RESEARCH DEPARTMENT REPORT SERIES no. 68-2009 ISSN 1749-8775

THE CHANTRY, CHANTRY PLACE, MORPETH, NORTHUMBERLAND
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 68-2009

THE CHANTRY, CHANTRY PLACE, MORPETH, NORTHUMBERLAND

TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: NZ 200 858

ISSN 1749-8775

SUMMARY

Analysis of material from the present roof structure of the western end of the nave of the Chantry, Morpeth, has resulted in the production of a single site chronology comprising all 12 samples obtained. This site chronology has an overall length of 316 rings, which are dated as spanning the years AD 1336–1651.

Interpretation of the sapwood indicates that all the timbers were probably cut as part of a single programme of felling, dated to the mid-AD 1650s. As suspected following a more recent survey of the building, the present roof is, therefore, not the original, but a later seventeenth-century replacement.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to thank Mr David Thompson of Morpeth Borough Council's Corporate Property Office for his unfailing cooperation and considerable help with this programme of analysis. The Laboratory would also like to thank Martin Roberts, Historic Buildings Inspector at English Heritage's Newcastle-upon-Tyne Office, for his help and advice during sampling, for providing background material used in the introduction below, and for the provision of plans and drawings used in this report. We would also like to thank Isabelle Parsons, Assistant Scientific Dating Coordinator, also of English Heritage, for commissioning the tree-ring analysis at this site.

ARCHIVE LOCATION

Northumberland Historic Environment Record
Northumberland County Council Conservation Team
Environment Directorate
County Hall
Morpeth NE61 2EF

DATE OF INVESTIGATION

2009

CONTACT DETAILS

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

CONTENTS

INTRODUCTION

The Chantry, Morpeth, is a grade 1 listed building located adjacent to the north end of the site of the medieval bridge (NZ 20042 85889, Figs 1 and 2).

The chapel of All Saints, now known as The Chantry, is believed to have been built in AD 1296 by Richard of Morpeth, clerk to John de Greystock, Baron of Morpeth, and documentary evidence certainly notes that as early as AD 1310 a chaplain was being paid for divine service. As acts of religious beneficence, the building of bridges and the making of roads were considered to be particularly pious undertakings, especially if a chapel endowed with a chantry was included as part of the work. In the case of bridges, the chapel was usually built on a starling, or pier, to one side, though sometimes, as in the case of The Chantry, it would stand at one end. Whilst the records show that many such chantry chapels once existed, the Morpeth example is now one of only a handful of bridge chapels still in existence, other examples being found at Rotherham, Wakefield, and Derby..

Despite purges by Henry VIII and Edward VI, Morpeth Chantry survived, Henry's commissioners noting in AD 1535 that it was also used '*to keep a grammar school for the erudition and bringing up of children*'. The Chantry was given a new charter in AD 1552. The south side and east end of the building were remodelled in the mid-eighteenth century. The north side, however, still retains much of its medieval stonework, and the west end its pointed arched doorway in a multi-moulded surround, with two double-chamfered windows above and a bellcote (Fig 3). Further work was undertaken on the building in the nineteenth century and the early twentieth century, and it was further restored in AD 1980.

The following roof description is based on Martin Roberts (pers comm). It is only at the western end of the former nave of the chantry that any substantial oak timberwork now remains, there being four principal-rafter trusses with tiebeams, the trusses having upper and lower collars, and carrying double purlins to each pitch of the roof (Figs 4 and 5). All these timbers appear to be pegged with mortice and tenon joints, many of the timbers having corresponding assembly marks.

Unusually, there are vertical 'hanging ties', or struts, between the lower collars and the principal rafters (Fig 4), and although the lower ends of these verticals are given dove-tailed tenons, the dovetails are not set into corresponding mortices in the tiebeams. Instead, these timbers are fixed, by large-headed bolts with nuts and small flanges, face-on to the tiebeams. The top ends of the verticals are also face-bolted to the principal rafters. The majority of these timbers are of oak, but there appear to be no assembly marks on them.

There are also straight, softwood, braces from the tiebeams to the lower purlins, and from the lower collars to the upper purlins. These braces, of smaller scantling than the vertical ties, are held by nails into notches cut in the timbers they join. It is likely that these nailed and bolted timbers are later additions, the oak timbers possibly being reused here, inserted to strengthen the earlier frame and prevent raking.

SAMPLING

Sampling and analysis by tree-ring dating of the roof timbers within The Chantry was requested by Martin Roberts, Historic Buildings Inspector based at English Heritage's Newcastle-upon-Tyne office in order to inform statutory advice during restoration and as part of English Heritage casework. It was hoped that dating the timbers would establish their age and confirm whether or not they represented part of the original structure, or, as suspected following a more recent, though brief, examination by Martin Roberts, a later reroofing, probably of seventeenth-century, or possibly eighteenth-century, date.

Although a few other timbers could possibly represent reused older pieces or more recent inserted repair pieces, the English Heritage brief requested that only the main roof structure be sampled. Thus, from the oak timbers available, a total of 12 samples was obtained by coring, each sample being given the code MRP-A (for Morpeth, site 'A') and numbered 01–12. All sampled timbers appeared to be of a single phase of construction, being marked out, jointed, and pegged together as an integral structure

Where possible, the positions of these samples are marked on drawings provided by English Heritage. These are reproduced here as Figures 6 and 7. Details of the samples are given in Table 1. In this table all the trusses have been numbered from east to west with individual timbers further identified on a north south basis as appropriate.

ANALYSIS

Each of the 12 samples obtained was prepared by sanding and polishing and the width of its annual growth rings were measured. The data of these measurements are given at the end of this report. The data of these 12 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a particularly high minimum value of t=8.0, a single group comprising all 12 samples could be formed, the samples cross-matching with each other at the offset position shown in the bar diagram, Figure 8.

The 12 samples were combined at these positions to form site chronology MRPASQ01, this having an overall length of 316 rings. Site chronology MRPASQ01 was then compared with an extensive series of reference chronologies for oak, cross-matching repeatedly and consistently with a number of these when the date of its first ring is AD 1336 and the date of its last ring is AD 1651. The evidence for this dating is given in Table 2.

INTERPRETATION

Of the 12 dated samples in site chronology, MRPASQ01, one, sample MRP-A07, retains complete sapwood. This means that it has the last ring produced by the tree it represents before it was cut down. Unfortunately, due to the decay of this soft and fragile portion of the wood, only the first 24 sapwood rings can be measured, the outer sapwood rings being not only indistinct but compacted as well. It is estimated, however, that there are approximately 25 unmeasured sapwood rings in this part of the core. Given that the last measured sapwood ring on sample MRP-A07 is dated to AD 1630, such a number of unmeasured sapwood rings would give the timber represented an estimated felling date of approximately AD 1655.

Two other samples, MRP-A06 and A10, are from timbers which also retained complete sapwood but from which, again due to the fragile nature of the wood, part, or all, of the sapwood disintegrated during coring. Although the lost portions are quite large, 20–30 mm, making estimates less accurate, observations and notes made at the time of sampling and during measurement would suggest that the likely numbers of rings in the lost sapwood portions would not be inconsistent with the trees they represent being felled in the AD 1650s as well.

Such a felling date indicates that at least two of the trees represented by these three samples have a noticeable higher number of sapwood rings than normal, the usual upper limit of the 95% confidence limit being 40 sapwood rings. Sample MRP-A07 has an estimated 49 sapwood rings and sample MRP-A10 would have 56 rings were it felled at the estimated dated of *c* AD 1655. It is also noticeable that there is some variation in the position of the heartwood/sapwood boundary on these three samples, from AD 1599 on sample MRP-A10, to AD 1606 on A07, and AD 1624 on sample MRP-A06.

The relative position and date of the heartwood/sapwood boundary on the three remaining dated samples where it exists, MRP-A04, A09, and A12, is similarly variable, (and the number of sapwood rings they have potentially similarly high) to that on the three samples discussed above with lost or unmeasureable sapwood rings to bark edge. The outermost measured, sapwood, ring on any of these three other samples, MRP-A12, is dated to AD 1651, but this is not at bark edge. As such, there is no reason to suspect that the timbers represented by these three were not also felled in the AD 1650s.

There is little reason, also, to suspect that those timbers represented by the six samples without the heartwood/sapwood boundary, were not felled at this time too. With one exception the end dates of all such samples is in the latter half of the sixteenth century, the exception being sample MRP-A01 with an end date of AD 1511. This sample, however, gives a same-tree match with sample MRP-A04, and hence is simply likely to represent the inner section of a larger tree that has been trimmed heavily during conversion into a tiebeam.

Supporting evidence for all the dated timbers, those with sapwood, those with only the heartwood/sapwood boundary, as well as those without the heartwood/sapwood boundary, being cut as part of a single programme of felling is found in the unusually high degree of cross-matching between the samples here analysed. This process produces several cross-matches, almost 30% of the cross-matches indicated, with values, in excess of t=10. Such high t-values would suggest that the trees were growing very close to each other in the same copse or stand of woodland. Indeed, values of these levels, ranging from *t*=10.0 to a maximum of *t*=19.6, would strongly suggest that some timbers have been derived from the same tree, a view supported by the fact that a number of timbers appear to be half-trees or quarter-trees. It would be relatively unexpected to find timbers in the same structure which had originally been growing close to each other, but which had been felled at different times. All the evidence of the tree-ring analysis therefore strongly indicates a single felling date.

CONCLUSION

Analysis of material from the present roof structure over the western end of the nave of The Chantry, Morpeth, has resulted in the production of a single site chronology comprising all 12 samples obtained. This site chronology has an overall length of 316 rings which are dated as spanning the years AD 1336–1651.

Interpretation of the sapwood indicates that all the timbers were cut as part of a single programme of felling, probably dated to the mid AD 1650s. As suspected following a more recent examination, the present roof is, therefore, not the original, but a later, mid-seventeenth century replacement.

The potential age at felling of some the trees from which the timbers used at this site were obtained is particularly noteworthy. As may be seen from Table 1, all the samples have well over 100 rings, with some of them having more than 200 rings. The greatest number of rings, 242, is found on sample MRP-A12. Assuming that all the trees were felled in the mid AD 1650s and that the core samples do not include the oldest tree rings from the centre of each trunk, the true ages of the trees at felling appears likely to be in 200–300 year old range with some potentially exceeding this. Core samples with such high numbers of rings are not unknown, particularly in the early medieval period, but they are certainly not frequent in post-medieval structures. There is also something of a trend through the medieval and post-medieval periods towards the felling of younger trees, making trees as old as this in the mid-seventeenth century an even more unusual phenomenon.

The source woodland for the timbers dated here cannot be identified precisely by dendrochronology (eg Bridge 2000), but it seems probable that they are relatively local to Morpeth, and certainly to the region. As may be seen from Table 2, which lists a short selection of the reference chronologies used to date site sequence MRPASQ01, the highest *t*-values, and thus the greatest degree of similarity, are with the reference chronologies made up of material from other sites in the north-east.

BIBLIOGRAPHY

Arnold, A J, Laxton, R R, and Litton, C D, 2002 *Tree-ring analysis of timbers from Bull Hole Byre, Bearpark, Durham,* Centre for Archaeol Rep, 111/2002

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

Arnold, A J, Howard, R E, and Litton, C D, 2006 *Tree-ring analysis of timbers from Low Harperley Farmhouse, Wolsingham, County Durham,* Res Dep Rep Ser, 6/2006

Arnold, A, Howard, R, and Tyers, C, 2007 *Durham Cathedral, County Durham, tree-ring analysis of timbers from the Refectory and Librarian's Loft*, Res Dep Rep Ser, 39/2007

Arnold, A J, Howard, R E, and Tyers, C, 2008 *28–30 The Close, Newcastle Upon Tyne, Tyne and Wear: tree-ring analysis of timbers*, Res Dep Rep Ser, 56/2008

Bridge, M, 2000 Can dendrochronology be used to indicate the source of oak within Britain? *Vernacular Architect*, 31, 67–72

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 List 39 no 10 - Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* 22, 40–3

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, and Roberts, H M, North East Vernacular Architecture Group, 1996 List 67 no 1 - Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in medieval Durham; dendrochronological survey 1994– 5, *Vernacular Architect*, 27, 85–6

Howard, R E, Laxton, R R, and Litton, C D, 2001 *Tree-ring analysis of timbers from Hallgarth Manor Cottages, Hallgarth, Pittington, County Durham,* Centre for Archaeol Rep, 86/2001

TABLES

Table 1: Details of tree-ring samples from the roof of the Chantry, Morpeth, Northumberland

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
MRP-A01	Tiebeam, truss 1	176	no h/s	AD 1336	------	AD 1511
MRP-A02	North principal rafter, truss 1	173	no h/s	AD 1389	------	AD 1561
MRP-A03	Collar, truss 1	129	no h/s	AD 1456	------	AD 1584
MRP-A04	Tiebeam, truss 2	180	9	AD 1430	AD 1600	AD 1609
MRP-A05	North principal rafter, truss 2	145	no h/s	AD 1416	------	AD 1560
MRP-A06	South principal rafter, truss 2	171	3c	AD 1457	AD 1624	AD 1627
MRP-A07	Tiebeam, truss 3	211	24+nm25?C	AD 1420	AD 1606	AD 1630
MRP-A08	North principal rafter, truss 3	185	no h/s	AD 1410	------	AD 1594
MRP-A09	South principal rafter, truss 3	160	10	AD 1457	AD 1606	AD 1616
MRP-A10	Tiebeam, truss 4	160	h/s c	AD 1440	AD 1599	AD 1599
MRP-A11	North principal rafter, truss 4	120	no h/s	AD 1473	------	AD 1592
MRP-A12	South principal rafter, truss 4	242	28	AD 1410	AD 1623	AD 1651

*h/s = the heartwood/sapwood ring is the last ring on the sample
nm = estimated number of rings not measured (due to decay, compaction, or other reasons)
C = complete sapwood is retained from the sample.
c = complete sapwood is found on the timber, but all or part has been lost from the sample in coring

Table 2: Results of the cross-matching of site sequence MRPASQ01 and relevant reference chronologies when first ring date is AD 1336 and last ring date is AD 1651

Reference chronology	Span of chronology	*t*-value	
35 The Close, Newcastle upon Tyne	AD 1365–1513	7.3	(Howard *et al* 1991)
Bull Hole Byre, Bearpark, Durham	AD 1452–1620	6.4	(Arnold *et al* 2002)
Durham Cathedral, refectory roof	AD 1431–1683	6.2	(Arnold *et al* 2007)
Hallgarth Pittington, Co Durham	AD 1336–1624	6.2	(Howard *et al* 2001)
The Close, Newcastle upon Tyne	AD 1461–1616	6.2	(Arnold *et al* 2008)
Low Harperley Farmhouse, Wolsingham, Co Durham	AD 1356–1604	6.0	(Arnold *et al* 2006)
Kepier Farm Hospital, Durham	AD 1304–1522	5.7	(Howard *et al* 1996)
Pontefract Castle, Pontefract, South Yorks	AD 1507–1656	5.0	(Arnold and Howard 2006)

FIGURES

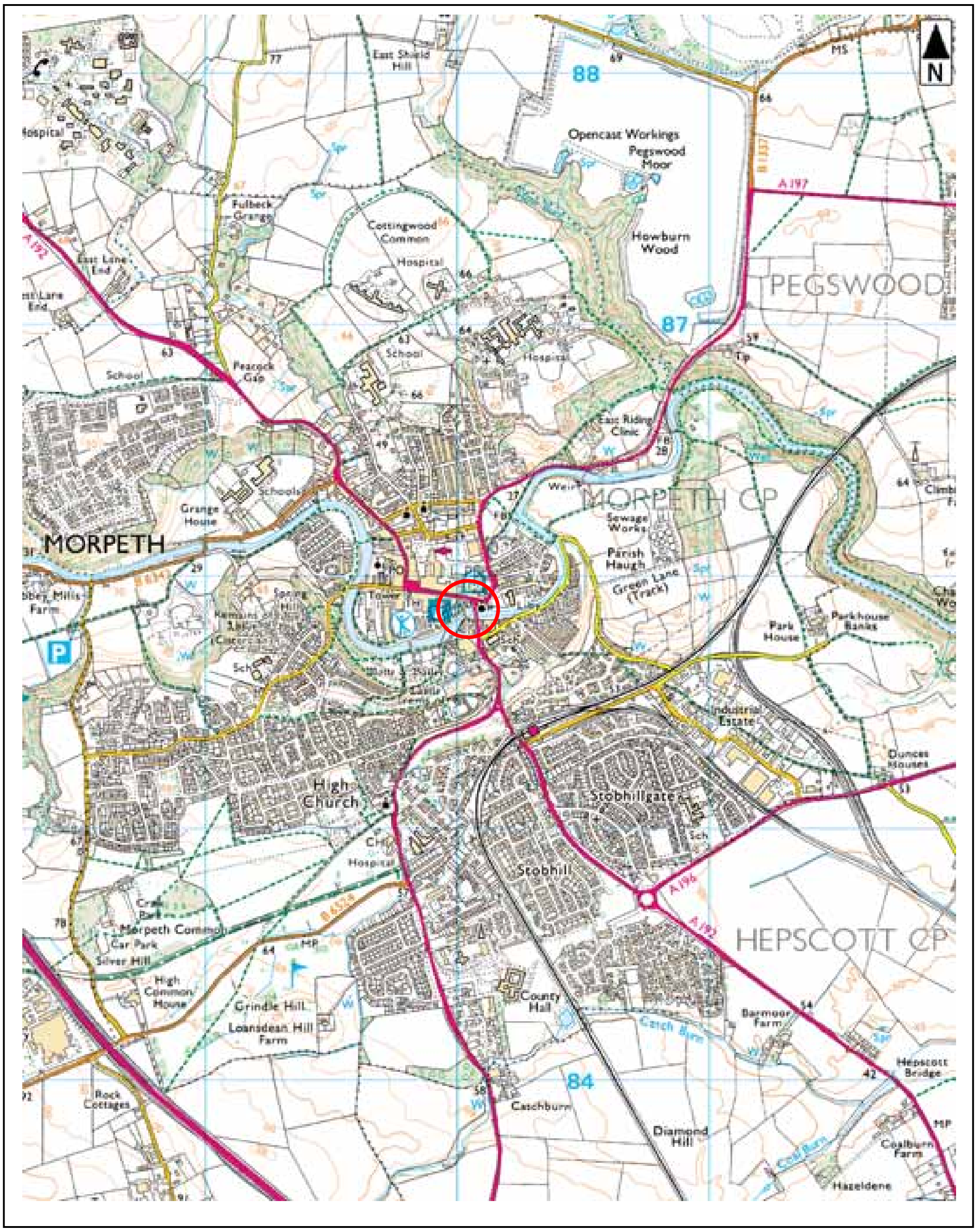


Figure 1: location of Morpeth Chantry (circled)

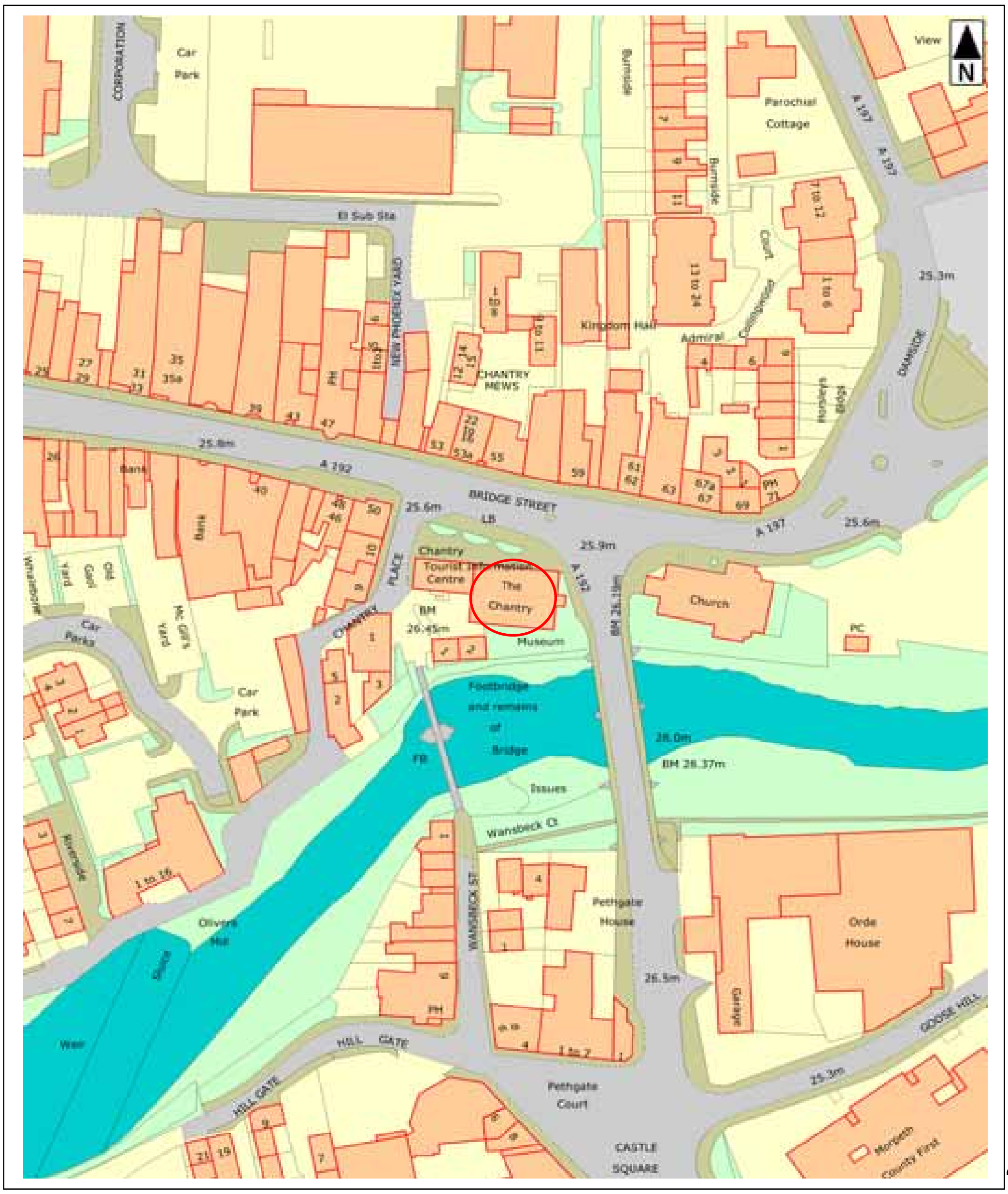


Figure 2: location of the buildings

Figure 3: Morpeth Chantry from the west

Figure 4: View of the Chantry roof looking west to east

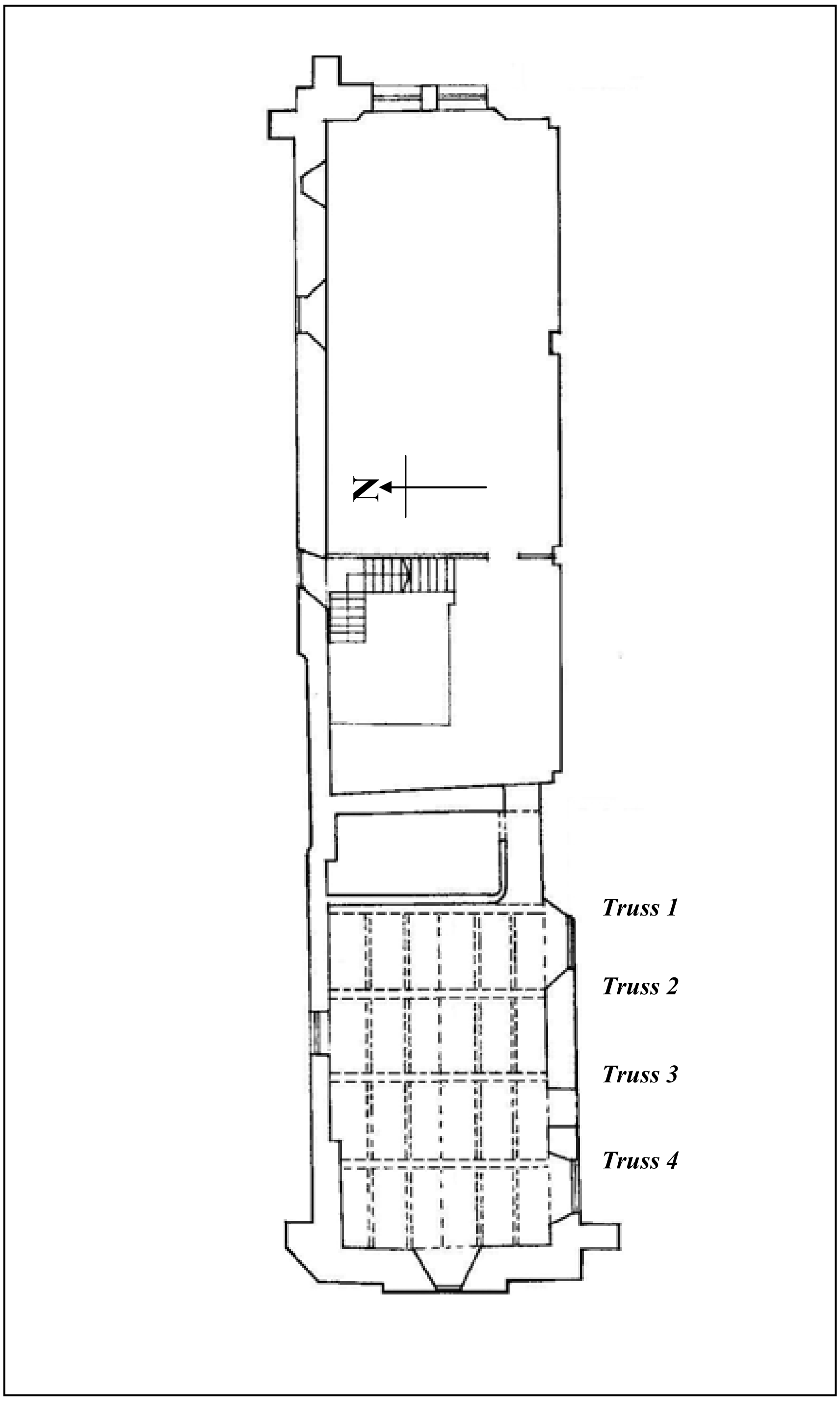


Figure 5: Basic plan of the chantry showing positions of the four trusses at the west end of the nave (after Martin Roberts)

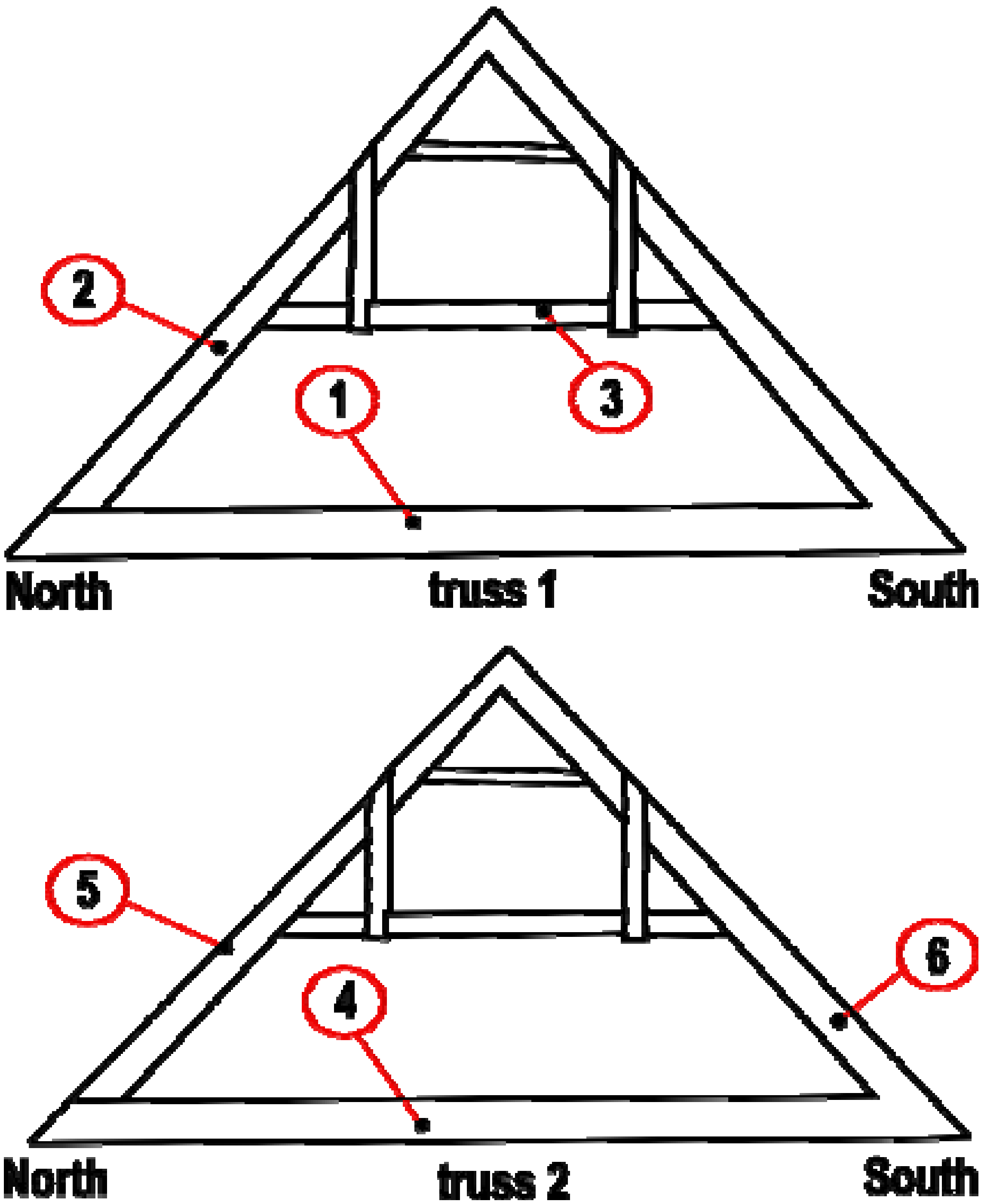


Figure 6: Schematic sections of trusses 1 and 2, showing positions of the sampled timbers

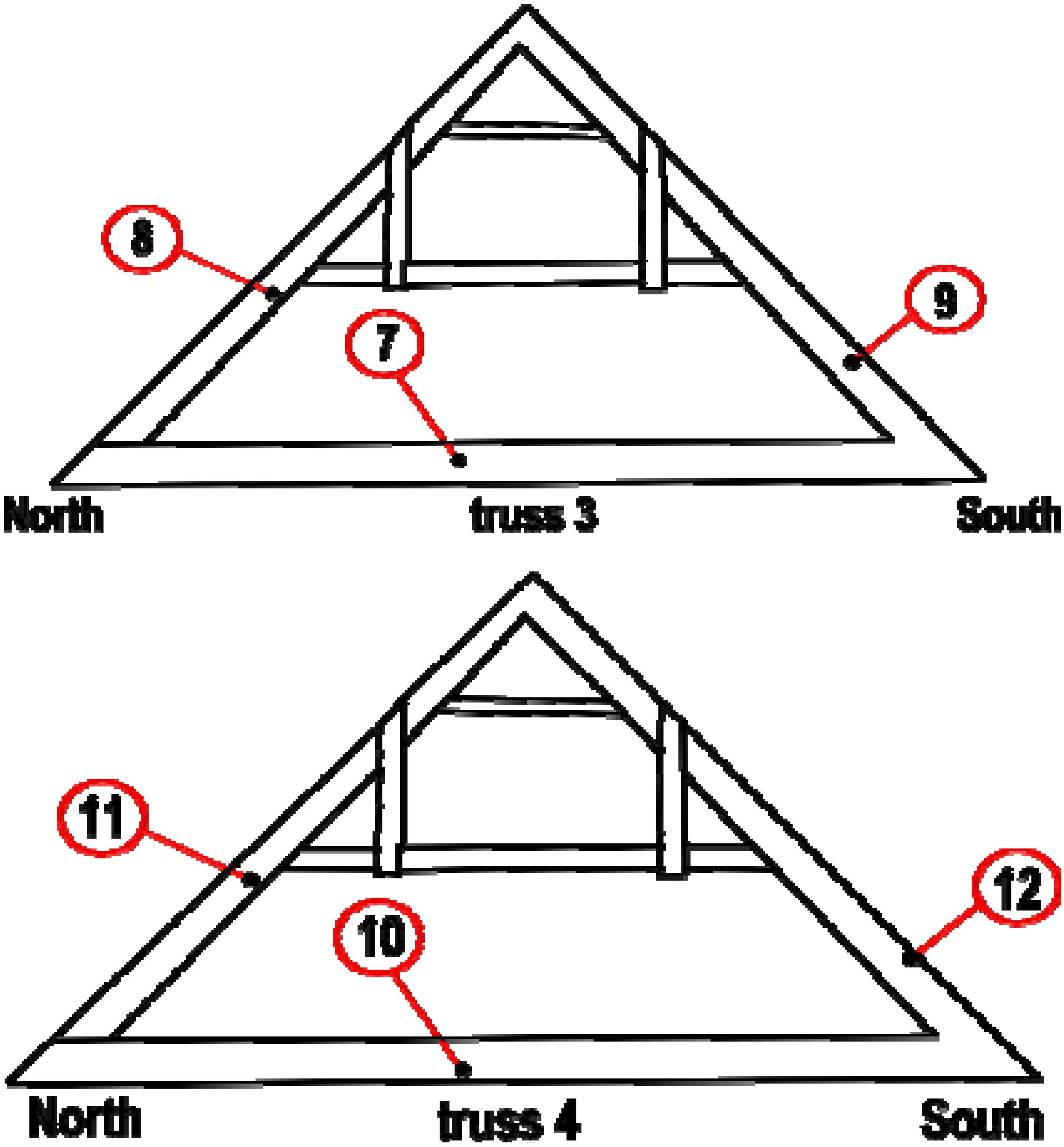
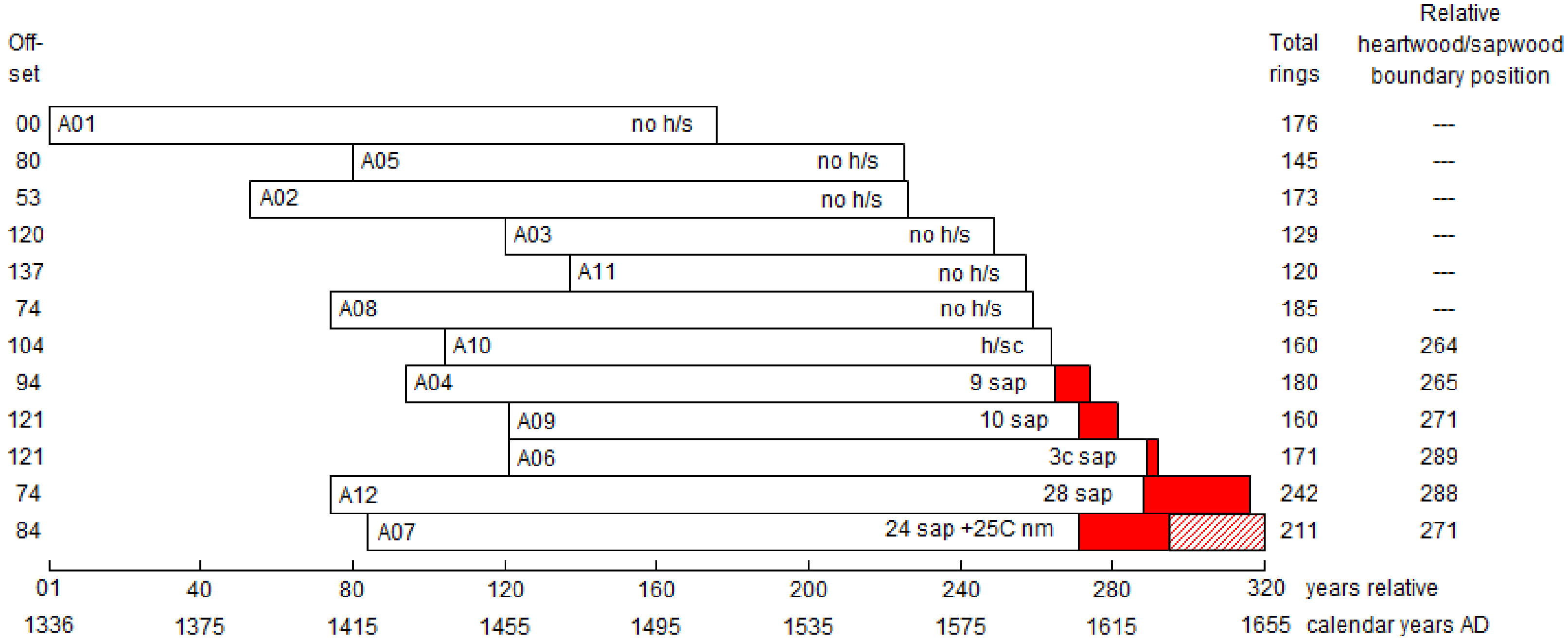


Figure 7: Schematic sections of trusses 3 and 4, showing positions of the sampled timbers



White bars = heartwood rings, shaded area = sapwood rings, hatched area = unmeasured sapwood ring
h/s = the last ring on the sample is at the heartwood/sapwood boundary; only the sapwood rings are missing
c = complete sapwood is found on the timber, but all or part has been lost from the sample in coring
C = complete sapwood is retained on the sample

Figure 8: Bar diagram of the samples in site chronology MRPASQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

MRP-A01A 176
295 292 350 327 426 391 413 344 320 382 232 220 191 158 114 228 327 373 246 267
274 241 168 155 191 218 185 185 118 110 108 104 105 110 79 116 143 136 176 177
136 118 91 156 122 136 132 173 184 152 171 176 149 116 115 99 123 105 118 106
156 130 130 149 168 134 130 165 150 118 100 88 83 113 162 115 112 120 95 76
124 175 176 142 175 150 134 117 111 84 84 65 104 116 103 121 90 72 91 94
127 91 92 91 107 90 100 138 195 169 122 121 137 138 102 75 127 156 142 160
123 112 124 47 66 51 75 81 83 122 113 118 194 126 113 126 90 158 194 213
174 231 178 153 128 117 80 128 175 174 229 231 197 150 81 98 68 89 97 106
180 184 188 146 113 127 178 174 238 292 201 111 193 229 189 183
MRP-A01B 176
310 302 343 313 423 361 412 337 414 363 221 235 165 144 125 231 341 361 238 201
267 252 170 155 187 207 201 176 131 112 92 104 112 111 82 114 151 122 186 165
143 110 94 150 139 137 128 178 168 183 135 171 153 118 106 115 126 106 106 120
163 126 138 143 174 130 152 156 149 134 108 81 93 105 144 134 118 130 83 70
125 179 178 157 184 153 120 132 106 84 82 82 100 122 114 128 85 74 71 121
106 112 96 85 111 88 103 128 206 156 136 116 133 138 114 87 115 134 152 163
125 115 122 67 60 54 63 79 101 109 106 127 201 117 122 132 91 143 171 234
188 218 189 154 113 119 94 113 175 169 196 241 208 131 71 94 78 96 82 104
180 195 188 142 115 119 174 187 218 285 209 122 208 198 174 185
MRP-A02A 173
197 187 156 168 211 196 168 236 283 259 246 249 210 280 265 324 336 249 234 265
237 271 236 233 197 69 86 118 187 235 170 205 204 221 205 135 129 98 106 117
180 125 177 78 74 88 138 118 91 95 83 95 40 40 64 85 115 86 64 52
92 98 59 170 124 138 80 115 79 81 49 37 48 67 97 128 106 117 86 97
65 77 75 49 102 73 99 87 83 74 80 72 84 39 83 86 80 77 92 55
61 39 34 48 46 57 63 72 70 72 75 44 33 37 75 83 99 78 81 93
84 77 87 62 52 70 66 70 71 87 86 75 55 54 50 79 86 73 94 118
70 63 60 63 91 103 93 118 108 132 131 127 104 81 102 124 108 113 105 123
73 99 98 141 112 109 118 160 74 82 138 107 182
MRP-A02B 173
189 199 163 163 229 194 169 223 270 254 244 251 235 299 272 327 336 256 252 245
214 264 204 249 208 96 61 104 189 234 160 190 211 248 227 120 110 89 102 124
168 130 182 85 66 88 124 110 95 91 98 95 43 32 74 81 110 89 68 55
87 94 62 162 132 121 85 120 92 72 49 41 43 73 85 123 109 113 71 104
73 80 75 55 84 80 91 90 85 70 91 78 74 46 79 95 75 82 90 71
54 33 39 43 45 53 63 76 72 66 77 44 38 39 73 74 107 71 66 98
78 83 85 65 55 60 75 61 73 93 86 65 63 49 52 80 86 75 89 105
83 54 70 53 97 99 105 103 94 125 135 118 112 78 98 130 119 110 113 103
77 107 104 117 124 108 117 158 78 84 124 110 183
MRP-A03A 129
147 129 105 66 61 51 97 101 115 117 116 116 142 116 150 104 78 133 141 176
170 152 148 129 107 136 79 101 126 129 159 173 123 105 81 115 73 126 102 96
165 150 151 131 94 102 135 144 161 158 124 63 69 104 103 90 68 62 84 100
117 106 118 100 71 52 55 63 68 73 79 64 73 79 62 79 44 72 71 91
86 68 64 123 78 88 40 61 83 83 80 64 69 67 63 94 88 111 106 91
75 76 67 88 94 113 89 69 97 73 76 47 67 91 109 106 105 147 117 91
71 61 82 112 101 54 57 58 91

MRP-A03B 129
186 114 110 66 67 60 95 92 111 120 132 120 151 110 126 110 72 130 140 197
155 169 132 134 101 135 72 127 137 154 152 158 135 102 83 113 77 110 105 96
163 159 150 133 96 101 141 129 167 162 124 72 86 95 114 90 70 56 85 91
108 108 122 97 80 52 51 59 78 70 77 65 76 79 61 79 45 70 74 83
82 67 76 125 79 91 42 57 82 77 84 59 74 57 75 86 87 112 100 91
87 75 62 96 89 108 97 62 100 76 74 45 65 92 105 103 113 141 119 103
62 70 79 106 104 54 43 61 98
MRP-A04A 180
196 175 167 120 121 157 165 161 168 119 169 126 104 127 262 191 152 145 151 136
112 64 117 193 214 175 168 193 158 105 79 71 93 128 131 133 139 137 173 102
105 143 94 147 149 208 194 200 143 124 107 131 65 124 150 123 180 191 142 138
86 92 63 78 96 101 133 149 145 100 95 73 118 144 160 148 137 81 145 172
101 100 74 91 102 111 143 97 148 104 43 35 55 66 91 87 60 70 97 110
72 85 48 79 92 90 90 88 102 177 82 129 66 80 131 128 152 139 122 85
120 151 126 154 178 157 141 127 108 159 156 172 165 120 181 88 140 90 92 155
171 167 137 202 162 163 71 76 96 151 159 62 50 76 127 140 156 86 53 68
73 64 79 95 130 133 113 145 109 89 116 65 89 65 45 49 45 66 89 92
MRP-A04B 180
191 182 176 116 118 152 169 171 153 126 156 150 109 134 257 185 159 141 157 138
103 70 123 197 189 173 169 194 170 102 81 63 100 127 124 143 145 127 174 104
98 136 96 143 147 205 192 198 155 119 110 131 70 111 157 132 194 196 150 97
91 90 64 75 93 101 138 140 152 106 78 68 120 134 165 146 147 81 150 160
105 107 82 92 98 107 147 96 153 105 50 38 58 58 92 76 66 69 100 103
81 76 49 79 102 96 72 103 102 163 83 128 59 88 123 126 158 127 127 97
105 146 127 158 181 157 148 126 97 148 148 177 176 124 182 82 131 99 82 156
182 159 139 195 165 157 74 86 93 141 152 68 44 90 133 137 162 77 64 58
78 66 85 97 110 139 98 118 94 104 109 68 86 57 44 50 43 71 93 97
MRP-A05A 145
135 255 215 189 292 198 245 219 89 89 69 92 126 185 142 181 102 60 103 165
134 96 84 83 111 44 34 78 105 131 86 72 50 98 119 106 159 132 111 109
118 112 83 53 37 45 68 116 141 131 149 105 158 100 95 123 78 118 91 141
130 108 129 123 98 71 48 137 140 137 137 155 97 88 53 34 63 78 85 111
112 102 121 124 57 44 52 101 124 132 139 78 150 127 138 141 80 73 116 123
126 132 144 146 102 111 76 57 111 129 113 110 165 126 115 84 107 121 164 163
167 159 202 207 166 141 74 113 148 127 153 136 128 92 107 160 167 134 155 157
177 89 100 127 148
MRP-A05B 145
154 221 227 189 284 181 254 217 90 70 75 85 121 172 132 168 87 67 72 129
130 103 76 94 96 57 41 73 115 119 86 77 51 96 131 83 180 147 106 109
116 123 86 53 38 42 78 98 134 130 176 112 140 102 87 134 74 123 87 142
129 109 128 120 97 71 54 138 135 157 148 156 92 90 49 35 61 77 94 109
106 107 121 131 54 38 56 98 122 142 119 72 153 126 124 141 99 70 107 124
111 146 149 138 111 102 61 58 125 115 118 123 162 129 107 91 111 122 176 160
153 158 207 210 165 124 74 115 154 132 151 131 127 97 118 142 166 134 156 166
173 94 85 137 131
MRP-A06A 171
130 109 70 41 58 71 103 189 106 84 195 163 124 82 102 84 85 166 229 200
181 169 173 139 179 126 185 236 165 165 177 185 142 135 91 80 112 109 111 144
138 103 139 117 69 119 151 129 165 127 102 142 111 118 136 94 93 121 151 134
120 137 145 132 116 58 67 73 100 108 110 150 117 139 122 138 158 218 222 222
265 262 304 218 172 80 102 116 94 89 95 94 67 97 80 95 111 96 109 191
115 178 192 233 284 195 175 160 93 82 71 121 135 170 93 84 95 110 72 80

48 72 77 126 82 64 140 79 120 129 123 69 93 91 76 96 109 132 176 135
140 120 93 152 111 81 113 126 125 107 128 100 79 87 73 87 91 88 124 64
75 62 92 116 48 111 80 40 54 58 73
MRP-A06B 170
134 105 62 45 60 73 109 175 104 96 195 155 116 85 99 88 91 119 253 207
155 158 181 146 157 139 190 230 160 168 215 166 149 118 63 89 125 96 126 140
109 114 132 99 67 107 141 135 164 130 98 145 105 121 132 93 93 125 152 130
119 138 143 137 121 72 61 71 99 102 108 146 124 134 130 144 160 232 231 202
253 270 281 226 147 76 95 122 99 93 85 96 61 99 74 93 115 95 104 191
107 203 201 218 253 204 177 164 88 87 81 111 136 173 98 95 81 115 68 73
58 65 88 118 72 70 128 89 112 135 127 60 103 85 76 97 99 139 187 115
131 132 103 143 95 84 89 114 142 114 124 98 86 84 78 77 92 92 119 69
51 79 97 94 59 100 88 46 56 61 75
MRP-A07A 211
382 293 211 263 226 139 159 119 218 276 167 150 142 93 104 155 92 174 128 121
216 128 117 126 211 213 151 112 127 141 116 72 134 150 162 141 175 154 141 89
65 87 116 111 111 161 129 170 170 97 121 134 91 162 173 211 213 192 154 127
117 112 69 103 142 155 207 211 161 158 112 96 81 112 101 115 175 179 211 156
102 110 129 142 189 187 142 113 141 148 125 117 107 123 138 133 156 101 147 124
68 53 64 61 84 78 87 85 71 101 95 93 71 72 96 106 121 118 118 178
106 126 63 103 144 125 171 169 140 125 112 134 125 95 145 153 150 136 104 144
143 253 172 142 180 106 124 100 85 122 151 163 142 164 136 137 75 76 68 97
136 55 56 64 93 84 98 60 49 59 85 64 65 96 86 94 63 68 81 75
75 64 52 74 89 38 51 56 62 65 94 70 73 55 79 79 63 65 97 24
38 25 26 17 18 23 23 24 20 26 39
MRP-A07B 202
374 297 219 262 204 147 159 139 214 263 169 154 134 89 90 174 97 168 125 120
202 129 111 141 207 215 151 100 128 137 112 71 132 155 184 145 174 145 142 88
71 79 116 117 110 169 132 156 180 104 119 140 103 156 184 228 214 212 149 130
113 111 76 78 139 169 197 207 159 143 114 110 80 108 102 113 159 184 210 165
105 107 129 146 184 187 148 117 136 150 118 125 95 126 142 134 149 107 151 115
86 40 68 64 87 76 88 88 84 105 92 90 68 78 99 96 115 117 106 187
114 127 65 95 145 125 162 175 126 130 111 147 113 109 141 160 156 130 101 149
145 245 185 133 179 103 132 90 81 135 155 154 148 157 138 137 73 67 75 100
124 65 46 67 102 75 102 61 53 59 82 58 74 85 93 92 54 81 87 84
78 56 52 68 90 49 50 50 59 67 95 68 74 61 70 90 55 77 88 28
35 33
MRP-A08A 185
316 202 213 252 80 54 108 201 225 160 249 243 276 349 193 147 91 89 135 176
116 171 72 77 110 114 108 89 84 85 81 46 38 65 73 106 83 68 45 68
76 58 142 104 106 65 87 97 73 47 38 61 63 84 110 95 106 78 89 73
80 102 54 77 68 111 96 92 90 84 90 99 66 81 97 79 71 73 64 62
44 38 51 61 83 74 96 82 88 90 47 45 69 77 93 104 57 59 113 77
82 100 69 77 69 96 66 62 67 70 64 61 44 48 63 58 92 70 87 73
68 73 91 82 93 90 81 96 90 113 117 113 112 108 156 122 118 98 92 88
133 92 109 113 105 116 162 80 111 128 104 124 109 98 104 83 82 72 79 104
147 94 90 84 103 91 85 58 73 65 106 55 51 84 73 88 85 76 55 67
74 65 77 84 117
MRP-A08B 185
328 202 201 260 82 53 97 211 229 150 255 248 273 356 181 150 94 102 120 185
120 160 73 82 104 110 109 83 89 87 85 43 39 67 65 106 87 70 48 66
80 60 137 114 94 67 91 91 68 54 34 53 68 88 118 93 104 72 96 76
80 104 54 73 75 101 96 86 111 75 91 103 64 88 96 74 74 70 63 62

48 42 45 66 81 71 107 78 92 79 58 41 67 75 90 96 68 58 104 82
85 103 66 71 64 100 68 61 70 67 61 63 39 45 70 57 99 66 90 68
73 76 90 82 98 85 80 99 88 111 122 117 110 105 148 128 117 110 85 96
136 87 118 102 108 114 151 83 121 109 122 125 118 83 99 88 84 73 77 116
142 94 92 81 95 89 73 77 70 81 106 49 52 77 80 83 84 78 57 67
76 58 84 73 120
MRP-A09A 160
116 91 59 42 74 114 143 251 183 98 99 129 92 80 118 70 118 130 193 154
145 168 172 148 114 70 164 186 201 173 135 99 96 53 33 47 78 98 96 129
95 149 169 107 59 101 144 157 209 164 97 232 137 123 219 110 114 161 186 147
165 192 166 152 158 101 83 109 136 139 123 141 134 137 119 120 136 203 174 152
154 217 223 251 205 111 111 204 142 184 148 157 110 168 146 145 181 184 131 202
110 130 143 138 198 168 144 114 61 66 59 66 136 137 84 106 89 93 83 66
72 65 98 119 92 62 107 111 126 136 123 75 81 99 81 97 114 122 143 92
112 114 88 139 83 54 61 117 88 91 134 112 82 83 74 99 105 80 88 111
MRP-A09B 160
140 92 59 51 64 116 153 249 140 125 101 133 79 91 105 77 145 93 188 137
151 163 162 157 116 62 161 192 201 167 128 111 94 54 34 56 76 83 98 143
107 158 176 111 59 94 144 157 241 151 85 229 145 121 211 118 124 168 182 149
172 191 207 157 151 97 88 106 105 138 123 162 141 143 113 129 148 195 174 143
152 216 217 203 213 114 116 207 143 175 140 168 131 174 165 152 189 158 154 208
116 145 145 126 212 138 126 96 68 69 59 70 134 135 90 100 99 94 81 64
64 70 91 143 93 63 119 119 111 142 109 84 86 106 80 102 141 104 150 78
120 114 87 144 69 69 54 118 88 84 134 113 88 83 58 98 113 91 79 109
MRP-A10A 160
168 129 173 144 232 186 153 129 136 169 103 75 170 195 161 133 174 172 148 111
96 79 121 125 136 149 131 144 200 128 163 122 91 136 136 227 188 133 145 129
94 116 76 102 140 154 213 198 159 87 66 76 49 80 94 85 179 195 153 122
96 88 125 147 185 194 224 77 124 150 149 135 92 94 122 151 151 129 130 95
66 39 51 64 72 79 72 80 91 98 52 82 32 61 79 89 65 84 79 121
61 111 51 73 116 108 107 100 76 61 90 102 106 137 130 132 90 86 64 92
88 88 118 75 105 83 60 48 57 86 110 130 118 115 97 117 47 39 66 50
58 22 27 24 61 81 86 57 34 40 47 79 53 70 42 49 46 55 41 45
MRP-A10B 160
167 143 163 151 229 181 155 125 145 160 105 73 167 199 169 142 167 167 142 99
109 82 117 129 138 149 137 133 214 117 152 130 94 136 126 232 178 145 142 129
102 113 82 110 120 143 207 193 154 98 57 92 46 85 84 99 166 192 153 131
86 93 129 162 191 200 216 75 128 157 142 131 101 92 121 144 150 126 141 95
61 43 48 71 76 77 64 75 101 100 61 63 35 61 81 81 78 75 87 123
63 102 54 82 112 115 100 116 74 56 88 101 112 133 129 131 88 87 68 101
89 95 111 73 101 83 55 47 54 92 98 125 114 112 108 110 45 38 50 59
64 32 25 24 63 75 87 60 38 38 49 69 55 64 52 51 46 55 41 44
MRP-A11A 120
250 155 229 260 162 177 242 166 82 75 219 182 122 169 185 128 76 57 59 66
86 116 111 135 155 124 90 81 77 154 149 150 111 119 77 128 118 141 123 80
70 105 125 141 110 120 76 81 67 58 60 79 93 114 78 94 69 75 82 64
90 104 142 118 131 201 156 153 67 52 70 84 98 121 118 110 48 50 58 69
87 95 82 91 72 71 80 88 74 88 79 90 55 53 57 56 97 117 96 107
84 72 100 61 51 52 69 94 68 57 68 100 99 100 97 61 93 87 72 126
MRP-A11B 120
240 151 230 260 169 170 232 171 90 81 206 164 134 153 177 133 76 51 48 83
83 100 115 142 143 123 112 68 75 151 139 146 109 114 71 132 117 137 118 81
81 108 125 143 106 121 82 82 57 70 42 90 92 111 85 86 78 93 74 57

97 113 136 111 131 203 160 156 72 47 75 84 135 107 99 95 54 52 83 75
91 86 95 77 81 79 78 92 69 88 75 95 64 53 46 63 97 123 87 99
85 84 93 72 43 47 70 102 62 55 83 104 101 105 87 65 92 91 73 127
MRP-A12A 242
265 189 177 171 64 25 68 148 214 141 171 173 165 182 114 107 92 90 106 150
85 125 59 58 81 110 134 107 100 88 79 43 40 72 72 84 72 70 41 67
96 70 141 120 114 76 97 91 79 66 45 52 88 98 136 106 102 85 86 67
84 90 60 81 77 120 104 97 94 99 91 92 65 79 118 72 82 65 56 70
53 42 34 49 73 62 98 67 78 159 113 55 122 104 105 105 83 75 124 94
92 99 85 89 106 113 94 82 100 76 77 62 60 52 79 52 89 69 75 67
49 60 64 88 84 85 68 74 57 87 80 70 58 73 75 78 90 67 77 81
125 111 109 107 103 112 138 90 94 118 115 136 103 108 101 91 90 90 78 103
100 84 96 73 84 91 84 71 67 64 76 55 46 65 71 84 88 85 68 67
71 67 86 83 96 101 69 84 71 72 101 73 52 62 83 70 78 73 75 79
64 66 68 64 74 58 51 64 51 52 52 45 52 53 39 46 52 46 41 77
59 52 46 33 41 39 33 47 69 63 69 53 50 51 44 42 61 69 68 63
50 78
MRP-A12B 242
200 199 172 155 59 40 67 150 220 125 171 172 164 185 113 106 86 93 107 157
79 109 69 54 77 107 131 98 91 87 78 34 48 69 64 96 81 68 38 63
109 72 148 132 103 82 101 92 76 59 40 55 82 107 124 117 99 82 90 74
82 91 62 82 81 118 102 99 96 95 89 101 59 86 108 75 90 61 55 72
57 44 30 51 72 70 91 69 78 163 122 52 118 105 111 106 93 66 135 99
90 92 85 92 102 112 95 77 108 75 67 60 55 58 80 60 81 67 75 73
56 61 78 70 87 93 62 65 72 69 92 77 55 64 83 76 94 80 75 86
119 102 120 100 116 107 137 92 93 119 112 143 120 119 93 92 85 77 73 108
106 91 91 72 86 81 80 67 68 67 88 60 42 72 63 84 99 83 66 66
74 60 77 85 112 93 66 83 74 69 109 59 53 63 78 86 64 82 80 64
73 66 75 61 72 62 58 63 52 46 52 46 52 56 33 42 51 53 46 64
50 58 54 36 30 47 41 41 63 63 53 60 51 42 55 42 68 72 64 63
58 75

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 compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/ sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

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

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

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

t-value/offset Matrix

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

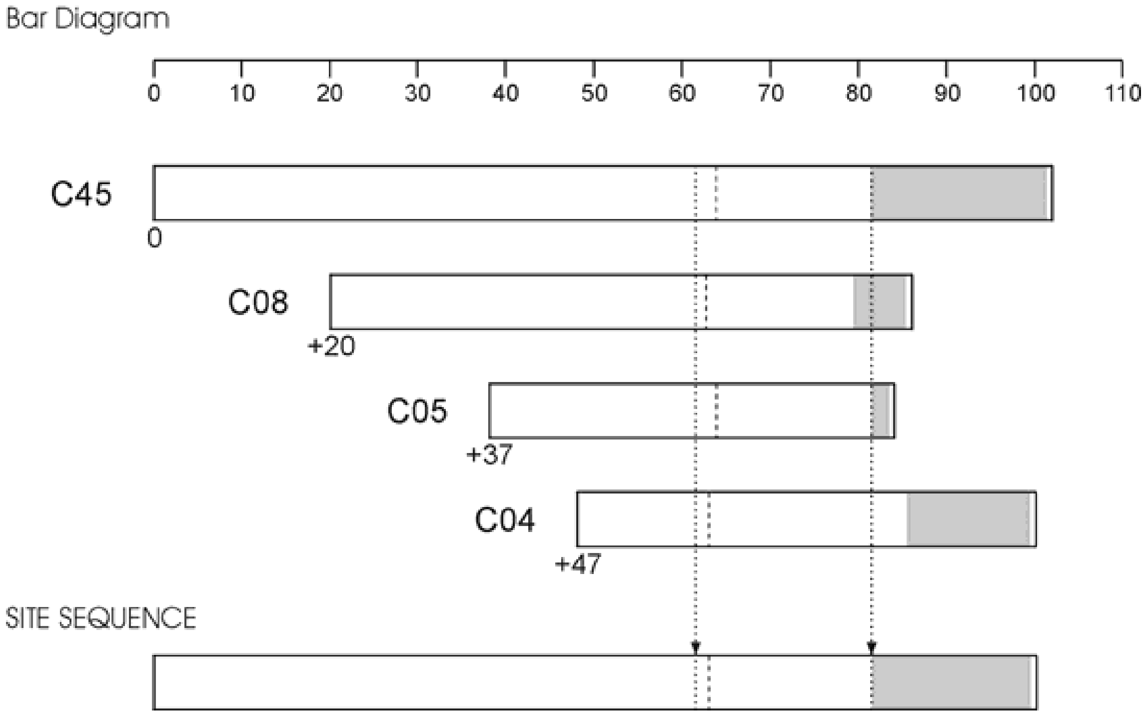


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

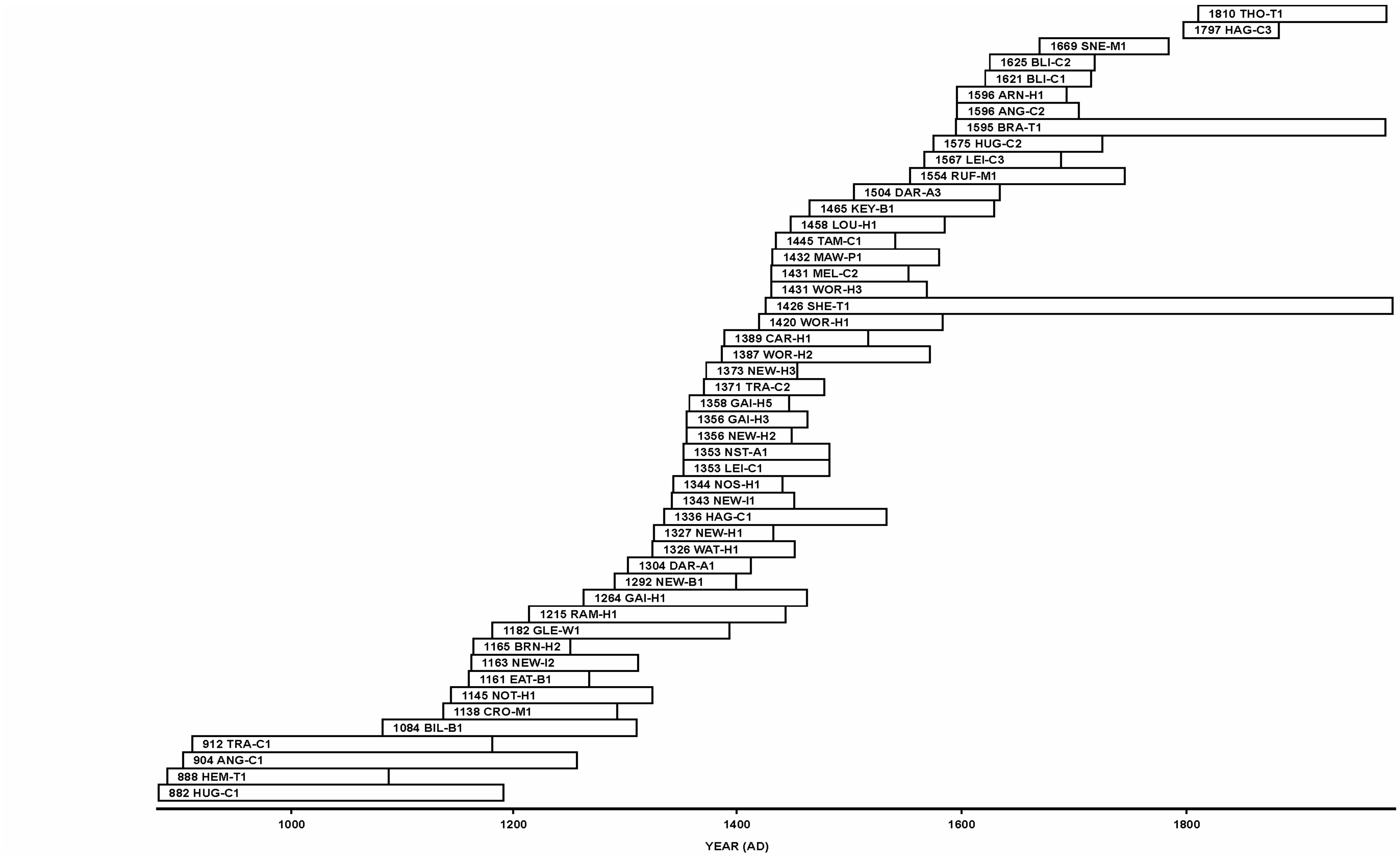
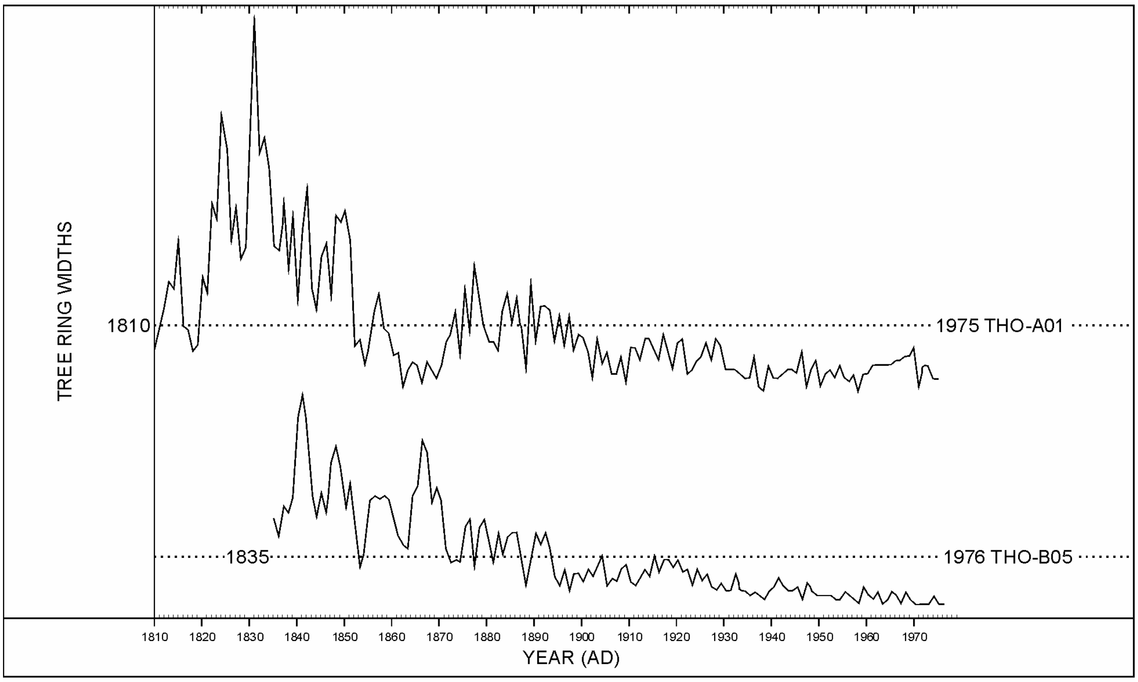


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

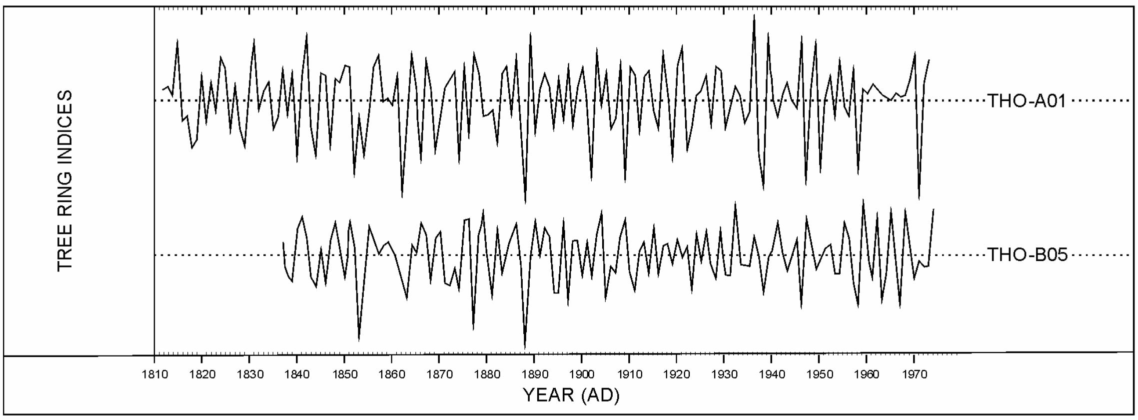


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

References

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

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

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

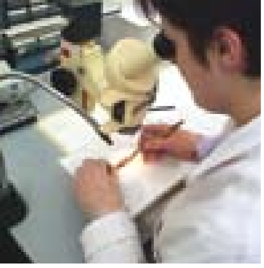
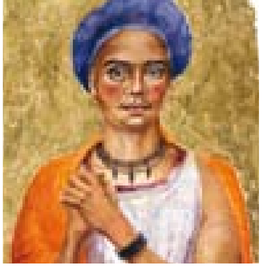
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

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



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

- *Aerial Survey and Investigation*
- *Archaeological Projects (excavation)*
- *Archaeological Science*
- *Archaeological Survey and Investigation (landscape analysis)*
- *Architectural Investigation*
- *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
- *Survey of London*

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

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE