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26-27 Market Place North Walsham Norfolk

Tree-ring Analysis of Oak and Elm Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

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Front Cover: Street view of 26-27 Market Place in North Walsham with the former Public House seen just on the corner. Photograph: Alison Arnold

26–27 MARKET PLACE
NORTH WALSHAM
NORFOLK

Tree-ring Analysis of Oak and Elm Timbers

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SUMMARY
Dendrochronological analysis was undertaken on samples from the roof and ceiling frames at this building resulting in the successful dating of 24 timbers. Analysis has demonstrated that the ceiling frame in the cellar contains timber felled in or around the winter of AD 1599/1600, the ground-floor ceiling utilises timber felled in or around the winter of AD 1597/8, with a first-floor ceiling beam having a felling date within the range of AD 1595–1620. The majority of the roof timber was felled in AD 1598–1623. However, at least four other roof timbers, likely representing later modifications, were felled in the winter of AD 1639/40.

CONTRIBUTORS
Alison Arnold, Robert Howard, and Cathy Tyers

ACKNOWLEDGEMENTS
We would like to thank the owners of 26/27 Market Place for agreeing to the work being undertaken and for being so understanding during the sampling, and the tenant at The Feathers for allowing access to the cellar beneath number 27 Market Place. We'd also like to thank Historic England's Project Lead for the High Street Heritage Action Zone programme in North Walsham, Emily Cole (Senior Architectural Investigator), and Architectural Investigators Katie Carmichael and James Shemmonds for facilitating access. Thanks too to Shahina Farid (HE Scientific Dating Team) for commissioning and facilitating this study.

ARCHIVE LOCATION
The Historic England Archive
The Engine House
Fire Fly Avenue
Swindon SN2 2EH

HISTORIC ENVIRONMENT RECORD
Norfolk Historic Environment Record
Historic Environment Service, Union House
Gressenhall, Dereham
Norfolk NR20 4DR

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INTRODUCTION

North Walsham High Street Heritage Action Zone

North Walsham, located some 24km north of Norwich (Fig 1) has just over 100 listed buildings which is the highest number of any town in North Norfolk, with most of these thought to date from the eighteenth and early nineteenth century. The town was badly damaged by a fire on 25 June AD 1600, but fabric pre-dating this event is believed to survive, possibly in cellars and around the Market Place. The town is one of the 69 (HSEE014) successful High Street Heritage Action Zones (HSHAZ) bids selected in 2019, which is being delivered by Historic England to unlock potential of high streets across England, fuelling economic, social and cultural recovery. Dendrochronology is one of the supporting elements of the HSHAZ programme, as part of improving the understanding of the town centre area to inform and support future planning and improvement decisions. The centre of North Walsham was designated as a conservation area in 1972, with the area extended in 2009.

26–27 Market Place

This Grade II listed building (List Entry Number: 1373969), located on the west side of Market Place (Fig 1), was originally one house but is now divided into two commercial premises. It is aligned north–south and is of two stories plus attics, and is thought to date to the early seventeenth century. There are later additions to the rear.

Roof

The roof of the main, north–south, range consists of six principal rafter and collar trusses, although only the east principal of truss 3 remains, with some additional collars and rafters located within the central bays. Between these are common rafters and butt purlins (Figs 2 and 3).

Ceiling frames

At ground-floor level, within the main, primary range of the building, are some large, chamfered ceiling beams (Fig 4); also visible within this range, at first-floor level, are three main ceiling beams (Fig 5). Two other ground-floor ceiling beams are located towards the rear of the building (Fig 6). Timbers of the cellar ceiling frame are visible beneath both number 26 (Fig 7) and number 27 (Fig 8).

SAMPLING

Thirty-two oak timbers (*Quercus* spp) and one elm timber (*Ulmus* spp) of the roof and ceiling frames at this building were sampled by coring. Initially, all sampled timbers were believed to have been in the main range, but two of the ground-floor ceiling beams are now thought to be located in a rear range. Each sample was given the code NHW-B and numbered 01–33. Further details relating to all samples can be found in Table 1. The location of all sampled timbers has been indicated on Figures 9 and 10. Sampled trusses and main beams have been numbered from east to west and north to south. Main ceiling beams in the cellar were sampled, but none of the exposed common joists were deemed suitable as these were assessed as having too few rings for reliable dating purposes (< 30 rings), being derived from young, fast-grown trees.

ANALYSIS AND RESULTS

Four samples were found to have less than 40 growth rings, and so were judged unlikely to produce secure dating and thus rejected prior to measurement. The remaining 29 samples, including the single elm sample, 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. All measurements were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in 23 oak samples matching at a minimum value of $t = 4.5$, to form a single group.

These 23 ring-width series were combined at the relevant offset positions to form NHWBSQ01, a site sequence of 170 rings (Fig 11). Attempts to date this site sequence against a series of relevant reference chronologies for oak resulted in it matching securely and consistently at a first-ring date of AD 1470 and a last-measured ring date of AD 1639. The evidence for this dating is given in Table 2.

Attempts were then made to individually date the remaining ungrouped samples, including the elm sample, by comparing them against the reference material. Sample NHW-B33 was found to match consistently and securely as spanning the period AD 1524–1573 (Table 3). The other individual samples could not be matched and remain undated.

INTERPRETATION

Tree-ring dating has resulted in the successful dating of 24 samples from the roof and ceiling frames of the main range at this building. Three of the samples retain complete sapwood but, where this is not present, the estimate that 95% of mature oak trees in this region have between 15 and 40 sapwood rings has been used to calculate felling date ranges or *terminus post quem* dates for felling. To aid interpretation the samples from different areas of the building are considered separately.

Roof

Seventeen of the roof samples have been dated indicating the presence of two different felling events.

One sample, NHW-B07, taken from an intermediate rafter, retains complete sapwood and has a last-measured ring date of AD 1639. This has both the spring and summer growth cells of its final ring, with the timber represented having been felled in the winter of AD 1639/40.

Nine of the other roof samples have the heartwood/sapwood boundary ring. Seven of these are in the AD 1580s and are broadly contemporary (Table 1; Fig 11). The combined average heartwood/sapwood boundary ring for these seven samples is AD 1583 allowing an estimated felling date to be calculated for the timbers represented to within the range of AD 1598–1623. The heartwood/sapwood boundary ring dates of the other two samples are somewhat later. The combined average heartwood/sapwood boundary ring date of these is AD 1610, giving an estimated felling date for these two timbers to within the range of AD 1625–50, consistent with these timbers being felled in the winter of AD 1639/40.

The other seven dated roof samples do not have the heartwood/sapwood boundary ring and so estimated felling date ranges cannot be calculated for them. Six of these have last-measured heartwood ring dates ranging from AD 1533 (NHW-B13) to AD 1569 (NHW-B17) giving a series of *terminus post quem* dates for felling, the earliest of which is AD 1548 and the latest AD 1584, making it possible that the timbers represented were felled in either of the two felling phases identified above (AD 1598–1623 and the winter of AD 1639/40). The seventh sample, NHW-B19, has a last measured heartwood ring date of AD 1603 giving the timber a *terminus post quem* for felling date of AD 1618, consistent with it having been felled in the winter of AD 1639/40.

Ceiling frames

Two of the samples from the ceiling frame in the cellar have been dated. One of these, NHW-B32, has complete sapwood and a last-measured ring date of AD 1599. When inspected under the microscope it is possible to see both the spring and summer growth cells of the final year, which gives the timber represented a felling date of winter AD 1599/1600. The second sample, NHW-B33, has the heartwood/sapwood boundary ring date of AD 1573, giving the timber represented a felling date within the range of AD 1588–1613, consistent with this timber also having been felled in or around the winter of AD 1599/1600.

Four of the samples taken from the ground-floor ceiling frame have been dated. Sample NHW-B24 has complete sapwood and a last-measured ring date of AD 1597. When inspected under the microscope it is possible to see that the final ring on this sample has both the spring and summer growth cells, thus demonstrating that the timber represented was felled in the winter of AD 1597/8. A second sample, NHW-B25, was taken from a timber with complete sapwood but some of the outer rings (an estimated 5–10mm) were lost during the sampling process. Using the average ring width of this sample (1.86mm) this would equate to an estimated 3–6 rings having been lost. With a last-measured ring date of AD 1592, this would give the timber represented a felling date within the range of AD 1595–98, consistent with it also having been felled in the winter of AD 1597/8. Neither of the other two dated ground-floor ceiling beams have the heartwood/sapwood boundary ring and so estimated felling date ranges cannot be calculated for them. However, with last-measured ring dates of AD 1551 (NHW-B23) and AD 1568 (NHW-B28) these would have *terminus post quem* dates for felling of AD 1566 and AD 1583, respectively, making it possible that these were also felled in or around the winter of AD 1597/8.

Sample NHW-B30 taken from a first-floor ceiling has also been dated. This sample has the heartwood/sapwood boundary ring date of AD 1580, giving the timber represented a felling date within the range of AD 1595–1620.

DISCUSSION AND CONCLUSION

The tree-ring dating has successfully dated timbers from the roof and ceiling frames of the cellar, and the ground, and first floor of the main range at this building; the two ground-floor ceiling timbers sampled from the rear range failed to date. The analysis has shown that the ceiling frame in the cellar utilises timber felled in or around the winter of AD 1599/1600 and the ground-floor ceiling frame is constructed from timber likely to have been felled in or around the winter of AD 1597/98. A beam from the first-floor ceiling has a felling date range of AD 1595–1620. At least seven of the roof timbers were felled in AD 1598–1623, whilst at least three timbers, probably four, thought to represent modifications, are somewhat later, dating to the winter of AD 1639/40.

The remaining six dated roof timbers have *terminus post quem* dates for felling in the sixteenth century, which would allow them to have been felled either as part of the earlier felling campaign or with the timbers that are associated with later modifications. However, the overall high level of matching, including a series of *t*-values ranging from 6 to 9, between these and the roof timbers identified as part of the earlier primary felling suggests that these are also primary timbers. This interpretation is supported by the similarity in average ring widths of these six samples to the samples from the earlier felling. Those four from the later felling are generally derived from slower-grown trees. The later timbers are also clearly modifications (in the case of the intermediary rafters), or more easily replaced (purlins), than the principal rafters or braces.

A potential same-tree match was noted between the samples representing the two later purlins (NHW-B11 and NHW-B21), with these matching at a high value of t = 12.8. It can be seen (Table 2), that the highest matches for the site chronology, NHWBSQ01, against the reference chronologies are with sites located most closely to North Walsham, and indeed actually in the town. This is what one would expect were the woodland source is a reasonably local one as was usual in this period.

It is unfortunate that, due to a lack of timbers with extant bark edge, absolute felling dates cannot be given for any of the earlier roof timbers or the first-floor ceiling beam. It can be seen (Table 1; Fig 11) that there is only a ten year difference between the heartwood/sapwood boundary ring dates of these samples and those of the cellar- and ground-floor ceiling samples, a difference which would usually be within acceptable limits, to assume one was dealing with a series of timbers from a single felling episode. As such it is possible that the roof and all ceiling frames are coeval, all utilising timber felled in the last years of the sixteenth century.

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TABLES

Table 1: Details of tree-ring series from 26–27 Market Place, North Walsham, Norfolk

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof (Nos 26 and 27)						
NHW-B01	East principal rafter, truss 1	61	h/s	1523	1583	1583
NHW-B02	West principal rafter, truss 1	49	--	1490	----	1538
NHW-B03	Collar, truss 1	94	04	1495	1584	1588
NHW-B04	East principal rafter, truss 2	NM (34)	--	----	----	----
NHW-B05	West principal rafter, truss 2	67	--	1490	----	1556
NHW-B06	Collar truss 2	NM (17)	--	----	----	----
NHW-B07	East Intermediate rafter, bay 3	106	31C	1534	1608	1639
NHW-B08	East purlin, truss 1-2	59	01	----	----	----
NHW-B09	West purlin, truss 1-2	48	h/s	----	----	----
NHW-B10	West common rafter 1, bay 2	70	h/s	1511	1580	1580
NHW-B11	West purlin, truss 2-intermediate rafter	131	h/s	1479	1609	1609
NHW-B12	East principal rafter, truss 5	NM (14)	--	----	----	----
NHW-B13	West principal rafter, truss 5	54	--	1480	----	1533
NHW-B14	Collar, truss 5	44	h/s	1538	1581	1581
NHW-B15	North brace, truss 5 (east)	54	13	1543	1583	1596
NHW-B16	East principal rafter, truss 6	52	h/s	1533	1584	1584
NHW-B17	West principal rafter, truss 6	76	--	1494	-----	1569
NHW-B18	North brace, truss 6 (west)	50	--	1516	----	1565
NHW-B19	East Intermediate rafter, bay 6	112	--	1492	----	1603
NHW-B20	East purlin, truss 4-5	86	h/s	1499	1584	1584
NHW-B21	West purlin, truss 5-6	131	h/s	1480	1610	1610
NHW-B22	East purlin, truss 6-west gable	59	--	1496	----	1554
Ground-floor ceiling (26 and 27; main range)						
NHW-B23	North-south ceiling beam 1	60	--	1492	----	1551
NHW-B24	North-south ceiling beam 2	128	23C	1470	1574	1597

NHW-B25	North-south ceiling beam 3	106	10	1487	1582	1592
NHW-B28	East-west ceiling beam	82	--	1487	----	1568
Ground-floor ceiling (Nos 26 & 27; rear range)						
NHW-B26	North-south ceiling beam 4	50	--	----	----	----
NHW-B27	North-south ceiling beam 5 (elm)	61	h/s	----	----	----
First-floor ceiling (No 27)						
NHW-B29	Beam 1	NM (12)	--	----	----	----
NHW-B30	Beam 3	105	08	1484	1580	1588
Cellar ceiling (No 27)						
NHW-B31	Beam 1	52	--	----	----	----
NHW-B32	Beam 2	123	16C	1477	1583	1599
NHW-B33	Beam 4	50	h/s	1524	1573	1573

NM = not measured
h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample; last-measured ring is the felling date

Table 2: Results of the cross-matching of site sequence NHWBSQ01 and example reference chronologies when the first ring date is AD 1470 and the last-measured ring date is AD 1639

Site reference	*t* – value	Span of chronology AD	Reference
Marriots Warehouse, Kings Lynn, Norfolk	7.1	1310–1583	Tyers 1999
Manor House, Alford, Lincolnshire	7.0	1500–1668	Arnold *et al* 2003
19 High Street, Debenham, Suffolk	6.9	1497–1600	Miles *et al* 2009
The Shambles, North Walsham, Norfolk	6.7	1463–1600	Arnold *et al* 2022
101 Meeting Street, Quorn, Leicestershire	6.4	1489–1658	Arnold *et al* 2010
Woolsthorpe Manor, Grantham, Lincolnshire	6.4	1506–1649	Arnold and Howard 2018 unpubl
Holy Cross Church bellframe, Epperstone Church, Nottinghamshire	6.2	1477–1647	Arnold *et al* 2016
Manor House, Long Clawson, Leicestershire	6.1	1483–1602	Howard *et al* 1991
Church Farm House, Ockbrook, Derbyshire	6.1	1491–1631	Arnold and Howard 2009
Weston Hall, Weston-upon-Trent, Derbyshire	6.0	1480–1628	Arnold *et al* 2020

Table 3: Results of the cross-matching of sample NHW-B33 and example reference chronologies when the first ring date is AD 1524 and the last-measured ring date is AD 1573

Site reference	*t* – value	Span of chronology AD	Reference
Holy Cross Church bellframe, Epperstone Church, Nottinghamshire	6.9	1477–1647	Arnold *et al* 2016
61 Long Acre, Bingham, Nottinghamshire	6.0	1478–1617	Arnold *et al* 2008
Church of St Andrew (bellframe), Welham, Leicestershire	5.9	1443–1633	Arnold *et al* 2005
Askham Church (bellframe), Nottinghamshire	5.6	1407–1588	Arnold *et al* 2016
Bingham, Nottinghamshire	5.6	1445–1752	Arnold and Howard 2014 unpubl
Melbourne Church, Derbyshire	5.4	1509–1638	Laxton *et al* 1984
Ash Farm, Etwall, Derbyshire	5.4	1442–1594	Arnold and Howard 2013 unpubl
Oxnead Hall, Oxnead, Norfolk	5.3	1402–1566	Tyers 2019
Powcher's Hall (east roof), Ely Cambridgeshire	5.2	1457–1609	Arnold *et al* 2004
11a Market Place, Bingham, Nottinghamshire	5.2	1508–1642	Arnold and Howard 2014 unpubl

FIGURES

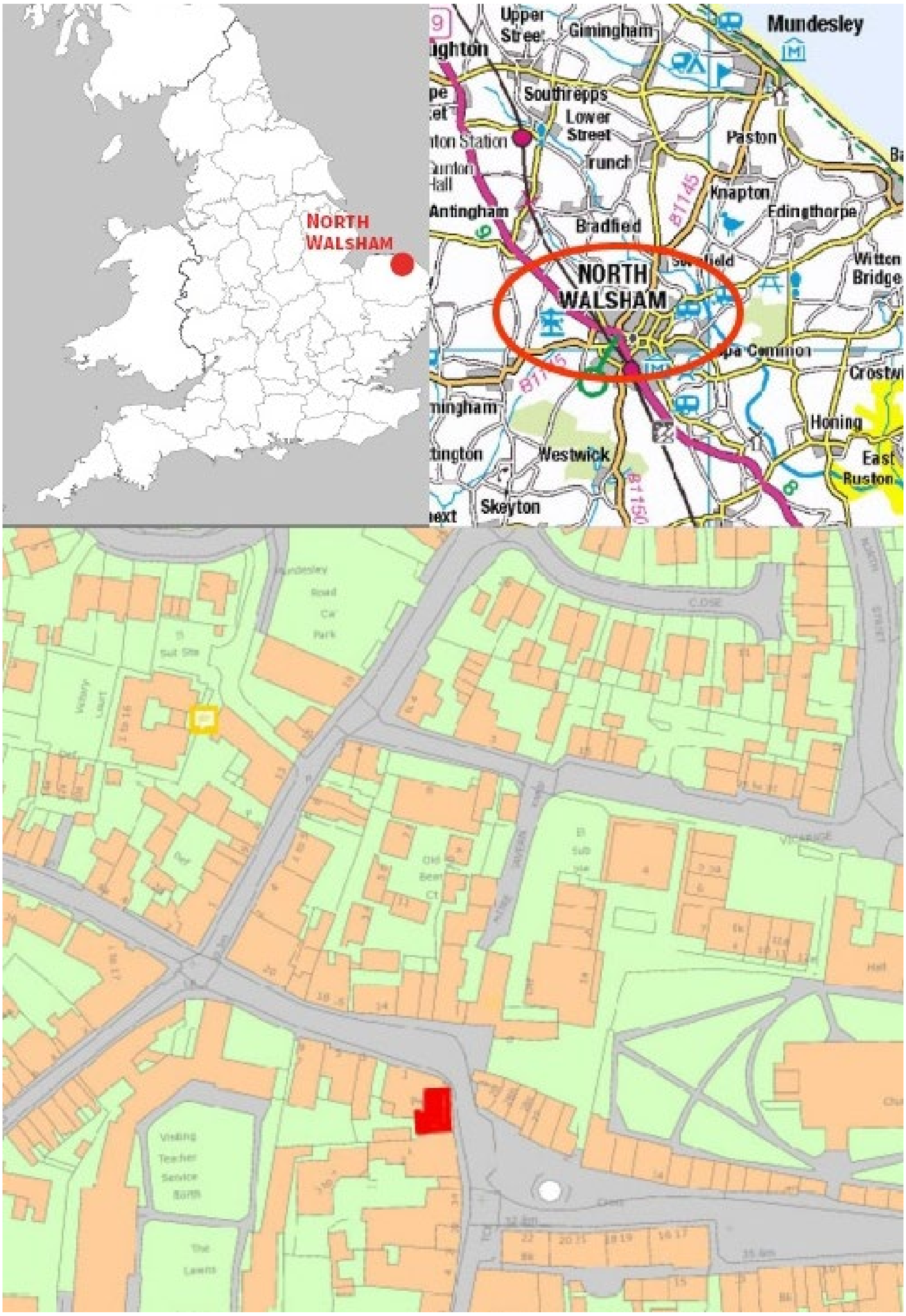

Figure 1: Map to show the location of 26-27 Market Place in North Walsham, marked in red. Scale: top right 1:120000, bottom 1:1250. © Crown Copyright and database right 2020. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: Roof (No 26), truss 5 and one of the intermediary collars in the foreground, photograph taken from the south (Alison Arnold)

Figure 3: Roof (No 27), truss 2 in foreground, photograph taken from the south (Alison Arnold)

Figure 4: Ground-floor ceiling (No 27), photograph taken from the south (Alison Arnold)

Figure 5: Two of the first-floor ceiling beams (No 27), photograph taken from the south-west (Alison Arnold)


Figure 6: Ground-floor ceiling beam (No 27), the chamfered beams can be seen in the background, photograph taken from the west (Alison Arnold)


Figure 7: Cellar ceiling (No 26), photograph taken from the north-west (Alison Arnold)

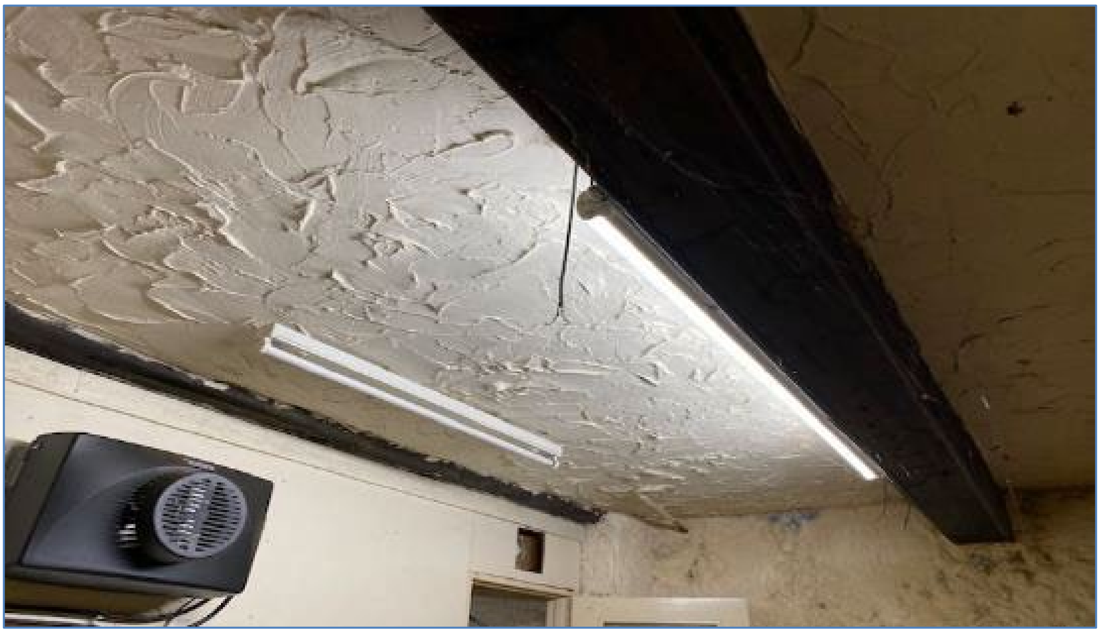

Figure 8: Cellar ceiling (No 27), photograph taken from the south-west (Alison Arnold)

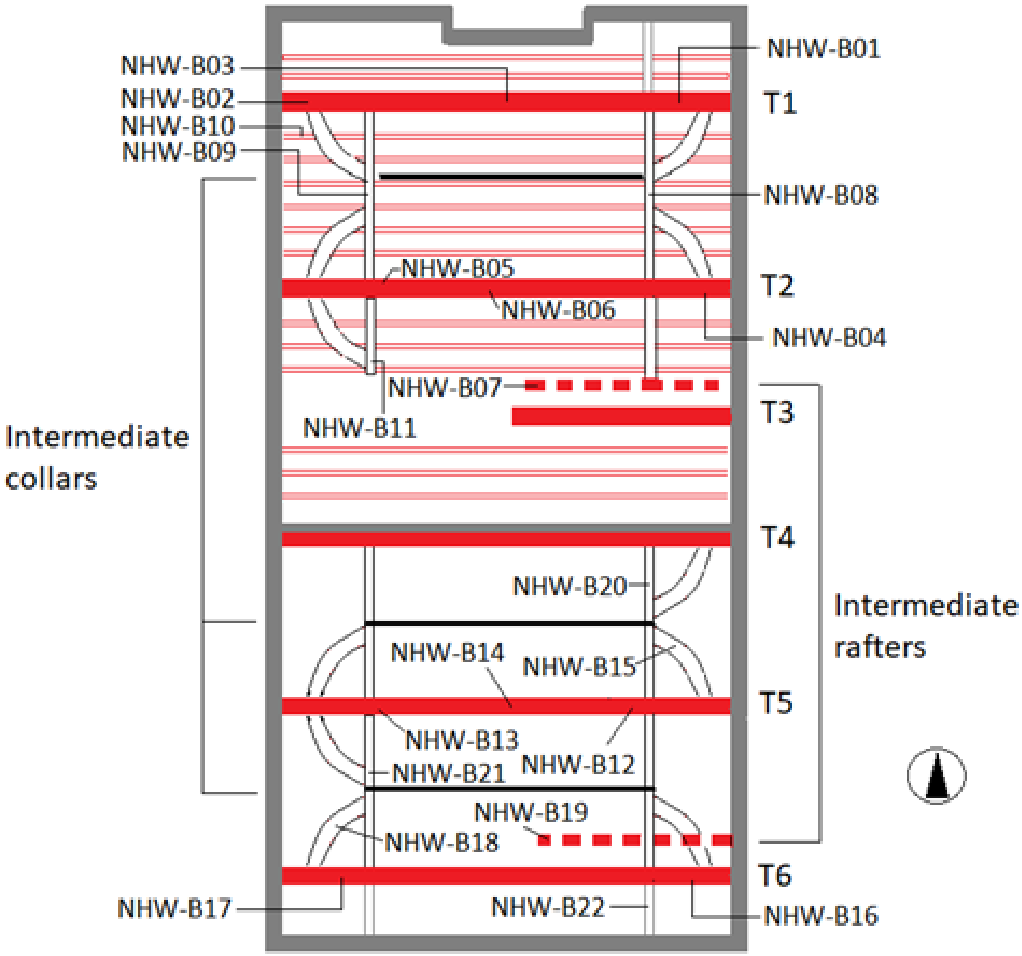

Figure 9: Sketch at roof level, showing sampled timbers

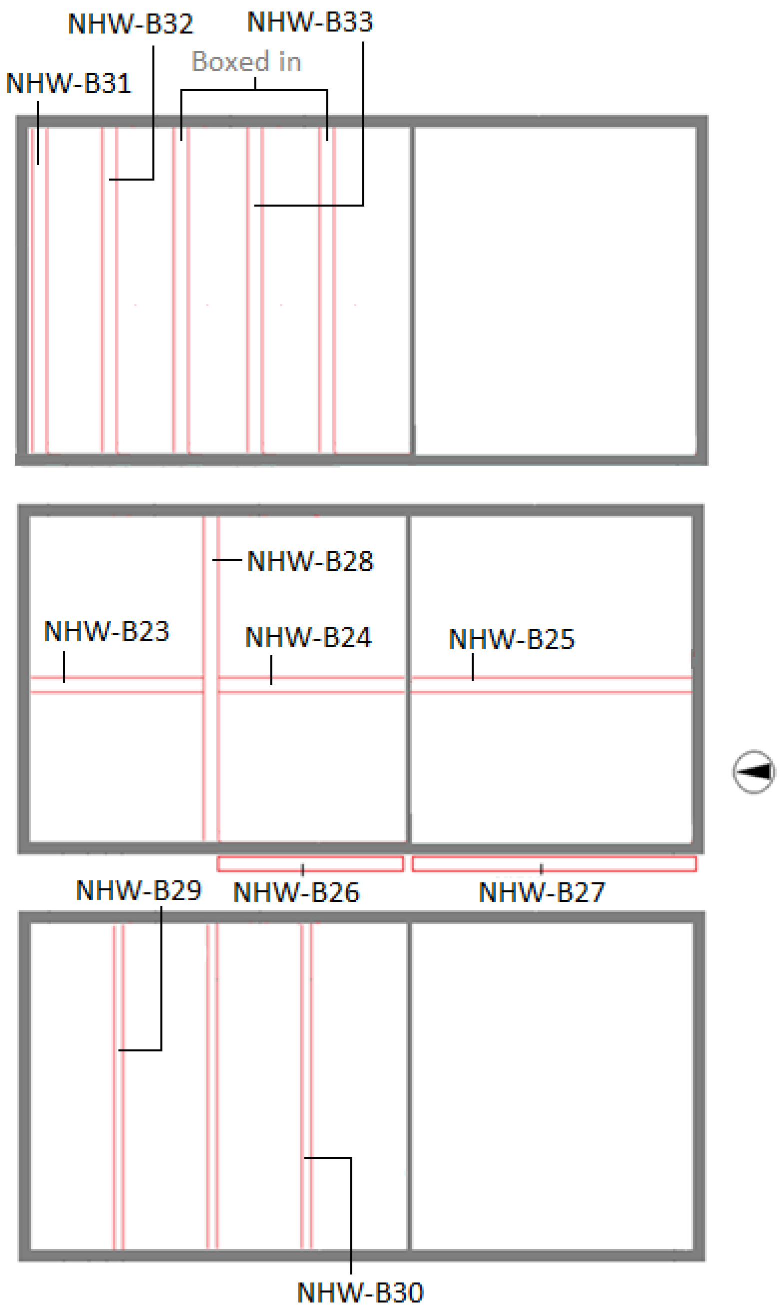

Figure 10: Sketch plans at cellar (top), ground- (middle), and first-floor level (bottom), showing sampled timbers

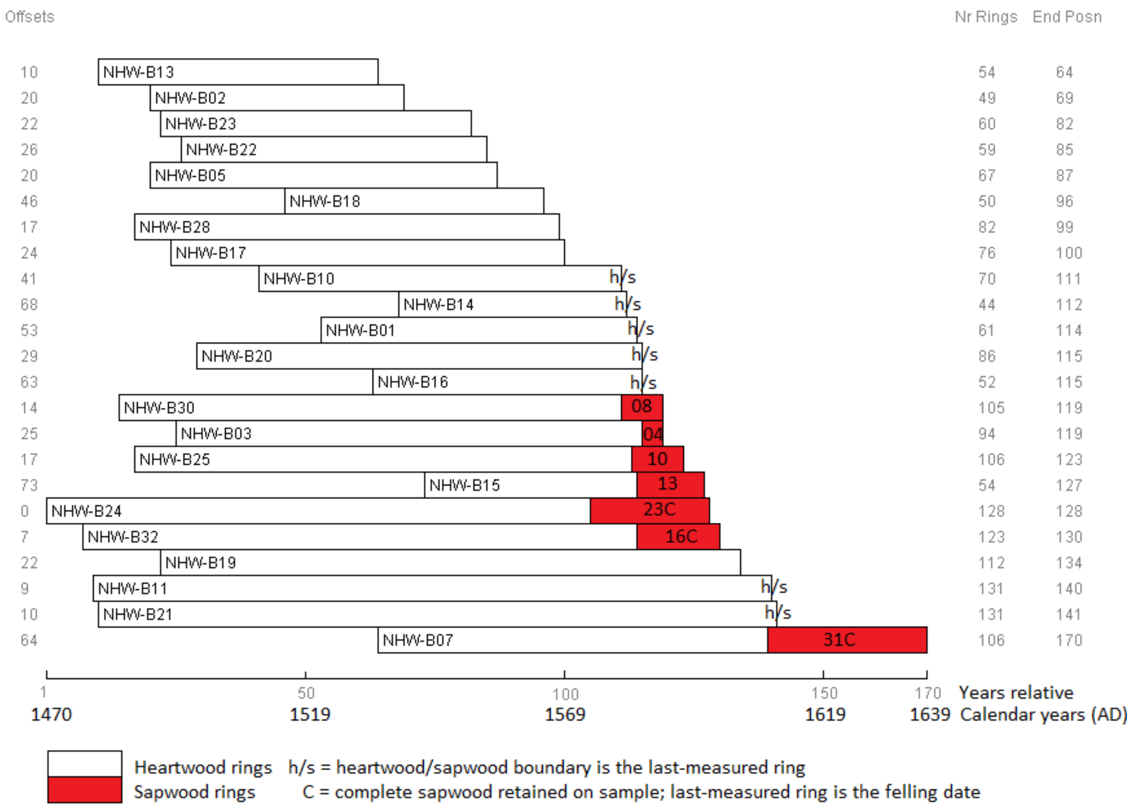

Figure 11: Bar diagram of samples in site sequence NHWASQ01

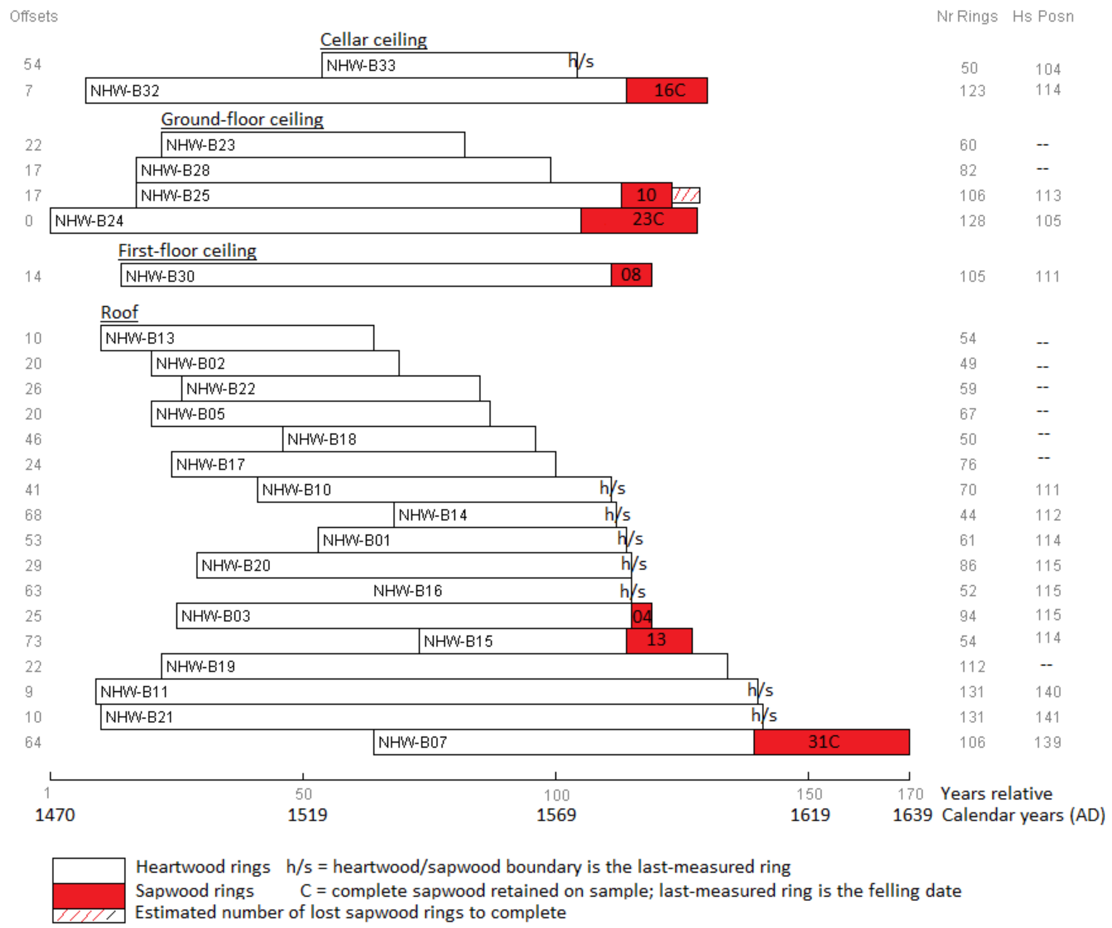

Figure 12: Bar diagram of all dated samples, sorted by area

DATA OF MEASURED SAMPLES

NHW-B01A 61
205 164 83 203 144 100 91 82 109 71 250 359 459 260 179 192 267 236 253 195
174 178 183 143 180 189 245 146 243 210 229 143 256 164 128 197 146 163 173 165
161 178 117 187 151 169 159 161 206 160 94 135 147 105 132 139 158 167 86 127
196
NHW-B01B 61
204 159 98 203 142 97 88 89 106 74 248 329 464 259 171 191 273 236 251 194
169 183 179 140 173 198 245 153 241 212 224 143 244 169 130 199 146 161 170 172
157 181 114 189 151 165 158 168 199 157 87 134 147 102 135 145 157 156 93 118
181
NHW-B02A 49
439 311 231 589 777 446 617 313 300 260 381 314 398 376 432 271 468 272 266 309
213 270 221 466 433 315 293 225 416 255 356 329 224 300 255 110 226 243 256 177
118 220 148 218 261 394 308 212 243
NHW-B02B 49
408 301 226 592 760 431 574 304 258 267 375 317 379 369 425 278 468 271 253 300
203 273 235 457 411 313 288 223 424 258 355 331 236 309 256 110 225 240 241 181
115 221 143 211 246 393 303 207 242
NHW-B03A 94
430 450 274 272 270 273 275 320 250 357 116 167 104 82 103 104 90 105 164 142
132 126 108 148 126 81 76 108 80 105 83 125 139 130 89 54 107 118 147 90
98 87 103 102 118 200 138 91 102 140 162 107 77 78 106 56 84 64 79 91
164 108 96 127 97 109 91 130 120 105 86 81 112 92 88 86 93 59 48 51
78 41 39 46 52 61 38 34 49 74 66 80 86 70
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133 117 113 144 129 83 70 106 76 108 89 125 132 134 84 59 103 115 147 90
105 92 118 100 106 208 137 89 100 143 159 105 79 76 105 53 77 63 80 86
171 103 98 123 96 107 91 126 118 111 83 80 118 88 90 85 97 64 46 52
76 36 42 49 51 57 39 42 47 68 68 77 83 88
NHW-B05A 67
366 164 102 148 270 257 202 98 94 75 94 95 80 113 214 199 162 152 139 181
119 127 110 103 100 123 136 119 232 124 169 185 147 146 88 74 143 173 188 110
84 95 104 148 198 240 193 130 178 301 324 201 267 252 298 390 303 297 346 533
375 357 363 229 88 131 101
NHW-B05B 67
387 153 95 159 284 257 209 107 101 77 83 94 80 120 201 186 176 150 129 166
121 128 100 95 90 138 132 125 239 121 158 205 139 144 105 70 158 181 160 107
85 93 95 150 211 232 191 123 187 299 307 202 272 247 281 389 305 320 367 459
402 367 334 253 100 120 96
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157 140 181 166 146 193 158 151 159 164 191 217 154 171 149 188 156 140 148 188
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78 91 108 117 178 350 410 365 286 195 164 140 204 139 183 146 115 114 82 127
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NHW-B09B 48
331 406 304 240 145 204 286 403 338 241 132 131 143 100 130 60 48 64 62 74
73 96 117 120 166 339 398 362 292 183 166 138 197 132 170 149 119 103 86 125
113 110 133 163 131 145 187 160
NHW-B10A 70
207 168 218 205 200 240 185 235 169 137 168 147 212 190 206 184 242 225 123 83
177 177 78 154 123 173 173 153 233 212 249 172 177 255 282 186 203 228 266 221
216 134 158 131 171 210 202 146 172 144 168 176 129 129 106 159 160 148 191 174
142 85 76 132 117 60 85 117 126 106
NHW-B10B 70
208 171 217 203 196 240 182 237 166 135 168 154 210 192 207 185 237 224 126 92
170 168 83 149 132 177 179 157 236 205 258 178 186 257 282 180 215 232 257 210
206 139 149 123 170 201 202 144 182 133 163 146 131 130 106 167 159 157 194 181
135 88 74 128 114 58 84 128 113 84
NHW-B11A 131
293 278 159 170 209 174 217 186 170 95 107 137 101 94 95 165 140 143 59 64
46 37 54 58 53 51 35 44 36 39 36 35 38 43 36 25 29 44 48 74
41 45 38 54 43 58 37 46 49 50 49 28 78 92 55 105 81 86 71 48
84 54 66 70 77 86 91 70 78 82 96 83 61 54 63 67 80 108 75 65
91 107 115 100 77 81 73 71 68 89 110 106 102 89 106 96 77 97 71 56
63 60 50 71 85 103 117 107 110 75 107 81 107 100 131 137 115 91 75 95
76 73 33 30 37 41 44 58 62 72 76
NHW-B11B 131
273 261 156 167 214 169 226 181 155 82 102 147 92 103 98 157 131 143 56 66
45 31 59 57 51 59 37 34 30 37 44 38 32 39 31 27 25 44 42 77
41 44 40 53 45 58 34 53 45 51 45 28 76 96 61 104 79 87 71 50
82 54 69 66 89 77 85 75 76 85 93 89 63 50 70 63 79 105 80 64
90 104 113 96 79 82 78 70 70 92 107 102 106 91 107 89 82 92 71 54
57 60 52 73 78 102 114 105 106 77 101 79 105 99 120 142 120 87 84 93
72 72 36 31 36 34 45 56 64 75 68
NHW-B13A 54
473 254 415 501 338 381 313 357 184 175 198 161 106 265 502 436 493 321 271 242
251 278 404 401 358 232 299 200 202 272 156 214 176 214 248 195 209 183 292 199
222 251 202 229 184 110 223 215 169 122 95 154 118 192
NHW-B13B 54
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265 293 393 394 371 230 301 200 203 267 158 215 171 208 239 196 205 176 295 196
229 259 220 222 191 108 223 194 174 122 100 163 126 207
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449 719 769 643 198 320 483 661 279 322 391 499 284 361 330 393 321 547 313 179
214 228 403 346 332 287 296 203 273 209 140 149 135 128 131 62 69 90 69 81
94 69 118 109
NHW-B14B 44
457 720 772 669 244 342 500 659 285 341 407 489 274 371 336 371 309 551 296 176
209 210 424 339 335 295 282 215 258 215 155 151 137 135 124 73 65 99 68 68
98 67 97 108
NHW-B15A 54
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77 88 63 74 85 67 83 72 84 61 51 58 65 32 43 62 70 77 58 61

80 92 73 80 74 72 83 67 89 78 93 110 129 103
NHW-B15A 54
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78 87 57 76 87 76 80 77 78 64 42 61 69 51 39 64 71 83 57 63
74 95 77 81 75 71 90 67 97 80 88 112 107 104
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171 105 158 169 124 233 218 228 196 200 184 223 130 242 144 117 177 144 187 178
110 146 119 100 141 102 107 151 94 164 241 187
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162 106 157 169 123 235 216 234 195 201 184 201 133 236 152 118 172 145 189 177
112 143 119 96 144 101 107 153 95 162 239 184
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131 134 128 147 234 152 152 181 169 173 107 101 144 149 159 67 51 40 46 71
128 102 95 67 123 211 206 182 114 106 156 170 185 227 245 276 168 222 188 154
120 220 197 216 252 242 350 290 278 241 275 215 381 315 281 218
NHW-B17B 76
358 384 415 219 151 210 208 235 258 253 192 136 151 155 122 159 129 136 120 138
130 129 130 147 239 154 145 173 178 179 123 94 142 137 154 66 44 51 51 68
124 108 107 90 134 192 210 179 117 105 157 168 187 225 248 280 172 214 190 153
123 240 195 218 245 248 357 292 283 252 279 218 380 308 298 214
NHW-B18A 50
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285 185 198 276 300 271 185 241 307 227 145 115 130 225 181 150 117 153 181 164
120 81 94 74 63 58 56 68 86 82
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125 137 95 112 139 104 134 88 95 60 87 87 92 71 70 76 77 56 50 81
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62 84 99 150 147 104 94 115 128 132 140 133 112 122 149 167 189 173 118 112
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130 130 106 114 152 107 150 94 94 55 90 84 93 74 72 82 73 62 39 85
97 79 108 101 115 117 95 129 97 68 104 125 159 128 106 105 144 125 102 88
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184 226 229 214 201 198 140 225 149 123 136 194 253 240 159 203 184 106 107 123
191 211 125 180 258 207
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117 186 174 111 152 152 74 175 170 113 120 110 150 106 276 254 345 301 188 238
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243 213 209 233 202 202 217 333 268 276 253 267 329 343 296 251 292 312 259 202
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253 238 326 301 225 182 98 124 290 291 219 176 132 135 219 217 261 250 146 174
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95 150 150 168 202 231 228 239 190 208 295 184
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130 223 162 243 111 191 406 266 286 332 219 347 222 182 203 153 302 356 322
NHW-B32B 51
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236 186 214 142 319 388 410 199 244 197 174
NHW-B33A 50
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NHW-B33B 50
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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	

Bar Diagram

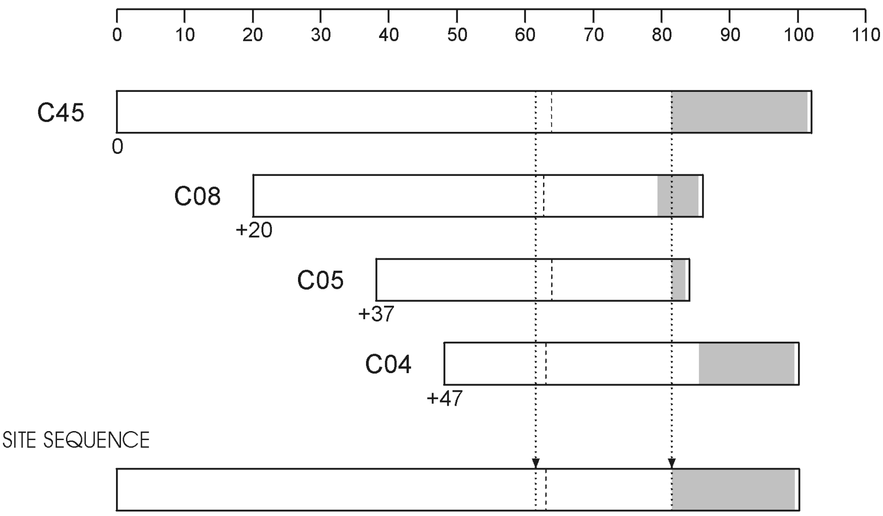


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

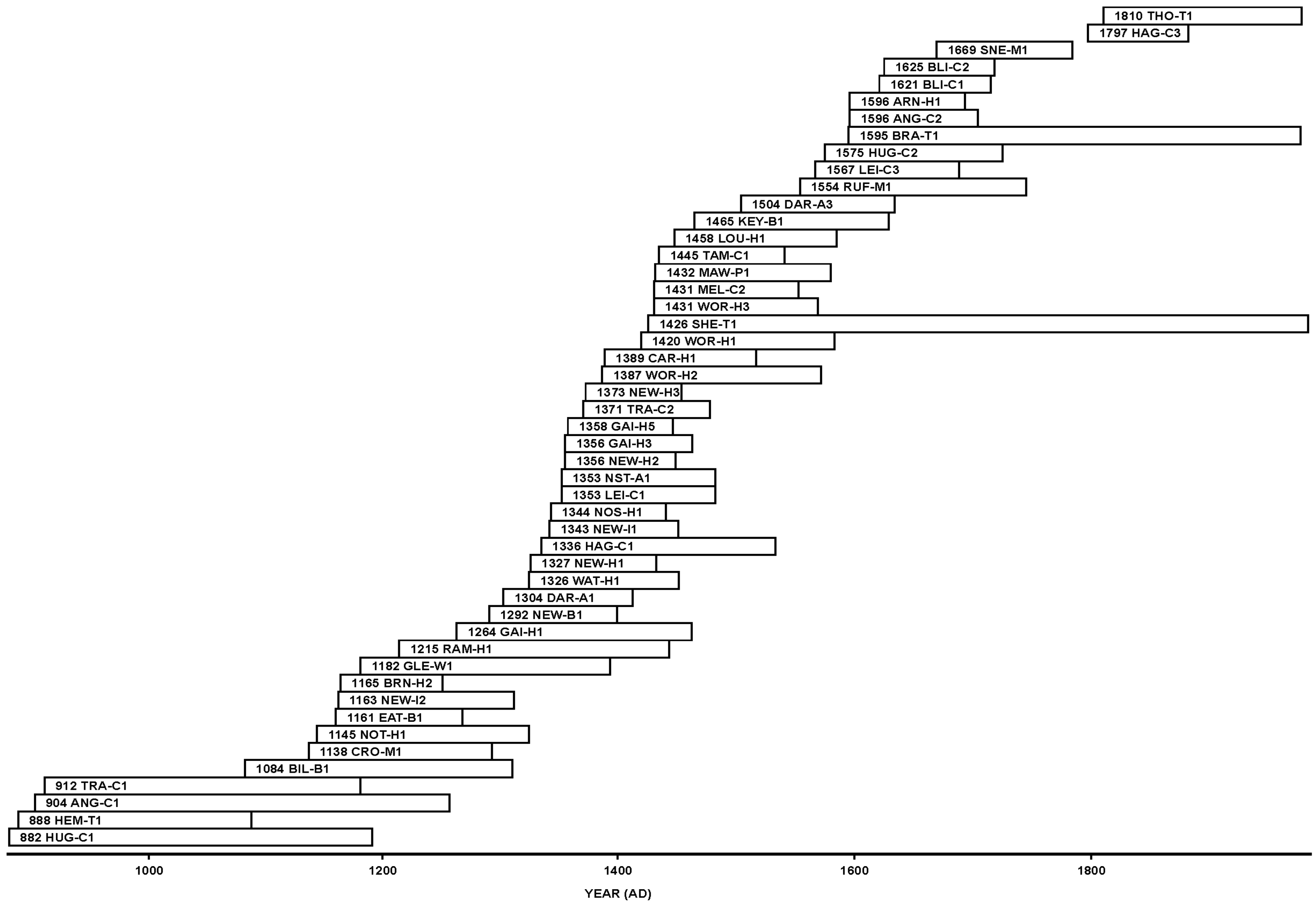
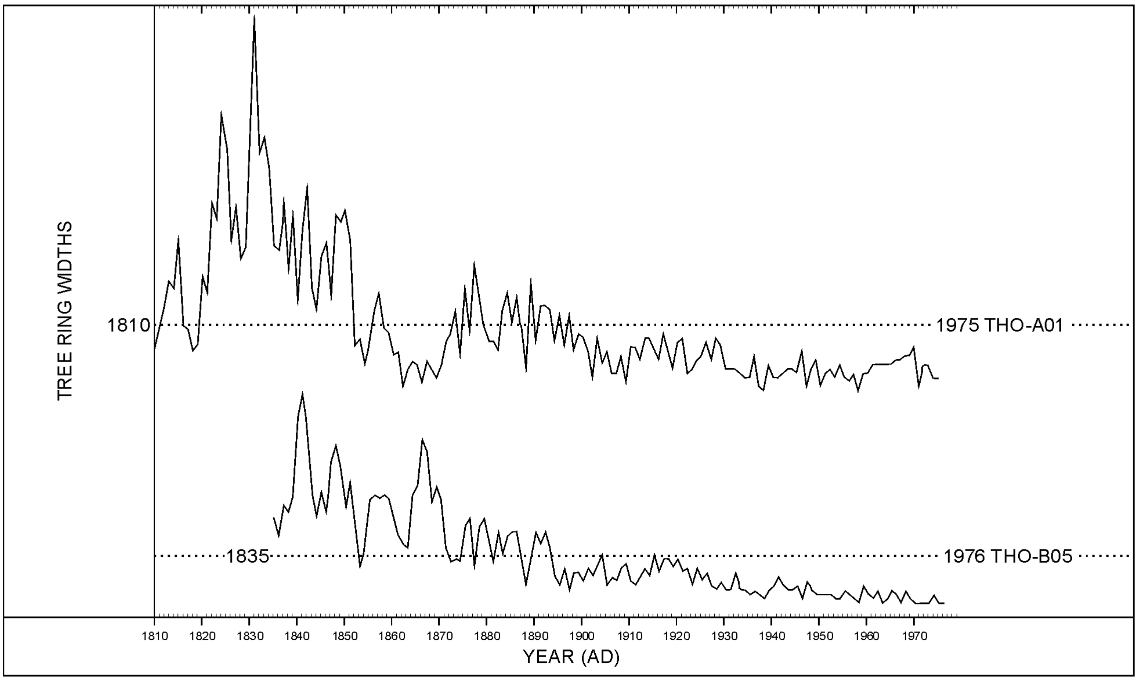


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

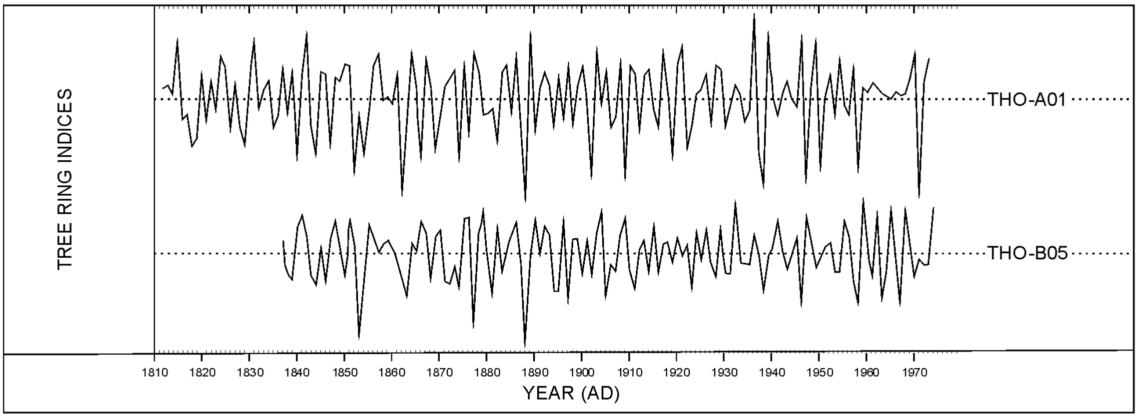


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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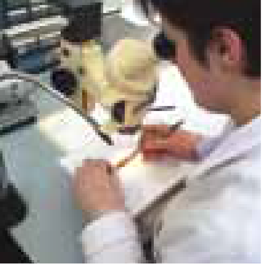
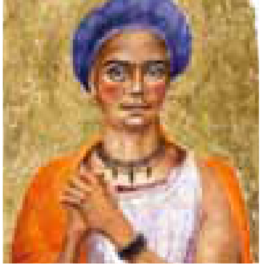


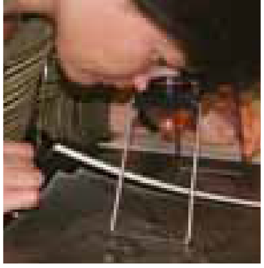


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