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# Battle Abbey, Battle, East Sussex

# Tree-ring Analysis of Oak Timbers from the Gatehouse, Dorter and Reredorter

Alison Arnold, Robert Howard and Cathy Tyers

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# BATTLE ABBEY, BATTLE, EAST SUSSEX

# TREE-RING ANALYSIS OF OAK TIMBERS FROM THE GATEHOUSE, DORTER AND REREDORTER

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SUMMARY
Analysis was undertaken on timbers from the Gatehouse, the Dorter, and the Reredorter resulting in the construction of two site sequences. Site sequence BTLASQ01 contains three samples, two from the Reredorter and one from the Dorter, and spans the period AD 1310–1437. The Reredorter timbers are both likely to have been felled in AD 1416, whilst the beam from the Dorter has a *terminus post quem* for felling of AD 1452. The second site sequence, containing two Gatehouse samples, is undated, as are the remaining individual samples.

CONTRIBUTORS
Alison Arnold, Robert Howard and Cathy Tyers

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ARCHIVE LOCATION
East Sussex Historic Environment Record
The Keep
Woollards Way
Brighton
East Sussex BN1 9BP

DATE OF INVESTIGATION
2016

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

Cathy Tyers
Historic England
1 Waterhouse Square
138142 Holborn
London EC1N 2ST
0207 973 3000
cathy.tyers@historicengland.org.uk

# CONTENTS

# INTRODUCTION

Battle Abbey is a Scheduled Monument which includes various Grade I listed buildings and is in the guardianship of English Heritage. It is located just south of the A2100 in Battle, which lies approximately 8km to the north-west of Hastings (Figs 1-3).

The following information is summarised from the listing entries and the English Heritage website (www.english-heritage.org.uk). It was founded as a Benedictine monastery in *c* AD 1071 by William the Conqueror, on the site of the battle of Hastings to commemorate his victory. The Abbey church was completed by AD 1094, followed by the remaining buildings of the cloister and outer court. Building work continued in the late-thirteenth century and throughout the subsequent centuries until the Dissolution in AD 1538. Following this the Abbey and associated lands were given to Sir Anthony Browne who demolished the majority of the church, chapter house and part of the cloister, and adapted the west range of buildings as a residence. The estate remained in the ownership of his family until AD 1715 when it was sold to Sir Thomas Webster. It remained in the ownership of the Webster family, with the exception of AD 1857–1901 when it was owned by the Duke and Duchess of Cleveland, until 1976 when it was purchased for the nation.

## Dorter

The Dorter is located to the south of the east range of the cloister and inner parlour (Figs 3–5). It survives almost complete with the exception of its roof and includes a common room and novices' chamber on the ground floor with the monks' dormitory above. In the south wall is a cupboard with several beams or lintels (Fig 6).

## Reredorter

Projecting east from the southern end of the Dorter is the Reredorter or monastic latrines (Figs 3–5). A window in the south wall has a number of surviving lintels (Fig 7).

## Gatehouse

The Gatehouse is situated at the entrance to the monastic precinct (Fig 3) and was built in AD 1338 by Abbot Alan of Ketling. Constructed in stone, it forms a pointed carriage archway and similar pedestrian archway. It is of two storeys with ornamental arcading on the first floor and a castellated parapet with four octagonal turrets at the angles. The western portion, forming the porters lodge, is believed to date to the twelfth century and is of two storeys. The portion to the east was added in the sixteenth century, probably by Sir Anthony Browne, on the site of the Almonry of the Abbey and was used as the court room of the manor of Battle until the eighteenth century (Fig 8). Exposed historic timbers are restricted to the doors, garderobe seat, two timbers within a window reveal, and a number of window lintels.

## SAMPLING

A dendrochronological survey was requested by Roy Porter to provide independent dating evidence in order to inform understanding of the development of the building as part of a major overarching project being undertaken at the property.

The assessment of dendrochronological potential of the relatively limited number of exposed historic timbers indicated that overall there were only a few timbers with good potential, although a number of others were considered to potentially just meet the minimum number of rings required for analysis. Following in depth discussion it was decided to proceed with the analysis of the structural elements but to exclude the wooden steps in the Dorter and the garderobe seat in the Gatehouse. Thus 12 core samples were taken from structural timbers of the Gatehouse, the Dorter, and the Reredorter. Additionally, another two timbers in the Gatehouse were measured *in situ*; with FIMO impressions and photographs also being taken of these timbers (Figs 9 and 10). Each sample was given the code BTL-A and numbered 01–14. Further details relating to the samples can be found in Table 1. The sampled timbers have been located on Figures 11–14. The timbers were numbered from east to west or north to south as appropriate.

## ANALYSIS AND RESULTS

Four of the samples, one from the Gatehouse, one from the Dorter, and two from the Reredorter had too few rings for secure dating and so were rejected prior to measurement. The remaining eight core samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements and the *in-situ* measurements from the wall beams are given at the end of the report. These measurements were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in five samples matching to form two groups.

Firstly, three samples, one from the Dorter and two from the Reredorter, matched each other and were combined at the relevant offset positions to form BTLASQ01, a site sequence of 128 rings (Fig 15). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently at a first-ring date of AD 1310 and a last-measured ring date of AD 1437 (Table 2).

Secondly, two samples from the Gatehouse matched and were combined at the relevant offset positions to form BTLASQ02, a site sequence of 93 rings (Fig 16). This site sequence was also compared against a series of relevant reference chronologies but could not be securely matched and remains undated.

The measurements of the remaining ungrouped samples were then compared individually against the reference chronologies but no further secure matches could be found and these are therefore also undated.

## INTERPRETATION

Analysis has resulted in the successful dating of three timbers, two from the Reredorter and one from the Dorter. Felling date ranges or *terminus post quem* dates for felling have been calculated using the estimate that 95% of mature oak trees from this area have between 15 and 40 sapwood rings.

### Reredorter

Two of the samples taken from this part of the abbey have been successfully dated. One of these, BTL-A14, has complete sapwood and a last-measured ring date of AD 1416, the felling date of the timber represented. The second timber, BTL-A11, has the heartwood/sapwood boundary ring date of AD 1400, allowing an estimated felling date to be calculated for the timber represented to within the range AD 1415–40, consistent with this timber also having been felled in AD 1416. However these two samples match each other at a value of $t$ = 10.3, a level high enough to suggest that the two lintels represented may have both been cut from the same tree, and hence felled at the same time.

### Dorter

One of the samples has been dated with a last-measured ring date of AD 1437. Unfortunately, this sample does not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for the beam except to say it would be after AD 1452, at the earliest.

## DISCUSSION

Two timbers of the Reredorter have been dated as felled in AD 1416, indicating building work being undertaken here in the first quarter of the fifteenth century. A beam in the cupboard in the south wall of the Dorter has a felling date of after

AD 1452. This demonstrates a second period of activity although quite when this activity was is unknown. However, taking into account the overall growth characteristics of the historic timbers it seems likely, though unproven, that this was at some point during the latter half of the fifteenth century, or possibly the early-sixteenth century. Thus all three dated timbers appear to be associated with monastic building works.

It can be seen (Table 2) that site sequence BTLASQ01 matches most highly against reference chronologies from Sussex and Kent, suggesting a local woodland source was utilised for the timber, as would be expected during this period.

It is unfortunate that the second site sequence, BTLASQ02, is undated and that neither of the samples contained within it have the heartwood/sapwood boundary. This means that, not only is it not possible to say when the timbers represented were felled, but even whether they were felled at the same time.

The two series in BTLASQ02 and the measured series from the remaining five ungrouped and undated samples do not show any notable growth anomalies that would hamper successful dating. However, the dating of individual samples of potentially different dates is generally more problematic than for a well-replicated long site master sequence.

# BIBLIOGRAPHY


Arnold, A J, and Litton, C D, 2003 *Tree-ring Analysis of Timbers from Chiddingly Place, Chiddingly, East Sussex*, Centre for Archaeol Rep, **14/2003**

Bridge, M C, 2000 *Tree-ring Analysis of Timbers from St Andrew's Church, Ford, West Sussex*, Anc Mon Lab Rep, **27/2000**

Bridge, M C, 2005 *Tree-ring Analysis of Timbers from the Church of St John the Baptist, Thaxted, Essex*, Centre for Archaeol Rep, **35/2005**

Hare, J N, 1985 *Battle Abbey The Eastern Range and the Excavations of 1978-80, Historic Buildings & Monuments Commission for* English Heritage Archaeological Report No **2**

Howard, R E, Laxton, R R, Litton, C D, and Pearson, S, 1988 Nottingham University Tree-Ring Dating Laboratory Results: Kent, *Vernacular Architect*, **19**, 48–49

Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring Analysis of Timbers from St Mary Magdalene Church, Cowden, Kent*, Anc Mon Lab Rep, **44/1999**

Miles, D, 2007 *The Tree-ring Dating of the White Tower, HM Tower of London (TOL99 and TOL100), London Borough of Tower Hamlets*, EH Res Dep Rep Ser, **35/2007**

Tyers, I, 1999 *Dendrochronological Spot-dates of Timbers from the Millennium Foot Bridge sites MBC98 and MFB98, London*, ARCUS Rep, **521**

# TABLES

*Table 1: Details of samples taken from Battle Abbey, Battle, Sussex*

| Sample number | Sample location | Total rings | Sapwood rings | First measured ring date (AD) | Last heartwood ring date (AD) | Last measured ring date (AD) |
|---|---|---|---|---|---|---|
| Gatehouse | | | | | | |
| BTL-A01 | Wall beam (east) | 84 | -- | ---- | ---- | ---- |
| BTL-A02 | Wall beam (west) | 80 | -- | ---- | ---- | ---- |
| BTL-A03 | South window, lintel 2 | 48 | -- | ---- | ---- | ---- |
| BTL-A04 | South window, lintel 1 | NM | -- | ---- | ---- | ---- |
| BTL-A05 | West window, lintel 1 | 88 | -- | ---- | ---- | ---- |
| BTL-A06 | West window, lintel 2 | 81 | -- | ---- | ---- | ---- |
| Dorter | | | | | | |
| BTL-A07 | Beam 1 | 120 | -- | 1318 | ---- | 1437 |
| BTL-A08 | Beam 2 | 63 | -- | ---- | ---- | ---- |
| BTL-A09 | Beam 3 | 55 | -- | ---- | ---- | ---- |
| BTL-A10 | Beam 4 | NM | -- | ---- | ---- | ---- |
| Reredorter | | | | | | |
| BTL-A11 | Lintel 1 | 91 | h/s | 1310 | 1400 | 1400 |
| BTL-A12 | Lintel 2 | NM | -- | ---- | ---- | ---- |
| BTL-A13 | Lintel 3 | NM | -- | ---- | ---- | ---- |
| BTL-A14 | Lintel 4 | 96 | 17C | 1321 | 1399 | 1416 |

KEY:
NM = not measured;
h/s = the heartwood/sapwood boundary is the last measured ring on the sample
C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the tree represented

*Table 2: Results of the cross-matching of site sequence BTLASQ01 and relevant reference chronologies when the first-ring date is AD 1310 and the last-measured ring date is AD 1437*

| Reference chronology | *t*-value | Span of chronology | Reference |
|---|---|---|---|
| Chiddingley Place, East Sussex | 7.1 | AD 1324–1531 | Arnold and Litton 2003 |
| Church of St Mary Magdalene, Cowden, Kent | 6.2 | AD 1257–1439 | Howard *et al* 1999 |
| St Andrew's Church, Ford, Sussex | 6.2 | AD 1286–1511 | Bridge 2000 |
| Clakkers Hall, Plaxtol, Kent | 6.1 | AD 1304–1442 | Howard *et al* 1988 |
| Millennium Foot Bridge site MBC98, London | 6.1 | AD 999–1389 | Tyers 1999 |
| White Tower, Tower of London, London | 5.9 | AD 1260–1489 | Miles 2007 |
| St John the Baptist's Church (chancel), Thaxted, Essex | 5.6 | AD 1212–1404 | Bridge 2005 |
| Rectory Park (wing), Horsmonden, Kent | 5.5 | AD 1313–1426 | Howard *et al* 1988 |

FIGURES


*Figure 1: Map to show the location of Battle, circled. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900*

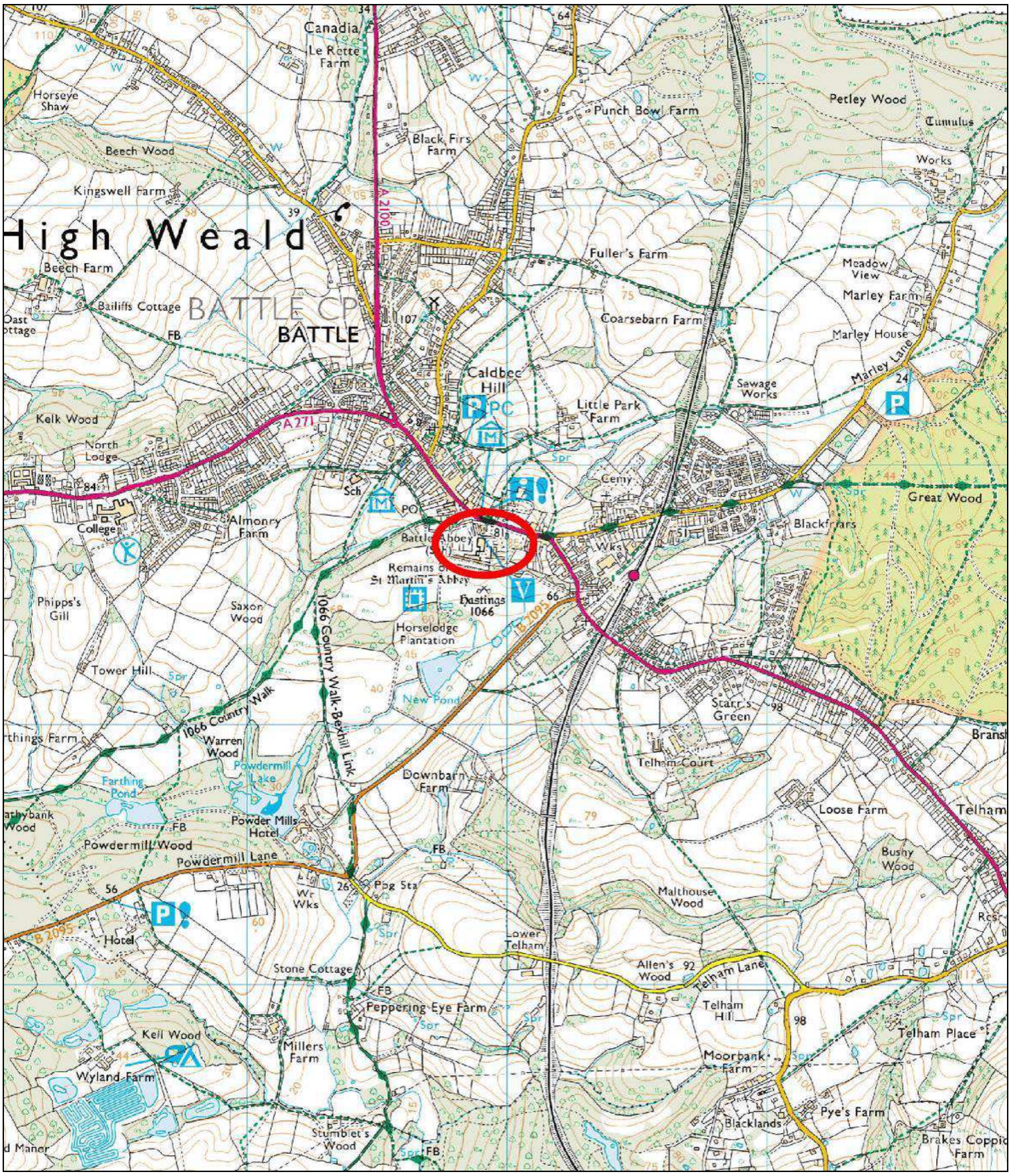



*Figure 2: Map to show the location of Battle Abbey, circled. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900*

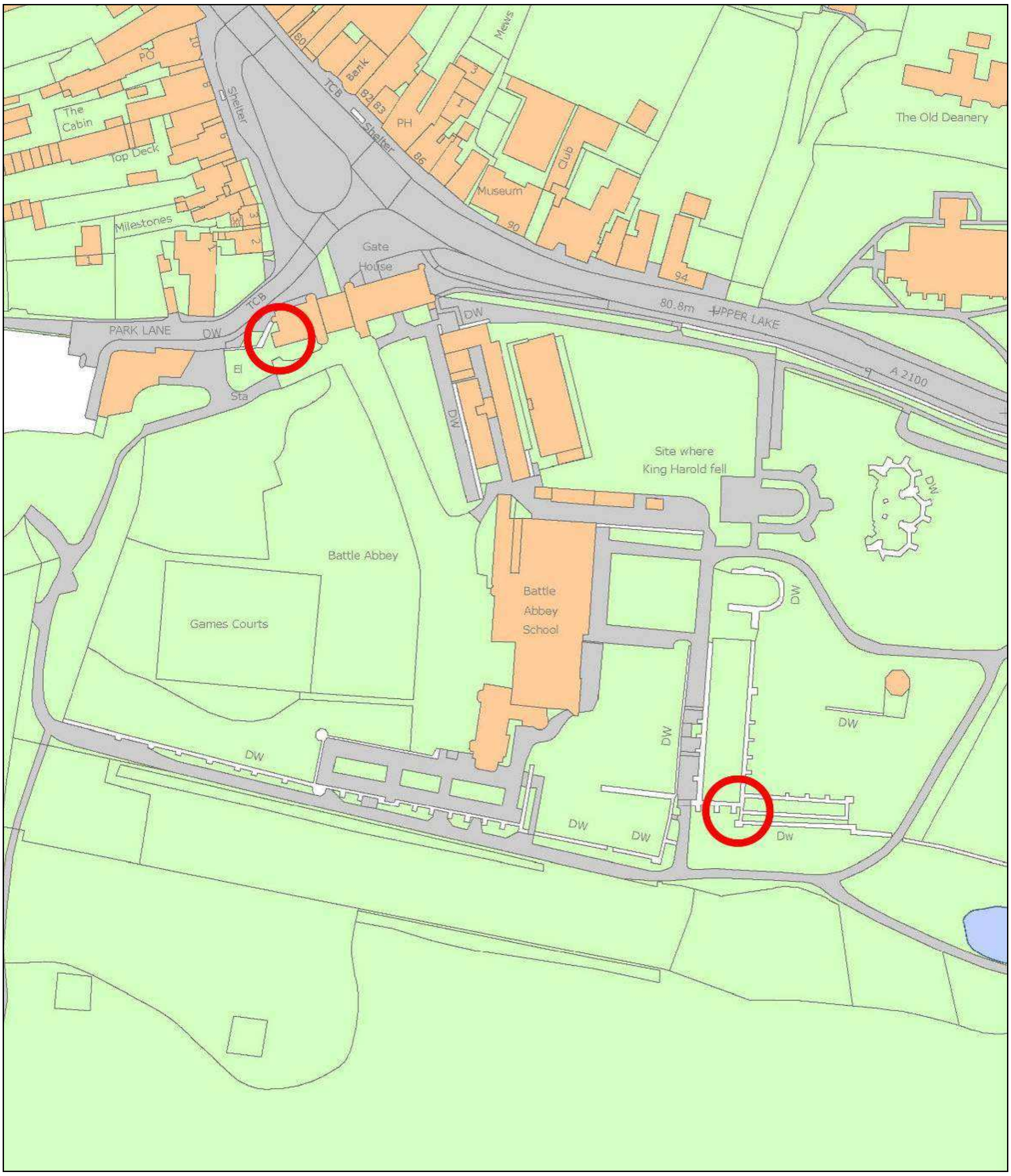



*Figure 3: Map to show the Battle Abbey site and the general locations of the timbers sampled, circled. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900*

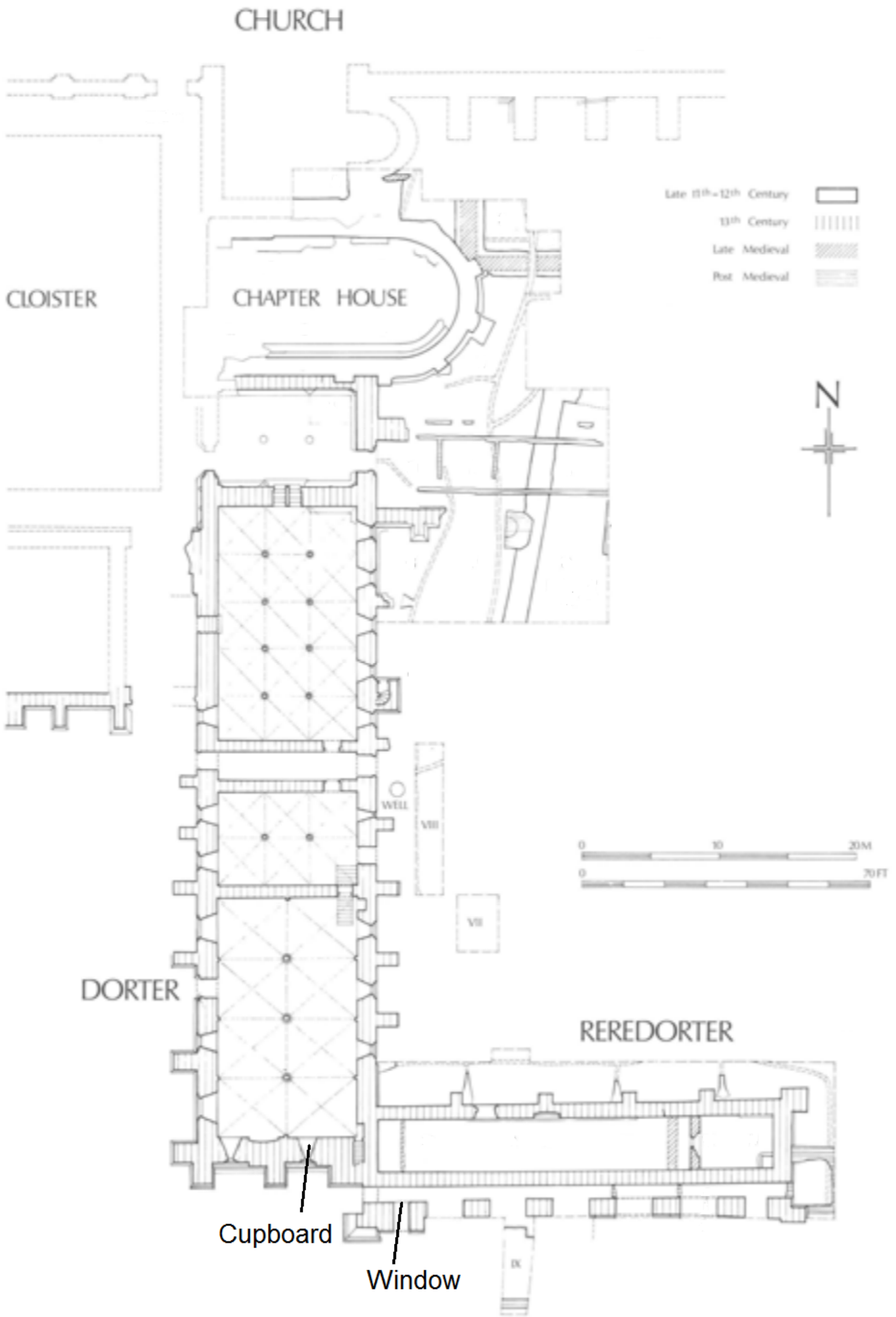



*Figure 4: Plan of Battle Abbey, showing the location of the Dorter and Reredorter ranges, with the approximate location of the sampled cupboard and window marked (Hare 1985)*

*Figure 5: South end of the Dorter range with the remains of the Reredorter range to the left, photograph taken from the south-west (Alison Arnold)*

*Figure 6: Cupboard in the south wall of the Dorter, photograph taken from the north (Alison Arnold)*

*Figure 7: Window in the south wall of the Reredorter, photograph taken from the south (Robert Howard)*

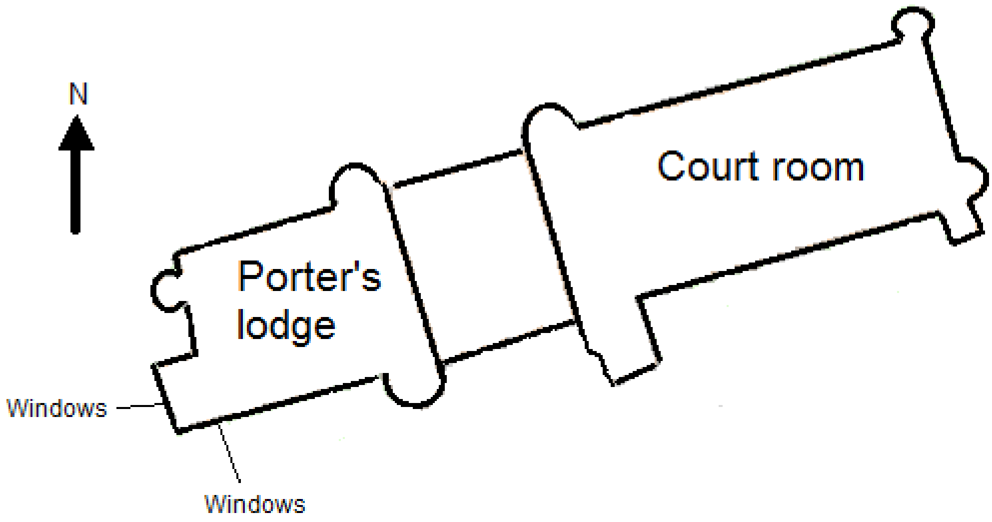



*Figure 8: Sketch plan of the Gatehouse, showing the approximate position of sampled windows*

*Figure 9: Gatehouse wall beam east, BLT-A01 (photograph taken by Robert Howard)*

*Figure 10: Gatehouse wall beam east, BLT-A02 (photograph taken by Robert Howard)*


*Figure 11: Window and wall timbers in the south wall of the Gatehouse, showing the location of samples BTL-A01–04, photograph taken from the north-west (Alison Arnold)*


*Figure 12: Window in the west wall of the Gatehouse, showing the location of samples BTL-A05 and BTL-A06, photograph taken from the east (Alison Arnold)*


*Figure 13: Cupboard in the Dorter, showing the location of samples BTL-A07–10, photograph taken from the north (Alison Arnold)*


*Figure 14: Window in the south wall of the Reredorter, showing the location of samples BTL-A11–14, photograph taken from the south (Alison Arnold)*

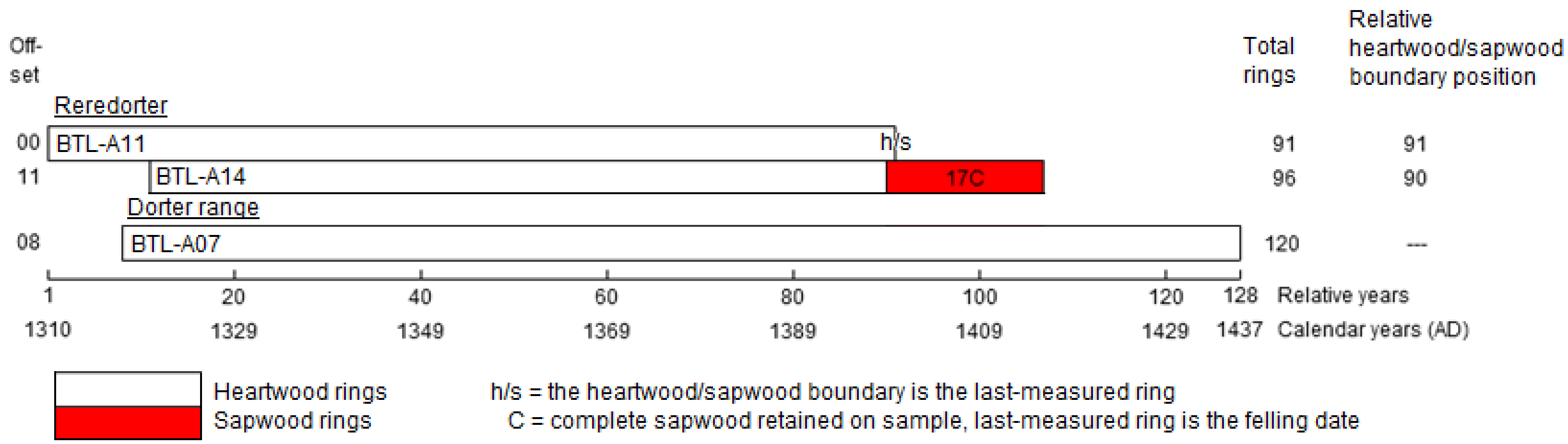



*Figure 15: Bar diagram to show the relative position of samples in site sequence BTLASQ01, sorted by area*

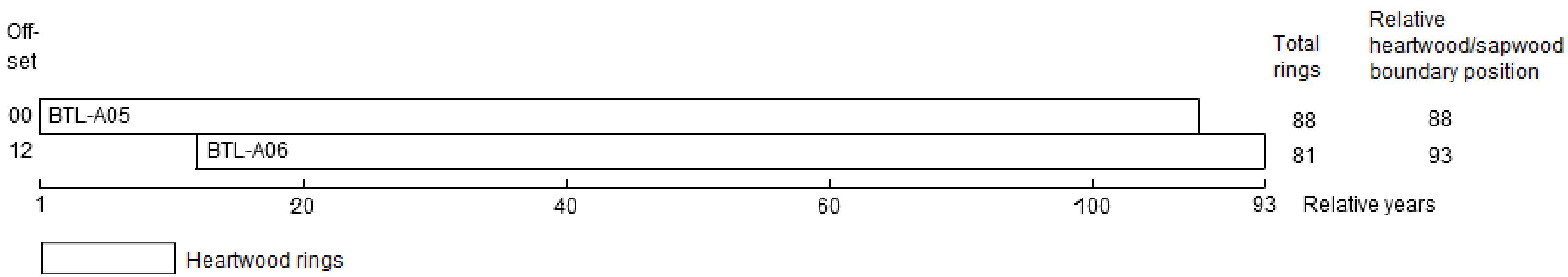



*Figure 16: Bar diagram to show the relative position of samples in undated site sequence BTLASQ02*

# DATA OF MEASURED SAMPLES

## Measurements in 0.01mm units with the exception of samples BTL-A01 and BTL-A02 which are in 0.1mm

BTL-A01A 84
19 21 21 20 24 28 22 16 14 15 22 27 29 29 24 29 24 25 21 29
28 25 26 22 25 29 30 27 33 24 23 21 22 28 27 23 18 19 13 17
18 20 15 15 20 23 17 13 11 13 14 30 18 24 30 21 23 22 17 18
19 17 15 18 17 17 21 20 19 19 11 12 14 13 15 20 18 17 19 16
17 15 12 18
BTL-A01B 84
18 21 22 19 23 28 22 17 16 15 23 25 30 28 26 31 25 21 22 30
29 24 26 22 26 28 31 26 31 25 23 20 24 28 27 23 18 19 13 17
18 19 16 15 20 23 18 11 12 13 15 28 17 24 30 21 23 23 16 18
19 18 16 18 18 17 20 21 19 18 11 12 14 11 16 21 17 16 19 16
16 18 12 16
BTL-A02A 80
41 34 37 38 50 34 32 32 40 44 36 30 39 26 33 31 40 33 32 33
26 30 25 21 23 26 33 32 36 32 29 20 19 18 21 15 16 17 16 21
14 14 19 17 15 19 16 14 18 24 17 15 17 18 17 24 22 21 19 23
24 28 29 31 23 20 35 40 29 23 21 24 27 29 16 25 19 23 22 49
BTL-A02B 80
42 36 35 38 50 34 33 32 37 46 36 30 39 26 31 33 35 34 32 34
26 32 26 24 25 29 33 35 41 26 27 21 23 16 21 17 15 18 17 21
14 14 21 18 15 20 18 11 19 22 19 14 17 18 18 23 21 24 17 21
23 28 30 30 24 20 35 41 28 24 21 24 28 25 16 24 19 27 17 44
BTL-A03A 48
271 219 232 233 176 137 221 193 210 160 151 152 178 210 158 159 158 144 163 153
132 154 168 119 99 106 104 96 118 144 206 316 322 269 212 169 221 287 294 356
331 366 418 443 386 243 247 325
BTL-A03B 48
273 224 242 235 177 140 227 194 215 171 145 143 186 215 168 169 155 142 166 156
140 153 165 109 99 101 102 102 118 137 201 325 332 270 221 174 218 281 307 357
329 382 441 435 381 233 237 322
BTL-A05A 88
179 195 198 217 181 129 117 189 168 162 151 124 178 185 261 191 229 199 206 195
220 170 173 191 177 102 74 68 52 53 67 61 101 94 69 85 75 73 77 79
46 43 31 57 50 47 57 75 92 77 108 106 75 90 87 66 48 54 56 51
66 85 74 55 79 73 74 69 85 79 67 76 101 81 78 97 96 117 91 136
106 97 74 115 117 122 137 128
BTL-A05B 88
182 197 180 188 181 107 123 198 181 164 152 129 177 216 261 206 228 197 201 193
201 181 162 170 165 102 73 67 54 49 66 63 96 96 64 69 88 87 84 69
46 46 37 52 51 48 63 67 91 79 111 101 70 86 93 63 55 54 47 48
69 89 83 56 87 57 71 79 75 77 76 73 97 80 86 92 97 119 85 138
106 93 76 111 120 126 133 135
BTL-A06A 81
113 120 106 152 159 184 187 162 205 153 138 152 136 87 72 70 62 51 71 54
90 90 66 80 73 82 77 72 51 52 43 51 50 39 57 65 83 79 101 86
52 66 69 55 47 37 32 34 41 50 56 35 67 76 77 109 147 106 86 154
234 215 258 253 256 243 172 218 229 217 148 209 206 170 206 160 187 172 151 147

148
BTL-A06B 81
102 126 117 156 166 178 179 175 210 165 138 156 127 94 76 75 63 52 52 69
75 90 72 82 81 91 81 79 52 60 37 51 48 47 53 65 79 84 97 89
48 67 66 54 45 36 41 31 37 56 54 41 63 73 77 111 129 116 113 153
267 210 257 248 263 245 164 211 226 224 151 214 205 176 202 180 182 178 149 138
134
BTL-A07A 120
235 365 256 284 268 191 243 175 144 188 175 211 118 83 82 111 157 165 114 135
115 110 103 89 103 94 88 112 78 83 67 61 67 75 82 75 69 71 63 65
39 66 70 51 54 86 88 87 92 65 84 81 83 54 62 44 48 51 46 63
58 56 44 45 53 32 43 38 53 78 54 52 41 33 33 44 42 43 40 48
46 50 46 48 38 38 43 45 36 30 39 39 64 36 41 29 28 31 26 24
31 34 51 49 50 50 52 47 40 42 44 36 39 50 49 41 36 41 43 40
BTL-A07B 120
261 354 247 284 259 201 233 171 148 181 152 206 116 78 92 101 157 167 122 130
115 108 100 91 101 89 93 105 94 76 76 59 63 88 79 86 65 67 63 61
53 60 64 45 52 86 98 81 90 67 82 77 84 58 56 46 54 47 46 61
47 57 47 43 50 31 48 38 50 81 55 50 44 34 35 40 40 46 37 43
43 64 38 46 38 35 51 42 32 32 42 34 61 40 38 31 27 27 26 28
33 27 51 53 42 50 47 49 39 37 43 41 35 50 47 41 40 31 34 59
BTL-A08A 63
64 85 83 118 109 118 98 84 79 78 74 103 103 75 114 117 110 96 140 100
95 84 84 87 97 109 126 113 100 78 118 112 151 163 118 121 148 163 168 159
122 114 131 142 126 141 123 138 119 107 103 77 95 112 110 105 146 167 114 80
94 88 112
BTL-A08B 63
84 78 87 111 122 107 100 84 78 77 86 96 104 81 114 118 109 96 142 103
92 78 83 101 93 113 120 117 95 79 134 94 168 170 116 114 149 161 166 164
129 115 127 141 131 142 119 137 130 101 107 77 102 109 107 109 145 170 113 77
90 87 113
BTL-A09A 55
374 359 425 319 341 333 279 233 223 257 213 200 175 172 243 188 211 208 165 195
220 203 230 222 218 209 178 198 141 228 191 196 187 252 190 177 208 259 239 239
196 206 185 194 152 163 144 115 118 118 146 138 147 107 111
BTL-A09B 55
389 360 441 333 349 348 305 235 229 243 219 213 146 160 246 184 225 197 149 190
228 207 233 220 215 208 180 199 140 229 190 202 195 234 196 176 198 249 235 260
193 206 194 190 153 165 174 120 119 115 142 131 160 108 98
BTL-A11A 91
328 233 187 96 162 259 236 170 291 285 268 323 279 338 312 209 181 168 219 232
111 60 65 122 206 150 113 148 211 193 122 109 137 76 102 97 103 82 60 44
62 89 112 152 153 148 108 112 70 77 71 85 82 137 200 136 137 161 122 178
202 166 151 139 103 144 138 147 120 138 161 171 126 108 88 98 143 211 153 129
101 123 147 141 268 259 181 183 169 187 231
BTL-A11B 91
310 227 197 125 161 249 252 175 298 289 277 317 277 331 314 207 184 170 208 240
100 57 63 118 195 149 108 136 218 198 134 105 135 81 99 97 108 81 60 48
55 93 105 157 154 150 107 108 68 83 73 83 76 139 205 138 131 157 123 179
194 151 149 137 101 146 142 138 124 146 148 177 125 108 90 98 146 211 157 128
92 118 131 150 256 252 177 175 164 227 222
BTL-A14A 96
153 233 183 192 162 141 141 199 234 91 44 57 71 138 125 79 98 190 195 115

119 193 106 131 106 120 116 80 67 110 161 91 122 102 157 100 84 76 97 97
118 114 181 215 179 127 197 245 185 217 227 170 136 108 178 178 170 171 178 167
167 129 116 113 141 178 198 161 174 114 147 138 123 223 183 197 176 144 130 156
149 99 154 156 140 125 103 171 186 154 106 92 86 73 58 64
BTL-A14B 96
160 228 179 194 163 147 147 195 228 95 40 59 77 131 122 87 87 188 198 113
124 194 103 129 98 133 118 86 74 105 161 83 126 101 155 97 87 80 95 102
114 116 176 215 184 131 203 233 186 217 220 172 139 111 174 180 169 170 176 168
171 123 119 114 141 178 194 170 165 114 147 139 123 218 188 197 178 136 138 152
141 105 155 153 141 132 109 162 180 154 116 83 91 72 64 61

# APPENDIX: TREE-RING DATING

## The Principles of Tree-Ring Dating

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

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

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

1. Inspecting the Building and Sampling the Timbers. Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can

sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings — the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

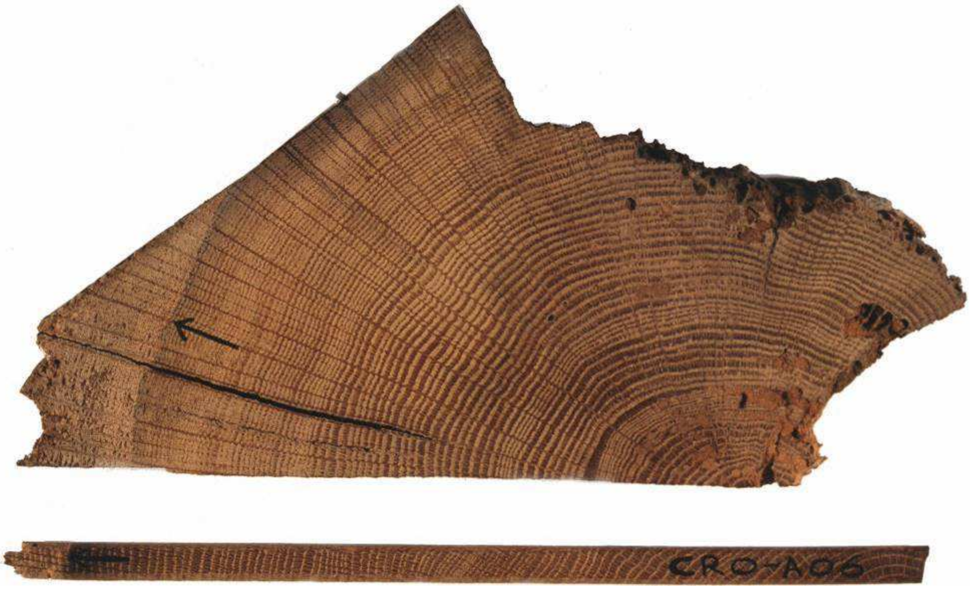



*Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil*

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


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

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

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

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

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

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

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

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

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

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

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

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

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

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form

they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth.  In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

*t*-value/offset Matrix

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

Bar Diagram

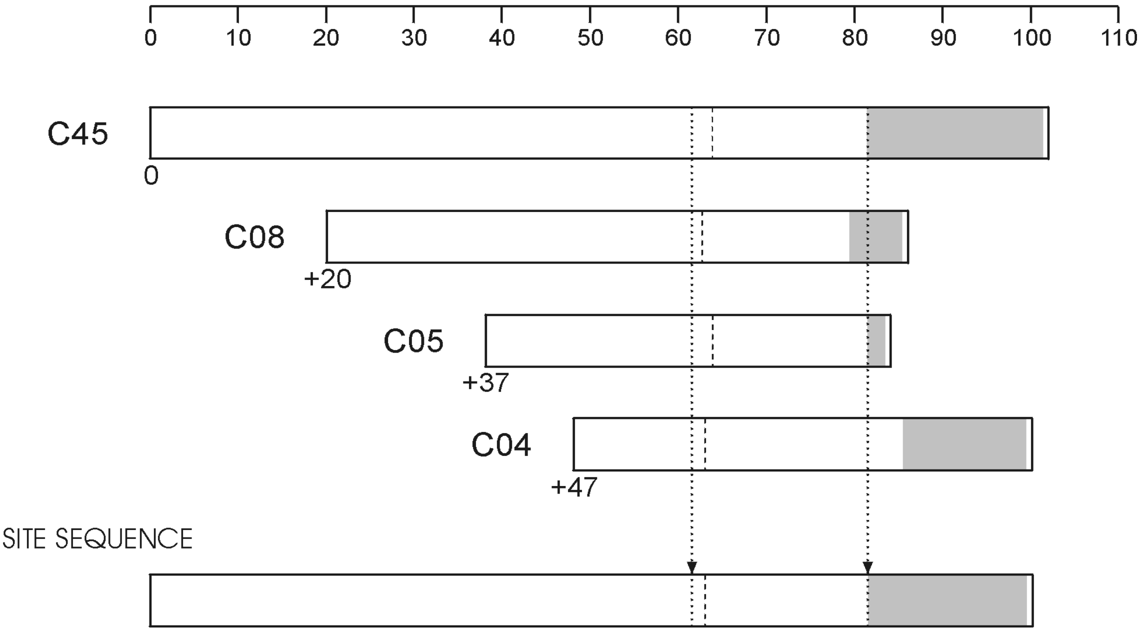



*Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them*

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

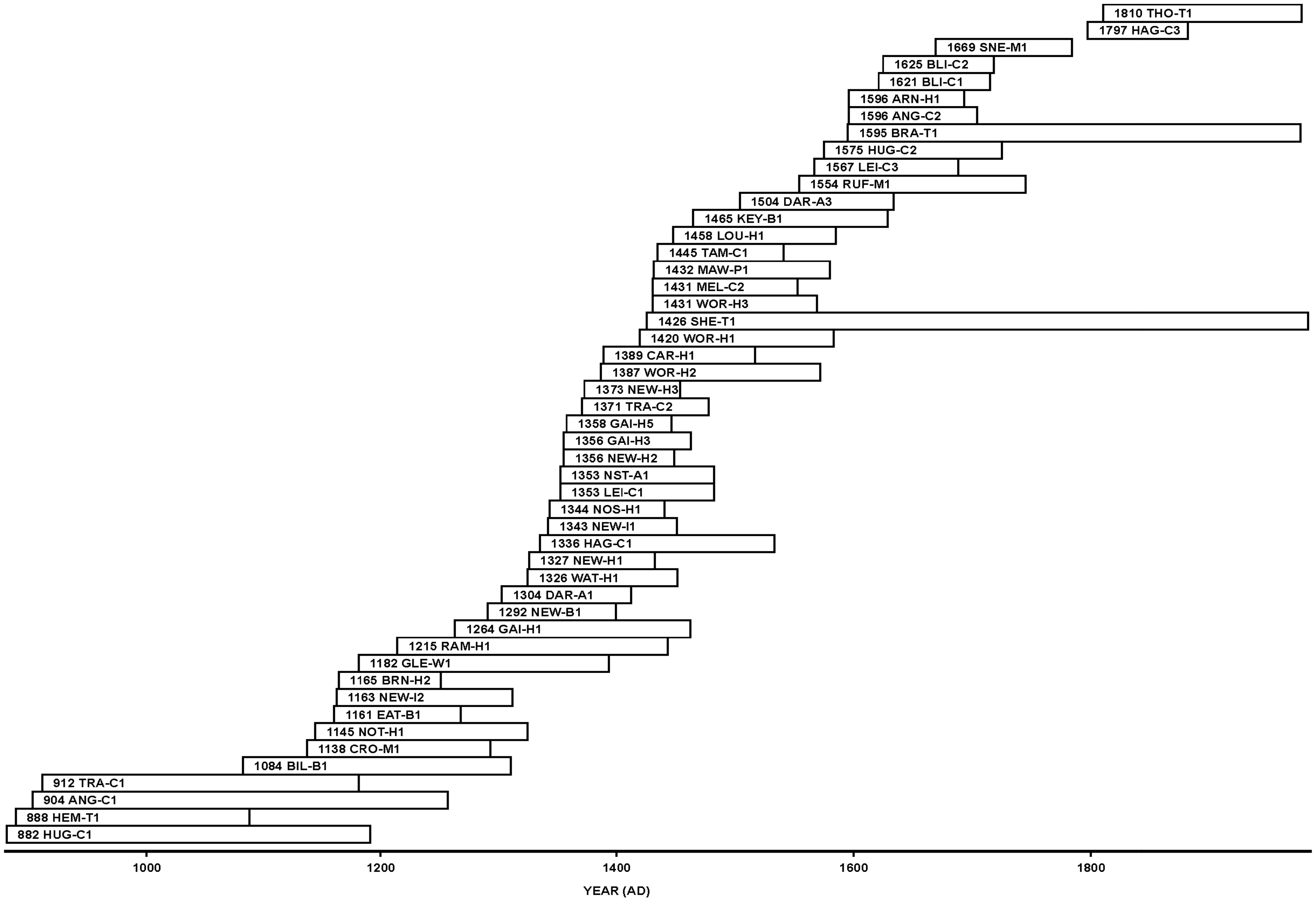
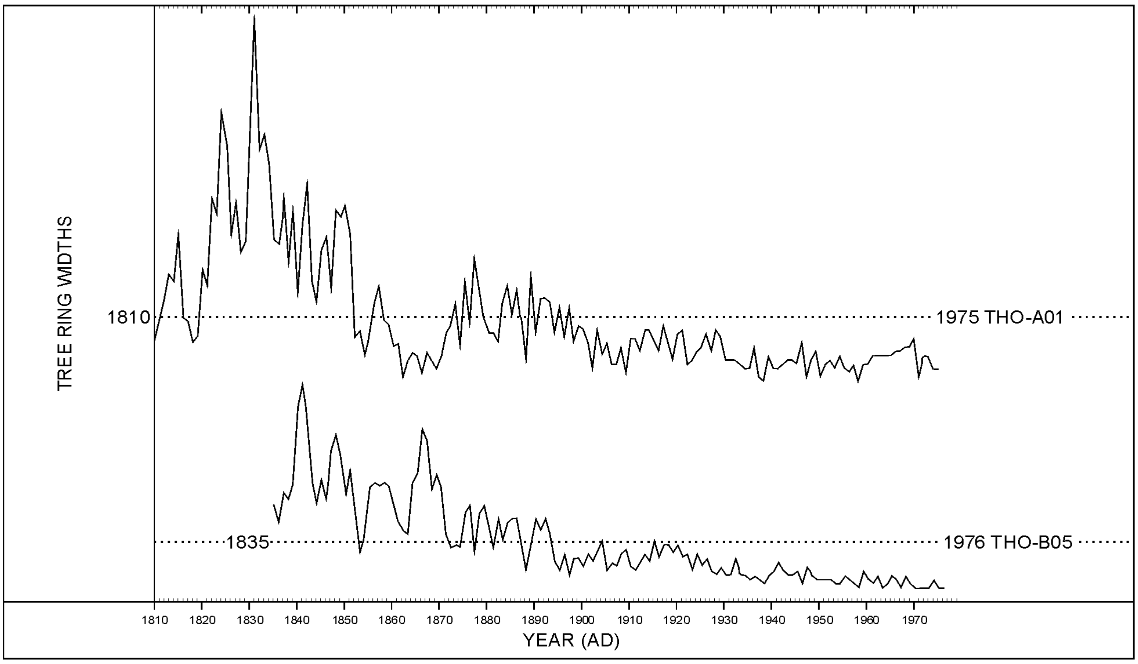



*Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87*

(a)




(b)

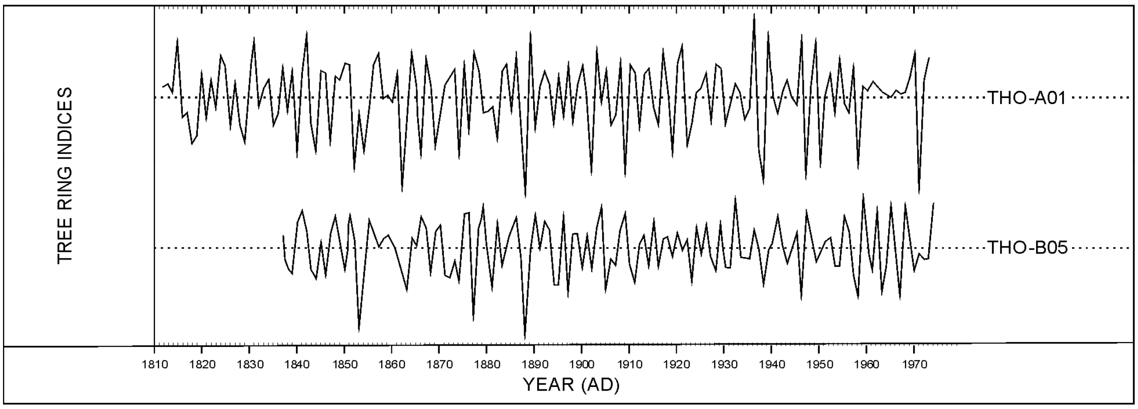



*Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

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

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

The growth trends have been removed completely.

## References


Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, **33**, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

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.

Laxton, 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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