

HARTLAW COTTAGES, NEWTON-ON-THE-MOOR, HARTLAW, SHILBOTTLE, NORTHUMBERLAND TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard



**HARTLAW COTTAGES
NEWTON-ON-THE-MOOR
HARTLAW, SHILBOTTLE
NORTHUMBERLAND**

TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

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SUMMARY

Samples were taken from the timbers of the roof structure and four window lintels, with these timbers all thought to be reused from a maritime context.

A single site sequence, containing three samples from principal rafters, was dated to span the period AD 1543–1651. Interpretation of the sapwood demonstrates that at least two of these samples are likely to have been felled in AD 1651 with it possible that the third was also felled at this time. Assuming that all three are reused, a *terminus post quem* for the building of AD 1651 is obtained. A further three site sequences are undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Andrew Woodhouse, agent, for arranging access to the building and Richard Annis of University of Durham Archaeological Services for supplying the figures used to illustrate this report and upon which the sample locations have been marked. Thanks are also given to Cathy Tyers of Sheffield University Dendrochronology Laboratory and the Scientific Dating Section at English Heritage for their advice and assistance throughout the production of this report.

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INTRODUCTION

The two cottages at Hartlaw (NU 2023 0607; Figs 1–3) were originally a late-seventeenth century farmhouse or small manor house, with a rear wing, and walled garden to the south. The surviving historic structure is of elongated rectangle in plan (Figs 4 and 5). It has two stories although there is evidence that there was a further set of rooms within the roof space, the floor of these rooms being set at tiebeam level. The rear wing has been lost, although there are remnants of it to be seen on site. The main building has obviously undergone substantial modification, presumably during its division into separate dwellings.

Once of quite high status, it is thought to have been superseded by the substantial farmhouse further to the east in the early-mid nineteenth century, at which point it was sub-divided into four separate cottages. At this time, utilitarian lean-tos were added to the rear. Further modifications and the removal of the rear wing were undertaken in the mid-late twentieth century.

The roof

With the exception of the existing tiebeams, the timbers of the present roof appear to be primary to construction. There are ten evenly spaced trusses, each truss consisting of principal rafters, halved, lapped and pegged at the apex, collars (again half-lapped and pegged), and tiebeams (Fig 6). These last components are softwood, but the remains of the sawn-off original oak tiebeams can be seen in the walls. There are a few original lower purlins still *in-situ*, which rest upon intervening blocks affixed to the upper surface of the rafters.

The majority of the apparently primary timbers of the roof are thought to be reused, with many of them having multiple large peg holes (Fig 7). These are thought to be trenails (large circular pegs within circular drilled holes), a characteristic of maritime construction whereby the outer planking of the hull is fixed to the main framing by large pegs. On some of the timbers these trenails inter-cut each other, suggesting the vessel itself had seen repeated repair. A number of the window lintels also have these trenails (Figs 8 and 9). The information above is based on the survey undertaken by Addyman Archaeology (2009).

SAMPLING

Sampling of the roof timbers and lintels was requested by Martin Roberts, prior to his retirement as English Heritage Inspector for the North-east region. It was hoped that dendrochronology would provide a precise date for the ships' timbers used in the construction of the roof and, in doing so give a *terminus post quem* for the building itself and hence potentially inform a possible listing upgrade.

A total of 17 timbers was sampled. Each sample was given the code HRT-L (for Hartlaw) and numbered 01–17. Thirteen of these samples are taken from timbers of the roof (HRT-L01–13) and four from lintels (HRT-L14–17). Trusses have been numbered from east to west (Fig 10). The location of samples was noted at the time of sampling and has been marked on Figures 11–19. Further details relating to these samples can be found in Table 1. It is unfortunate that only the principal rafters were suitable for sampling but a surface inspection of the ring pattern of the collars and purlins showed them to be fast-grown, with less than the minimum number of rings required.

ANALYSIS AND RESULTS

At this stage, three of the samples were seen to have too few rings to make secure dating a possibility, and were discarded prior to measurement. The remaining 14 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), resulting in nine samples forming four site sequences.

Three samples, all from the principal rafters, matched each other and were combined at the relevant offset position to form HRTLSQ01, a site sequence of 109 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 1543 and a last-measured ring date of AD 1651. The evidence for this dating is given by the *t*-values in Table 2. One of these samples (HRT-L08) has complete sapwood and the last-measured ring date of AD 1651, the felling date of the timber represented. A second sample (HRT-L10) has the heartwood/sapwood boundary ring date of AD 1635, which allows an estimated felling date to be calculated for the timber represented to within the range AD 1650–75. The third sample (HRT-L23) does not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated, except to say that it would be AD 1639 at the earliest.

Attempts were then made to date the other three site sequences (Figs 21–3) and the five ungrouped samples by comparing them against the reference chronologies. Although some tentative matching was noted for one of the individual samples, this was not considered of a satisfactory level for reliable and secure dating. None of the other site sequences or single samples could be matched and these are also 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 roof was believed to be primary to the building but utilising timbers reused from a maritime origin. A number of the window

lintels displayed the same large peg holes as those seen in the roof timbers, suggesting a similar previous use.

Dendrochronological dating has shown that the roof contains some timbers which were felled in AD 1651, giving the house a *terminus post quem* of AD 1651. Architectural survey had suggested a date in the late-seventeenth century for construction of the house, which would mean the timbers were only in their primary context for less than 50 years before being utilised at Hartlaw.

It is disappointing that we have only managed to provide dating for three timbers, but perhaps not surprising, given that these timbers are thought to be ships' timbers which conceivably could have come from anywhere and represent several broken-up ships of varying dates, or indeed repairs undertaken on these vessels.

BIBLIOGRAPHY:

Addyman Archaeology, 2009 *Old Hartlaw Manor near Alnwick, Northumberland*, a report undertaken for George and Angela Smith

Arnold, A J, Howard, R E, and Litton, C D, 2003 *Tree-ring analysis of timbers from the roof of the Keep, or Little Castle, Bolsover Castle, Derbyshire*, Centre for Archaeol Rep **15/2003**

Arnold, A J and Howard, R E, 2006 *The Commandery, Worcester, Tree-Ring Analysis of Timbers*, Engl Heritage Res Dep Rep Ser, **71/2006**

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

Arnold, A J, Howard, R E, and Litton, C D, 2008b Nottingham Tree-ring Dating Laboratory, *Vernacular Architect*, **39**, 129

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, **25**, 36–40

Howard, R E, Laxton, R R, and Litton, C D, 1999 Nottingham University Tree-ring Dating Laboratory: results, *Vernacular Architect*, **30**, 90–1

Howard, R E, 2004 unpubl site chronology for Manor House, Nether Poppleton, Yorkshire, unpubl computer file *NPPASQ02*, NTRDL

Table 1: Details of tree-ring samples from Hartlaw Cottages, Newton-on-the-moor, Hartlaw, Shilbottle, Northumberland

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
HRT-L01	North principal rafter, truss 1	88	h/s	----	----	----
HRT-L02	South principal rafter, truss 1	93	12	----	----	----
HRT-L03	North principal rafter, truss 2	49	--	----	----	----
HRT-L04	South principal rafter, truss 2	87	h/s	----	----	----
HRT-L05	South principal rafter, truss 3	81	h/s	----	----	----
HRT-L06	North principal rafter, truss 4	NM	--	----	----	----
HRT-L07	South principal rafter, truss 5	95	02	----	----	----
HRT-L08	South principal rafter, truss 6	81	14C	1571	1637	1651
HRT-L09	North principal rafter, truss 7	77	14+c3	----	----	----
HRT-L10	North principal rafter, truss 9	66	11	1581	1635	1646
HRT-L11	South principal rafter, truss 9	50	09	----	----	----
HRT-L12	North principal rafter, truss 10	NM	--	----	----	----
HRT-L13	South principal rafter, truss 10	81	--	1543	----	1623
HRT-L14	Inner lintel between trusses 1-2	82	--	----	----	----
HRT-L15	Outer lintel between trusses 3-4	61	--	----	----	----
HRT-L16	Lintel over south window between trusses 5-6	112	28C	----	----	----
HRT-L17	Outer lintel over south window between trusses 7-8	NM	--	----	----	----

*NM = not measured

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

C = complete sapwood retained on sample, last measured ring date is the felling date

Table 2: Results of cross-matching of site sequence HRTLSQ01 and relevant reference chronologies when the first-ring date is AD 1543 and the last-measured ring date is AD 1651

Reference chronology	z-value	Span of chronology (AD)	Reference
Bolsover (Little Castle), Derbys	6.7	1532–1749	Arnold <i>et al</i> 2003
The Commandery, Worcs	6.6	1569–1655	Arnold and Howard 2006
Manor House, Nether Poppleton, Yorks	6.1	1494–1619	Howard unpubl 2004
Nun Appleton, Tadcaster, West Yorks	5.9	1478–1657	Arnold <i>et al</i> 2008a
Stowmarket Church, Suffolk	5.8	1542–1671	Howard <i>et al</i> 1994
Lodge Farm, Staunton Harold, Leics	5.7	1533–1647	Arnold <i>et al</i> 2008b
Sinai House, Burton-on-Trent, Staffs	5.7	1555–1665	Howard <i>et al</i> 1999

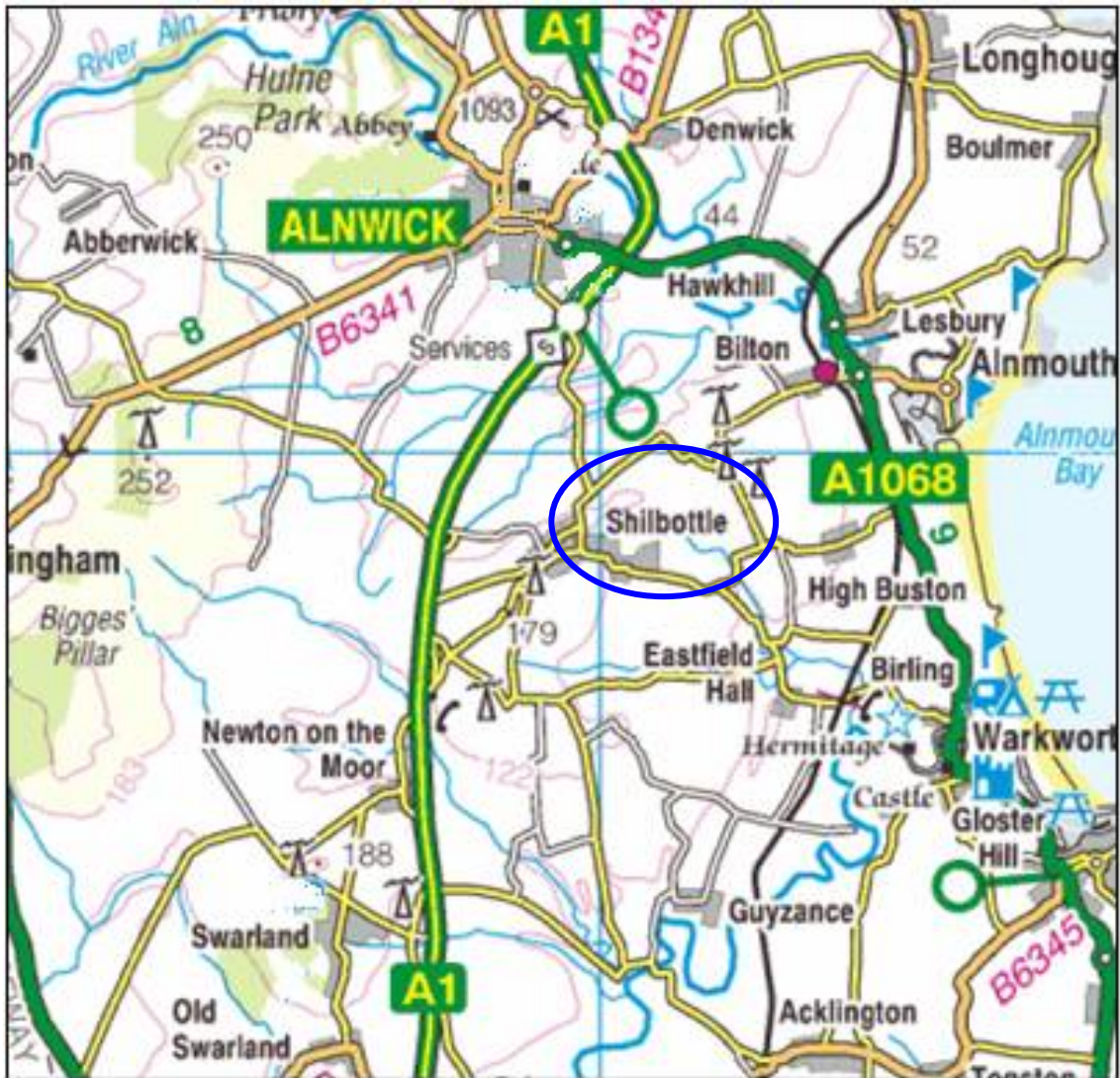


Figure 1: Map to show the general location of Shilbottle, circled

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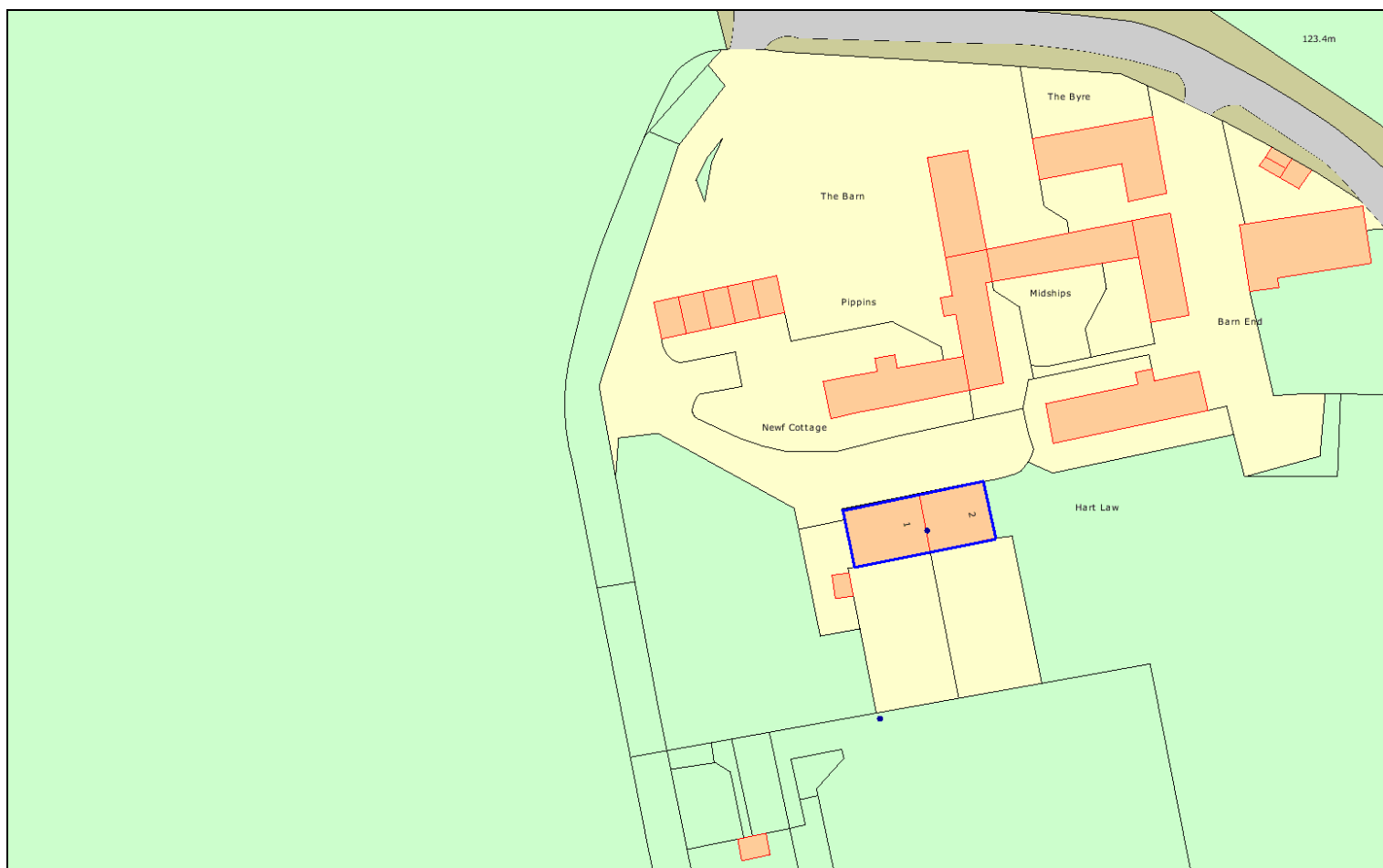


Figure 3: Map to show Hartlaw Cottages, outlined in blue

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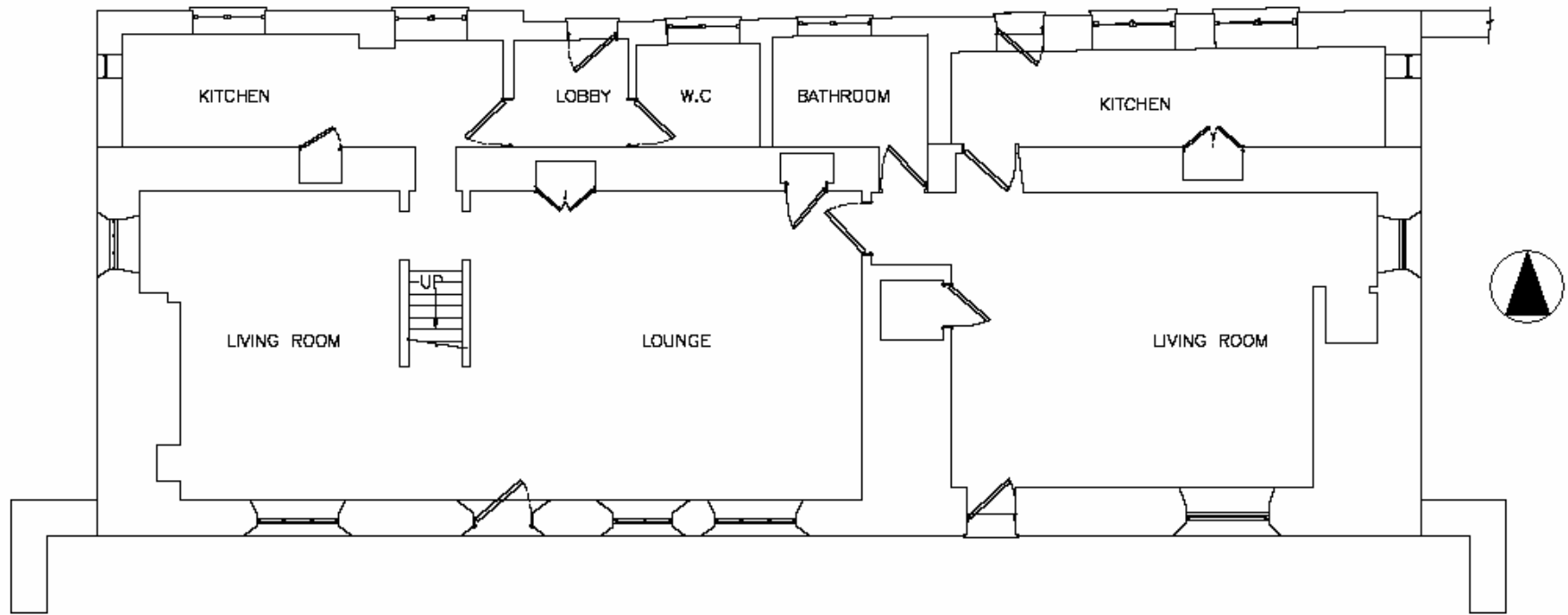


Figure 4: Ground-floor plan (Morton & Hall Consulting Ltd)

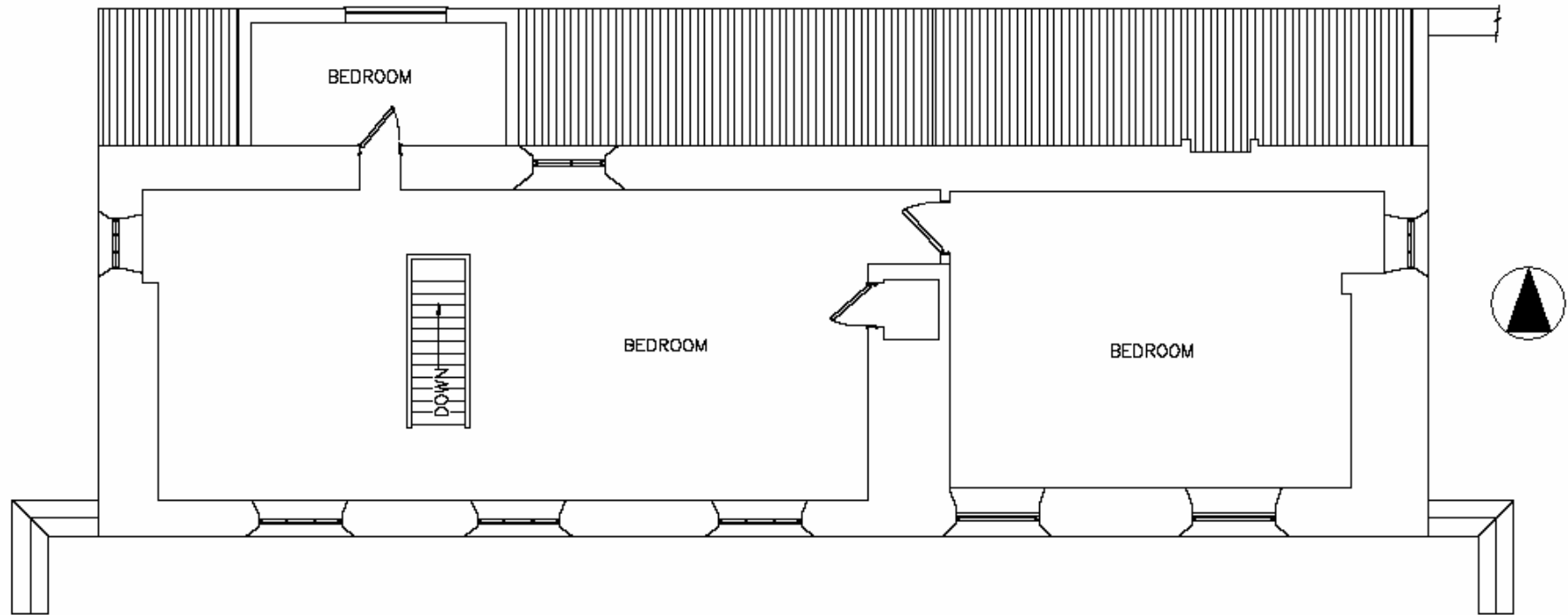


Figure 5: First-floor plan (Morton & Hall Consulting Ltd)



Figure 6: Roof, with truss 6 in the foreground (photograph taken from the east)



Figure 7: Close up of truss 6 showing the drilled holes for trenails (photograph taken from the east)



Figure 8: Lintel over the south window between trusses 5-6



Figure 9: Lintel over south window between trusses 5-6, close up showing the same large peg holes

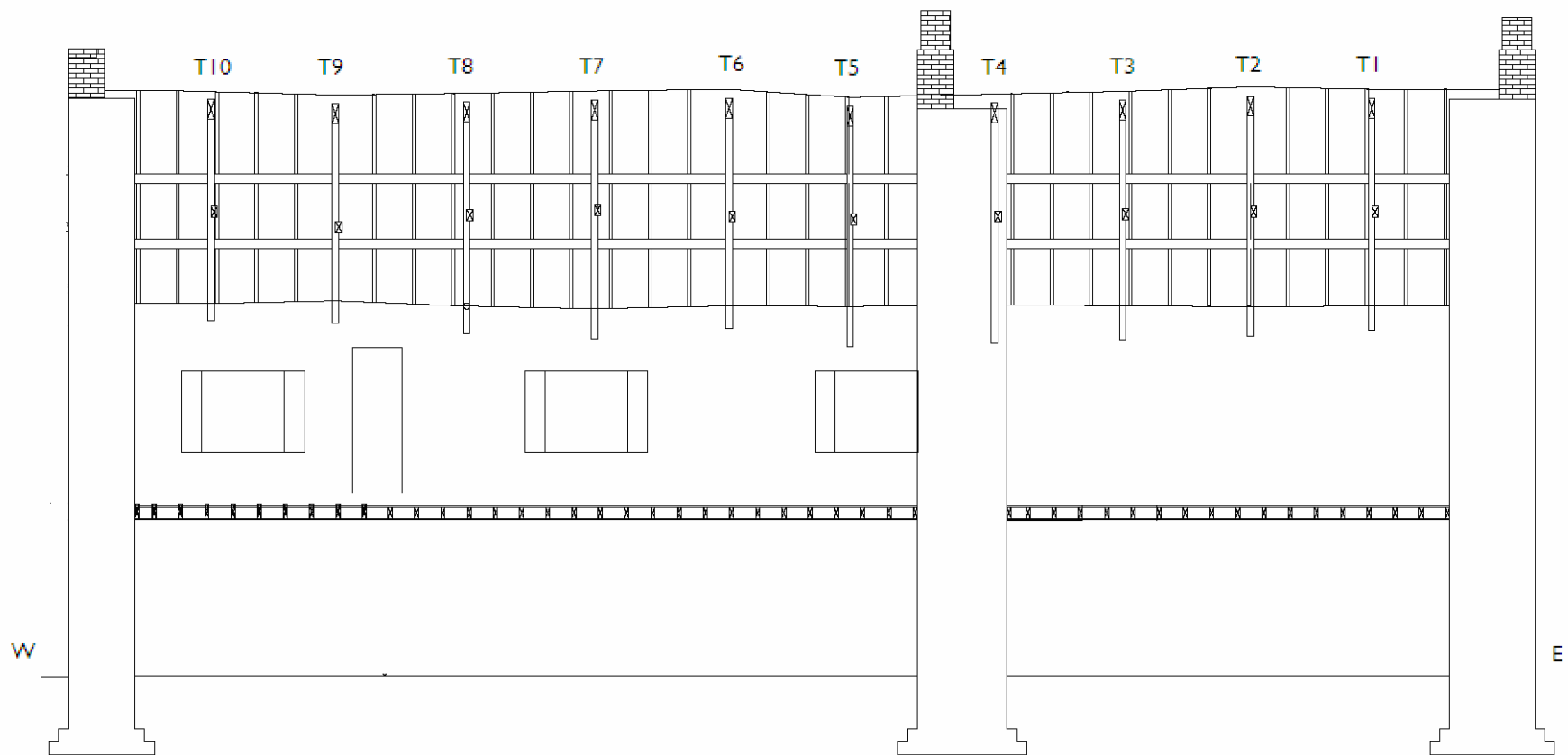


Figure 10: Section through building, showing truss numbering (Morton & Hall Consulting Ltd)

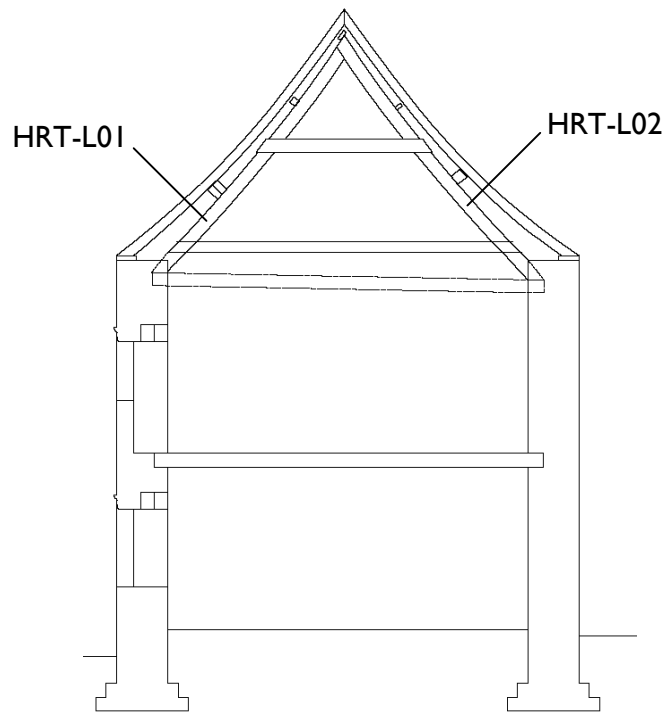


Figure 11: Truss 1 (west face), showing the location of samples HRT-L01 and HRT-L02 (Morton & Hall Consulting Ltd)

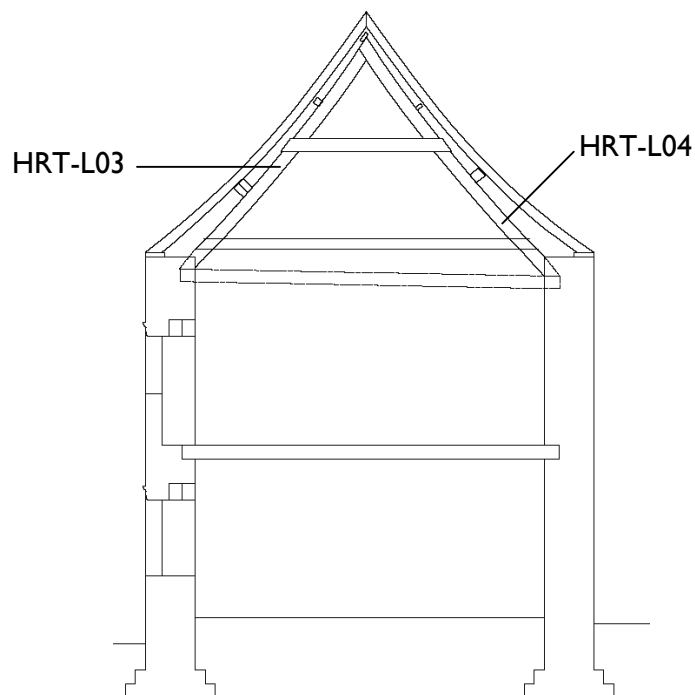


Figure 12: Truss 2 (west face), showing the location of samples HRT-L03 and HRT-L04 (Morton & Hall Consulting Ltd)

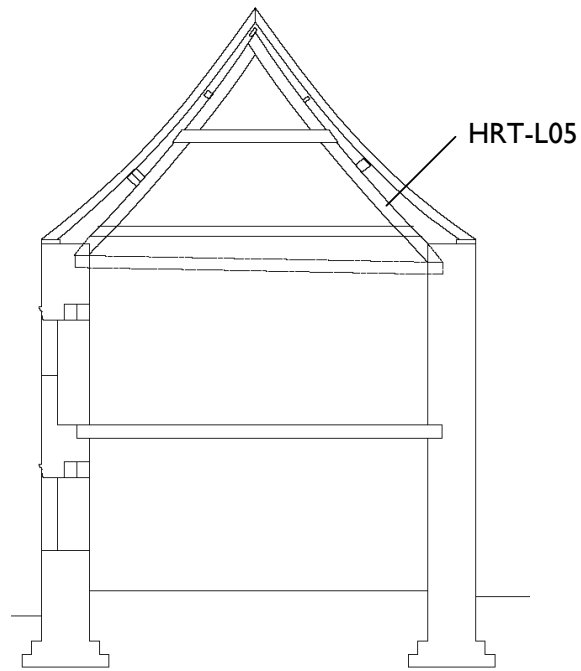


Figure 13: Truss 3 (west face), showing the location of sample HRT-L05 (Morton & Hall Consulting Ltd)

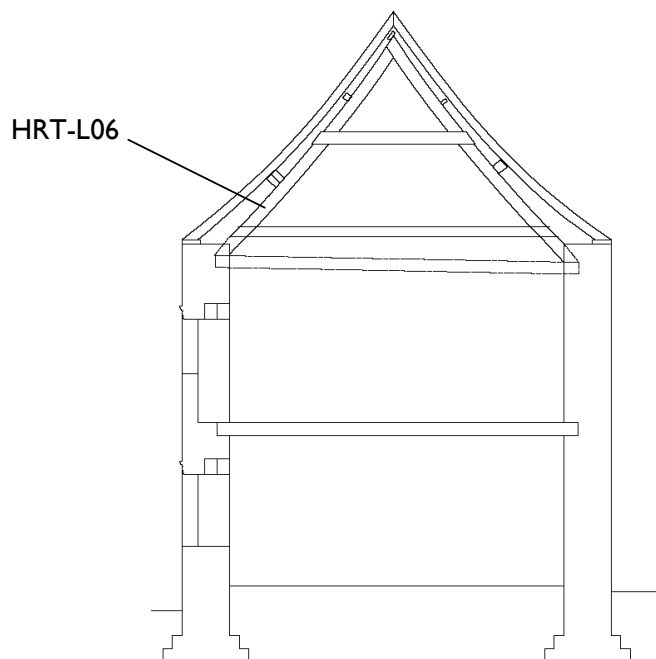


Figure 14: Truss 4 (west face), showing the location of sample HRT-L06 (Morton & Hall Consulting Ltd)

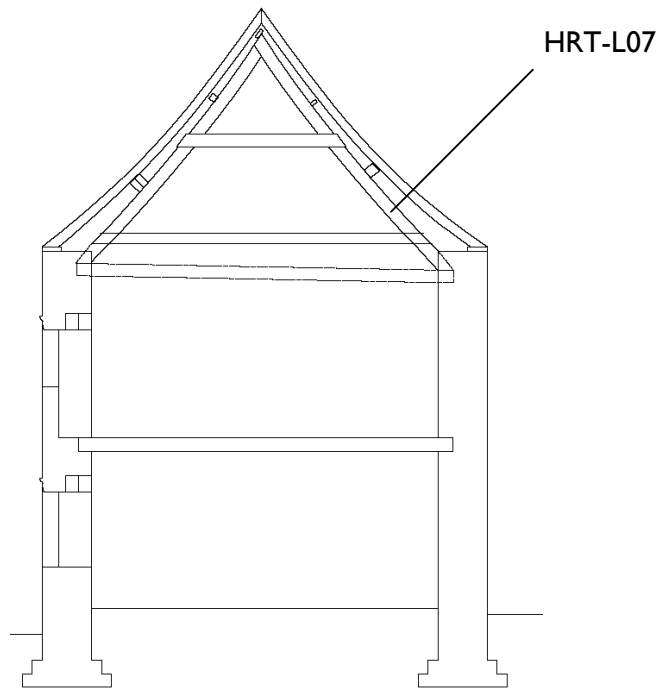


Figure 15: Truss 5 (west face), showing the location of sample HRT-L07 (Morton & Hall Consulting Ltd)

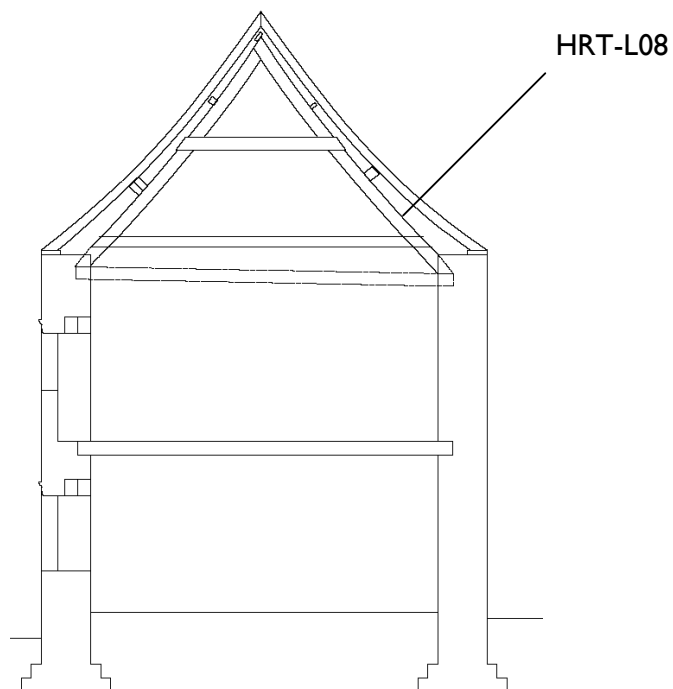


Figure 16: Truss 6 (west face), showing the location of sample HRT-L08 (Morton & Hall Consulting Ltd)

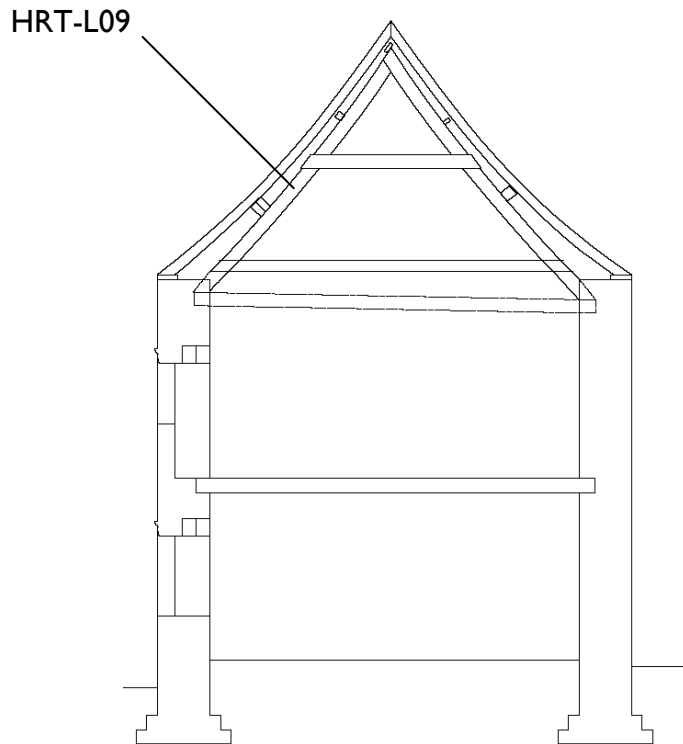


Figure 17: Truss 7 (west face), showing the location of sample HRT-L09 (Morton & Hall Consulting Ltd)

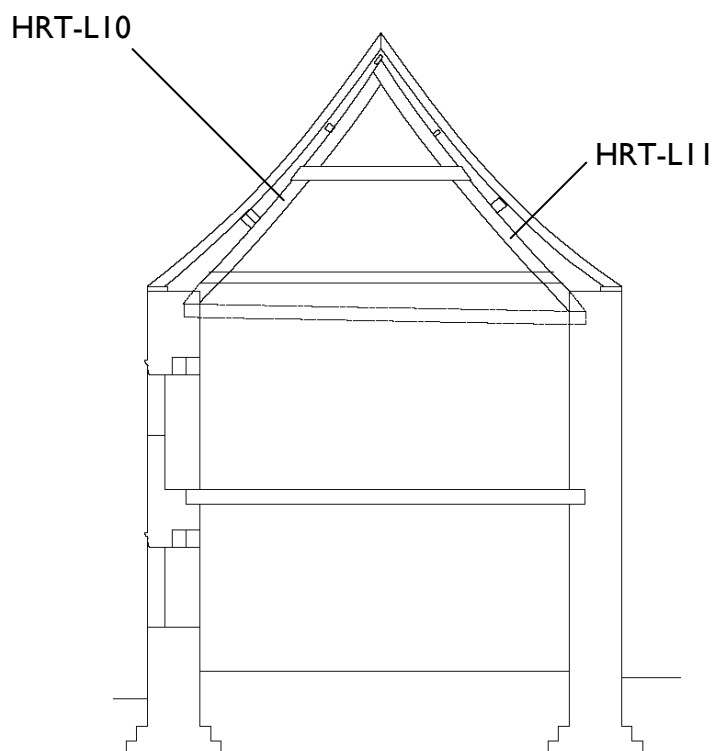


Figure 18: Truss 9 (west face), showing the location of samples HRT-L10 and HRT-L11 (Morton & Hall Consulting Ltd)

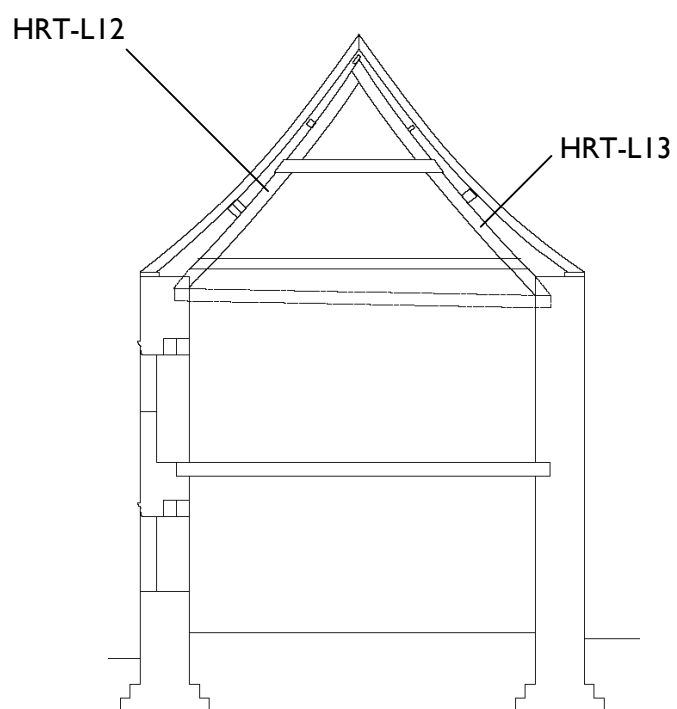


Figure 19: Truss 10 (west face), showing the location of samples HRT-L12 and HRT-L13 (Morton & Hall Consulting Ltd)

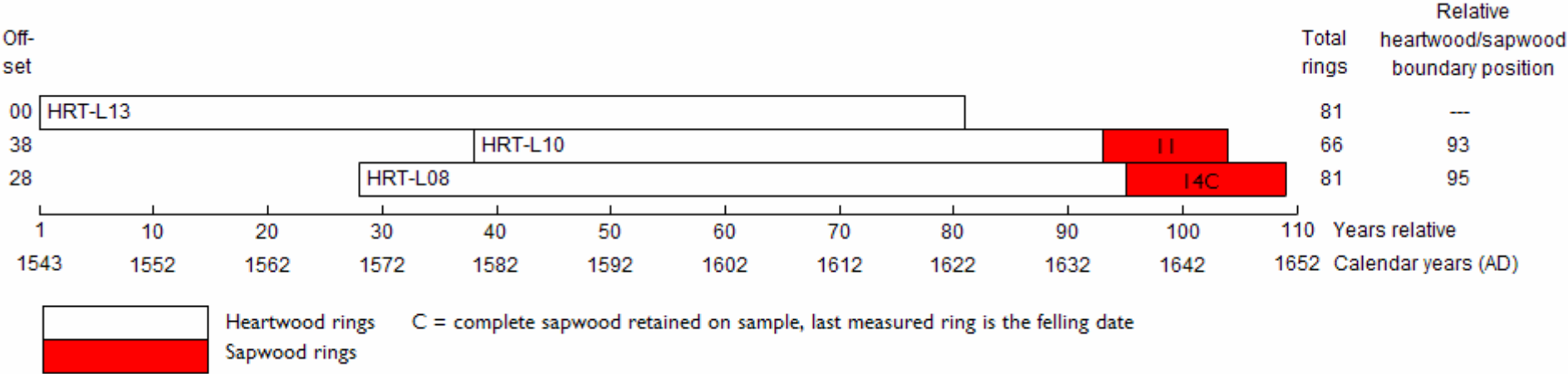


Figure 20: Bar diagram of samples in site sequence HRTLSQ01

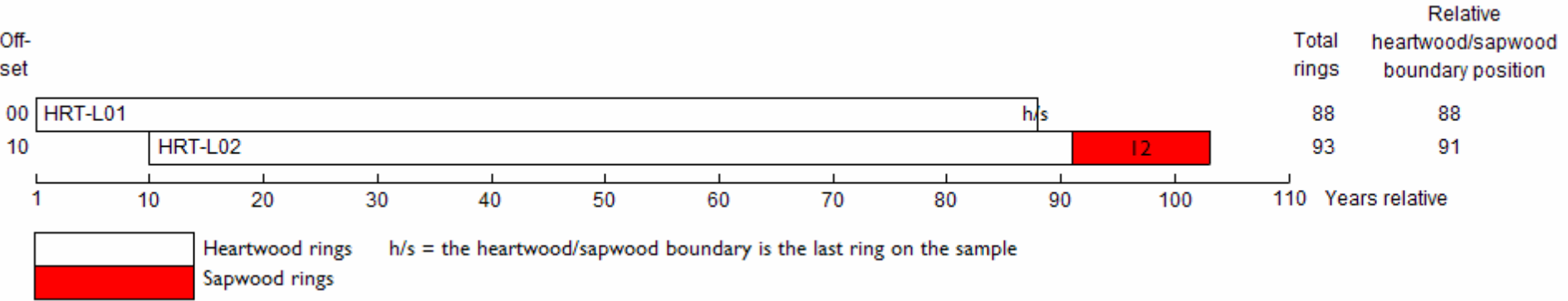


Figure 21: Bar diagram of samples in undated site sequence HRTLSQ02

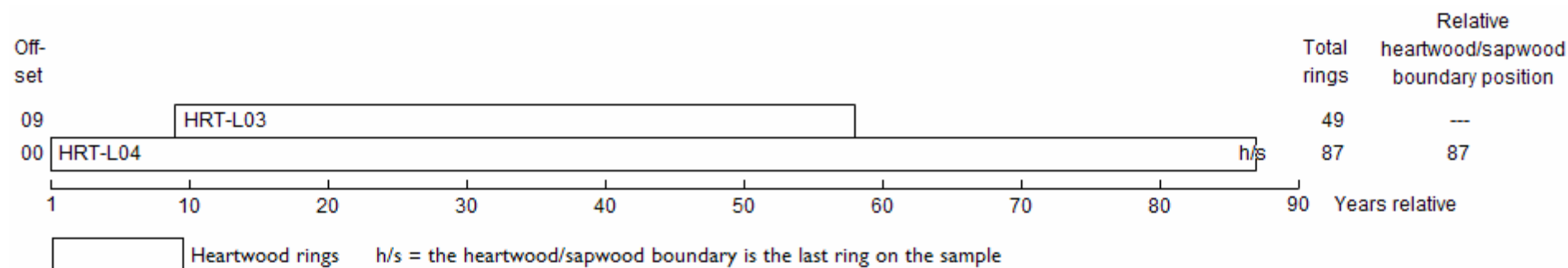


Figure 22: Bar diagram of samples in undated site sequence HRTLSQ03

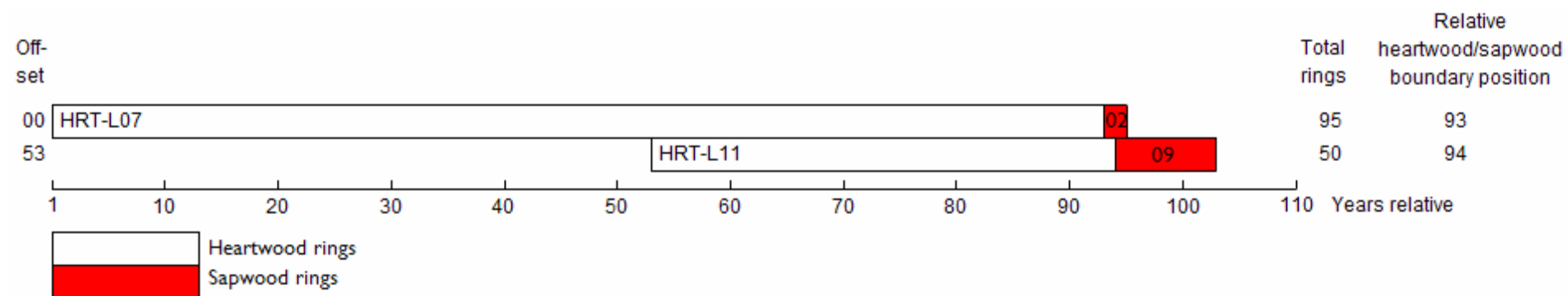


Figure 23: Bar diagram of samples in undated site sequence HRTLSQ04

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

HRT-L01A 88

216 148 166 206 166 143 154 148 89 97 101 148 121 141 75 46 56 53 47 73
337 321 171 109 78 79 98 187 159 196 177 159 163 193 124 134 173 150 149 209
132 116 132 142 132 229 422 260 198 147 151 163 192 188 173 167 189 235 221 201
148 134 174 174 125 207 239 276 205 253 187 183 163 175 194 136 181 171 149 170
154 149 142 136 117 125 221 179

HRT-L01B 88

218 144 166 200 175 159 139 147 87 100 100 147 126 140 77 45 56 55 41 68
332 320 172 108 88 75 99 185 159 201 177 164 162 193 124 135 171 152 148 211
133 116 132 142 127 234 418 262 195 149 149 164 192 186 176 166 196 233 224 196
152 133 172 172 121 210 235 273 209 257 189 177 167 172 192 141 177 172 148 172
154 150 140 116 103 148 209 189

HRT-L02A 93

179 175 256 189 192 85 78 100 104 121 320 194 72 58 77 58 79 140 111 149
158 139 147 188 125 115 130 98 102 156 114 104 107 114 124 165 161 125 105 77
103 101 120 163 124 137 149 142 112 84 90 77 95 121 88 118 131 146 78 89
91 106 133 109 94 92 139 117 97 98 93 106 102 85 98 108 178 181 110 110
98 128 116 78 72 88 76 91 101 83 124 98 94

HRT-L02B 93

180 166 254 186 190 94 74 105 108 115 323 197 79 56 72 63 78 143 116 167
163 144 148 191 123 101 130 100 98 158 121 99 108 98 121 164 161 127 108 71
105 102 117 168 127 134 152 136 105 98 94 80 102 124 85 123 134 154 77 89
92 109 137 105 96 91 133 117 104 96 103 109 100 83 105 100 176 179 114 106
99 131 110 82 65 89 83 89 101 88 122 102 90

HRT-L03A 49

309 470 476 446 405 398 505 460 446 409 491 364 444 416 460 355 350 314 441 388
212 260 295 237 300 452 536 545 360 409 395 320 278 248 184 163 162 151 210 270
289 250 312 192 143 192 202 245 240

HRT-L03B 49

318 482 516 456 397 390 490 448 449 415 471 366 439 430 469 355 347 310 448 387
215 258 311 230 309 439 539 557 372 400 380 327 283 243 182 165 158 157 198 276
288 258 309 193 141 200 210 227 252

HRT-L04A 87

224 251 215 246 206 175 93 127 64 97 159 157 118 130 148 180 168 200 170 158
178 231 203 244 222 220 190 196 175 74 102 136 101 127 211 292 251 130 149 130
91 93 77 58 56 56 74 101 97 94 73 120 79 59 63 86 72 118 111 127
153 158 135 82 61 33 36 33 39 41 57 63 87 75 76 50 39 50 67 91
95 113 196 138 150 127 89

HRT-L04B 87

235 250 215 248 209 182 89 131 72 87 162 154 124 128 148 183 170 201 168 158
180 232 199 245 225 220 183 207 169 69 107 129 98 127 216 296 249 138 139 125
95 96 75 43 59 64 76 100 100 87 81 113 72 67 61 83 76 117 110 125
153 169 122 85 60 35 35 39 36 42 58 56 84 82 71 53 46 47 60 89
95 110 196 138 146 123 93

HRT-L05A 81

193 144 170 178 279 270 235 249 171 169 224 193 326 313 225 246 209 227 242 302
225 227 290 188 193 183 168 206 187 174 219 249 204 215 222 232 191 175 252 257
317 304 251 247 201 183 207 169 255 233 257 188 230 268 313 188 186 125 158 193
216 166 201 149 168 145 129 151 95 162 204 172 181 127 138 123 84 104 102 115

129

HRT-L05B 81

170 144 176 215 286 258 243 258 172 172 243 205 291 290 226 252 218 222 253 281
235 224 292 182 146 175 176 200 176 180 218 253 201 219 206 232 191 175 239 258
319 306 261 242 210 174 201 172 253 240 255 186 240 264 322 192 183 125 156 195
213 161 199 149 159 147 130 157 102 155 197 165 196 114 140 111 80 94 104 114
132

HRT-L07A 95

108 74 69 100 93 129 194 215 181 141 130 159 171 124 86 51 61 115 134 159
231 211 169 126 194 220 240 213 95 87 55 59 131 96 102 88 89 122 99 89
109 119 117 107 118 107 75 54 73 114 177 222 159 111 116 95 83 97 72 101
71 93 107 123 168 226 242 166 158 153 147 175 203 165 136 106 119 85 72 112
97 105 100 90 106 115 159 128 96 88 89 148 107 54 61

HRT-L07B 95

101 80 71 98 93 130 193 213 188 141 133 149 170 118 89 52 62 99 160 169
229 208 171 120 200 220 239 209 96 83 58 67 127 83 93 89 97 117 96 89
111 120 114 111 120 102 76 58 65 114 174 218 156 115 117 96 87 92 72 100
72 91 107 127 149 229 243 164 160 158 141 175 204 166 136 104 121 78 69 114
101 103 102 89 103 118 162 124 95 84 94 143 92 61 65

HRT-L08A 81

235 162 194 212 139 93 63 145 182 246 180 169 215 255 385 368 377 420 407 252
363 320 308 336 334 361 306 302 218 281 248 264 262 294 225 304 271 273 301 271
228 240 243 199 183 137 179 189 161 209 197 208 223 159 179 134 213 244 190 206
188 218 210 149 161 149 177 268 209 208 161 176 140 146 166 200 200 143 167 155
118

HRT-L08B 81

228 167 195 206 143 98 62 146 186 245 193 187 213 252 381 375 386 418 394 259
367 306 296 329 330 366 309 308 213 284 250 272 259 297 222 308 264 280 297 271
228 242 240 200 186 132 182 184 165 207 194 217 216 162 192 136 208 243 193 207
191 213 207 154 168 152 169 258 215 211 164 173 150 141 166 206 197 145 164 159
120

HRT-L09A 62

187 200 161 179 267 285 208 241 311 241 248 230 301 363 368 352 303 367 193 255
289 276 236 178 247 232 339 312 255 253 298 321 249 211 300 387 272 227 212 328
301 265 236 225 229 177 201 206 182 224 221 188 159 114 145 202 197 208 151 99
83 88

HRT-L09B 51

378 320 302 270 296 346 264 231 335 399 326 186 215 282 276 255 240 186 179 113
221 258 225 236 228 167 161 121 144 191 204 216 177 88 100 98 78 83 83 110
135 122 111 124 111 70 109 165 181 171 152

HRT-L10A 66

146 177 193 197 162 225 174 145 187 154 185 217 264 341 314 262 192 199 145 91
69 100 147 198 216 320 265 210 188 146 156 180 165 155 116 97 122 161 184 226
175 177 143 134 179 138 195 180 166 142 90 118 117 101 99 80 99 143 135 138
128 81 97 92 158 242

HRT-L10B 66

180 177 188 200 156 227 181 138 192 164 173 221 257 342 317 260 198 204 134 88
69 102 149 193 219 318 263 215 185 145 157 185 161 160 118 94 110 167 192 236
169 187 142 134 175 137 197 173 161 148 85 133 111 99 108 96 86 152 130 132
124 84 100 94 157 236

HRT-L11A 50

218 258 236 288 270 328 368 350 325 332 247 250 246 304 195 184 148 150 194 234
282 237 304 298 232 257 331 364 378 370 318 262 346 396 311 202 211 230 293 232
225 220 175 210 180 247 246 272 269 239

HRT-LI1B 50

228 248 219 277 290 328 370 358 317 332 235 262 246 296 200 177 164 143 203 233
276 235 301 304 256 261 330 354 388 371 347 267 349 402 311 204 209 226 296 236
227 216 180 206 180 262 245 266 262 254

HRT-LI3A 81

278 245 252 138 131 110 138 183 169 178 207 230 414 321 281 216 293 338 284 267
216 137 122 156 186 321 292 323 238 215 184 298 318 191 189 266 239 307 202 217
285 396 353 400 332 256 279 223 248 275 302 347 350 351 355 314 257 225 164 170
257 298 336 334 338 354 397 270 228 285 297 252 201 159 155 222 239 314 237 258
230

HRT-LI3B 81

272 248 255 133 128 102 157 166 172 179 210 192 427 322 278 211 281 356 306 235
230 138 122 180 172 331 271 316 246 209 196 303 317 187 191 265 236 297 205 214
269 423 355 397 327 251 269 221 249 274 300 355 363 344 355 306 258 221 158 171
252 305 329 358 315 350 398 280 219 294 291 255 202 148 162 219 240 308 246 251
247

HRT-LI4A 82

227 275 230 277 187 248 213 247 197 233 233 300 382 338 159 162 217 173 306 217
224 287 130 124 167 96 101 138 144 114 135 121 101 97 79 84 75 90 91 96
103 106 69 88 80 73 69 91 90 91 99 141 111 83 119 122 104 138 85 124
134 105 102 70 95 119 154 162 147 125 135 153 145 93 82 72 89 72 69 78
85 92

HRT-LI4B 82

228 276 226 278 188 247 215 243 191 239 247 303 385 345 160 162 219 176 308 209
226 288 125 124 156 108 95 132 144 117 138 117 104 97 78 86 73 92 81 100
104 102 80 80 68 66 67 86 92 98 96 133 112 84 115 124 101 139 92 122
131 110 90 77 94 127 155 169 136 126 132 157 152 88 85 72 97 86 68 64
97 93

HRT-LI5A 61

294 221 287 314 292 301 288 315 269 263 290 305 260 286 228 258 248 234 225 327
249 162 154 200 166 184 112 176 181 180 162 158 229 230 181 133 153 175 162 183
279 241 217 198 87 107 81 79 95 70 99 103 132 109 104 117 126 112 130 150
125

HRT-LI5B 61

316 222 283 313 299 294 294 302 275 255 294 294 272 281 228 256 250 231 218 330
240 149 153 196 168 177 110 183 174 184 165 156 225 230 176 136 157 177 157 192
275 246 224 202 87 111 75 82 98 65 93 109 129 110 109 109 140 104 115 148
127

HRT-LI6A 112

138 137 118 358 415 324 172 193 366 356 184 261 247 131 134 121 221 378 203 198
113 166 96 391 279 151 116 103 118 101 115 108 83 93 97 96 105 86 140 218
172 165 161 127 83 82 76 66 70 73 87 69 63 78 49 81 72 68 60 56
64 74 80 72 43 52 63 61 72 65 63 75 70 58 60 58 69 63 56 65
67 55 65 73 63 72 68 83 66 53 65 51 65 93 66 88 65 85 47 74
95 81 85 75 64 52 43 77 50 49 72 61

HRT-LI6B 112

155 175 130 424 425 323 178 202 391 370 210 267 236 134 158 116 236 374 206 201
108 171 97 401 287 156 128 106 120 95 121 110 85 91 99 95 108 87 144 216
174 163 166 130 81 83 77 70 68 74 74 70 61 77 54 80 62 56 65 60
61 71 72 65 52 48 50 67 67 64 60 63 64 55 49 63 62 50 62 54
68 58 58 68 68 62 62 83 60 52 64 43 74 81 73 73 72 89 40 79
85 77 77 74 58 59 46 59 51 45 76 53

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.



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



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



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



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

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

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

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

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

sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a

number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

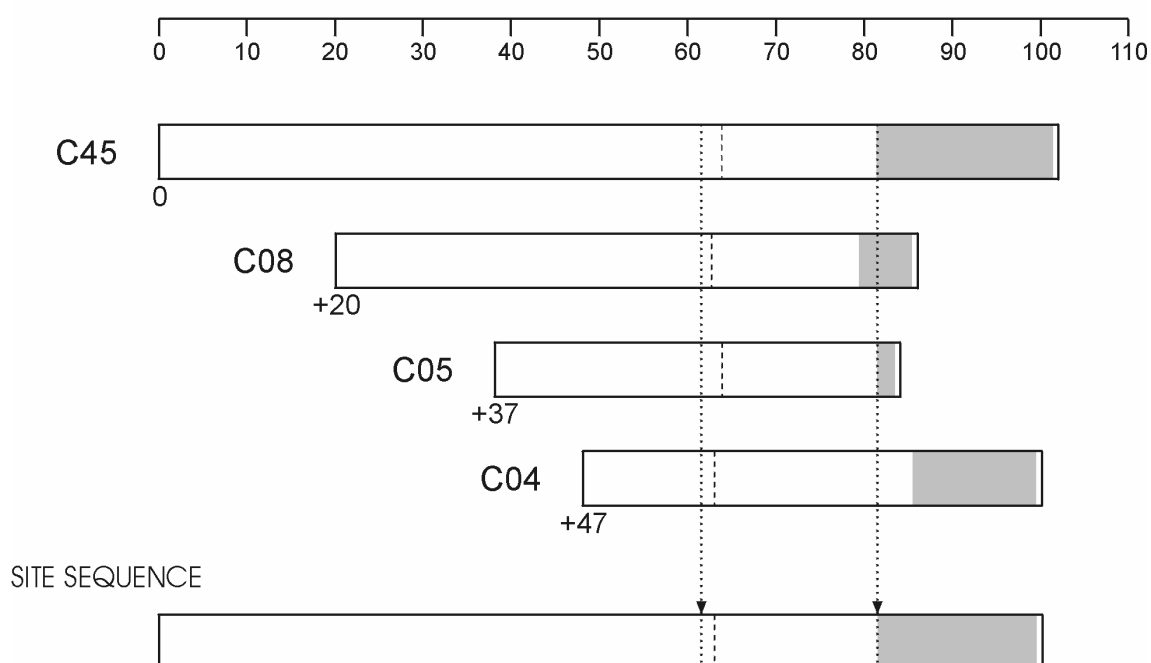


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

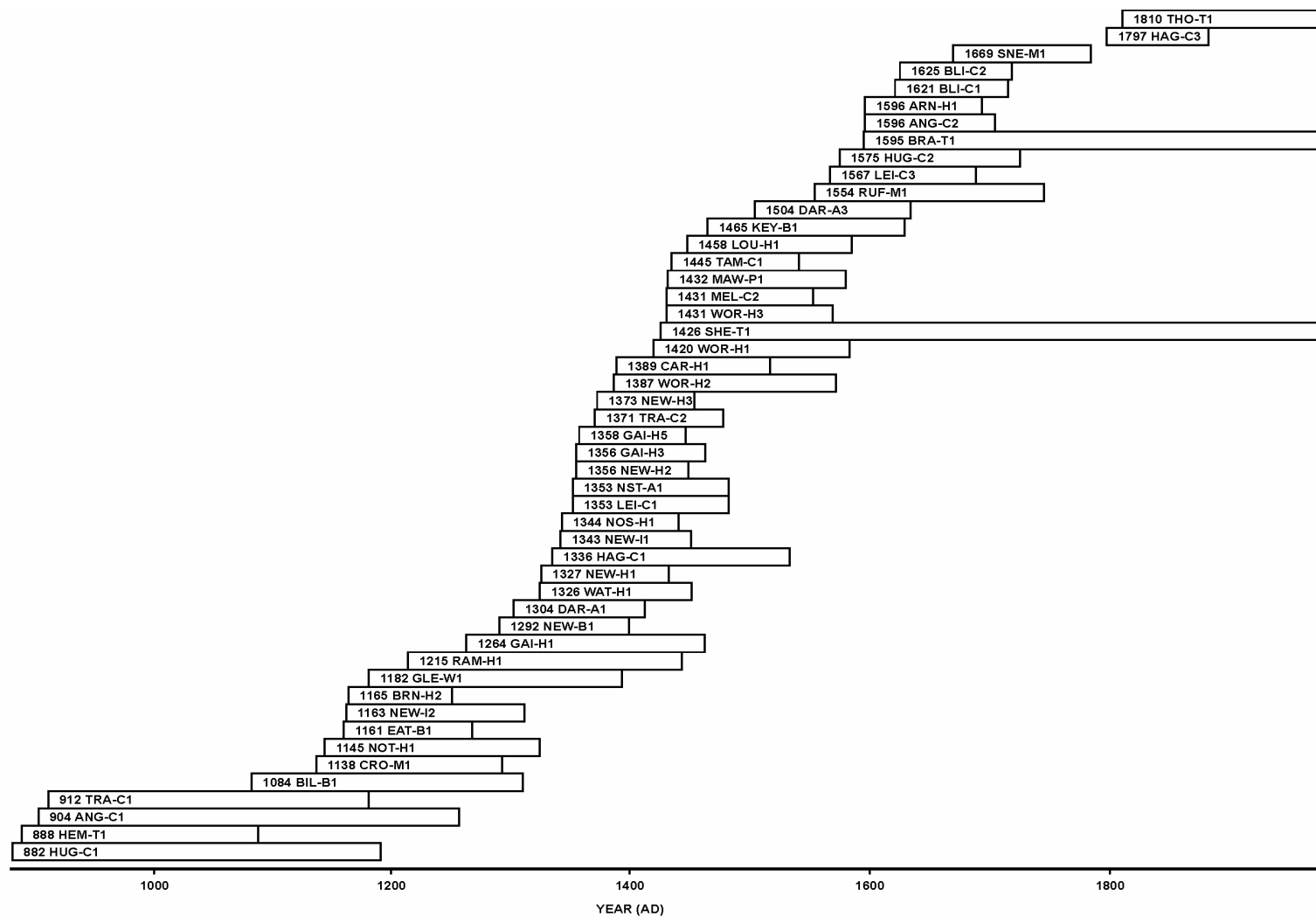
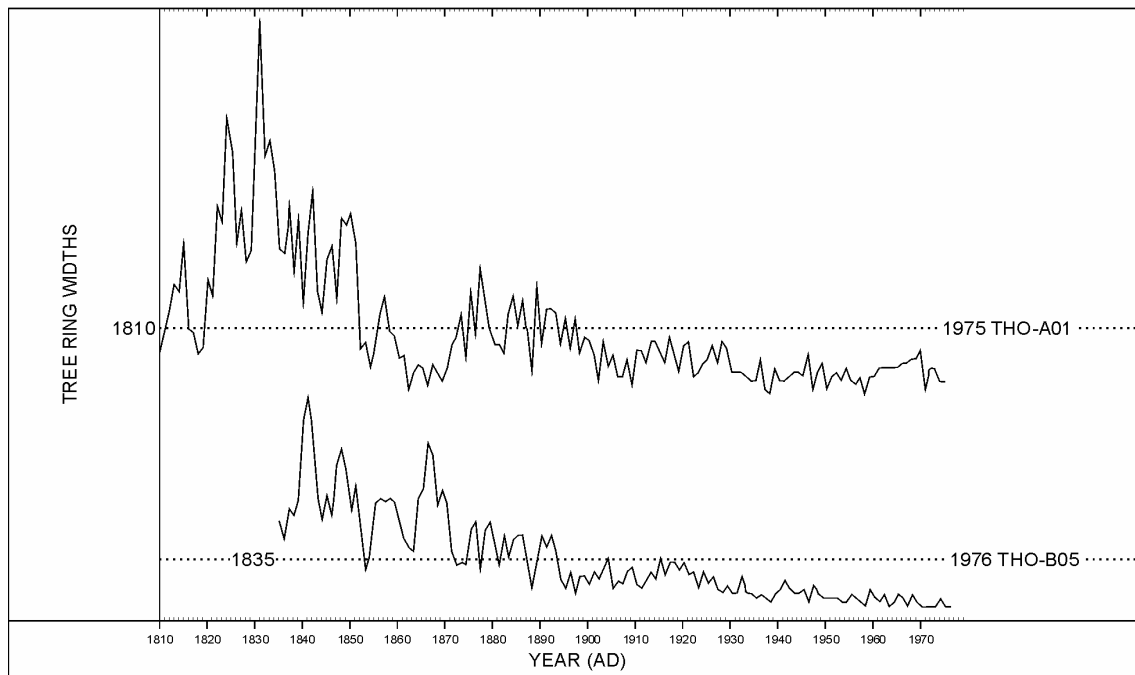


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

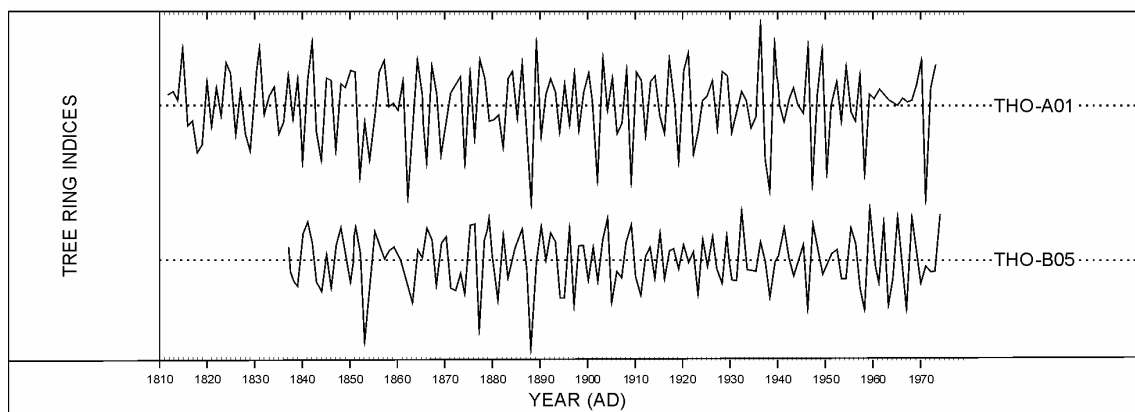


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

References

- Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, **33**, 7–14
- English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London
- Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165–85
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **15–26**
- 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