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Norton Hall Barn, Hall Lane, Stanton Street, Suffolk

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

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Front cover: Norton Hall Barn photographed by Alison Arnold

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SUMMARY
Analysis was undertaken on samples from timbers of the roof and wall framing, believed to be associated with the primary construction phase, and also from timbers associated with the later alterations in relation to the doorways, resulting in the construction of three site sequences. Site sequence NRTNSQ01 contains 13 samples from the primary structure and spans the period AD 1384–1481. One of these timbers, a wall plate, was felled in *c* AD 1489, with the other dated timbers having felling dates ranges of between AD 1469–94 (earliest) and AD 1488–1513 (latest). It is thought likely that all of these primary timbers were felled in, or around, *c* AD 1489, with construction following shortly after. Site sequence NRTNSQ02 contains seven samples associated with later alterations and spans the period AD 1519–1626. Doorway 1 contains two timbers which were felled in AD 1626, Doorway 2 contains two timbers felled in AD 1625–50, a single timber from Doorway 3 was felled in AD 1627–52, whilst two timbers from Doorway 4 were felled in AD 1613–38. These dates suggest the four doorways were all altered or inserted in the first half of the seventeenth century, possibly all in the AD 1620s. The third site sequence, NTRDSQ03 is undated.

CONTRIBUTORS
Alison Arnold, Robert Howard, and Cathy Tyers.

ACKNOWLEDGEMENTS
Stephen Honeywood, owner of the barn, is thanked for allowing access for assessment and subsequent sampling. Tim Buxbaum, Architect, and Moller Archaeology are thanked for providing survey drawings and information, and giving permission for various plans and sections to be used in this report. We would also like to thank Claire Fidler (Historic England Heritage at Risk Project Officer) for requesting dendrochronological input and both Beki Burns and Shahina Farid (Historic England Scientific Dating Team) for commissioning and facilitating this programme of dendrochronological analysis.

ARCHIVE LOCATION
Suffolk County Council Historic Environment Record
Suffolk County Council Archaeological Service
Bury Resource Centre
Hollow Road
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Suffolk IP32 7AY

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2016

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INTRODUCTION

Norton Hall Barn is a Grade II* listed timber-framed and weather-boarded structure, located in the Suffolk village of Stanton Street lying approximately 200m west of Hall's Farmhouse (Figs 1–3). The barn, thought to date in its primary form to the mid-sixteenth century, is currently on the Historic England Heritage at Risk register due to its 'poor condition' and continued decline.

The following background information is summarised from Moller Archaeology (2012). The barn is thought to have once been a threshing and storage barn. The primary structure is orientated north-south and consists of six bays, separated by five principal rafter and tiebeam trusses (Fig 4). Each truss also has a collar, raking struts, and braces between the collar and principal rafters. There are pairs of parallel braces rising from the jowled wall posts to the tiebeams. Located between the main trusses are intermediate trusses, consisting of posts, principal rafters, and a collar. There are two tiers of butt purlins, common rafters, wind braces, and a ridge piece (Fig 5). The roof is hipped at both ends and was originally thatched. A modern barn abuts it at its southern end on the eastern side and there are the remains of a lean-to shed along its southern side.

The barn has two sets of opposing doors located in bays 2 and 5 (bays and doors numbered from south to north as per Figure 4). Those on the western side (D1 and D2) are both large, double doors that extend from the brick floor up to the top plate (Figs 6 and 7), whilst those on the eastern side (D3 and D4) are small and of stable-door form (Figs 8 and 9). After close inspection of the timbers associated with these openings, Moller Archaeology (2012) suggested that the doorways in bay 2 (D1 and D3) had been altered from an earlier form and those in bay 5 (D2 and D4) had been inserted into previously plain walls. It is thought that at some point in the late eighteenth or nineteenth century a second threshing floor was required and the doorways in bay 5 (D2 and D4) were inserted to allow this, whilst at the same time the alterations to the doorways in bay 2 were undertaken.

SAMPLING

Dendrochronological analysis was requested by Claire Fidler, following the provision of a Historic England repair grant, to provide independent dating evidence. It was hoped that this would enhance understanding and hence inform advice and further discussions relating to the development management plan, including the programme of priority repairs, and the long term future of the barn.

Twenty-four core samples were taken from primary phase timbers of the roof and wall framing and a further 12 from timbers associated with later alterations relating to the doorways. Each sample was given the code NRT-N and numbered

01–36. Further details relating to the samples can be found in Table 1. Location of samples has been marked on Figures 10–17. Trusses, bays, and studs were numbered from south to north, as were the doorways, following the same scheme as that used by Moller Archaeology (2012) and Tim Buxbaum, Architect.

ANALYSIS AND RESULTS

Four of the samples, one from the primary phase timbers and three from timbers associated with the doorways had too few rings for secure dating and so were rejected prior to measurement. The remaining 32 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These measurements were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 22 samples matching to form three groups.

Firstly, 13 samples matched each other and were combined at the relevant offset positions to form NRTNSQ01, a site sequence of 98 rings (Fig 18). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently and securely at a first-ring date of AD 1384 and a last-measured ring date of AD 1481 (Table 2).

Secondly, seven samples matched and were combined at the relevant offset positions to form NRTNSQ02, a site sequence of 108 rings (Fig 19). This site sequence was also compared against a series of relevant reference chronologies where it was found to span the period AD 1519–1626 (Table 3).

Finally, two samples grouped and were combined to form NRTNSQ03, a site sequence of 80 rings (Fig 20). Attempts to date this site sequence and the remaining ten ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

Analysis has resulted in the successful dating of 20 timbers, 13 from the primary phase timbers and seven from timbers associated with the doorways (Fig 21). Felling date ranges and *terminus post quem* dates for felling have been calculated using the estimate that 95% of mature oak trees from this area have between 15 and 40 sapwood rings.

Primary phase timbers

Thirteen of the samples taken from timbers thought to represent the primary structure have been successfully dated. Unfortunately, none of these have complete sapwood and so an absolute felling date cannot be given. However, one of these (NRT-N18) was taken from a timber with complete sapwood but *c* 10mm of these friable outer rings were lost during the coring process. Based on an average ring width of 0.99mm for the outermost measured rings, it is possible to estimate that *c* 10 rings have been lost. Thus, with a last-measured ring date of AD 1479 and allowing for *c* 10 rings having been lost, the timber represented by NRT-N18 has an estimated felling date of *c* AD 1489.

The other 12 dated samples all have the heartwood/sapwood boundary ring which varies from AD 1454 (NRT-N21) to AD 1473 (NRT-N02), a difference of 19 years. Such a variation suggests that although these timbers may well represent a single episode of felling, this episode could have potentially spanned a small number of years rather than representing a single short intensive period of felling. Using the estimate above, it is possible to say that these 12 timbers have estimated felling dates which range from AD 1469–94 (NRT-N21) to AD 1488–1513 (NRT-N02).

Later alterations - doorways

Seven of the timbers associated with the doorways have been successfully dated demonstrating that they are all broadly coeval but again with the heartwood/sapwood boundary ring varying in date from AD 1591 (NRT-N32) to AD 1614 (NRT-N36), a difference of 23 years, they may represent either a felling period spanning a small number of years or they could be the product of a number of discrete felling phases also undertaken over a period of a few years.

One of these, NRT-N34, has complete sapwood and the last-measured ring date of AD 1626, the felling date of the timber represented. This sample was taken from the south post of doorway D1. Sample NRT-N33, from the north post of doorway D1, matches NRT-N34 at a value of t = 11.0, a level high enough to suggest both timbers may have been cut from the same tree and hence were felled at the same time in AD 1626.

Samples NRT-N35 and NRT-N36 taken from the north and south posts of doorway D2 have also been dated. The dates of the heartwood/sapwood boundary rings differ by only nine years and, with an average of AD 1610, an estimated felling date of AD 1625–50 is therefore obtained for these two posts.

Only one of the samples from doorway D3 has been successfully dated. Sample NRT-N25, taken from a cross-rail, has the heartwood/sapwood boundary ring date of AD 1612, giving an estimated felling date for the timber represented of AD 1627–52.

Samples from a cross rail (NRT-N31) and stud (NRT-N32) from doorway D4 have been dated. Both of these samples have the heartwood/sapwood boundary, the dates of which vary by 14 years. The average heartwood/sapwood boundary is AD 1598, allowing an estimated felling date range to be calculated for these two timbers of AD 1613–38.

DISCUSSION

Tree-ring analysis has dated a number of timbers from the roof and wall-framing, all thought to be associated with the primary construction phase, to *c* AD 1489 (one timber) and a series of overlapping felling date ranges of between AD 1469–94 and AD 1488–1513. It can be seen that all the felling date ranges overlap with each other and with *c* AD 1489 felling date. This, combined with the consistent level of cross-matching within this group of dated timbers, suggests that it is likely that these timbers are coeval and were all felled at a similar time in, or around, *c* AD 1489. Construction of the barn will have occurred shortly after felling, thus dating the barn to the latter part of the fifteenth century, making it slightly earlier than mid-sixteenth century date previously assumed.

Two of the barn openings (doorways D1 and D3 in bay 2) are believed to be original, although not in their original form, whilst the other two (doorways D2 and D4 in bay 5) are likely to be later insertions. Timbers from all four doorways have been dated and all are clearly broadly coeval. Two posts from doorway D1 are now known to have been felled in AD 1626, whilst a cross rail from doorway D3 was felled in AD 1627–52. The two posts from doorway D2 were felled in AD 1625–50, whilst a cross rail and a stud from doorway D4 were felled in AD 1613–38. The alterations or insertion of these four doorways could therefore have occurred at slightly different times in the first half of the seventeenth century but it is possible that all of these modifications were undertaken in the AD 1620s. This is somewhat earlier than the eighteenth-century date previously assigned to the insertion of two of the doorways (D2, D4) and alterations being undertaken to the original openings (D1, D3).

Both of the dated site sequences (NRTNSQ01, NRTNSQ02) can be seen to match most strongly against reference chronologies from Suffolk and counties to the south and north (Tables 2 and 3). This would suggest that the woodland source for the timber used within the barn for both its primary construction in the late-fifteenth century and for the later alterations associated with the doorways in the first half of the seventeenth century was relatively local.

It is unfortunate that the third site sequence, containing samples taken from two studs thought to be associated with the primary construction phase, is undated. These two samples have the same relative heartwood/sapwood boundary ring position (Fig 19), which suggests both samples were felled at the same time even if it is not possible to say when this might have been. It should be noted that all of the undated samples appear similar to the dated samples in overall growth characteristics and none show any strong growth disturbances that would hamper successful analysis. The inability to date some intrinsically suitable samples is, however, normal, although more prevalent in some counties such as Suffolk, and does not prove that the timbers represented are of a different date to those dated.

BIBLIOGRAPHY

Arnold, A J, and Howard, R E, 2008 Tree-ring analysis from Manor Farm (barn), Suffolk unpubl computer file *GTBASQ01/02*, NTRDL unpubl

Bridge, M C, 1998 *Tree-ring analysis of timbers from the Chicheley Chapel, St Andrew's Church, Wimpole, Cambridgeshire*, Anc Mon Lab Rep, **59/98**

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

Bridge, M C, and Miles D H W, 2004 *Tree-Ring Analysis of Timbers from the Hall Roof, West Gateway, and Gates at Fulham Palace, London Borough of Hammersmith and Fulham*, Centre for Archaeol Rep, **79/2004**

Dobbs, C, and Bridge, M, 2008 Construction and Refits: Tree-Ring Dating the Mary Rose, in Marsden, P. (ed) *Your Noblest shippe. Mary Rose: anatomy of a Tudor warship*, Portsmouth, Mary Rose Trust

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

Howard, R E, Laxton, R R, and Litton, C D, 1997 *Tree-ring analysis of timbers from the Keep of Walmer Castle, Walmer, Kent*, Anc Mon Lab Rep, **75/1997**

Howard, R E, Laxton, R R, and Litton, C D, 2000 *Tree-ring analysis of timbers from Headstone Manor Tythe Barn, Pinner View, Harrow, London*, Anc Mon Lab Rep, **61/2000**

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master chronological sequence for Oak, 1158–1540, *Medieval Archaeol*, **33**, 90–8

Miles, D H, Worthington, M J, and Bridge, M C, 2007 Tree-ring dates, *Vernacular Architecture*, **38**, 120–39.

Moller, J, 2012 *Large Barn, Hall Farm, Hall Lane, Stanton Street, Suffolk: An Historic Building Record,* Moller Archaeology Report

Tyers, I, 1995 *Tree-ring analysis of the bellframe at St Andrews, Sutton-in-the-Isle, Cambridgeshire*, Anc Mon Lab Rep, **15/95**

Tyers, I, 1998 *Tree-ring analysis of Cann Hall, Clacton, Essex*, Anc Mon Lab Rep, **25/98**

Tyers, I, 2002 *Dendrochronological spot-dates of samples from Ballingdon Bridge, Sudbury (BCB 012), Suffolk*, ARCUS Rep, **573c**

Tyers, I, 2004 *A report on the tree-ring analysis of properties in New Buckenham, Norfolk*, ARCUS Rep, **783**

TABLES

Table 1: Details of samples taken from Norton Hall Barn, Stanton Street, Suffolk

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Primary phase						
NRT-N01	Centre post, south gable wall	66	h/s	1396	1461	1461
NRT-N02	West lower stud 4, bay 1	63	08	1419	1473	1481
NRT-N03	West lower stud 8, bay 1	60	15C	----	----	----
NRT-N04	Tiebeam, truss 1	59	h/s	1401	1459	1459
NRT-N05	East wallplate, bay 2	70	h/s	1389	1458	1458
NRT-N06	Tiebeam, truss 2	73	01	1384	1455	1456
NRT-N07	East upper brace, truss 2	68	h/s	----	----	----
NRT-N08	West upper brace, truss 2	50	h/s	----	----	----
NRT-N09	West centre post, bay 3	65	03	1408	1469	1472
NRT-N10	West lower stud 4, bay 3	54	09	1424	1468	1477
NRT-N11	Tiebeam, truss 3	75	h/s	1390	1464	1464
NRT-N12	East lower stud 5, bay 4	65	h/s	----	----	----
NRT-N13	East lower stud 8, bay 4	NM	--	----	----	----
NRT-N14	West upper stud 3, bay 4	82	10	1398	1469	1479
NRT-N15	West post, truss 4	66	h/s	1404	1469	1469
NRT-N16	Tiebeam, truss 4	74	h/s	1391	1464	1464
NRT-N17	East upper brace, truss 4	60	h/s	----	----	----
NRT-N18	West wallplate, bay 5	93	13c(+*c*10 lost)	1387	1466	1479
NRT-N19	Tiebeam, truss 5	57	h/s	----	----	----
NRT-N20	East principal rafter, truss 5	59	h/s	----	----	----
NRT-N21	East upper brace, truss 5	88	25	1392	1454	1479
NRT-N22	East centre post, bay 6	56	--	----	----	----
NRT-N23	West centre post, bay 6	63	14	----	----	----
NRT-N24	West lower stud 6, bay 6	59	09	----	----	----

Doorway (D1)						
NRT-N33	North post	103	23	1519	1598	1621
NRT-N34	South post	108	30C	1519	1596	1626
Doorway (D2)						
NRT-N35	North post	59	02	1549	1605	1607
NRT-N36	South post	46	h/s	1569	1614	1614
Doorway (D3)						
NRT-N25	Cross rail	54	01	1560	1612	1613
NRT-N26	Stud	57	h/s	----	----	----
NRT-N27	Stud	NM	--	----	----	----
NRT-N28	Stud	NM	--	----	----	----
NRT-N29	Stud	88	22C	----	----	----
NRT-N30	Stud	NM	--	----	----	----
Doorway (D4)						
NRT-N31	Cross rail	64	07	1549	1605	1612
NRT-N32	Stud	51	05	1546	1591	1596

NM = not measured
h/s = the heartwood/sapwood boundary is the last-measured ring
c(+*cx* lost) = complete sapwood on timber, all or part lost during the sampling process with the estimated number of lost rings in brackets
C = complete sapwood retained on sample, last-measured ring is the felling date

Table 2: Results of the cross-matching of site sequence NRTNSQ01 and relevant reference chronologies when the first-ring date is AD 1384 and the last-measured ring date is AD 1481

Reference chronology	*t*-value	Span of chronology	Reference
Mary Rose warship	7.8	AD 1334-1540	Dobbs and Bridge 2008
Chilton Manor, Sittingbourne, Kent	6.6	AD 1368–1520	Laxton and Litton 1989
Fulham Palace, London	6.4	AD 1356–1494	Bridge and Miles 2004
Otley Halll, nr Ipswich, Suffolk	6.0	AD 1415–1587	Bridge 2001
Walmer Castle, Walmer, Kent	5.7	AD 1396–1523	Howard *et al* 1997
Headstone Manor Barn, Harrow, Middlesex	5.5	AD 1374–1505	Howard *et al* 2000
Cann Hall, Clacton, Essex	5.5	AD1301–1511	Tyers 1998

Table 3: Results of the cross-matching of site sequence NRTNSQ02 and relevant reference chronologies when the first-ring date is AD 1519 and the last-measured ring date is AD 1626

Reference chronology	*t*-value	Span of chronology	Reference
Bedfield Hall, Suffolk	7.1	AD 1473–1627	Miles *et al* 2007
Pinchpot, New Buckenham, Norfolk	6.9	AD 1530–1623	Tyers 2004
Stowmarket Church, Suffolk	6.8	AD 1542–1671	Howard *et al* 1994
Ballingdon Bridge, Sudbury, Suffolk	6.8	AD 1484–1790	Tyers 2002
St Andrews Church, Wimpole, Cambridgeshire	6.6	AD 1469–1615	Bridge 1998
Manor Farm, Suffolk	6.4	AD 1461–1661	Arnold and Howard 2008 unpubl
St Andrews Church, Sutton-in-the-Isle, Cambridgeshire	6.4	AD 1508–1615	Tyers 1995

FIGURES

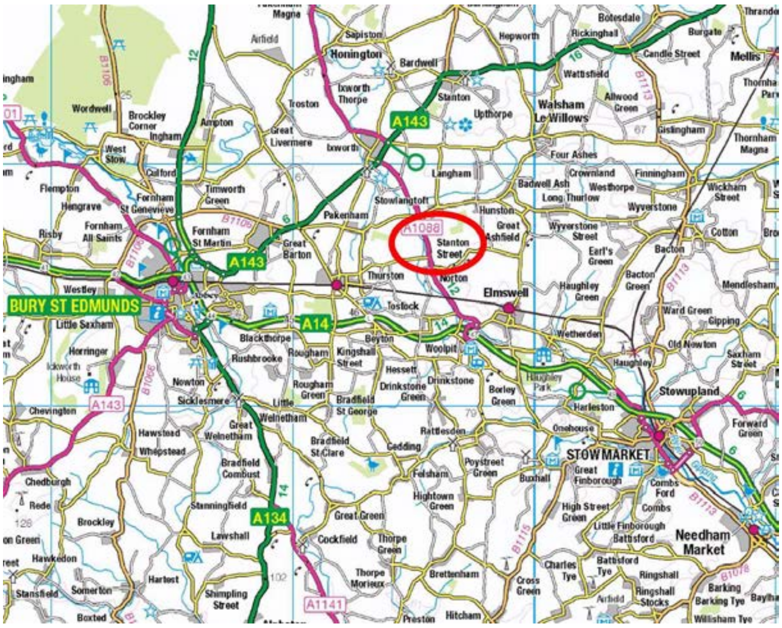

Figure 1: Map to show the general location of Stanton Street, circled. ©Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: Map to show the location of Stanton Street and Norton Hall Barn, circled. ©Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900.

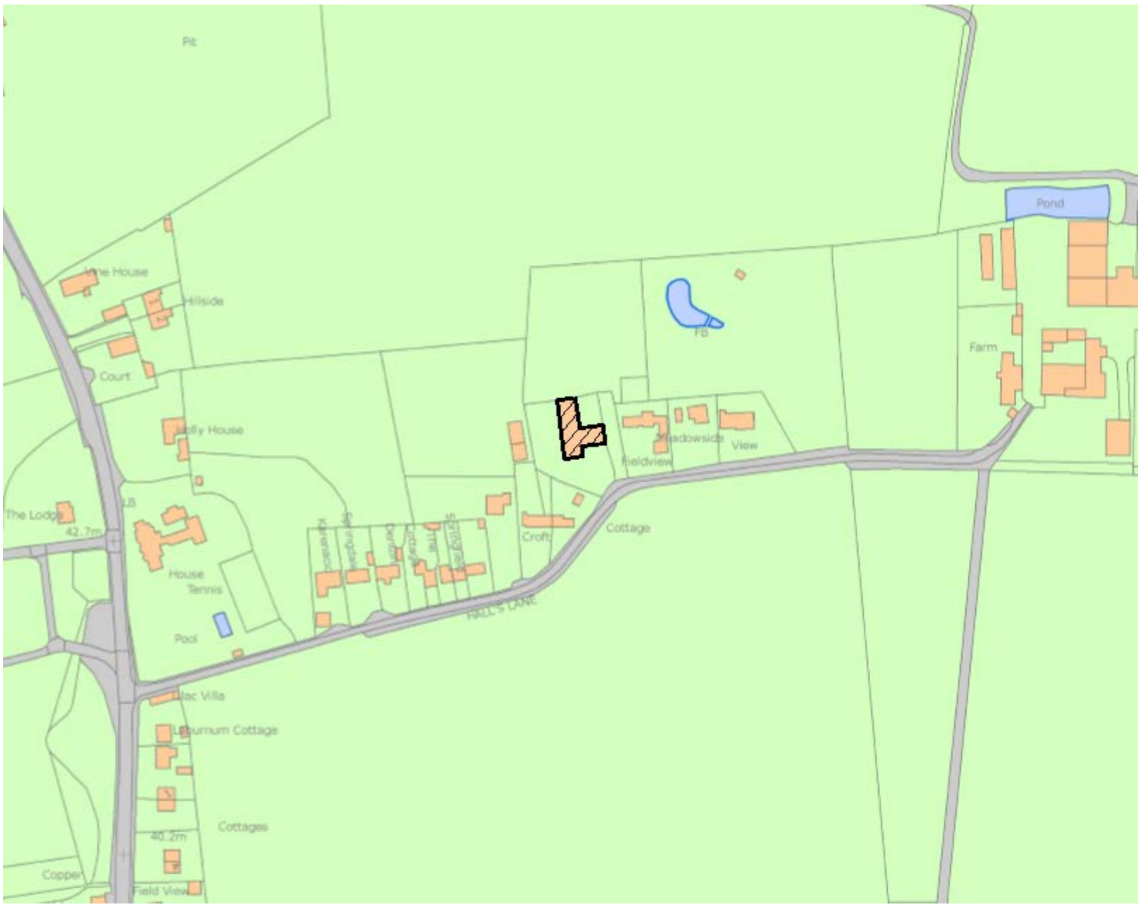

Figure 3: Map to show Norton Hall Barn, hashed. ©Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900.

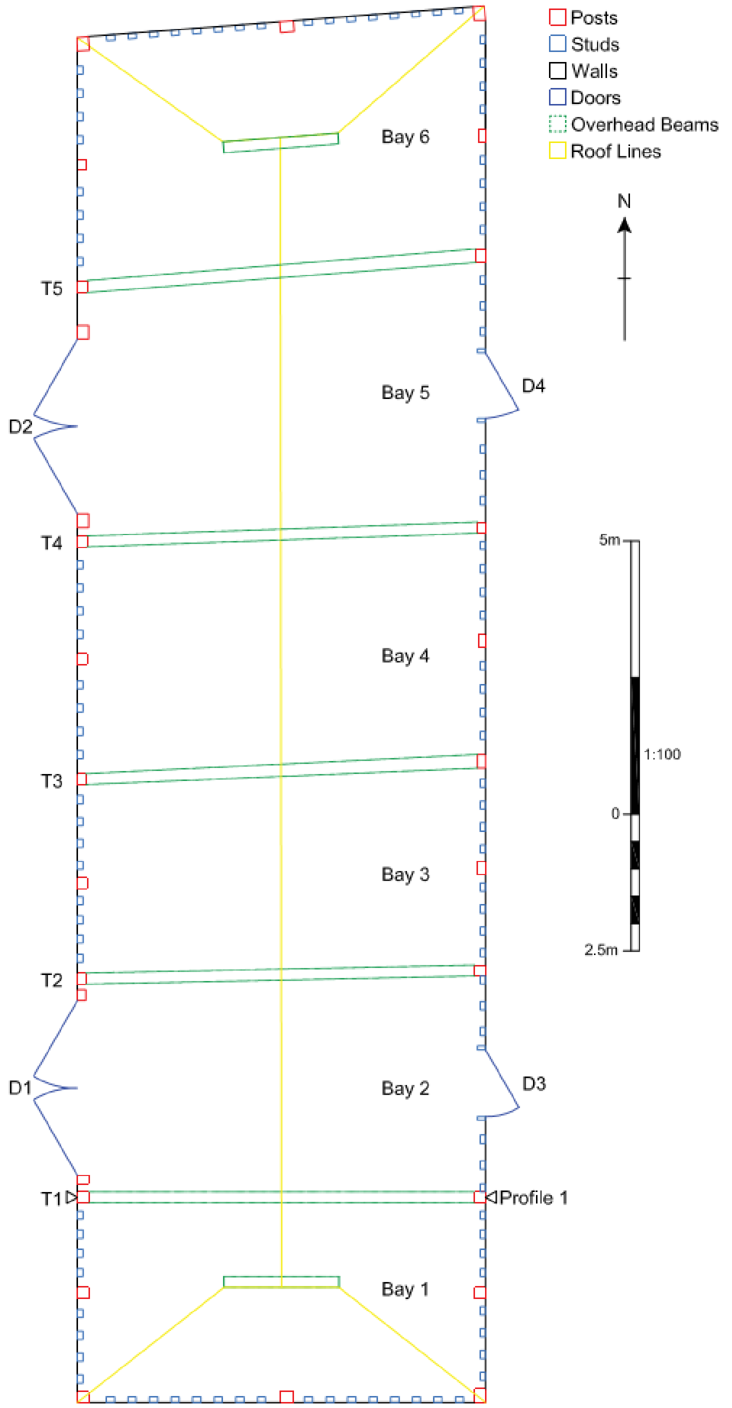

Figure 4: Plan of Norton Hall Barn, showing the location of trusses and bay and door numbering (Moller 2012)

Figure 5: The Barn, photograph taken from the north (Alison Arnold)

Figure 6: Doorway D1, photograph taken from the east (Alison Arnold)

Figure 7: Doorway D2, photograph taken from the east (Alison Arnold)

Figure 8: Doorway D3, photograph taken from the west (Alison Arnold)

Figure 9: Doorway D4, photograph taken from the west (Alison Arnold)

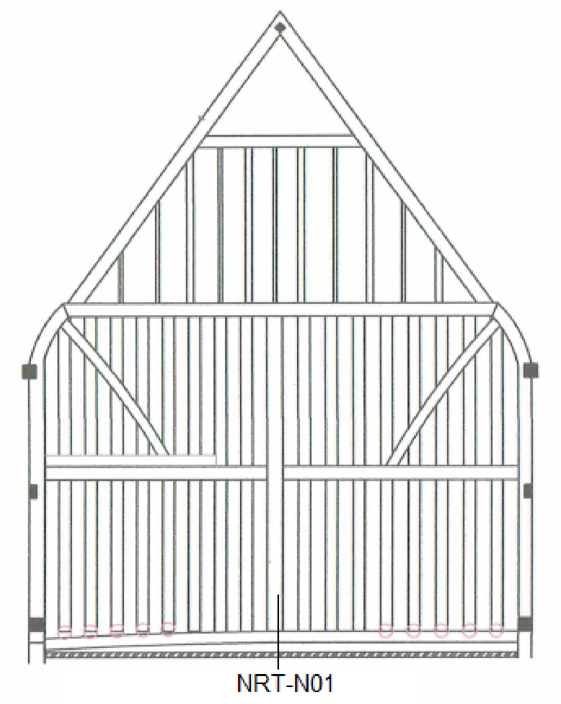

Figure 10: South gable wall (interior elevation), showing the location of sample NRT-N01 (after Tim Buxbaum Architect 2016 Drawing No 907/7)

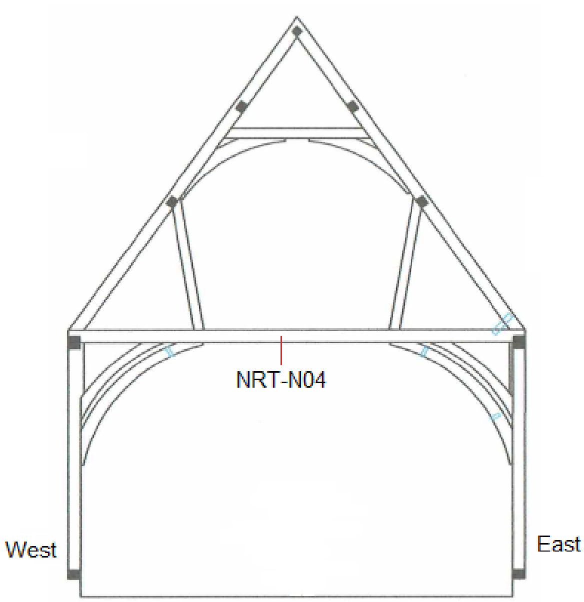

Figure 11: Truss 1, showing the location of sample NRT-N04 (after Tim Buxbaum Architect 2016 Drawing No 907/7)

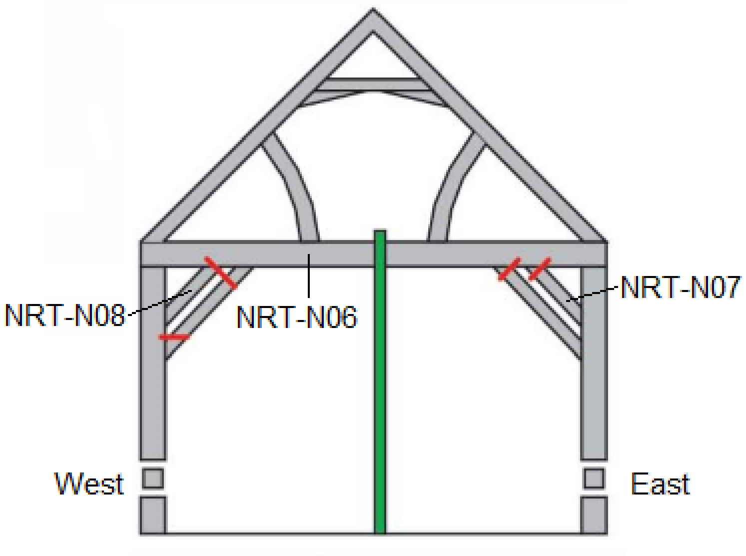

Figure 12: Truss 2, showing the location of samples NRT-N07–08 (after Moller 2012)

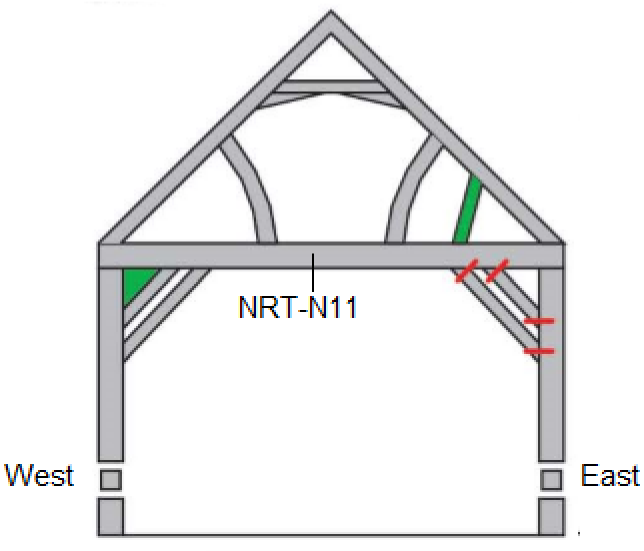

Figure 13: Truss 3, showing the location of sample NRT-N11 (after Moller 2012)

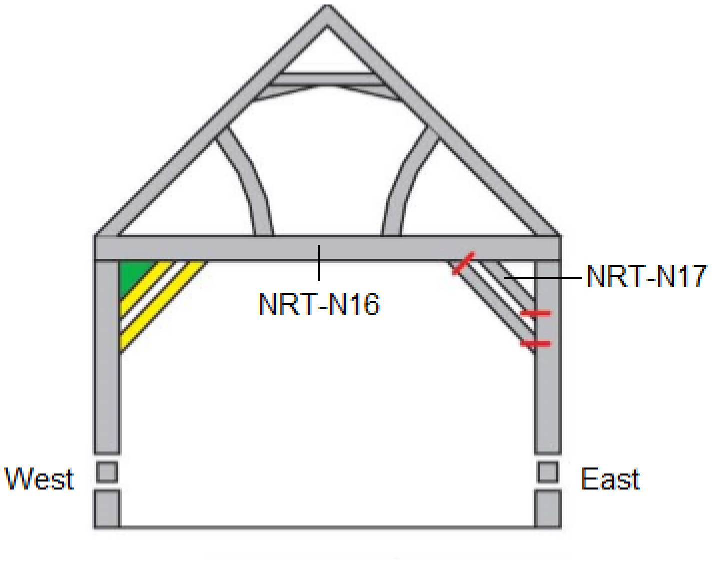

Figure 14: Truss 4, showing the location of samples NRT-N16–17 (after Moller 2012)

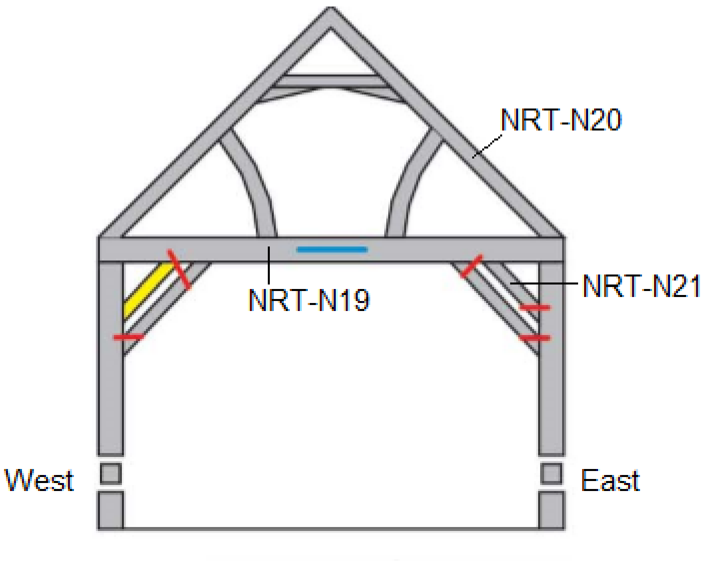

Figure 15: Truss 5, showing the location of samples NRT-N19–21 (after Moller 2012)

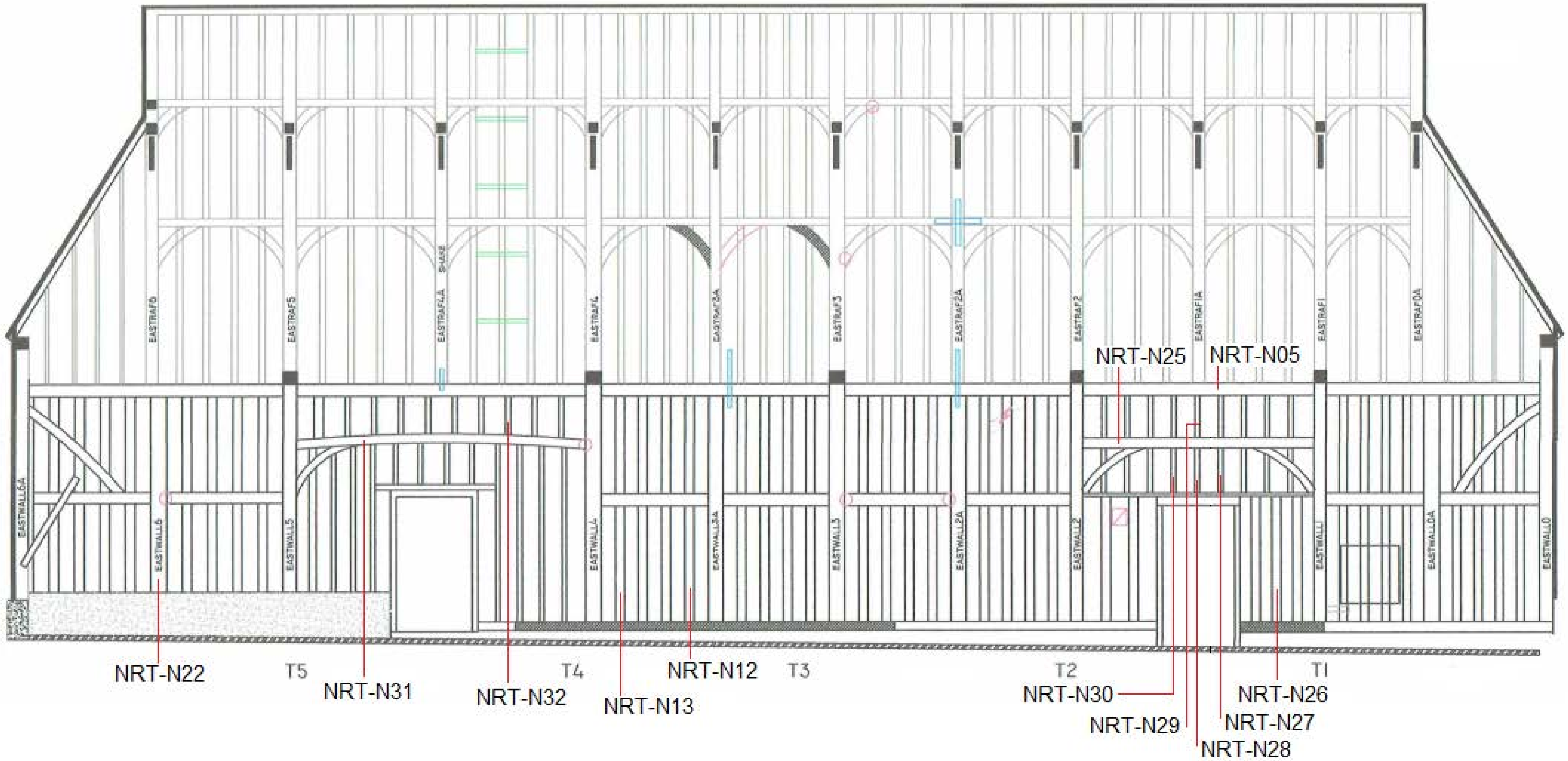

Figure 16: East wall (internal elevation), showing the location of samples NRT-N05, NRT-N12–13, NRT-N22, and NRT-N25–32 (after Tim Buxbaum Architect 2016 Drawing No 907/5)

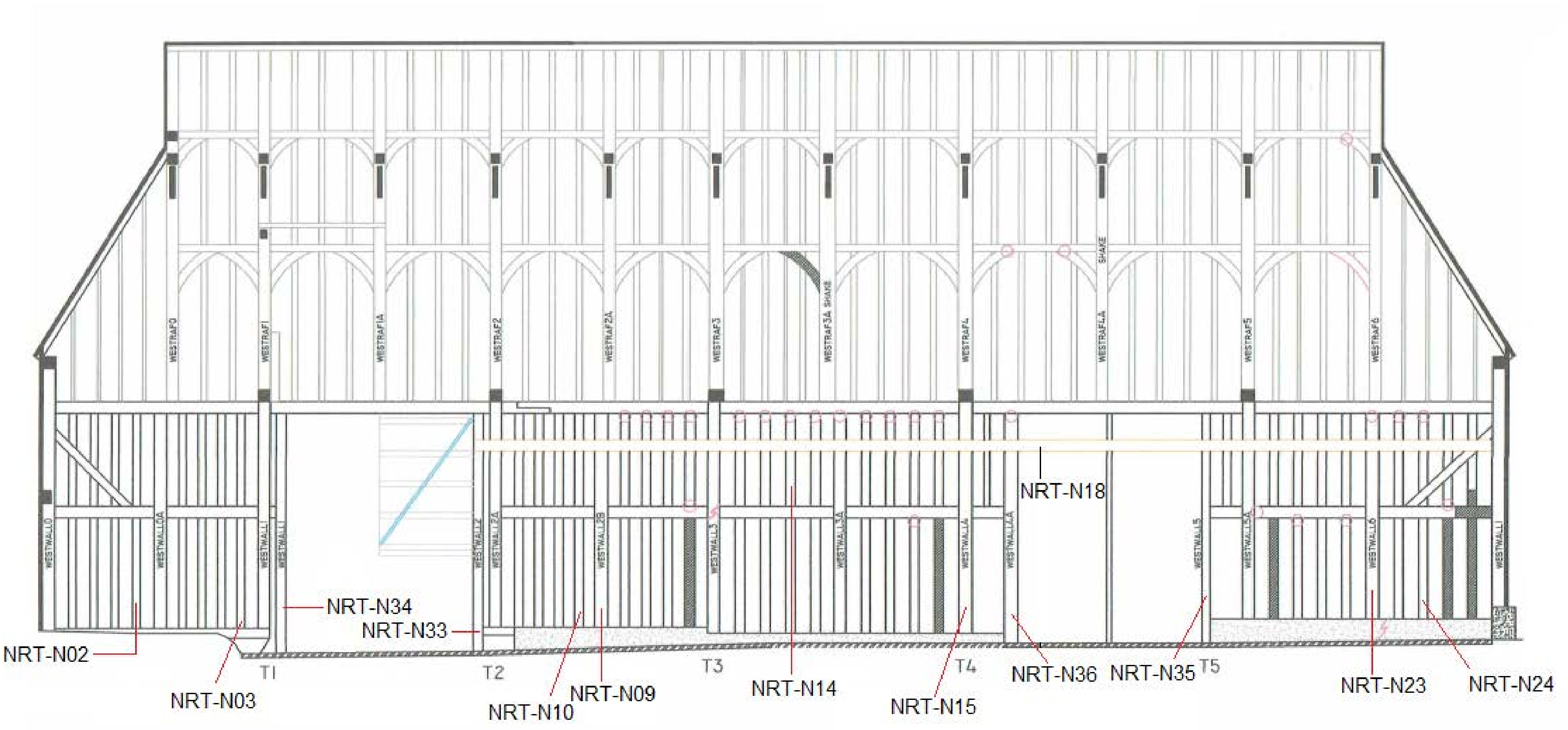

Figure 17: West wall (internal elevation), showing the location of samples NRT-N02–03, NRT-N09–10, NRT-N14-15, NRT-N18, NRT-N23–24, NRT-M33–36 (after Tim Buxbaum Architect 2016 Drawing No 907/6)

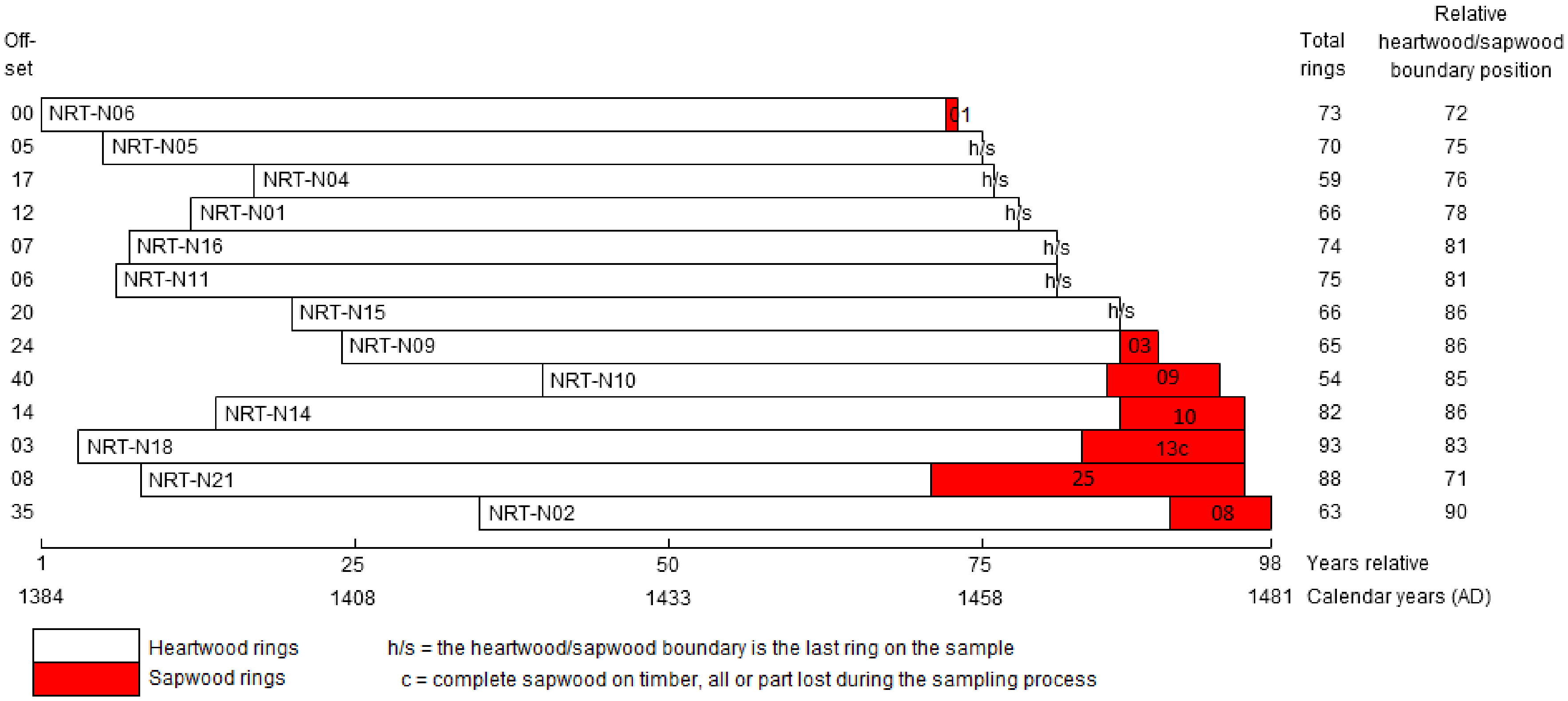

Figure 18: Bar diagram to show the relative position of samples in site sequence NRTNSQ01

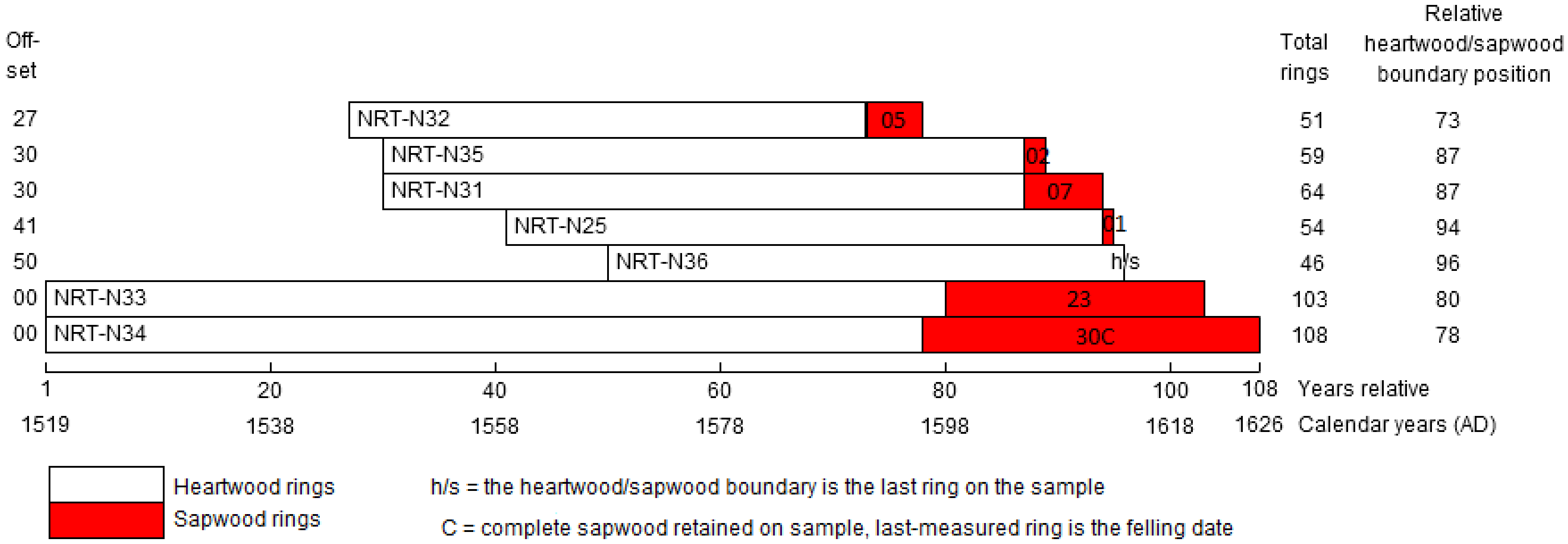

Figure 19: Bar diagram to show the relative position of samples in site sequence NRTNQ02

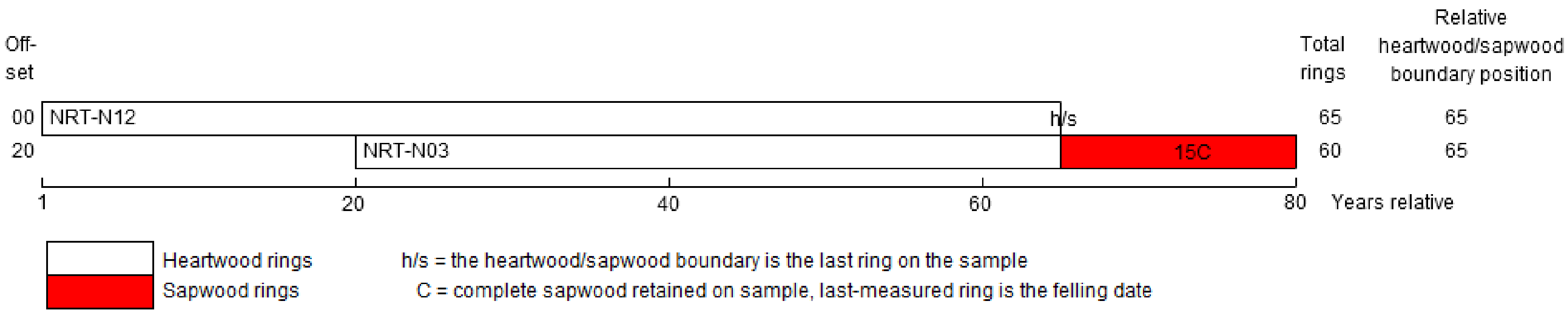

Figure 20: Bar diagram to show the relative positon of samples in undated site sequence NRTNSQ03

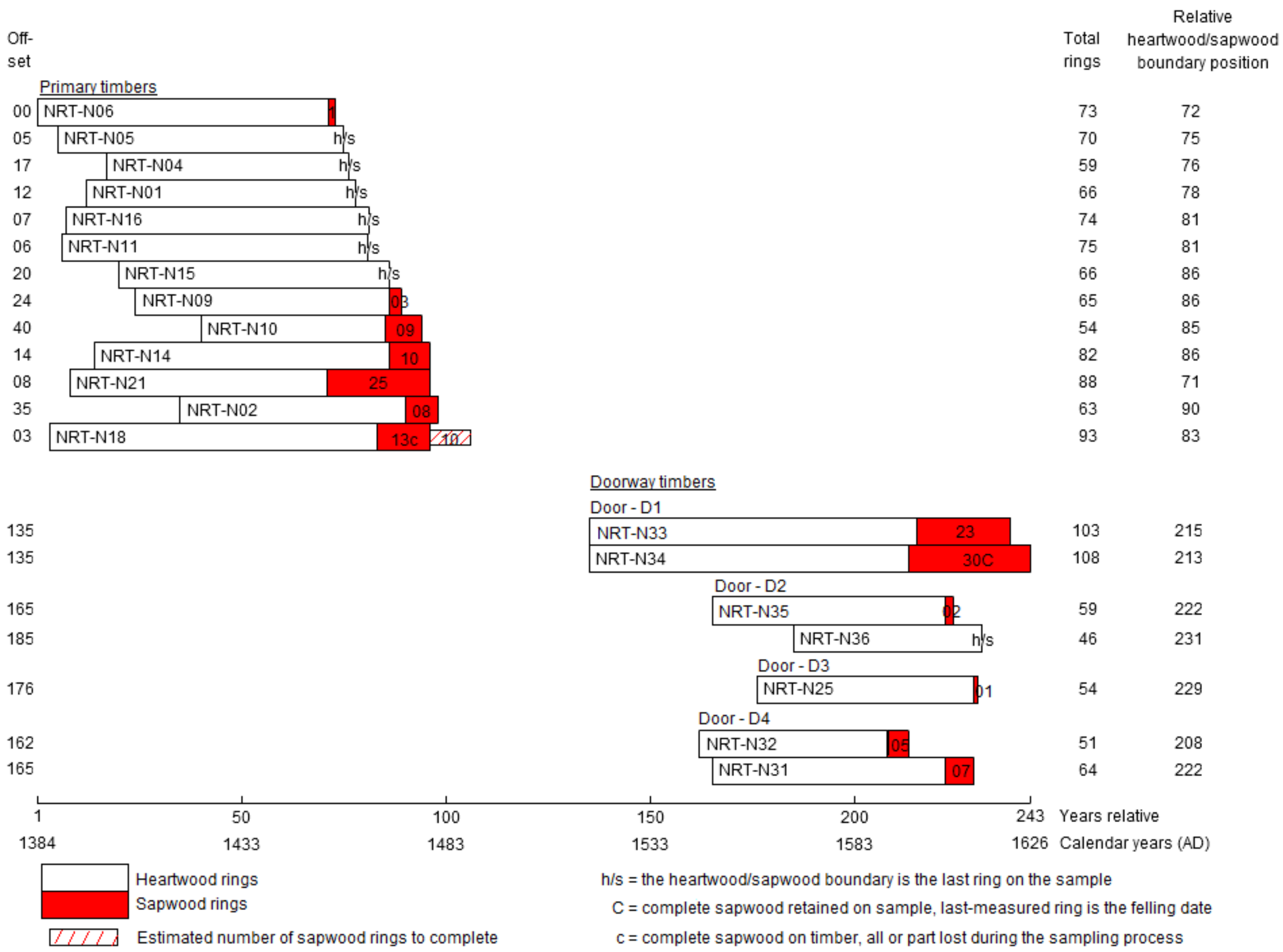

Figure 21: Bar diagram of all dated samples, sorted by phase

DATA OF MEASURED SAMPLES

NRT-N01A 66
369 390 406 452 295 187 178 270 502 472 405 301 235 242 142 162 138 143 100 102
75 125 135 100 92 163 115 105 140 85 101 106 134 114 136 109 140 86 93 84
93 133 103 104 180 156 175 172 115 83 121 125 94 135 85 83 91 86 120 123
149 136 120 83 85 102
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NRT-N02B 63
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84 113 109 121 147 87 91 159 112 105 111 98 109 83 108 166 123 148 162 169
150 110 82 98 93 101 129 118 95 96 107 130 114 142 113 128 145 123 95 86
107 93 76
NRT-N03A 60
261 289 286 237 238 244 191 214 232 173 118 126 122 141 205 178 216 209 258 250
292 263 248 270 269 212 243 239 225 195 164 183 219 216 183 135 119 100 74 87
127 136 128 149 145 202 264 214 186 154 150 104 121 94 135 118 148 140 140 189
NRT-N03B 60
225 288 275 239 242 229 191 222 230 178 119 121 114 154 194 183 209 224 253 252
283 266 244 268 270 211 243 238 227 195 164 184 209 223 187 137 125 99 77 85
127 134 125 145 142 180 247 244 180 167 147 88 126 102 118 129 147 144 137 149
NRT-N04A 59
290 367 239 402 364 373 232 314 199 123 136 166 162 96 72 107 69 120 97 147
213 131 132 147 84 80 84 134 117 91 112 116 59 92 92 104 142 160 111 145
107 125 125 94 93 100 93 86 113 87 124 89 93 135 118 204 133 119 98
NRT-N04B 59
351 336 197 387 414 354 205 312 206 130 133 164 164 94 72 104 74 101 100 143
212 123 145 152 88 78 86 147 114 91 109 127 60 94 92 106 150 156 108 137
117 117 115 102 82 105 93 84 109 91 122 97 90 126 117 204 129 116 106
NRT-N05A 70
219 260 346 351 574 285 267 254 251 373 270 172 196 190 176 277 259 289 188 254
188 182 213 197 200 144 118 73 68 150 118 152 132 108 173 146 101 118 105 139
126 131 160 98 58 70 75 119 130 126 173 117 124 153 176 76 111 128 81 100
137 105 131 86 81 89 134 168 157 116
NRT-N05B 70
222 251 362 355 532 244 256 257 242 373 263 171 201 191 176 273 264 289 186 270
190 181 215 191 199 140 124 74 66 146 118 149 130 108 180 151 111 111 107 136
122 141 154 101 57 77 68 123 127 125 178 113 129 156 166 75 108 117 88 87
127 109 119 86 76 91 132 169 161 112
NRT-N06A 73
165 144 360 426 307 236 295 340 297 277 277 244 263 195 287 269 204 101 217 256
441 356 342 205 223 173 134 145 169 243 132 112 111 106 148 98 94 73 52 88
81 57 71 94 140 112 104 126 139 72 55 108 83 82 89 105 132 110 107 134
72 72 66 71 53 78 55 76 71 73 103 100 155

NRT-N06B 73
161 141 367 409 308 227 290 342 310 284 274 244 255 202 286 274 200 102 210 266
435 358 346 198 219 176 129 148 176 239 139 115 108 102 149 110 97 73 50 96
74 54 71 93 133 109 102 131 135 65 64 99 91 86 86 108 139 105 115 130
80 66 68 70 59 75 57 73 73 74 98 102 156
NRT-N07A 68
304 249 200 224 193 132 196 138 149 119 142 86 103 78 75 64 80 131 98 107
164 194 75 68 61 62 61 177 124 98 96 69 83 152 123 149 165 164 129 90
83 112 96 97 76 81 85 79 53 60 59 40 32 65 53 91 56 55 100 98
134 129 93 63 74 73 106 138
NRT-N07B 68
295 250 196 228 193 133 205 136 148 120 147 86 106 76 76 66 94 130 100 103
169 194 76 70 60 62 61 179 123 99 109 67 71 150 122 152 168 165 126 99
87 103 111 82 79 74 91 73 54 57 56 40 40 64 52 88 54 60 102 94
144 117 99 69 70 79 110 127
NRT-N08A 50
146 186 188 172 103 101 134 118 164 159 124 135 115 135 173 103 150 176 134 130
78 86 123 135 181 119 108 77 82 62 46 65 99 65 151 112 127 116 143 178
161 195 119 201 150 181 205 214 222 147
NRT-N08B 50
145 174 193 175 107 99 133 115 162 163 123 133 115 140 167 99 154 179 131 125
84 88 122 135 179 123 113 78 74 60 54 70 95 64 149 114 130 116 149 177
191 190 126 204 146 159 204 205 229 160
NRT-N09A 65
293 164 172 133 157 207 124 114 107 157 262 213 237 247 160 248 224 209 214 203
213 200 180 171 103 63 62 95 87 131 135 131 163 130 169 170 95 110 143 114
107 156 104 120 98 108 145 137 189 177 155 110 65 72 94 126 108 98 89 98
130 155 159 151 129
NRT-N09B 65
288 165 170 142 163 199 125 114 109 154 242 230 248 250 154 256 222 204 221 187
205 200 174 176 108 55 58 99 89 132 139 126 163 127 166 171 99 110 138 117
101 158 106 118 102 105 142 138 188 177 152 113 65 74 90 106 105 96 84 91
126 170 165 149 113
NRT-N10A 54
136 153 154 161 197 197 202 242 163 118 95 148 123 179 188 140 184 163 230 211
168 195 256 250 239 268 238 237 228 258 253 240 266 238 242 204 137 147 137 152
172 152 175 137 221 216 198 181 170 132 143 142 145 146
NRT-N10B 54
162 148 154 159 190 179 206 223 159 114 78 143 115 179 191 147 182 156 226 215
148 187 256 243 219 277 224 231 230 257 256 234 272 242 259 195 145 142 127 134
167 154 159 129 224 206 209 176 168 133 123 142 137 121
NRT-N11A 75
336 379 334 281 261 290 348 180 333 392 323 231 277 236 397 402 352 254 361 317
219 245 220 227 125 86 163 155 149 128 138 170 112 155 171 152 116 112 129 103
120 135 227 137 68 89 62 70 66 71 93 91 92 90 48 74 75 63 53 97
44 60 54 62 72 52 86 67 67 54 61 58 93 77 90
NRT-N11B 75
347 375 337 287 248 290 355 182 327 384 336 228 277 240 401 400 327 246 370 322
219 256 220 229 120 88 166 154 127 132 140 162 105 146 174 139 123 118 133 105
121 134 239 146 84 86 63 81 66 75 98 102 83 94 55 72 75 67 56 94
52 54 52 61 60 54 88 61 66 57 48 75 87 82 95

NRT-N12A 65
117 65 73 37 108 144 151 133 150 193 209 189 238 289 382 182 87 79 138 105
148 204 155 151 202 319 228 181 220 106 69 65 101 163 262 215 159 183 148 156
201 135 124 204 197 165 189 162 188 157 183 262 261 245 170 165 125 90 45 39
42 43 46 59 96
NRT-N12B 65
104 66 77 39 104 144 149 140 154 193 219 199 247 299 384 180 91 67 139 110
178 190 137 144 194 328 228 182 227 104 65 71 97 165 267 217 167 176 123 144
209 129 124 205 186 165 184 171 189 159 178 270 258 248 169 163 122 75 46 42
44 47 40 67 91
NRT-N14A 82
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130 95 110 135 97 176 151 102 99 112 110 134 101 137 122 74 82 125 90 103
101 73 95 94 123 117 93 85 123 138 127 167 160 143 115 121 146 151 173 143
131 113 50 43 65 59 91 89 132 168 181 158 125 96 93 70 92 140 141 130
160 129
NRT-N14B 82
557 532 581 405 365 221 328 330 324 224 172 187 167 163 172 149 144 133 113 118
127 97 112 131 102 174 150 100 104 109 107 135 105 133 118 74 85 127 84 111
91 83 89 98 117 119 104 74 129 138 134 166 162 139 120 123 140 155 176 143
130 109 54 50 65 71 92 100 122 161 177 165 123 98 92 71 90 140 142 133
152 164
NRT-N15A 66
165 257 288 223 247 228 244 262 261 316 244 244 234 452 406 224 324 266 171 250
253 205 225 219 298 228 212 291 150 170 161 150 195 208 149 171 179 173 172 201
136 177 164 127 105 190 133 160 107 123 125 147 280 248 224 181 116 108 85 90
83 119 111 95 123 154
NRT-N15B 66
206 252 270 233 251 215 236 271 289 332 240 250 236 458 414 226 328 266 166 264
242 211 236 215 301 212 207 297 147 167 140 147 200 195 155 171 180 171 170 182
143 176 170 132 108 184 134 166 112 119 129 145 273 237 232 193 122 92 85 75
80 118 109 95 103 109
NRT-N16A 74
493 303 327 285 330 304 318 356 277 189 217 214 224 312 271 254 207 253 220 187
211 190 238 139 113 76 212 301 250 266 212 171 222 205 194 215 156 171 180 184
187 108 54 35 59 45 44 47 63 106 88 106 146 92 108 143 131 87 139 87
110 91 107 144 109 123 101 96 45 48 46 57 65 64
NRT-N16B 74
524 336 332 289 313 304 322 364 295 207 207 214 222 299 280 258 204 253 221 188
210 189 239 136 121 72 204 306 256 259 214 176 227 205 200 226 151 160 178 179
179 106 54 40 57 40 50 41 69 105 97 104 134 86 104 148 132 88 144 84
109 89 98 139 112 124 99 97 50 50 42 55 63 80
NRT-N17A 60
336 285 268 228 202 211 177 185 154 143 144 422 247 194 220 212 189 280 321 208
195 240 192 220 231 276 216 81 174 103 86 104 94 87 92 88 96 102 122 121
96 140 135 125 153 153 146 127 133 103 156 128 137 116 142 109 162 187 182 126
NRT-N17B 60
376 281 284 226 212 217 222 184 159 147 147 427 262 191 218 227 191 283 321 218
198 242 199 214 236 280 216 88 106 81 78 101 94 89 91 85 96 108 125 114
94 143 138 130 154 156 150 136 128 103 143 128 136 110 140 115 158 194 177 128

NRT-N18A 93
334 277 332 294 268 305 230 234 222 218 186 193 245 142 115 89 170 390 329 330
216 236 176 122 136 112 123 96 99 149 90 100 87 101 129 105 147 182 128 131
138 184 119 171 142 209 154 102 50 52 77 52 62 96 78 90 121 68 81 105
93 71 126 68 83 74 77 86 90 129 84 98 78 101 150 188 151 126 200 141
120 123 106 170 151 79 82 82 77 92 84 49 120
NRT-N18B 93
330 273 332 298 273 307 238 237 219 219 192 198 238 157 109 93 151 391 336 335
219 232 180 122 136 115 129 92 99 145 92 106 86 103 127 105 149 180 132 126
139 191 111 175 142 211 156 99 52 53 77 53 59 95 78 91 119 71 82 103
88 77 124 61 95 70 77 95 82 135 89 97 74 106 140 186 143 125 206 143
112 131 100 178 148 82 74 87 82 95 69 49 126
NRT-N19A 57
429 431 423 411 326 230 85 96 164 193 311 225 261 280 258 252 147 154 123 85
72 89 139 174 160 125 118 180 193 154 124 102 124 169 144 186 243 217 136 98
117 132 143 117 133 113 147 126 120 114 98 100 84 92 103 98 114
NRT-N19B 57
387 425 452 398 314 238 93 101 154 207 322 190 226 280 272 266 152 157 127 89
75 91 139 171 159 125 118 187 203 160 126 113 121 163 144 180 244 208 148 108
128 163 146 112 133 111 142 123 113 107 84 97 71 94 88 99 117
NRT-N20A 59
350 285 335 378 381 361 342 345 367 381 377 378 166 199 196 126 157 134 108 132
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111 82 60 75 81 145 104 103 121 84 107 127 97 94 100 117 81 99 98
NRT-N20B 59
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151 199 152 225 145 198 98 65 47 66 57 79 115 103 92 110 132 86 68 80
109 86 61 75 81 143 105 99 121 90 105 124 100 95 100 114 81 96 95
NRT-N21A 88
194 285 251 292 434 361 560 941 640 361 390 250 331 298 340 184 309 204 158 210
292 296 178 146 83 47 62 45 64 88 65 112 110 116 114 113 135 86 100 83
72 50 39 46 44 46 58 53 61 57 63 103 42 56 46 53 50 42 49 54
57 47 45 63 96 76 71 53 49 54 62 58 63 80 62 59 62 82 126 88
82 65 61 65 74 52 77 67
NRT-N21B 88
193 273 265 290 431 362 551 999 660 368 394 248 358 310 336 188 319 198 152 215
289 303 175 146 82 45 68 42 64 86 65 115 110 112 116 111 139 92 98 82
72 50 38 50 40 46 61 48 68 61 58 101 46 55 50 53 37 51 40 60
48 64 43 60 107 69 78 56 47 55 70 50 59 81 59 58 64 86 124 86
82 67 56 65 74 80 56 58
NRT-N22A 56
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142 211 210 206 204 174 214 240 196 237 315 286 295 289 257 230 188 227 331 279
318 278 258 186 160 158 149 150 117 129 147 146 164 204 284 253
NRT-N22B 56
355 387 293 244 338 299 179 272 196 219 267 269 267 348 384 352 157 192 122 123
133 210 215 202 204 176 207 241 202 233 323 287 289 298 256 231 186 219 340 282
312 278 260 189 158 157 151 149 122 125 150 148 173 194 285 260
NRT-N23A 63
159 201 230 280 402 375 398 341 340 494 368 304 372 199 107 94 132 147 166 135
263 193 160 199 316 220 268 219 222 245 261 252 273 274 192 190 159 139 104 131
97 100 76 73 60 90 110 122 213 226 284 234 162 176 177 169 151 164 172 120
126 122 151

NRT-N23B 63
157 184 342 256 446 373 397 344 330 491 373 300 376 199 92 79 122 139 154 144
273 188 183 199 332 204 241 223 244 245 264 245 285 250 194 188 160 141 106 135
92 102 80 69 55 86 105 131 195 265 271 234 145 177 156 167 153 181 144 116
131 132 137
NRT-N24A 59
184 187 283 206 197 247 212 195 209 189 245 85 55 185 183 178 210 149 149 259
157 223 269 187 120 303 300 238 339 287 239 197 200 246 211 297 210 216 154 321
471 328 331 225 231 224 182 247 293 292 182 180 161 143 169 118 116 117 134
NRT-N24B 59
192 177 267 209 192 265 228 189 208 189 246 82 58 185 182 178 212 143 141 256
156 217 271 180 109 307 313 239 343 297 243 209 195 241 207 299 210 217 154 322
471 327 331 233 230 221 179 242 296 279 165 192 166 116 180 110 122 113 122
NRT-N25A 54
182 232 348 200 173 199 228 309 375 165 305 310 247 188 204 196 208 173 162 159
285 161 138 189 147 188 228 142 151 136 85 105 136 153 242 268 202 164 186 94
172 160 105 126 155 108 178 181 156 79 148 145 157 199
NRT-N25B 54
168 223 337 172 168 188 221 304 337 161 307 316 247 187 205 192 203 175 161 160
279 170 130 184 136 167 223 132 143 127 90 112 128 156 247 256 209 162 188 93
169 154 110 121 150 119 177 179 148 88 147 153 162 190
NRT-N26A 57
131 110 68 50 59 135 104 170 170 174 168 173 154 178 196 136 300 284 99 142
107 111 77 63 145 162 211 237 226 271 227 224 107 114 60 108 132 134 98 107
80 107 166 193 127 104 133 135 137 138 120 125 76 83 89 57 79
NRT-N26B 57
150 116 66 41 70 133 98 171 169 174 171 167 161 187 184 139 305 292 107 140
104 111 73 75 143 160 208 241 228 273 223 230 107 111 64 108 133 126 101 103
84 111 162 196 124 114 125 130 123 143 113 105 94 85 80 67 79
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83 81 107 100 128 95 124 90 75 80 49 74 70 67 64 79 41 72 84 78
99 64 94 82 50 75 87 95 56 64 65 67 50 72 82 80 70 121 99 86
173 151 143 112 118 137 142 131 99 71 86 128 114 124 96 153 200 103 112 122
124 116 117 137 164 118 111 181
NRT-N29B 88
66 62 63 125 99 76 81 104 74 107 110 90 134 131 146 120 74 113 83 93
77 78 112 105 127 102 126 98 85 83 56 73 69 72 68 77 49 69 84 77
110 56 107 79 56 74 92 96 61 68 69 63 68 65 91 74 87 99 95 88
163 156 158 113 117 142 138 134 93 83 90 125 109 120 100 151 197 98 117 122
122 114 123 144 162 117 108 188
NRT-N31A 64
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233 255 93 104 113 179 216 136 120 112 82 164 109 98 111 142 155 142 95 72
60 45 77 79 107 142 153 97 80 126 86 138 110 95 157 138 92 159 167 154
81 64 76 183
NRT-N31B 64
241 185 138 238 249 151 177 224 143 151 145 204 284 256 142 86 99 125 167 246
246 254 99 99 118 172 212 130 123 117 77 169 112 90 116 133 168 136 97 71
60 50 80 76 118 128 148 98 84 129 91 131 108 102 153 140 101 153 171 159
88 61 79 187

NRT-N32A 51
157 185 221 249 198 164 181 152 121 156 107 98 115 114 150 119 127 99 79 65
71 59 96 72 97 89 65 91 92 76 66 78 59 78 79 73 66 53 77 60
101 79 82 114 71 76 84 84 98 84 104
NRT-N32B 51
150 183 225 240 187 167 182 149 125 155 107 97 116 116 148 121 124 94 83 73
67 62 93 78 93 91 64 89 88 80 65 80 63 75 86 67 55 55 85 60
103 85 88 104 73 81 81 90 101 74 107
NRT-N33A 103
186 151 331 356 404 302 360 371 381 500 370 404 398 297 325 297 402 329 276 298
274 282 337 215 211 167 198 146 120 165 200 198 258 173 194 200 226 145 94 112
179 197 129 167 165 107 102 133 85 103 105 129 89 101 129 145 94 101 105 55
81 122 85 59 75 68 78 78 55 59 41 54 63 43 56 64 66 60 45 57
49 62 58 49 48 50 36 62 62 66 34 28 43 38 32 36 46 39 41 30
32 43 37
NRT-N33B 103
185 154 336 354 405 295 353 355 389 470 393 394 406 301 336 287 406 324 275 298
272 287 319 205 208 161 209 141 122 183 205 196 246 163 193 203 223 154 97 121
192 179 138 170 166 125 88 134 86 108 100 123 94 99 127 147 94 119 96 54
83 116 94 62 74 63 76 86 51 58 51 48 64 46 54 69 78 50 50 62
50 61 62 57 50 41 34 61 69 64 35 34 31 46 37 42 41 38 37 29
32 41 43
NRT-N34A 108
193 194 294 445 436 327 452 416 392 420 374 361 335 282 434 326 366 282 279 310
289 351 366 235 165 152 201 113 121 183 194 137 189 137 130 156 195 142 109 98
130 169 155 171 143 89 85 128 105 131 118 132 111 86 106 91 80 99 99 75
91 165 83 89 74 55 76 77 57 59 46 49 50 45 57 60 65 50 47 55
52 64 43 48 49 50 41 48 52 47 31 25 43 45 35 32 55 56 42 34
46 45 50 51 43 48 38 47
NRT-N34B 108
183 190 302 453 436 322 456 413 402 421 371 351 358 284 432 324 373 277 276 313
291 345 365 235 166 154 205 117 123 174 196 148 191 145 131 156 204 139 111 113
141 180 153 176 143 82 103 114 98 133 114 140 111 79 117 90 77 106 101 67
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41 44 50 48 47 44 41 40
NRT-N35A 59
291 166 232 262 367 273 347 287 175 188 192 229 258 281 153 126 123 146 147 226
217 228 163 168 195 203 208 223 216 226 202 349 163 153 260 230 210 251 213 181
157 104 142 158 179 269 314 191 127 183 174 203 143 139 174 173 135 186 175
NRT-N35B 59
284 166 237 264 363 288 362 292 185 234 207 222 264 280 159 127 132 134 148 230
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154 97 153 157 181 248 329 183 127 186 150 198 147 135 173 171 129 203 173
NRT-N36A 46
351 425 464 318 301 351 406 287 265 251 221 295 145 125 146 218 272 356 245 237
165 179 252 285 367 367 298 301 271 218 201 213 130 171 299 370 200 310 226 188
137 126 135 221 212 224
NRT-N36B 46
319 432 450 310 308 352 403 289 299 268 214 269 145 132 141 208 264 352 281 247
190 212 268 297 353 354 290 293 272 220 196 216 128 171 307 375 198 316 228 189
148 122 137 210 223 211

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

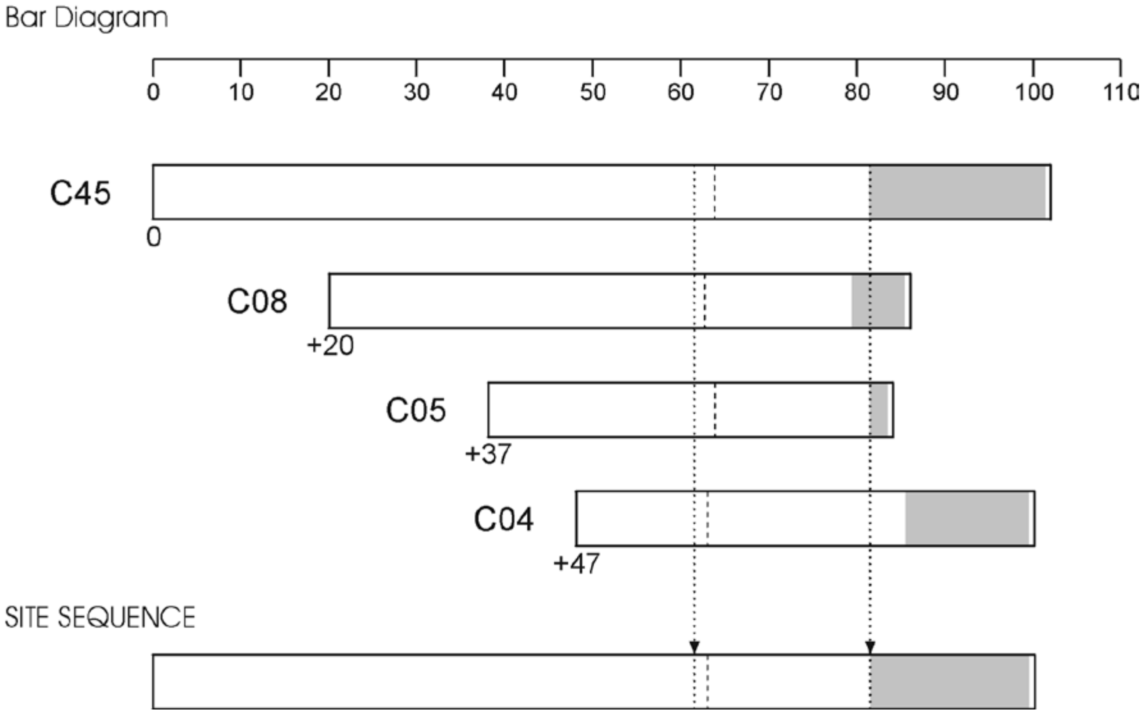


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

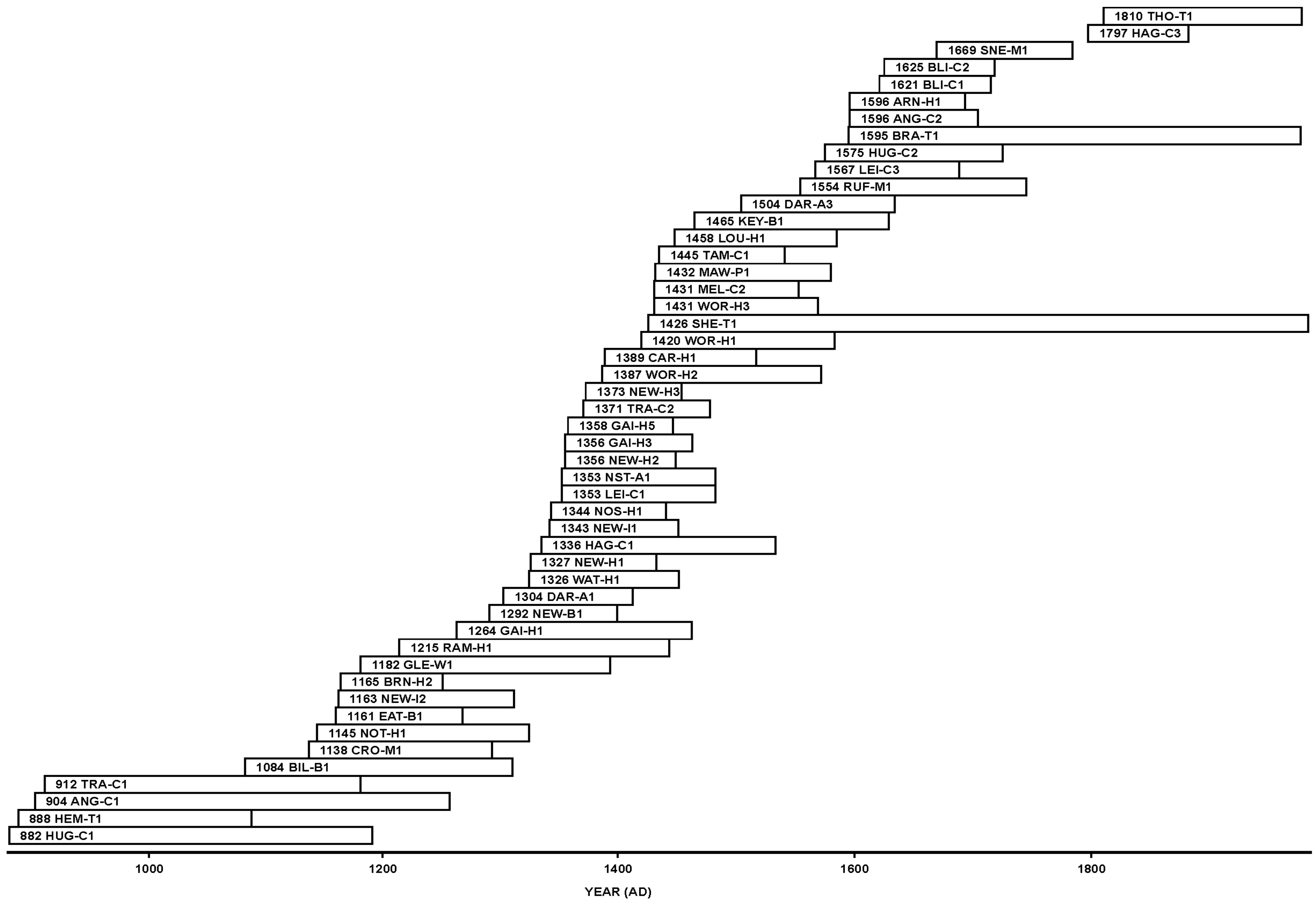
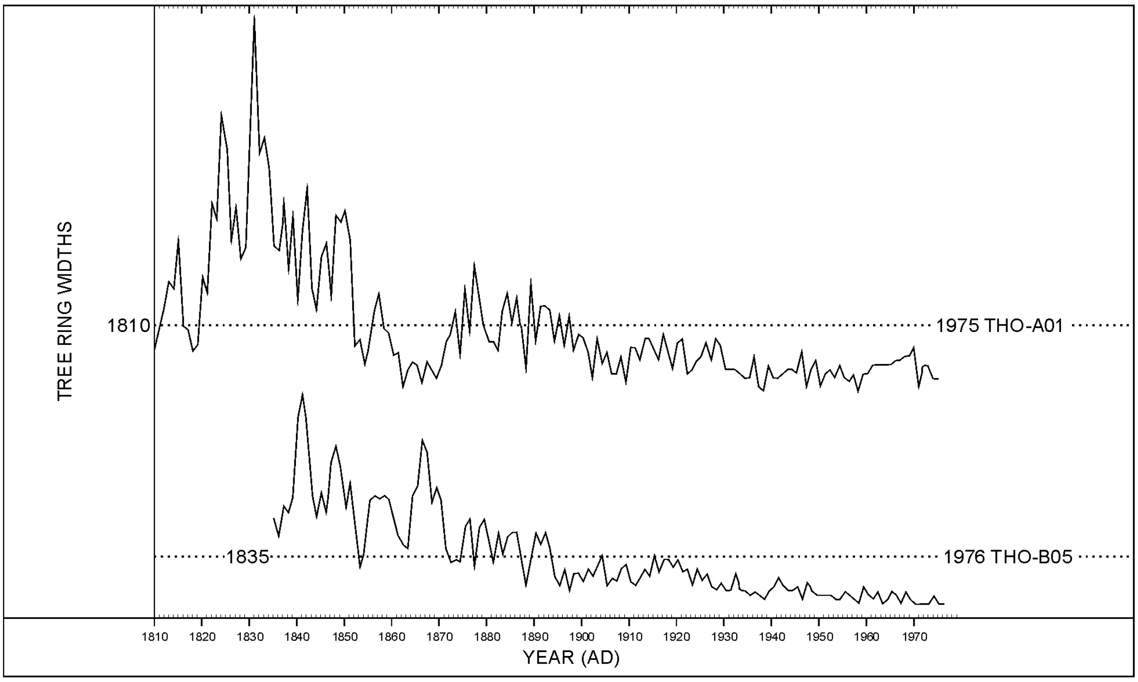


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

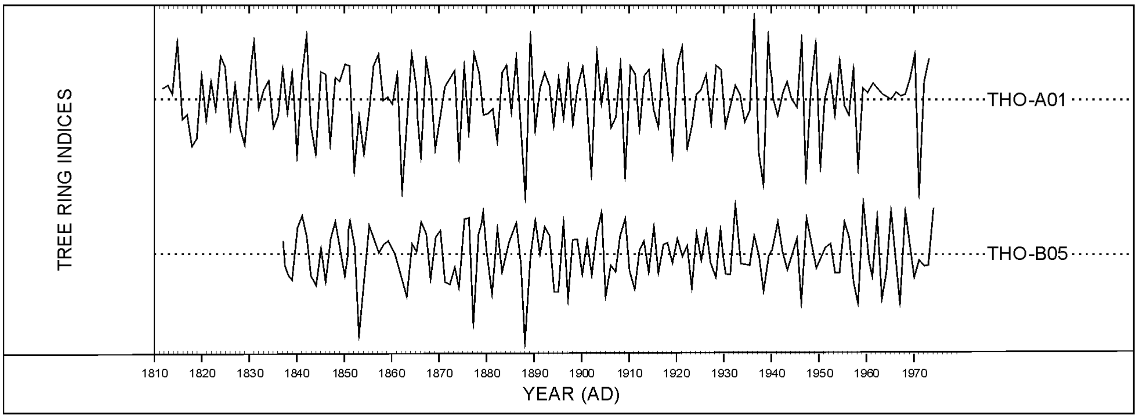


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

References

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

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

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **15–26**

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 17 - Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in the East Midlands, *Vernacular Architect*, **23**, 51–6.

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90–8

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

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*¸ **18**, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, **28**, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London

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