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Scientific Dating

The Bobbin Mill, Stott Park, Finsthwaite, Cumbria

Tree-ring Analysis of Timbers

Alison Arnold and Robert Howard

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THE BOBBIN MILL, STOTT PARK, FINSTHWAITE, CUMBRIA

TREE-RING ANALYSIS OF OAK AND PINE TIMBERS

Alison Arnold and Robert Howard

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SUMMARY

Pine timbers were sampled in the roof of the New Lathe Shed, the ground-floor ceiling of the original mill, and posts also on the ground-floor of the original mill. Four oak timbers were sampled in various locations within the complex.

Analysis resulted in the dating of a single site sequence, STTPSQ01, which comprises eight pine samples from the New Lathe Shed roof and spans the period AD 1539–1817. The tree-ring dating suggests construction of this part of the mill after AD 1817 and before it appears on an Ordnance Survey map of AD 1869.

No other timbers were successfully dated.

CONTRIBUTORS

Alison Arnold and Robert Howard

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ARCHIVE LOCATION

Lake District National Park Historic Environment Record
Lake District National Park Authority
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Oxenholme Road
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DATE OF INVESTIGATION

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INTRODUCTION

Stott Park bobbin mill, mill ponds and smithy, situated just to the north-east of Finsthwaite near Newby Bridge in Cumbria (Figs 1 and 2) form a Scheduled Ancient Monument. The bobbin mill is probably the last remaining of the Lakeland type mills built specifically for bobbin making. It comprises a multi-phase complex of buildings, streams, ponds, machinery, and furniture and fittings. It is divided into two separate areas: the larger area contains the bobbin mill, its associated buildings, a mill pond, an outlet stream, and the smithy, while the smaller area contains a mill pond and outlet stream (Fig 3). Further information can be found in the guidebook (White 2015).

Old Mill

In its original form the mill is thought to have consisted of a two-storey, rectangular stone structure of five bays with a chimney stack at either end (Fig 4). The exposed ground-floor ceiling consists of four main beams and associated common joists (Fig 5). A series of posts have been inserted at ground-floor level, presumably to help support the first floor (Fig 6). Documentary sources record the mill as 'newly erected' in 1835 but it is unclear as to whether there was an earlier building on the site.

Waterwheel pit

The north bay of the original mill was later partitioned off to create space for an enclosed waterwheel and deep wheel pit. The deep wheel pit has four platforms; at the top level there is a structure consisting of cross-beams and bearers (Fig 7). By 1858 the water wheel had been removed and replaced with a water turbine. This modification may have required some reconstruction of the partition wall.

Southern extension

A two-storey extension was added to the south gable wall of the original building (Fig 8). This extension (and the original building) are both shown on the Ordnance Survey map of AD 1846–8.

New Lathe Shed

This structure was built along the west side of the original mill building. The roof over this part of the building consists of four trusses of tiebeam, principal rafters, king post, struts and a single row of purlins (Fig 9). It appears on the Ordnance Survey map of AD 1869.

SAMPLING

Sampling was requested by Kevin Booth (English Heritage Senior Curator) and Paul Pattison (English Heritage Senior Properties Historian) to attempt to determine with more precision, the dates of certain areas and hence elucidate the chronological development of the site.

Following an extensive assessment across the entire site it was clear that the dendrochronological potential was relatively limited due to a combination of timbers having too few rings for analysis, too few timbers being associated with certain phases or sub-phases, and the overall complexity of development of this series of associated structures. Hence, following detailed discussions sampling was restricted to the roof of the New Lathe Shed, timbers at ground-floor level in the Old Mill, and the few extant oak timbers. Thus, a total of 28 samples (24 pine and four oak) were taken. Each sample was given the code STT-P (for Stott Park) and numbered 01–28. Seventeen samples (STT-P01–17) were taken from the roof of the New Lathe Shed, seven from posts and the ground-floor ceiling of the Old Mill (STT-P18–24), three oak lintels (STT-P25–6 and STT-P28), and the final sample was taken from an oak timber in a structure within the waterwheel pit (STT-P27). The location of samples was noted at the time of sampling and has been marked on Figures 10–16. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Pine samples

Five of the pine samples, one from the New Lathe Shed roof, two ceiling beams, and two posts, were found to have too few rings for secure dating and so were discarded prior to analysis. The remaining 19 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 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in 10 samples matching to form two groups.

Firstly, eight samples matched each other and were combined at the relevant offset positions to form STTPSQ01, a site sequence of 279 rings (Fig 17). This site sequence was compared against a series of relevant reference pine chronologies where it was found to span the period AD 1539–1817. The evidence for this dating is given in Table 2.

Two further samples matched each other and were again combined at the relevant offset positions to form STTPSQ02, a site sequence of 138 rings (Fig 18). Attempts to date this site sequence and the remaining ungrouped pine samples were unsuccessful. As both of the samples in STTPSQ02 have a series of extremely narrow rings towards the beginning of their sequences the first 40 rings were removed from STTPSQ02 to enable this edited site sequence being compared against the reference chronologies in case these narrow rings were interfering with the climatic signal and hence reducing the chances of successful dating. Unfortunately, there was still no secure match against the reference chronologies and this site sequence remains undated.

Oak samples

Two of the oak samples (STT-P25 and STT-P28) were found to have too few rings for secure dating and so were discarded prior to analysis. The remaining two samples were prepared and measured following the same protocol as with the pine samples. The data of these measurements are also given at the end of the report.

These two samples were then compared against each other but did not match. Attempts to date them individually by comparing them against reference chronologies for oak were unsuccessful and both remain undated.

INTERPRETATION

Tree-ring dating has resulted in the successful dating of eight of the samples taken from the New Lathe Shed roof. Due to the extreme variation in sapwood numbers seen within pine trees it is not possible to calculate an estimated felling date range in the same way as one is able to with oak samples. However, it can be seen that the heartwood/sapwood boundary ring dates of the five samples which retain this are broadly contemporary (Fig 17). Therefore, it is not unreasonable to suggest that all of these timbers (and most probably the three without the heartwood/sapwood boundary) were felled at the same time. Sample STT-P11 has the latest measured ring date of AD 1817 giving the timber represented (and most probably the other seven) a felling date of after AD 1817. Taking into account the number of sapwood rings present, the age of the trees, and the source of the trees, it appears likely that these timbers were felled at some point during the nineteenth century and probably not much later than the mid-nineteenth century.

DISCUSSION

Prior to the tree-ring analysis being undertaken the dating of the various parts of Stott Park Bobbin Mill was based upon public records, archived materials and Ordnance Survey maps. Unfortunately, dendrochronology has not been able to produce any dating evidence for the original mill, the southern extension or the structure in the waterwheel pit and, hence, has been unable to elucidate the chronological development of the complex. However, it has demonstrated that the roof of the New Lathe Shed incorporates timber felled after AD 1817 and probably not much later than the mid-nineteenth century. It is known that this part of the mill appears on Ordnance Survey maps of AD 1869 and, therefore, it appears that the extant roof is the original roof and that construction must have occurred after AD 1817 and before AD 1869.

The intra-site cross-matching of samples in site sequence STTPSQ01 is generally good (Table 3). If the samples were from oak timbers then a number of the *t*-values are of a level to potentially represent same-tree matches. However, when analysing pine samples one looks for substantially higher *t*-values between samples before suggesting the timbers represented are derived from the same tree. Within this group of samples only STT-P08 and STT-P09 match each other at a value (*t*=19.7) to suggest that they were potentially cut from the same tree. The overall level of intra-site cross-matching suggests that the trees were probably sourced from a single, albeit potentially extensive, area of forest.

The reference chronologies against which site sequence STTPSQ01 matches most highly are those from central Sweden as well as those from other imported assemblages in England that are thought to be of Scandinavian origin and, hence, it is likely that the timbers in the New Lathe Shed roof were imported from Scandinavia, possibly Sweden, and are likely to be Scots pine (*Pinus sylvestris* L.).

With only eight of the 21 measured samples being successfully dated, the results from this site are somewhat disappointing. Eight of the 16 measured New Lathe Shed roof samples group and date, two group but are not dated and a further six are ungrouped. This might suggest that the timber utilised within this structure was from multiple woodland sources. Alternatively, the narrow bands of growth rings noted in samples STT-P03 and STT-P07 (above) and also seen in several of the other samples may be due to non-climatic influences and, as such, interfere with their intra-site grouping and matching with the reference chronologies. The fact that there is no grouping between samples of the ceiling beams and posts of the original mill suggests that this is a disparate group of timbers of different dates and/or sources.

Only two of the oak samples proved to be suitable for measurement; these represent two separate areas likely to be of different dates. Therefore, it is unsurprising that the two samples do not group and cannot be individually dated. It is significantly more difficult to date single samples, especially when, as in the case of STT-P26, they only have 52 rings. Added to this, these timbers are likely to be nineteenth century in date, a period not especially well represented within the reference databank.

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TABLES

Table 1: Details of tree-ring samples taken from the Bobbin Mill, Stott Park, Cumbria

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
New Lathe Shed - roof						
STT-P01	East principal, truss 1	89	--	----	----	----
STT-P02	West principal rafter, truss 1	78	08	----	----	----
STT-P03	King post, truss 1	138	--	----	----	----
STT-P04	West strut, truss 1	69	--	1675	----	1743
STT-P05	East principal rafter, truss 2	217	07	1578	1787	1794
STT-P06	West principal rafter, truss 2	55	10	----	----	----
STT-P07	King post, truss 2	133	--	----	---	---
STT-P08	East strut, truss 2	200	--	1539	----	1738
STT-P09	West strut, truss 2	233	04	1540	1768	1772
STT-P10	East principal rafter, truss 3	144	36	1673	1780	1816
STT-P11	West principal rafter, truss 3	151	37	1667	1780	1817
STT-P12	Tiebeam, truss 3	182	57	----	----	----
STT-P13	East strut, truss 3	89	03	1689	1774	1777
STT-P14	West strut, truss 3	103	--	1662	----	1764
STT-P15	West principal rafter, truss 4	NM	--	----	----	----
STT-P16	Tiebeam, truss 4	121	13	----	----	----
STT-P17	King post, truss 4	186	--	----	----	----
Old mill - ground floor timbers						
STT-P18	Ceiling beam 1	71	50	----	----	----
STT-P19	Ceiling beam 2	NM	--	----	----	----
STT-P20	Ceiling beam 3	64	48	----	----	----
STT-P21	Ceiling beam 4	NM	--	----	----	----
STT-P22	Post 1	NM	--	----	----	----
STT-P23	Post 2	120	--	----	----	----
STT-P24	Post 3	NM	--	----	----	----

Oak timbers						
STT-P25	Lintel in north gable wall	NM	--	----	----	----
STT-P26	Waterwheel pit - structure	52	--	----	----	----
STT-P27	Lintel between old mill & extension (east)	147	--	----	----	----
STT-P28	Lintel between old mill & extension (west)	NM	--	---	----	----

*NM = not measured

Table 2: Details of cross-matching of site sequence STTPSQ01 and the reference chronologies when the first-ring date is AD 1539 and the last-measured ring date is AD 1817

Reference chronology	t-value	Span of chronology (AD)	Reference
Sweden - Harjedalen	11.4	1349–1788	Bartholin *pers comm*
Sweden - Dalarna	9.8	1001–1852	Bartholin *pers comm*
Sweden - Jaemtland	8.7	1305–1827	Bartholin *pers comm*
Sweden - Helsingland	6.3	1001–1861	Bartholin *pers comm*
Norway - Grunskala Flesberg	6.3	1383–1954	Eidem 1959
Norway - south west region	5.9	765–1996	Thun *pers comm*
Norway - south east region	5.3	871–1986	Thun *pers comm*
Durham Cathedral Librarians Loft, Durham (imported)	8.6	1585–1900	Arnold *et al* 2007
Berwick upon Tweed, Northumberland (imported)	7.5	1486–1762	Arnold *et al* 2015
Whitefriars, London City (imported)	6.5	1651–1779	Tyers 2004

Table 3: Matrix to show the level of t-values seen between the eight cross-matched and dated pine samples. The possible same-tree match is highlighted in bold; – indicates either no overlap or a not statistically significant t-value between samples

	STT-P04	STT-P05	STT-P08	STT-P09	STT-P10	STT-P11	STT-P13	STT-P14
STT-P04	*							
STT-P05	3.5	*						
STT-P08	7.6	3.6	*					
STT-P09	10.0	5.2	**19.7**	*				
STT-P10	--	3.2	--	4.3	*			
STT-P11	--	3.6	--	5.4	10.2	*		
STT-P13	7.9		7.8	9.7	4.0	3.7	*	
STT-P14	9.9	5.8	11.7	11.2	--	--	9.8	*

FIGURES

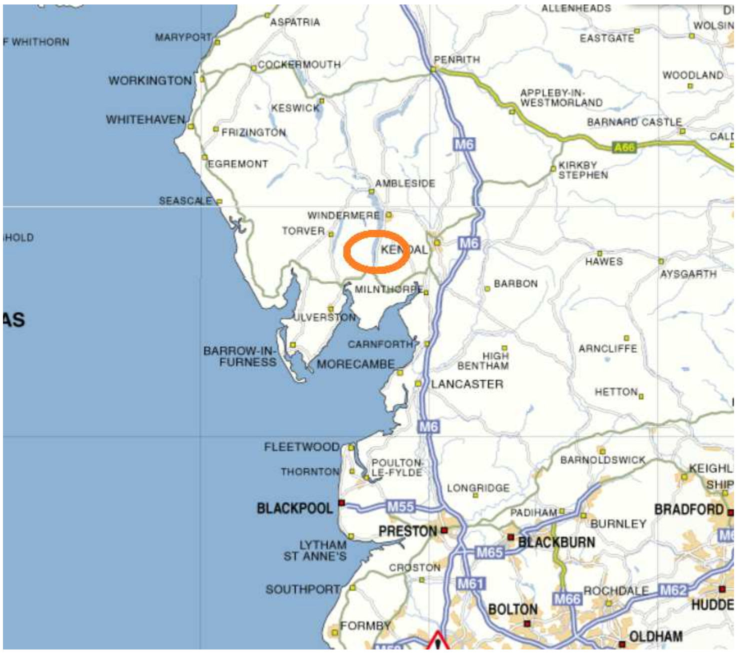


Figure 1: Map to show the general location of Stott Park Bobbin Mill, circled, © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence 100024900

Figure 2: Map to show the location of Stott Park Bobbin Mill, in red. © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

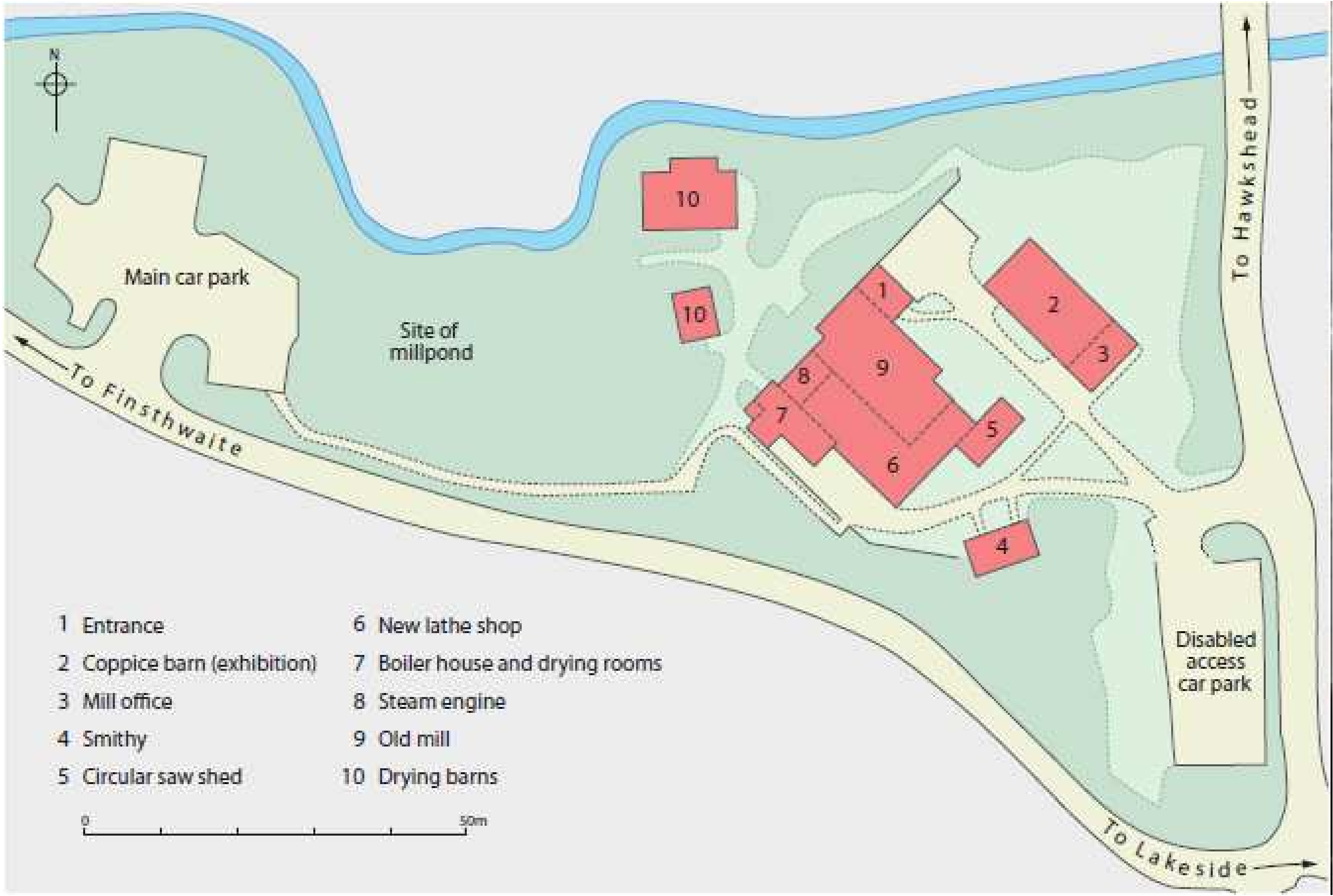


Figure 3: Stott Park Bobbin Mill, site map (White 2015)

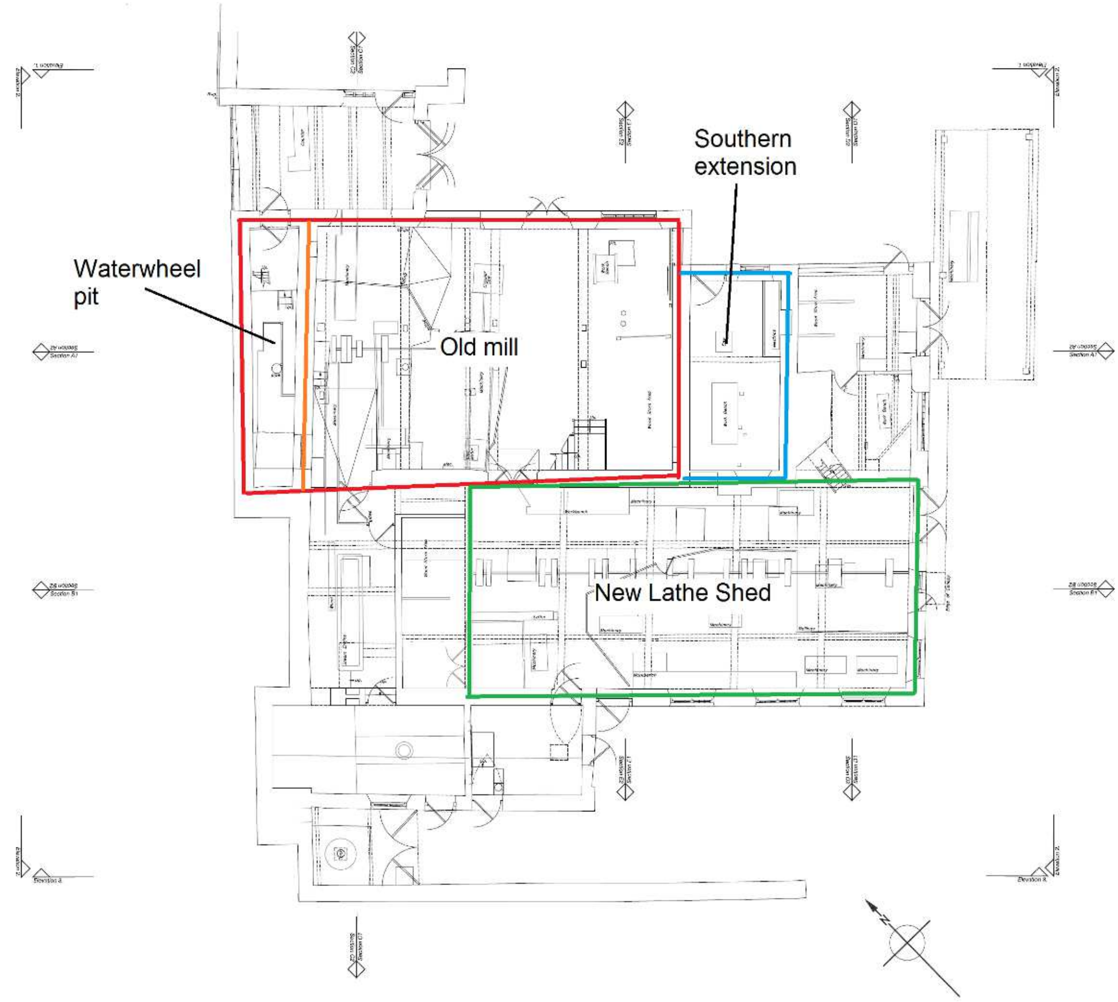


Figure 4: Ground-floor plan showing areas investigated (Greenhatch Group)

Figure 5: Old mill, ground-floor ceiling, photograph taken from the north (Alison Arnold)

Figure 6: Old mill, supporting posts, photograph taken from the north-east (Alison Arnold)

Figure 7: Waterwheel pit, structure, photographed from below (Alison Arnold)

Figure 8: Doorway between southern extension and Old mill, photograph taken from the Old mill (Alison Arnold)

Figure 9: New lathe shed roof (Alison Arnold)

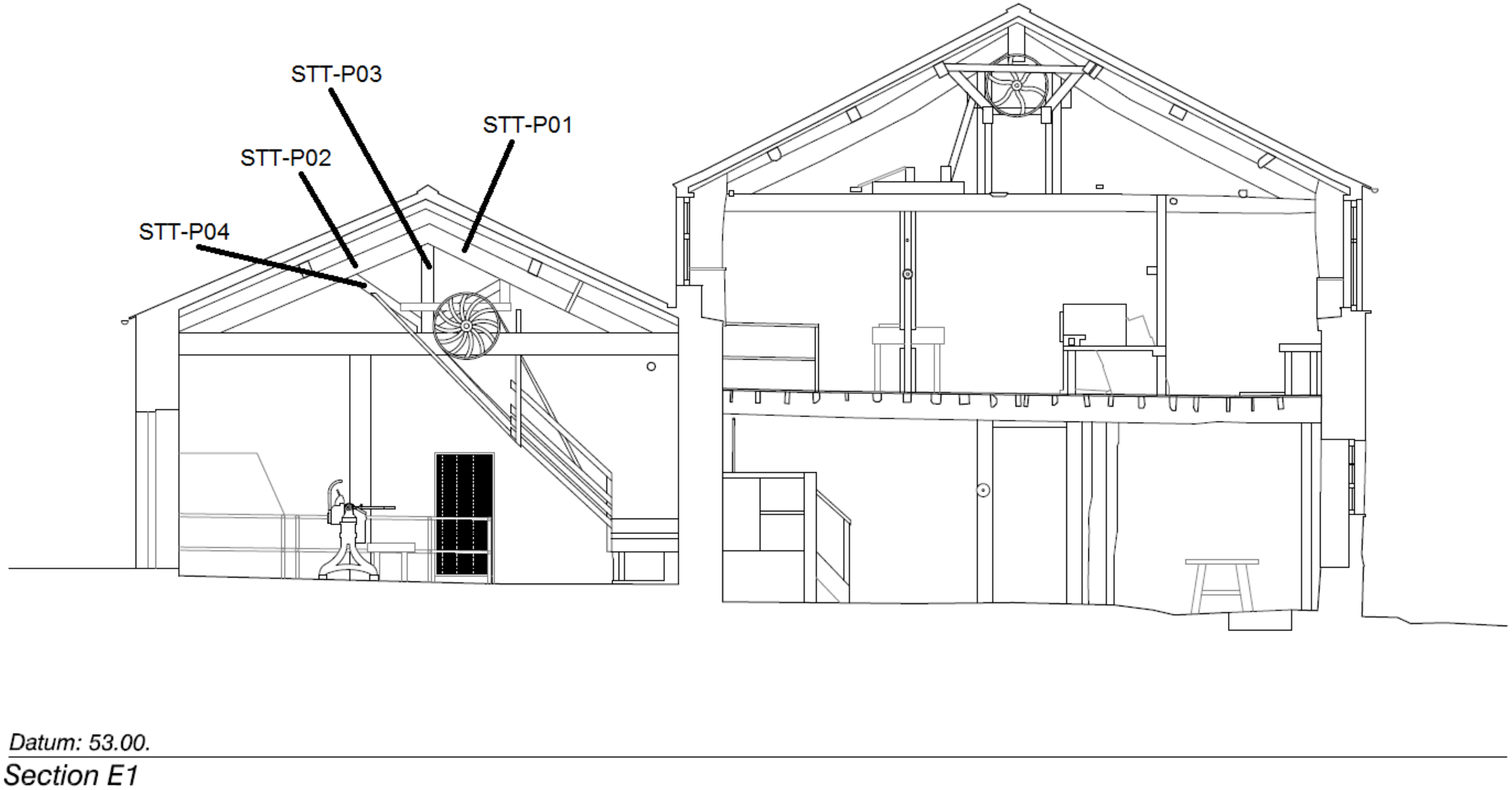
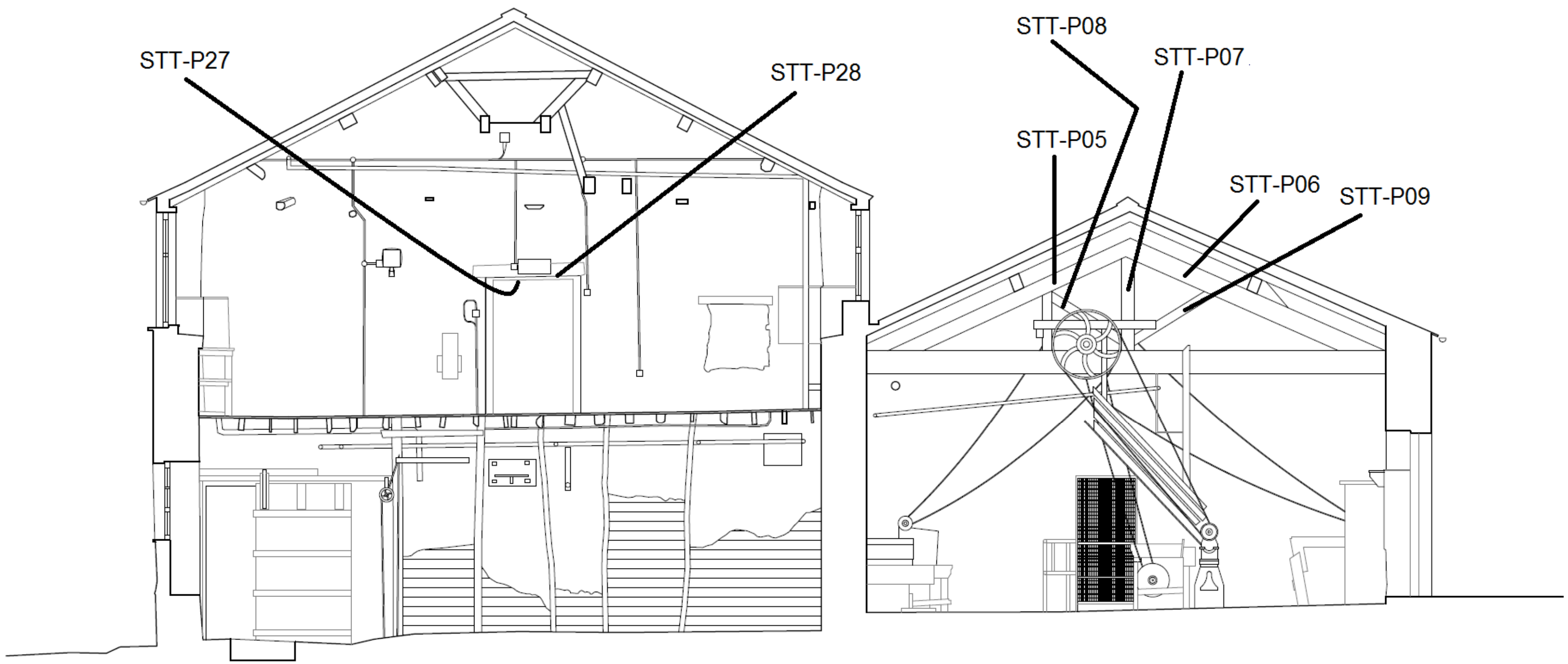


Figure 10: Section E1 (truss 1), showing the location of samples STT-P01–04 (Greenhatch Group)



Datum: 53.00.

Section E2

Figure 11: Section E2 (truss 2), showing the location of samples STT-P05–09 and STT-P27–28 (Greenhatch Group)

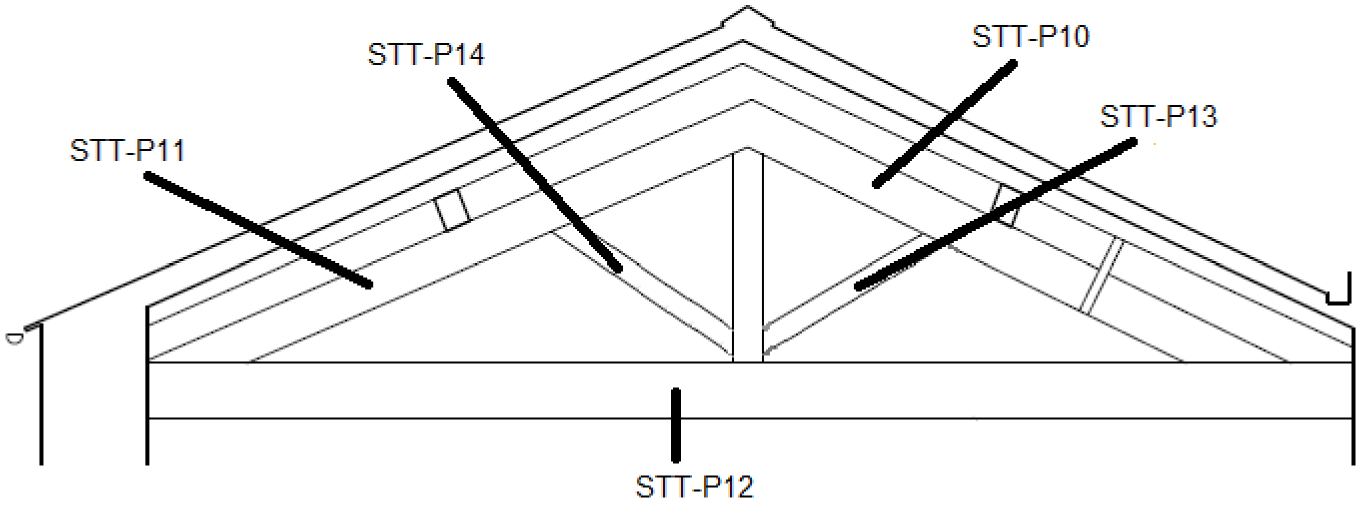


Figure 12: Truss 3 (based on truss 1), showing the location of samples STT-P10–14 (after Greenhatch Group)

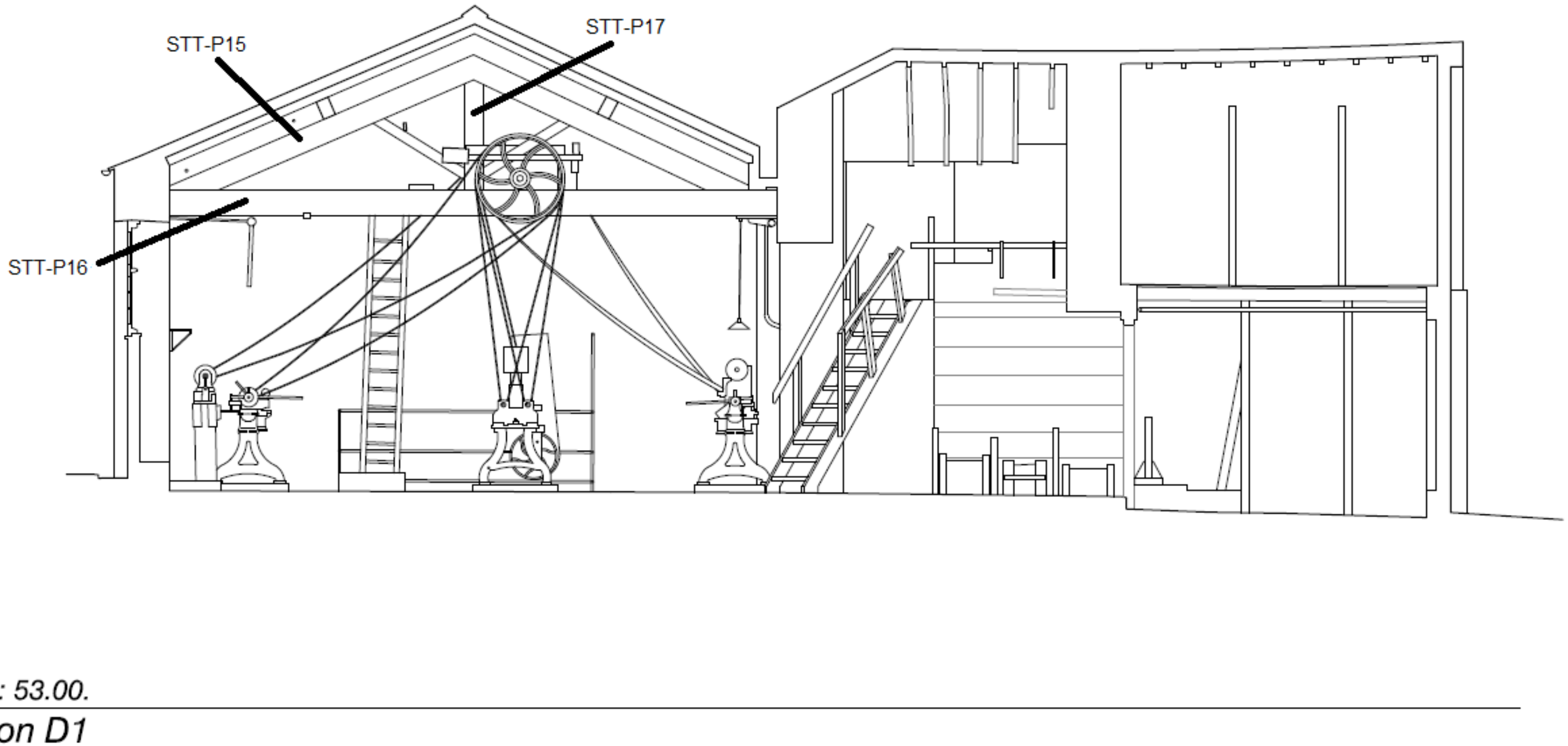


Figure 13: Section D1 (Truss 4), showing the location of samples STT-P15–17 (Greenhatch Group)

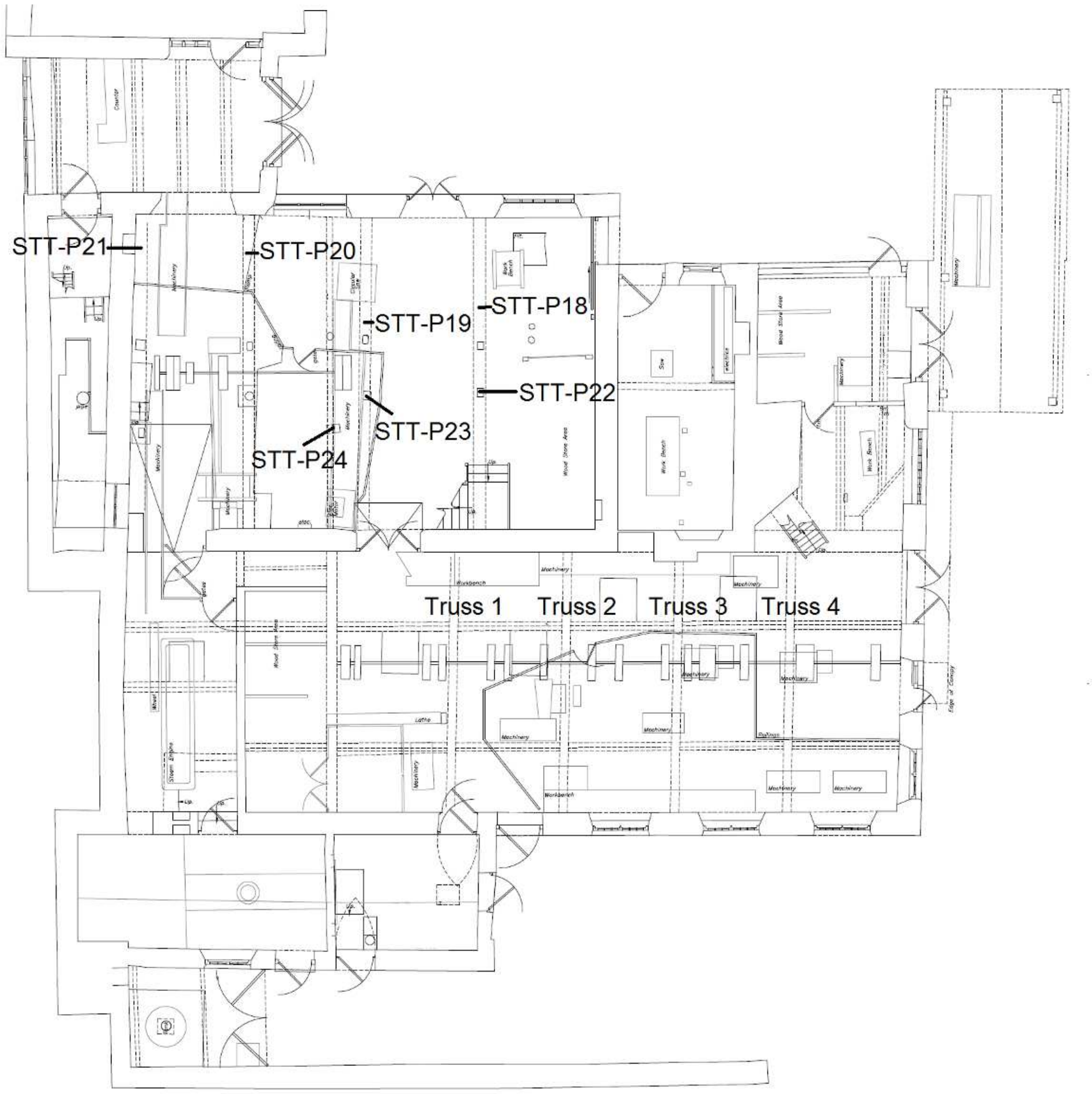


Figure 14: Ground-floor plan, showing the location of samples STT-P18–24 and truss positions in the New Lathe Shed (Greenhatch Group)

Figure 15: Lintel in the north gable wall, showing the location of sample STT-P25 (Alison Arnold)

Figure 16: Waterwheel pit, structure, showing the location of sample STT-P26 (Alison Arnold)

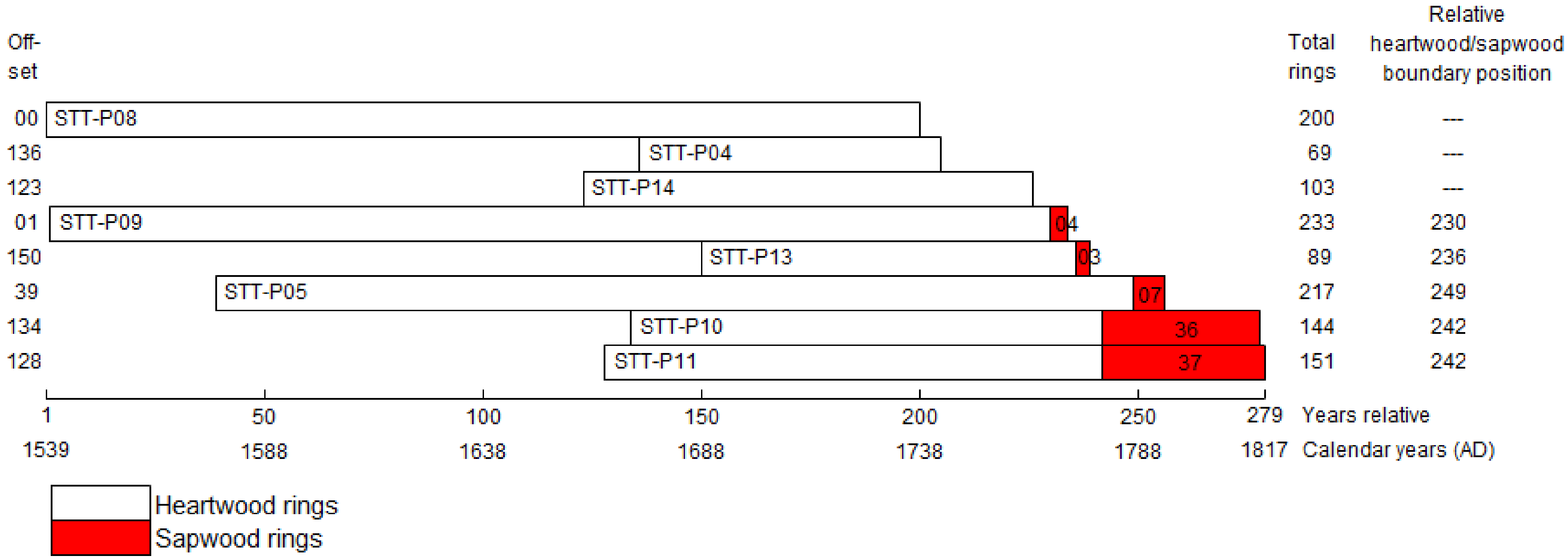


Figure 17: Bar diagram of pine samples in site sequence STTPSQ01

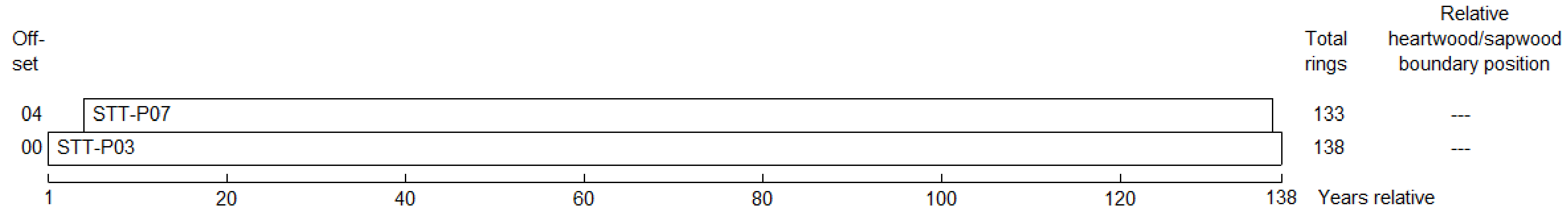


Figure 18: Bar diagram of pine samples in undated site sequence STTPSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

STT-P01A 89
226 222 231 223 271 253 304 257 271 268 240 164 193 180 233 234 235 218 155 154
177 173 158 136 147 141 194 149 155 141 161 132 105 50 66 92 139 176 199 182
174 136 160 164 113 104 135 129 132 200 189 142 129 148 115 151 148 174 148 135
143 145 112 94 40 98 94 113 125 104 103 118 84 124 115 129 96 81 88 76
120 72 95 120 140 119 144 117 125
STT-P01B 89
219 214 243 219 271 256 303 254 273 309 236 166 191 180 233 231 232 221 156 151
181 172 161 143 142 141 185 148 152 137 154 131 104 46 66 88 134 164 205 193
179 146 165 162 116 101 143 123 137 199 191 151 141 153 119 151 149 170 150 135
145 143 113 96 42 96 98 104 113 108 103 111 84 126 116 130 95 74 87 81
118 72 101 117 144 116 146 114 116
STT-P02A 78
160 329 272 273 283 234 196 159 183 246 257 298 313 325 303 318 315 242 240 36
39 58 49 110 90 80 106 125 159 211 209 228 314 249 224 249 157 190 145 163
119 189 174 144 172 150 233 167 169 137 202 172 142 158 155 184 157 189 165 191
202 123 87 127 123 125 97 93 91 94 126 111 61 79 89 76 66 83
STT-P02B 78
183 250 301 275 277 241 196 163 181 242 257 293 323 318 307 306 314 266 236 32
39 60 48 114 80 86 100 131 154 211 208 230 306 250 218 256 174 193 125 165
139 182 182 130 177 151 223 174 169 130 193 187 148 161 180 162 157 200 180 196
196 120 90 132 120 121 103 97 90 96 122 110 55 81 105 72 72 86
STT-P03A 138
160 151 199 142 159 151 130 157 114 122 82 102 82 88 68 49 26 31 26 19
21 26 36 46 30 41 29 25 39 37 34 35 56 49 48 10 3 10 14 26
40 38 42 44 41 41 34 43 54 63 69 95 88 74 68 92 70 47 53 75
82 89 101 87 112 132 120 125 102 134 112 102 89 85 86 68 84 96 107 105
103 117 102 98 88 70 75 68 74 72 51 54 63 62 65 72 69 62 65 96
81 101 74 97 94 71 74 68 97 102 105 110 129 126 113 147 110 119 116 82
69 86 91 86 69 125 113 113 84 78 96 115 97 130 88 116 109 99
STT-P03B 138
183 155 204 152 154 163 136 158 111 116 93 88 94 79 78 46 25 23 28 28
26 24 37 36 33 47 30 22 34 39 36 41 45 52 51 12 6 9 12 22
32 47 44 41 36 46 38 41 47 72 66 97 82 79 69 87 78 41 51 82
75 94 95 90 114 126 125 127 94 135 114 95 97 82 88 64 93 85 110 104
103 116 97 106 85 73 68 67 77 69 52 51 59 68 54 63 71 61 74 89
78 93 79 92 98 79 89 89 100 100 104 108 131 128 111 144 115 122 112 87
67 91 83 87 71 124 110 114 78 85 94 115 96 128 100 108 114 101
STT-P04A 69
19 24 27 36 35 25 43 55 82 69 52 76 101 52 73 100 114 97 66 95
114 93 105 105 68 129 149 155 151 117 116 120 107 103 89 82 66 73 53 71
80 109 126 102 85 116 98 111 110 82 83 89 73 74 62 71 72 76 67 71
56 48 48 78 53 44 40 55 54
STT-P04B 69
18 20 27 39 37 22 45 53 83 68 55 76 106 54 71 98 118 106 68 97
108 103 101 110 73 145 158 158 143 121 119 129 132 100 86 78 71 76 48 81
69 112 119 102 111 108 103 107 107 88 86 94 73 69 67 70 66 62 62 73
60 48 52 71 59 43 38 47 54

STT-P05A 215
76 64 81 103 76 74 58 114 109 115 83 62 70 92 78 74 75 99 97 95
76 79 65 45 86 102 105 115 114 132 113 114 111 98 92 90 113 77 105 142
124 86 118 128 104 146 88 79 68 65 68 102 102 86 67 56 51 76 81 84
66 56 74 60 50 51 50 49 45 39 50 31 23 38 40 47 44 60 62 40
31 15 31 31 53 55 52 57 33 32 51 45 55 35 47 50 26 28 25 26
52 62 66 86 74 65 47 37 67 78 58 63 61 96 92 100 138 108 124 127
96 98 108 69 73 94 72 65 70 75 55 32 32 53 52 59 55 69 53 40
28 30 59 52 84 98 89 69 54 44 48 43 43 41 43 28 38 33 31 21
51 36 32 19 28 27 32 24 25 31 37 40 37 42 51 46 45 26 28 30
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41 31 34 34 36 34 39 31 39 39 35 28 27 30 32
STT-P05B 217
45 68 100 111 77 77 67 115 109 112 75 65 69 92 76 76 75 92 100 95
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32 35 33 46 39 42 47 38 39 41 29 28 23 25 38 29 36 29 28 39
47 34 33 31 36 30 39 34 38 40 29 29 19 26 29 37 38
STT-P06A 55
246 266 311 295 293 321 284 322 341 385 354 430 418 375 436 350 344 316 388 303
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STT-P06B 55
224 266 311 295 292 320 286 318 344 382 350 451 410 366 449 347 343 323 389 303
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76 76 82 100 80 89 72 70 80 99 100 105 91 95 87 107 70 95 88 93
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85 119 97 127 98 105 105 117 107 135 119 131 125

STT-P08A 200
69 168 133 119 71 99 91 106 77 72 75 104 122 84 56 69 71 66 74 101
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34 39 31 39 37 44 57 38 45 16 15 25 34 38 59 72 76 62 68 57
39 31 51 57 40 34 41 35 35 22 20 28 32 48 31 22 17 21 28 22
33 40 39 39 32 31 20 23 30 35 35 32 47 41 41 33 50 44 52 89
47 57 49 26 24 32 34 41 36 29 28 38 25 35 19 32 37 42 37 30
21 27 23 22 22 42 24 22 31 41 42 77 44 55 41 25 24 18 23 38
37 29 63 49 59 60 60 76 115 76 89 86 121 101 61 99 97 91 84 69
62 93 115 110 112 77 75 94 96 71 75 70 78 83 52 57 29 60 89 74
101 140 83 100 128 138 121 125 121 112 130 135 99 105 66 80 72 68 55 99
STT-P08B 200
83 167 132 105 82 94 102 97 81 67 81 100 126 72 72 61 71 72 73 102
105 119 132 73 76 77 75 81 85 74 68 72 72 71 77 97 66 57 48 31
29 39 36 42 40 40 64 37 36 13 17 25 32 49 48 76 74 61 70 53
41 35 52 49 38 38 45 37 31 22 22 28 39 45 29 23 19 28 38 23
34 43 43 38 33 22 20 22 29 32 32 34 31 46 45 32 43 45 58 83
50 55 46 27 25 40 38 27 37 34 36 32 24 34 20 31 41 41 34 33
23 21 26 24 23 41 27 27 29 40 37 79 42 54 43 35 23 22 26 33
43 28 60 49 67 64 55 80 104 75 81 89 105 102 57 90 90 91 77 76
53 95 108 113 108 74 90 102 98 74 72 74 71 77 59 52 36 59 79 74
95 135 86 99 125 130 136 124 117 106 127 133 101 111 81 88 78 66 54 91
STT-P09A 233
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121 149 74 65 62 58 77 73 67 71 61 79 60 70 93 62 77 46 33 29
38 31 31 37 40 60 35 38 17 20 28 31 35 53 77 61 56 63 51 43
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32 30 32 31 27 23 28 35 29 40 34 46 33 36 33 50 49 58 86 57
67 54 27 25 32 33 38 33 28 27 29 26 27 23 27 38 36 33 23 16
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61 45 64 61 77 59 58 42 64 67 73 82 94 84 80 77 67 30 23 45
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STT-P09B 233
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115 148 83 63 53 62 77 71 77 69 66 78 59 75 90 65 71 47 31 37
31 29 35 40 40 52 36 41 20 23 25 28 34 55 74 62 61 57 52 46
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62 41 66 59 75 62 48 44 64 70 75 82 97 80 76 80 64 33 22 47
54 57 66 80 68 64 76 55 48 48 55 39 40

STT-P10A 144
85 120 142 191 189 196 193 223 243 251 220 195 180 181 221 180 225 224 206 176
134 145 100 92 95 121 143 181 172 197 184 174 182 161 177 162 120 109 101 119
155 170 172 148 167 128 118 172 169 162 138 126 105 108 128 130 174 170 178 182
155 194 152 113 93 88 63 85 46 63 75 77 80 62 64 78 50 45 67 76
66 62 64 69 48 38 56 63 49 55 57 56 59 80 56 39 49 42 40 45
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58 54 49 49
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132 137 106 87 105 125 150 184 176 198 184 183 167 160 180 153 120 112 106 116
151 156 158 165 155 153 123 175 162 163 137 117 108 101 132 148 174 163 173 188
159 191 142 116 93 96 64 83 47 64 79 76 76 65 62 79 50 47 64 74
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50 43 39 47 56 63 66 79 61 57 56 60 54 52 54 62 65 38 61 73
58 86 75 50 48 50 76 43 58 47 59 57 60 43 70 66 77 69 70 69
55 53 53 50
STT-P11A 151
143 165 188 171 145 165 197 165 184 232 147 162 121 136 132 114 129 133 138 136
186 168 151 171 170 178 119 148 113 103 132 151 149 197 185 235 210 183 155 177
166 155 123 116 127 125 165 161 184 151 144 131 138 195 175 167 160 124 120 115
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56 64 60 53 68 79 55 63 60 50 33 30 62 61 51 59 57 49 60 80
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66 51 62 41 65 65 64 70 64 44 45 53 57 49 50 42 50 55 61 46
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STT-P11B 151
134 162 189 164 141 163 190 155 169 220 148 158 115 133 149 128 135 146 128 156
184 177 152 170 176 175 125 137 118 112 131 135 145 168 159 206 201 186 159 175
176 145 123 128 114 132 150 161 183 166 144 130 138 203 168 157 142 121 110 109
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59 65 58 57 65 80 54 66 56 51 37 28 61 60 51 57 57 52 66 76
57 41 28 41 39 43 45 51 51 60 55 71 87 73 51 57 52 69 50 59
62 52 62 46 60 67 61 72 65 46 47 48 61 46 49 38 52 59 68 43
54 54 63 59 55 58 49 52 73 55 51
STT-P12A 182
105 158 188 196 113 203 154 175 242 109 124 159 168 151 137 142 104 106 115 75
79 63 53 112 147 123 116 84 66 33 70 77 116 185 156 154 176 172 157 198
255 87 62 162 180 197 132 74 89 124 172 134 120 105 97 117 147 155 122 143
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99 102 114 113 122 81 77 68 89 80 86 79 63 104 107 75 111 81 144 77
83 115 135 64 127 73 112 110 40 56 59 57 77 53 49 50 57 49 64 67
71 64 80 61 67 53 74 33 75 63 33 33 43 50 40 38 49 54 52 95
61 42 61 86 76 82 91 64 70 94 114 74 76 67 103 103 67 80 73 64
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STT-P12B 182
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73 64 59 109 149 128 115 77 72 34 63 84 106 177 165 158 173 172 156 199
253 86 60 161 184 197 131 79 87 122 171 133 120 108 94 121 150 155 117 136
129 171 120 82 111 134 89 104 119 144 116 132 114 143 84 114 100 108 89 101
68 122 67 75 81 72 62 70 66 83 82 75 58 68 72 88 97 76 71 109
98 104 108 102 124 83 77 73 83 77 85 83 61 106 119 76 105 76 149 75
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71 73 84 58 57 53 78 36 72 62 37 32 41 49 40 42 45 47 55 90
63 40 63 85 74 84 92 63 72 93 113 77 79 67 103 102 67 76 79 59
83 57
STT-P13A 89
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STT-P13B 89
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65 69 64
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60 73 68
STT-P16A 121
183 114 67 75 70 40 67 81 49 37 80 68 123 140 162 93 42 66 30 109
90 48 146 200 162 83 67 43 43 73 170 242 60 119 131 139 200 139 177 261
143 278 178 251 204 137 64 128 128 148 121 159 170 234 198 220 125 59 107 85
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92 49 146 200 166 78 66 43 44 67 171 258 61 119 118 137 199 138 171 284
138 301 170 276 224 132 68 132 136 152 137 159 182 231 185 218 123 56 107 95
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129

STT-P17A 186
218 297 222 274 323 277 215 198 194 118 188 86 56 112 230 54 142 164 164 182
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130 99 128 35 22 48 97 86 115 113 97 60 105 120 151 100 102 122 60 25
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STT-P17B 186
223 308 214 296 311 283 213 169 198 124 184 88 54 130 230 45 152 158 164 201
192 144 102 84 125 110 131 194 164 173 103 87 144 131 50 104 147 117 77 76
127 96 122 35 23 56 88 98 109 117 98 58 99 126 151 92 93 129 58 25
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STT-P18B 71
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99 78 37 65 44 46 74 89 95 96 112 124 99 98 77 82 72 81 49 43
97 88 130 118
STT-P20B 64
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120 97 148 113 123 153 178 94 105 72 105 121 55 65 108 91 69 46 58 117
103 76 41 64 42 44 81 76 104 72 107 122 96 103 83 77 70 81 46 51
92 90 132 112
STT-P23A 120
806 599 397 346 334 255 301 327 270 272 258 238 211 202 176 207 221 233 238 145
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177 150 170 187 234 183 226 194 192 165 185 168 199 208 180 204 186 162 183 166
167 203 244 227 211 110 201 170 149 190 220 167 168 173 177 207 175 174 201 213
132 201 176 174 148 176 136 158 158 100 191 157 106 167 151 135 142 159 159 190
151 161 189 121 173 167 151 155 147 180 153 155 177 153 173 175 157 136 147 173

STT-P23B 120
794 618 412 352 333 264 286 317 270 286 249 244 210 198 170 208 222 231 239 143
132 206 219 245 303 215 179 170 148 157 192 182 174 157 148 177 190 184 195 215
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134 202 181 174 158 177 130 160 163 97 189 160 104 169 151 137 142 163 162 191
152 158 198 120 178 159 155 151 150 180 153 152 183 156 169 175 155 131 152 170
STT-P26A 52
278 273 292 314 239 123 183 202 322 220 245 227 227 266 226 230 196 247 261 235
197 224 250 289 262 302 300 236 196 261 215 218 234 285 209 175 166 132 144 160
188 168 168 182 214 239 296 309 246 169 244 141
STT-P26B 52
367 226 301 344 211 143 177 218 322 221 243 228 237 248 234 223 206 245 260 235
194 229 241 287 273 312 301 240 203 252 219 217 224 282 228 182 168 130 141 158
189 179 166 195 216 237 308 310 251 183 230 142
STT-P27A 147
198 133 116 96 119 124 104 82 83 84 80 116 140 136 176 138 133 116 113 147
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60 71 54 51 64 74 45 55 53 57 71 99 65 69 59 56 60 89 85 72
114 104 99 154 100 75 78 88 76 74 61 56 73 71 64 74 76 97 62 56
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133 113 105 111 88 113 86 125 104 79 123 99 85 78 69 95 97 100 91 70
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STT-P27B 147
203 126 112 101 106 129 112 73 77 73 85 117 158 139 178 143 107 120 113 137
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65 72 37 55 75 67 35 57 48 56 84 91 70 59 61 65 54 91 82 72
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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 Building* (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

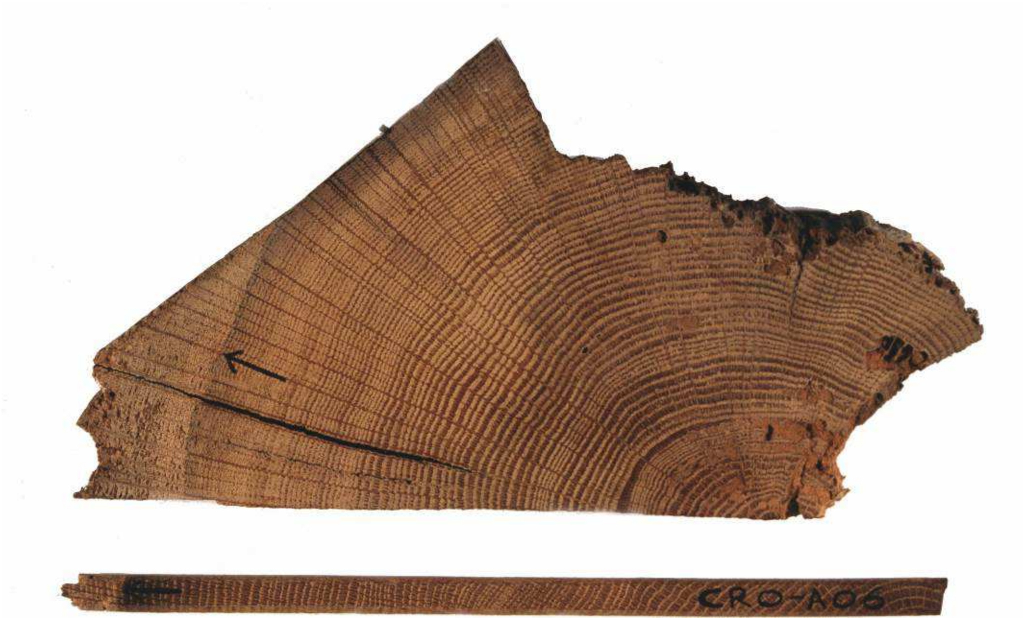


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

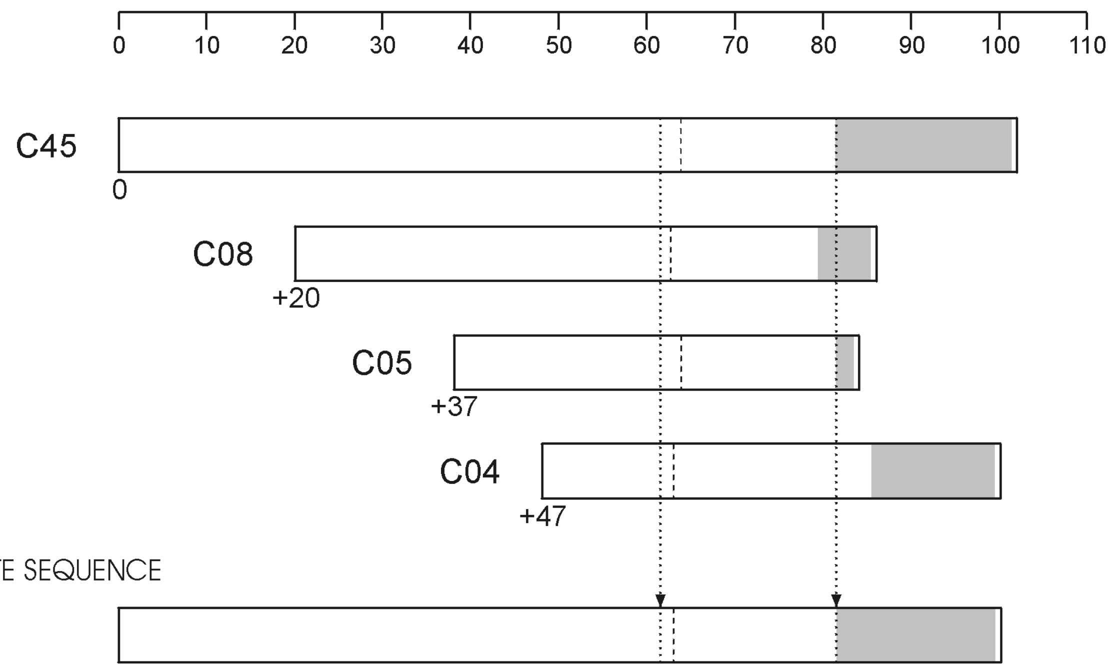


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

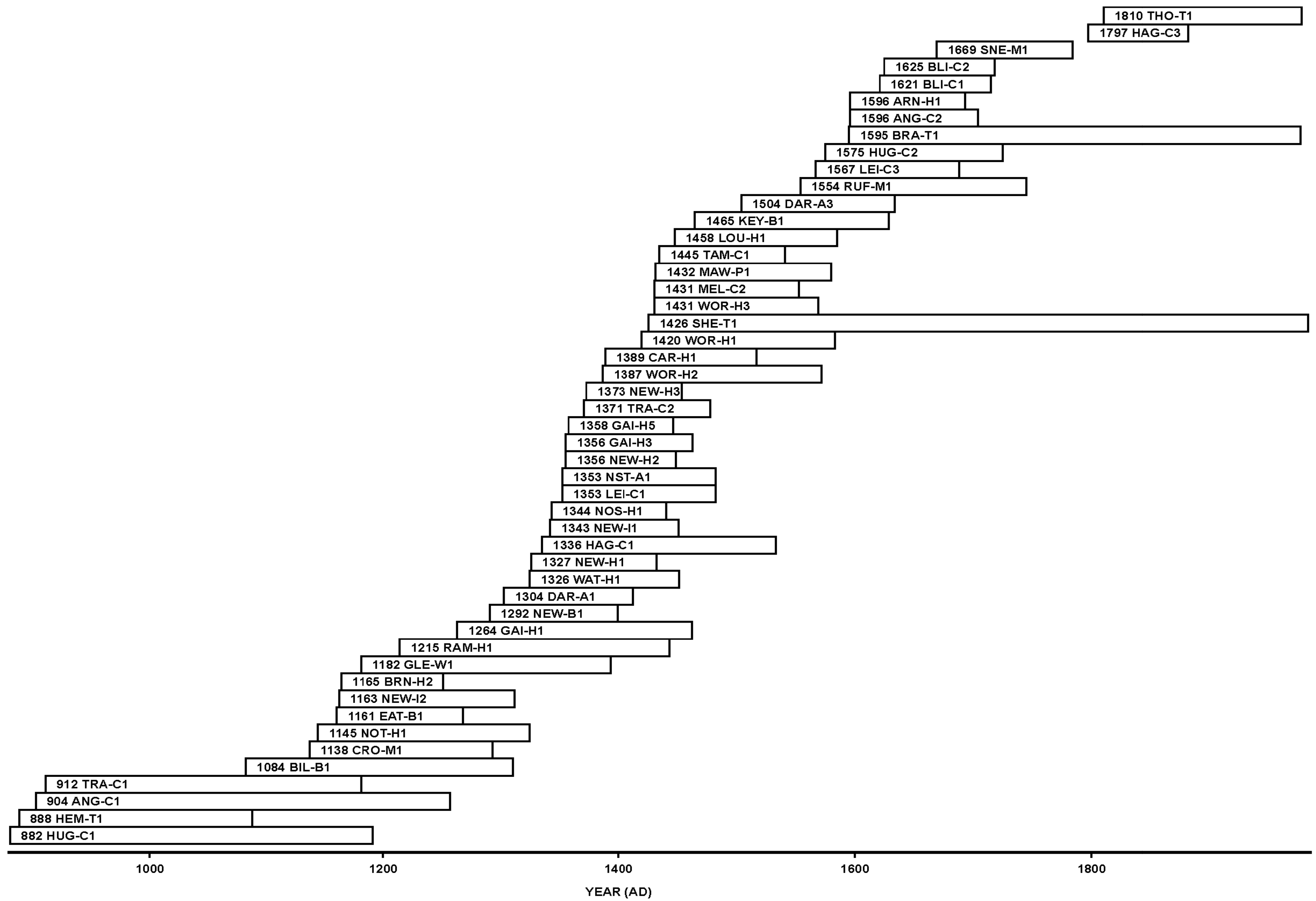
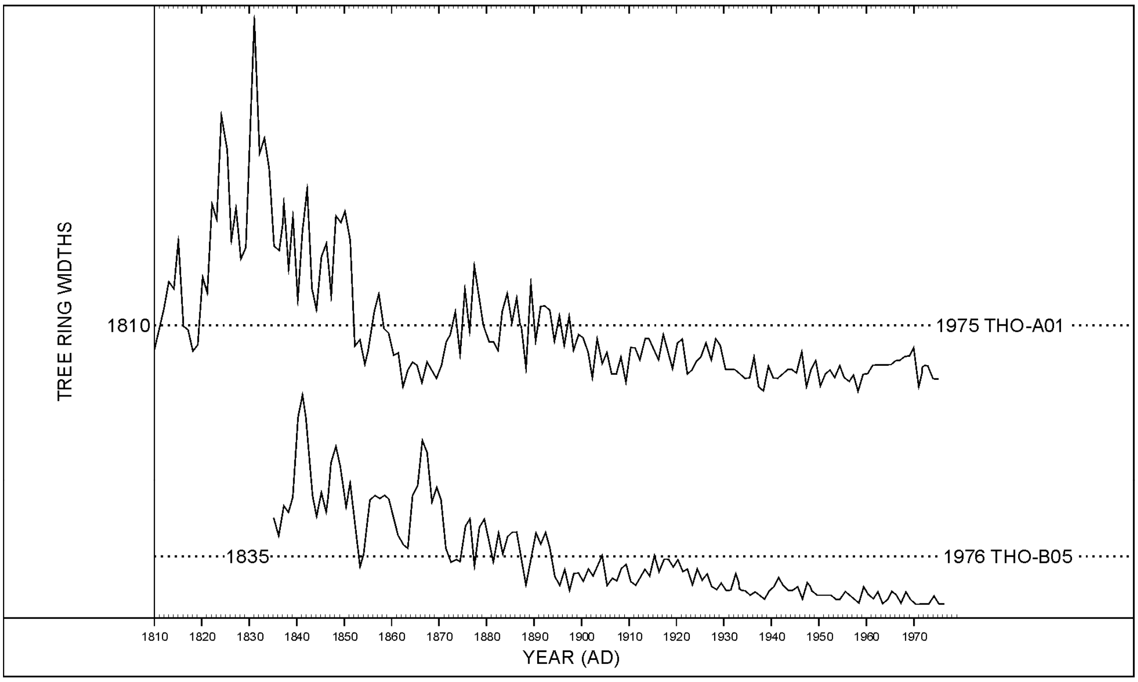


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

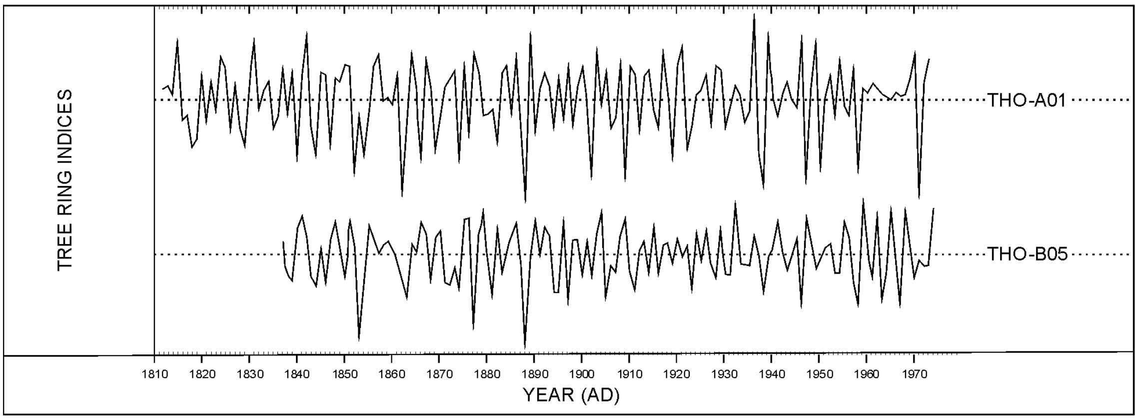


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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