 260 368 336 227 161 136
119 168 182 222 180 230 171 153 197 176 162 179 130 186 146 177 136 149 130 155
241 167 144 181 195
THU-B22B 45
362 368 542 413 370 226 223 271 153 200 226 195 284 272 252 371 334 227 163 136
118 174 192 228 182 231 173 154 196 173 159 175 136 181 144 176 135 150 128 156
251 178 133 184 193
THU-B23A 70
260 116 228 182 172 202 393 301 208 217 139 151 252 209 217 243 324 352 301 285
229 161 206 336 214 208 197 217 210 175 193 155 165 174 148 239 229 273 290 215
244 214 246 177 253 216 248 242 125 142 131 136 162 122 112 81 92 93 159 78
100 92 79 54 47 69 41 34 38 75
THU-B23B 70
275 113 228 158 167 201 391 307 214 228 143 149 238 202 211 261 327 349 303 282
236 161 203 342 211 206 196 223 192 185 183 152 165 169 143 249 221 272 271 218
242 205 248 182 244 214 245 245 125 143 137 142 155 125 114 84 93 110 145 85
81 100 80 64 56 56 40 39 38 77
THU-B24A 88
524 406 347 229 178 205 225 213 164 123 200 185 206 135 253 253 169 196 205 302
295 487 390 199 183 202 206 315 139 151 127 84 83 64 93 114 166 112 88 127
175 133 175 112 164 159 201 149 152 210 212 198 241 186 152 80 100 91 193 209
156 119 174 201 263 172 228 157 82 83 71 129 108 137 135 155 200 156 232 212
236 239 165 280 260 307 190 154
THU-B24B 88
525 409 344 232 179 207 220 214 164 128 205 183 200 142 249 256 167 199 199 309
307 477 390 189 177 185 198 319 157 150 124 90 83 65 96 121 153 103 92 124
175 132 168 117 162 146 207 141 165 214 216 182 260 177 154 80 100 83 187 214
149 122 175 196 255 169 222 163 87 87 67 131 97 139 133 153 190 162 231 214
251 224 168 293 253 309 187 157
THU-B25A 68
169 262 260 257 396 391 428 304 456 332 310 220 299 212 160 176 143 128 184 137
198 180 198 239 220 167 155 128 156 227 161 177 145 215 157 165 125 100 140 109
94 126 125 178 141 166 168 146 251 167 169 162 182 232 127 131 136 135 164 135
100 107 110 81 121 83 116 137
THU-B25B 68
191 264 262 250 418 390 436 284 446 327 296 207 299 220 157 176 141 139 177 139
202 182 194 234 219 173 147 129 153 229 157 180 147 224 146 160 122 103 135 117
89 127 125 173 150 161 167 144 258 171 171 163 179 230 135 119 129 141 163 135
114 104 112 87 114 79 93 137
THU-B26A 54
715 232 238 212 132 120 109 166 199 273 194 189 255 317 334 408 257 294 332 306
295 303 416 279 282 294 192 82 52 50 78 144 159 109 135 146 276 270 208 406
160 98 82 64 120 123 201 230 206 394 298 370 456 297
THU-B26B 54
718 207 249 216 117 137 118 152 196 287 202 197 223 314 335 395 252 303 346 306

307 302 446 291 277 298 195 80 53 58 74 141 166 109 137 146 265 290 205 388
206 61 83 69 108 117 201 225 206 364 307 364 462 296
THU-B27A 44
169 177 205 313 204 201 188 169 263 159 242 262 299 314 350 314 295 278 257 169
104 143 194 231 200 112 177 213 237 203 173 215 195 113 179 159 196 127 152 137
126 240 182 231
THU-B27B 44
169 168 209 321 201 209 200 188 274 211 247 269 305 315 381 314 295 288 294 164
106 142 188 224 202 114 166 203 228 197 172 210 189 115 183 151 203 126 153 123
136 237 176 221
THU-B28A 46
187 166 161 177 172 199 219 234 200 223 249 284 330 245 176 233 208 143 117 134
270 208 242 166 162 202 196 226 282 277 348 208 341 264 311 207 267 216 207 272
226 289 356 293 326 267
THU-B28B 46
184 174 147 182 170 203 204 228 196 230 246 299 331 250 190 238 199 153 116 142
275 206 236 166 167 206 198 235 282 275 350 209 342 253 313 209 279 221 214 280
219 270 375 298 329 285
THU-B29A 48
194 220 273 197 121 190 237 248 244 179 156 214 276 193 211 230 257 248 253 198
182 210 214 142 105 138 240 248 250 170 268 273 202 242 222 248 307 170 317 219
314 173 258 152 163 275 153 98
THU-B29B 48
198 230 270 207 121 179 243 245 242 172 160 214 272 197 216 235 261 245 256 207
176 219 214 137 98 128 235 253 245 171 266 275 203 248 214 266 287 171 317 215
325 172 254 154 160 266 158 109
THU-B30A 46
78 81 37 31 56 211 274 219 251 369 409 330 445 431 463 294 322 291 305 288
283 137 96 137 275 297 290 153 225 208 224 213 178 237 276 193 346 249 401 227
291 242 256 397 212 191
THU-B30B 46
76 83 39 29 60 208 271 215 249 366 410 323 448 391 466 289 323 290 239 286
293 138 94 150 274 308 283 161 225 207 230 222 198 235 311 183 332 254 393 237
281 248 227 404 215 212

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 1988). 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.

© ENGLISH HERITAGE

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

© ENGLISH HERITAGE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

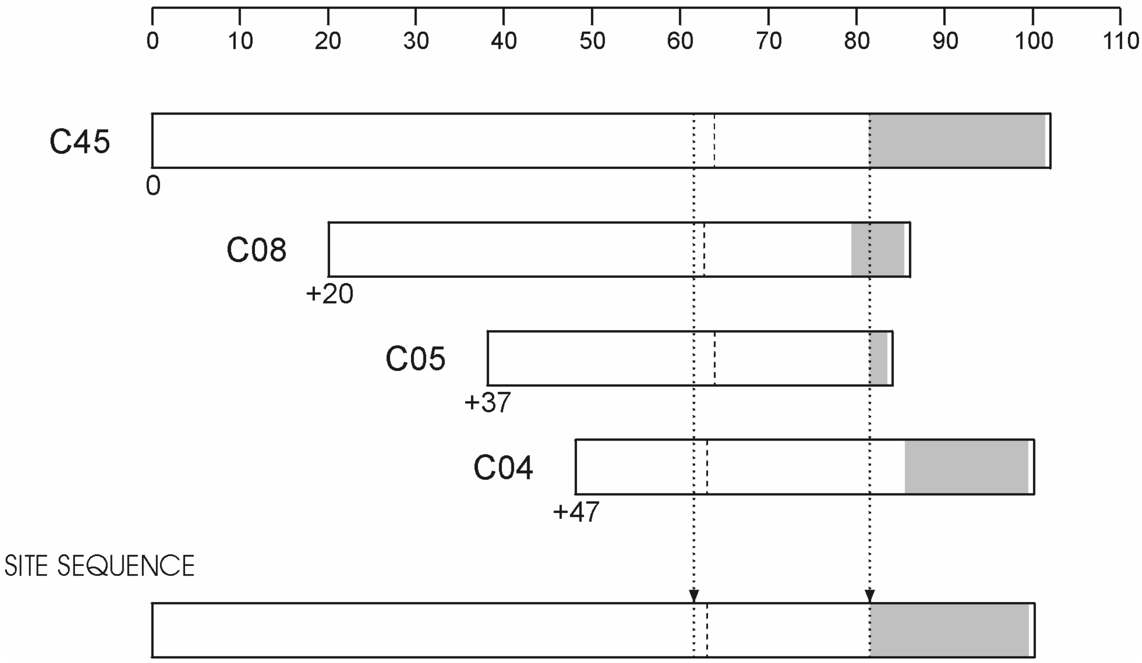


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

© ENGLISH HERITAGE

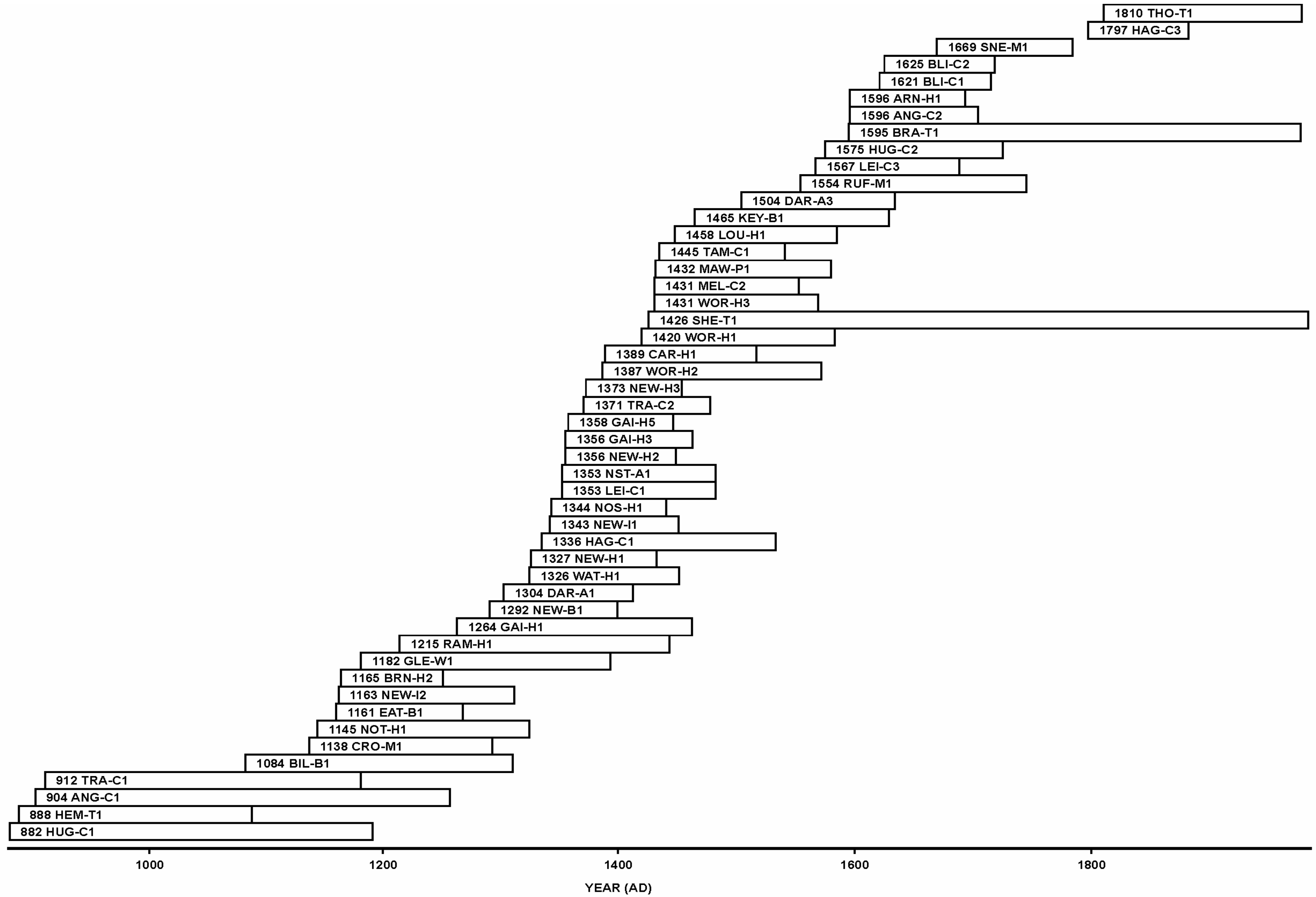
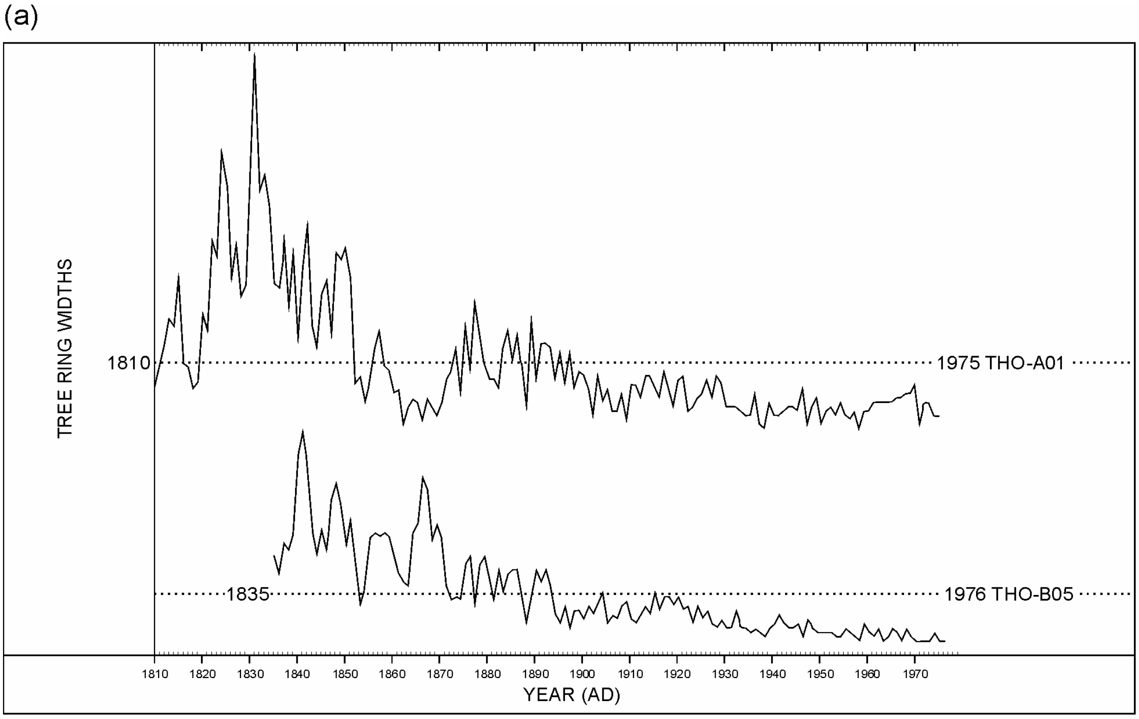


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

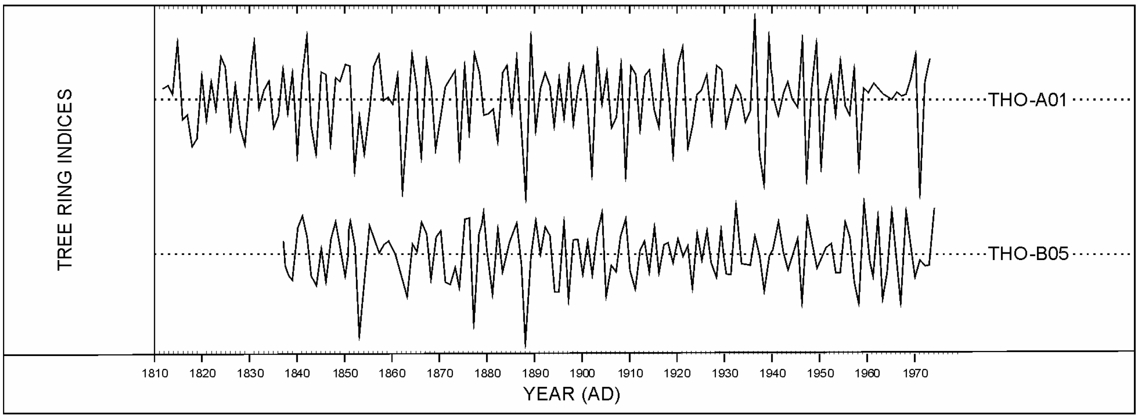


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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