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The Dower House, Bayham Abbey, Little Bayham, East Sussex Tree-Ring Analysis of Timbers

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Summary

Dendrochronological analysis undertaken on 45 samples taken from the north and south-wing roofs of this building resulted in the construction of a number of site sequences, only two of which could be dated.

The first, BAYASQ01, contains five samples, all from the south-wing roof, and spans the period AD 1298–1373. All of these samples are believed to have been felled in AD 1380–1405. The second, BAYASQ02, contains two samples, again from the south wing, and spans the period AD 1469–1550, with these samples thought to have been felled in AD 1560–85.

Prior to the tree-ring analysis being carried out, the south wing was thought to date to the first quarter of the eighteenth century, with a large number of the roof timbers being reused. It is now known that this roof contains timbers of the fourteenth/early fifteenth and the sixteenth centuries. No timbers from the eighteenth-century phase of construction have been identified.

Unfortunately, no timbers from the north-wing roof have been dated. This part of the building remains dated on documentary and structural grounds to the second half of the eighteenth century.

Keywords

Standing Building
Dendrochronology

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Introduction

Lying immediately to the west of the ruined Premonstratensian Abbey, on the Kent-Sussex border, is the Grade II* listed post-medieval Dower House (TQ649365; Figs 1, 2, and 3). The estate has been in the hands of the Camden family since it was purchased from Ambrose Browne by Sir John Pratt in AD 1714. The Dower House was the local residence for the Camden family until a new mansion was built to the north-west of the ruins in AD 1870. This new house was called Bayham Abbey House and the old house became known by its present name.

The Dower House comprises two parallel wings aligned north-south, with a further wing aligned east west at the northern end (Fig 4). The house and the ruined Abbey are now within the guardianship of English Heritage.

Whilst work was being undertaken on some of the roofs, English Heritage commissioned Archaeology South-East to produce an interpretative survey of the affected roof areas. This survey was carried out by David Martin and Simon Knight in November 1999. The description of the building and north and south-wing roofs below are taken (in an abridged form) from this survey (Archaeology South-East 1999).

Building Description and suggested Development

The structural evidence indicates the earliest surviving work within the mansion to be the central section (south wing). This Period A work dates from *c* AD 1700 (most likely subsequent to the acquisition of the site by Sir John Pratt in AD 1714) and consisted of a symmetrically-fronted terminal-chimney house, probably with a two-storeyed central porch (porch now destroyed). There is sufficient evidence to demonstrate that this initial house incorporated some form of now-destroyed rear (western) service area, probably in the form of a rear lean-to outshut.

Relatively soon after the construction of the initial house, probably during the second quarter of the eighteenth century (Period B) the house was enlarged by the addition of the north wing. Although a date between AD 1725 and AD 1750 seems most likely for this extension, a date around AD 1760 would not be entirely out of keeping. It too incorporated a symmetrical façade, though in this instance with deep cant-sided bay windows, hipped roof terminals and rear stacks.

The house was further remodelled and extended during the closing years of the eighteenth century and opening years of the nineteenth century, this work almost certainly having been carried out by the second Lord Camden, probably between AD 1799 and AD 1814. The extensions were not carried out in a single phase, but during two – perhaps three – separate building campaigns. The first of these (Period C) was the extension of the original period-A house southwards and to a greater height. The next, and quite separate addition, was the demolition of the rear section of the Period-A part and its replacement by a second two-storeyed wing constructed parallel to the original house. This Period D work, which dates from *c* AD 1800, but is probably early-nineteenth century, shows constructional variations between its northern (Period D2) and southern (Period D1) ends which may indicate that in itself this addition is of two phases, though these constructional variations may reflect nothing more than differences in the internal layout of the attic rooms. The northern part includes a short contemporary wing set at right angles and extending out westwards.

North and South-wing Roofs

The roof over the initial house (Period A or south wing) is framed in five bays with the end trusses incorporated into the internal faces of the end gables. It is of standard staggered-butt-purlin construction with collar trusses and no ridgeboard. Much of the material is reused from a medieval structure and a considerable proportion is soot stained. Nailed-on collars between the trusses support the plastered ceilings of the attic rooms, whilst inset slightly from the eaves are nailed-in ashlar pieces (effectively studs) which support low lath-and-plaster partitions forming the side walls of the attic rooms. Between the ashlar pieces and the ceiling the soffits of the common rafters are masked by lath-and-plaster skeelings. The attic rooms – almost certainly originally three in number with the central room the smallest – appear always to have been lit by a series of three dormer windows incorporated into the eastern roof slope.

The Period B, or north wing, roof is a sturdily built fully hipped staggered-butt-purlin roof (Fig 5) framed in three bays, the short central bay coinciding with the centrally placed entrance and staircase area. In keeping with the likely construction date during the second quarter of the eighteenth century, the hipped terminals do not incorporate high-set collars at their apex, though there is a central jack rafter. Heavier common rafters are included above the level of the purlins to coincide with the apex of the hips. Both hips incorporate return butt purlins, again a feature typical of the period. Both hips were designed from the outset to incorporate a central dormer window. As with the period-A roof, the attic rooms were designed from the outset to have plastered ceilings and skeelings with ashlars supporting low plastered side walls. The partitions dividing the two attic rooms from the stair area have been modified so as to allow the doorways to be moved northwards away from the head of the stairs.

Valley rafters are incorporated where the period-B roof intersects with the northward extension to the period-A roof. This allowed the construction of new in-built flues against the earlier period-A chimney and gable so as to serve the addition.

Objectives of the tree-ring analysis

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was hoped that the results would help inform the future conservation and management of the building. Dating the primary roof timbers of the north and south-wing roofs would provide dates for their construction. Additionally, it has been suggested that the reused timbers within the south-wing roof might be from the east end of the former Abbey Church. Therefore, by gaining a date for these it was hoped to potentially provide dating evidence for the roofing of the church.

Acknowledgements

The Laboratory would like to thank John Meadows, of the English Heritage Scientific Dating Section, and Richard Morrice, Historic Buildings Inspector from their Guildford office, for their on-site advice and assistance with access. As noted above, the description of the building and of the two roofs is taken from the Archaeology South-East survey (Archaeology South-East 1999), as are Figures 4 and 7–10). Additionally, John Meadows, and Cathy Tyers of the Sheffield Dendrochronology Laboratory, were very helpful during discussions throughout various stages of this work. Mick Worthington of the Oxford Dendrochronology Laboratory kindly ran some of the data against the reference material held there.

Sampling

Initially, 32 core samples were taken from timbers of this building. Each sample was given the code BAY-A (for Bayham) and numbered 01–32. Fourteen of these were from the north-wing roof (BAY-A01–14) and 18 from the south-wing roof (BAY-A15–32). Initial analysis pointed to the site being potentially more complex than originally thought and so following discussions with English Heritage it was agreed that the investigation should be extended and the Laboratory returned and took a further 30 samples (BAY-A33–62). The position of all samples was noted at the time of sampling and has been marked on Figures 6–10. None of the timbers sampled in the north wing showed any sign of reuse. In contrast to this, many of the timbers within the south wing showed obvious signs of previous use, such as smoke blackening and/or carpenters marks which did not appear to fit with the extant roof. Whether the sample displayed any of these characteristics or not was noted at the time, and this and further details relating to each sample can be found in Table 1.

Analysis and Results

Seventeen of the samples (nine from the north roof and eight from the southern roof) had too few rings to make secure dating a possibility and these samples were rejected prior to measurement. The remaining 45 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 divided into those from the north and those from the south roof and samples from each group compared with the others within it by the Litton/Zainodin grouping procedure (see appendix).

South-wing roof

At a least value of t=4.5, nine samples formed three groups. Firstly, five samples matched each other and were combined at the relevant offset positions to form BAYASQ01, a site sequence of 76 rings (Fig 11). This site sequence was then compared with a large number of relevant reference chronologies for oak, indicating a consistent match when the date of its first ring is AD 1298 and of its last measured ring is AD 1373. The evidence for this dating is given by the t-values in Table 2.

Two samples matched and were combined at the relevant offset positions to form BAYASQ02, a site sequence of 82 rings (Fig 12). This site sequence was found to consistently match the reference chronologies at a first-ring date of AD 1469 and a last-ring date of AD 1550. The evidence for this dating is given by the t-values in Table 3.

Two further site sequences, BAYASQ03 and BAYASQ04, containing two samples each (Figs 13 and 14), could not be matched against the reference chronologies and are undated.

Attempts to date the remaining ungrouped samples from the southern roof by individually comparing them against the reference chronologies were unsuccessful and these samples are also undated.

North-wing roof

At a least value of t=4.5, 17 samples formed three groups. Firstly, six samples matched and were combined at the relevant offset positions to form BAYASQ05, a site sequence of 69 rings (Fig 15). Five samples matched and were combined at the relevant offset positions to form BAYASQ06, a site sequence of 80 rings (Fig 16). Finally, six samples matched and were combined at the relevant offset positions to form BAYASQ07, a site sequence of 73 rings (Fig 17).

These three site sequences were then compared with the reference material but unfortunately, no secure match could be found and all remain undated. Attempts were then made to date the ungrouped samples by individually comparing with the reference material but again this was unsuccessful and these samples are also undated,

Interpretation

Analysis of 45 samples taken from this building resulted in the construction of several site sequences, only two of which could be successfully dated.

Site sequence BAYASQ01, contains five samples and spans the period AD 1282–1373. All of these samples have the heartwood/sapwood boundary ring. This ranges in date from AD 1362 to AD 1373, which is consistent with a single felling. The average of these dates is AD 1365, allowing an estimated felling date to be calculated for the five timbers represented to within the range AD 1380–1405. All of these samples were taken from timbers which showed signs of previous use.

Site sequence BAYASQ02 contains two samples, and spans the period AD 1469–1550. Only one of these samples (BAY-A20) has the heartwood/sapwood boundary ring. This gives an estimated felling date for the timber represented within the range AD 1560–85. The second sample (BAY-A60) has a last-measured ring date of AD 1534 which means it is not impossible that this timber was also felled in AD 1560–85. Both of these samples are from common rafters in the southern roof. Although neither of these timbers showed any obvious sign that they were reused, sample BAY-A20 was from a timber which had lots of old nails in it, in contrast to many of the timbers around it.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees from this area have 15–40 sapwood rings.

Discussion

Tree-ring analysis has successfully dated seven timbers from the south-wing roof. Five of these were felled in AD 1380–1405 and two in AD 1560–85. The five earlier timbers show obvious signs of reuse and at least one of the sixteenth-century timbers has indications that it may also have been used previously.

On the basis of the use of staggered purlins and other structural details, a date in the late seventeenth or (more likely) early part of the eighteenth century had been suggested for the south wing, making it the earliest surviving part of the building. It is now known that the roof contains timbers from both the fourteenth (or very early fifteenth) and the sixteenth centuries. No timbers have been identified from the late seventeenth or eighteenth century, so the analysis has neither confirmed nor refuted the expected date of construction.

With a further two undated site sequences and 15 ungrouped samples, it may well be the case that more than the two identified fellings are represented within the timbers of this roof. Indeed there is great variation in the length of ring-width sequences of these samples (the shortest having too few to be deemed worth measuring and the longest having 211 rings) which may support the idea that timbers of various fellings/sources have been utilised during the construction of this roof. This may have attributed to the poor grouping and lack of successful dating.

On documentary and structural grounds the north-wing roof had been dated to the second half of the eighteenth century. It is unfortunate that, despite the production of three site sequences, no timbers from the north-wing roof were dated during the analysis. The fact that the samples formed three separate groups, as well as the two ungrouped samples, may again indicate a number of different fellings/sources are represented within the timbers of the roof. However, in contrast to the timbers of the south-wing roof, all of the samples have similarly short ring-width sequences, with the longest sample (BAY-A08) having only 73 rings, and nearly 80% of the measured samples having fewer than 60 rings. This shortness of ring-width sequences in itself would have hindered grouping and successful dating.

It is disappointing that none of the north-wing roof timbers have been dated nor any of the timbers considered primary to the construction of the south-wing roof. In addition to the potential difficulties in dating timbers from several sources/periods mentioned above, another likely reason for this lack of dating could be the period from which this building is thought to date. It has long been acknowledged that there is a distinct scarcity of reference chronologies covering the post-medieval period in the south-east of the country. Thus the dating of buildings of this period, from this part of the country, is problematic. An English-Heritage-funded project designed to combat this problem has gone some way to alleviating this difficulty but it is still an area where reference chronologies are limited.

Perhaps, it is of consequence then, to note that although only seven timbers have been securely dated at Bayham, tentative dates were found for a number of the other sequences. However, the statistical evidence for these dates was weak, and therefore they remain unproven, despite both the Sheffield and Oxford Laboratories kindly running the data against their reference material. It is hoped that at some point in the future, when further post-medieval reference chronologies are available, some of the undated Bayham Abbey material will be successfully dated.

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Table 1: Details of tree-ring samples from The Dower House, Bayham Abbey, Little Bayham, East Sussex

Sample number	Sample location*	Total rings**	Sapwood rings***	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Northern Wing (roof)						
BAY-A01	North upper rafter, frame 2, bay 1	49	14C	----	----	----
BAY-A02	North lower rafter, frame 3, bay 1	57	11C	----	----	----
BAY-A03	North lower rafter, frame 4, bay 1	51	08	----	----	----
BAY-A04	North upper rafter, frame 5, bay 1	46	15C	----	---	----
BAY-A05	South lower rafter, frame 5, bay 1	64	h/s	----	----	----
BAY-A06	South upper rafter, frame 5, bay 1	68	16	----	----	----
BAY-A07	South purlin, east hip to truss 1	45	h/s	----	----	----
BAY-A08	Purlin, east hip	73	19C	----	----	----
BAY-A09	North stud 1, truss 2	54	05	----	----	----
BAY-A10	North upper rafter, frame 3, bay 3	54	h/s	----	----	----
BAY-A11	South upper rafter, frame 3. bay 3	60	10	----	----	----
BAY-A12	North upper rafter, frame 4. bay 3	66	12C	----	----	----
BAY-A13	South purlin, west hip to truss 2	NM	--	----	----	----
BAY-A14	North-west diagonal rafter	NM	--	----	----	----
BAY-A33	North lower rafter, frame 5, bay 1	57	03	----	----	----
BAY-A34	North lower rafter, frame 6, bay 1	55	03	----	----	----
BAY-A35	Joist frame 6. bay 1	NM	--	----	----	----
BAY-A36	North upper rafter, frame 3, bay 1	NM	--	----	----	----
BAY-A37	North lower rafter, frame 8, bay 1	NM	--	----	----	----
BAY-A38	North purlin, east hip to truss 1	48	02	----	----	----
BAY-A39	North lower rafter, frame 10, bay 1	NM	--	----	----	----
BAY-A40	North lower rafter, frame 11, bay 1	46	15C	----	----	----
BAY-A41	North principal rafter, truss 1	NM	--	----	----	----
BAY-A42	South principal rafter, truss 1	NM	--	----	----	----
BAY-A43	North principal rafter, truss 2	48	--	----	----	----
BAY-A44	South principal rafter, truss 2	51	h/s	----	----	----
BAY-A45	Collar, truss 2	55	01	----	----	----
BAY-A46	North purlin, truss 1–2	NM	--	----	----	----
Southern Wing (roof)						
BAY-A15	East principal rafter, truss 15 ®, cm	57	h/s	----	----	----
BAY-A16	West principal rafter, truss 15 ®, cm	51	h/s	1314	1364	1364

BAY-A17	East rafter 1, truss 15–16	86	h/s	----	----	----
BAY-A18	East rafter 6, truss 14–15	101	h/s	----	----	----
BAY-A19	East rafter 3, truss 14–15	128	h/s	----	----	----
BAY-A20	East rafter 2, truss 14–15	67	05	1484	1545	1550
BAY-A21	West rafter 2, truss 14–15	92	h/s	----	----	----
BAY-A22	East lower rafter 7, truss 13–14 cm	NM	--	----	----	----
BAY-A23	East principal rafter, truss 13 ®	62	h/s	1302	1363	1363
BAY-A24	West principal rafter, truss 13 ®, sm	54	04	1313	1362	1366
BAY-A25	Collar, truss 13 ®	NM	--	----	----	----
BAY-A26	West rafter 5, truss 12–13	52	10C	----	----	----
BAY-A27	West common rafter 1, truss 13–14 sm	NM	--	----	----	----
BAY-A28	East principal rafter, truss 12 ®, cm, sm	52	h/s	1322	1373	1373
BAY-A29	West principal rafter, truss 12 ®, cm	66	h/s	1298	1363	1363
BAY-A30	Collar, truss 12 ®	211	h/s	----	----	----
BAY-A31	West rafter 1, truss 11–12	77	04	----	----	----
BAY-A32	East purlin, truss 11–12 ® sm	68	h/s	----	----	----
BAY-A47	West purlin, truss 15–16 ®	NM	--	----	----	----
BAY-A48	West rafter 1, truss 15–16	57	h/s	----	----	----
BAY-A49	East lower rafter 2, truss 15–16 ®	140	01	----	----	----
BAY-A50	Collar, frame 4, truss 15–16	53	h/s	----	----	----
BAY-A51	East lower rafter 4, truss 15–16 sm	90	06	----	----	----
BAY-A52	Collar, frame 4, truss 11–12	NM	--	----	----	----
BAY-A53	West upper rafter 2, truss 12–13	NM	--	----	----	----
BAY-A54	Collar, frame 1, truss 12–13	49	16	----	----	----
BAY-A55	West upper rafter 1, truss 12–13 sm	NM	--	----	----	----
BAY-A56	East purlin, truss 12–13 ®	52	h/s	----	----	----
BAY-A57	Collar, frame 2, truss 12–13	82	15	----	----	----
BAY-A58	Collar, frame 3, truss 12–13	61	h/s	----	----	----
BAY-A59	Collar, frame 6, truss 12–13 ®?	80	h/s	----	----	----
BAY-A60	East rafter 3, truss 15–16	66	--	1469	----	1534
BAY-A61	West principal rafter, truss 14 ®, cm	NM	--	----	----	----
BAY-A62	South valley rafter west, truss 14–15	67	--	----	----	----

* = ® = reused, cm = carpenters mark, sm = smoke blackening; **NM = not measured
***h/s = the heartwood/sapwood ring 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 BAYASQ01 and relevant reference chronologies when the first-ring date is AD 1298 and the last-ring date is AD 1373

Reference chronology	*t*-value	Span of chronology	Reference
England, London	4.7	AD 413–1728	Tyers and Groves 1999 unpubl
Kent	5.0	AD 1158–1540	Laxton and Litton 1989
Rectory Park (wing), Horsmonden, Kent	5.3	AD 1313–1426	Laxton and Litton 1989
Lower Newlands, Teynham, Kent	5.3	AD 1278–1366	Laxton and Litton 1989
Barbican/Gatehouse, Warwick Castle	5.1	AD 1310–1503	Howard 1995 unpubl
Wells Cathedral, E range roof C1 - 19	5.0	AD 1279–1451	Howard *et al* 2001
Cowden, Kent, St Mary Magdalene	4.9	AD 1254–1377	Howard *et al* 1999

Table 3: Results of the cross-matching of site sequence BAYASQ02 and relevant reference chronologies when the first-ring date is AD 1469 and the last-ring date is AD 1550

Reference chronology	*t*-value	Span of chronology	Reference
England, London	5.8	AD 413–1728	Tyers and Groves 1999 unpubl
Southern England	5.0	AD 1083–1981	Bridge 1988
Stonepits Manor, Seal, Kent	6.3	AD 1445–1542	Arnold *et al* 2003
Brewhouse Yard Museum, Nottm	6.2	AD 1445–1551	Howard et al 1994
Chiddingly Place, East Sussex	5.7	AD 1324–1576	Arnold and Litton 2003
Walmer Castle, Kent	5.5	AD 1396–1523	Howard *et al* 1997
Sandiacre Tithe Barn, Derbys	5.3	AD 1427–1611	Howard 2004 unpubl
The Forge, Church St, E Hendred, Oxon	5.5	AD 1379–1521	Alcock *et al* 1989

Figure 1: Maps to show the location of Bayham Abbey, East Sussex

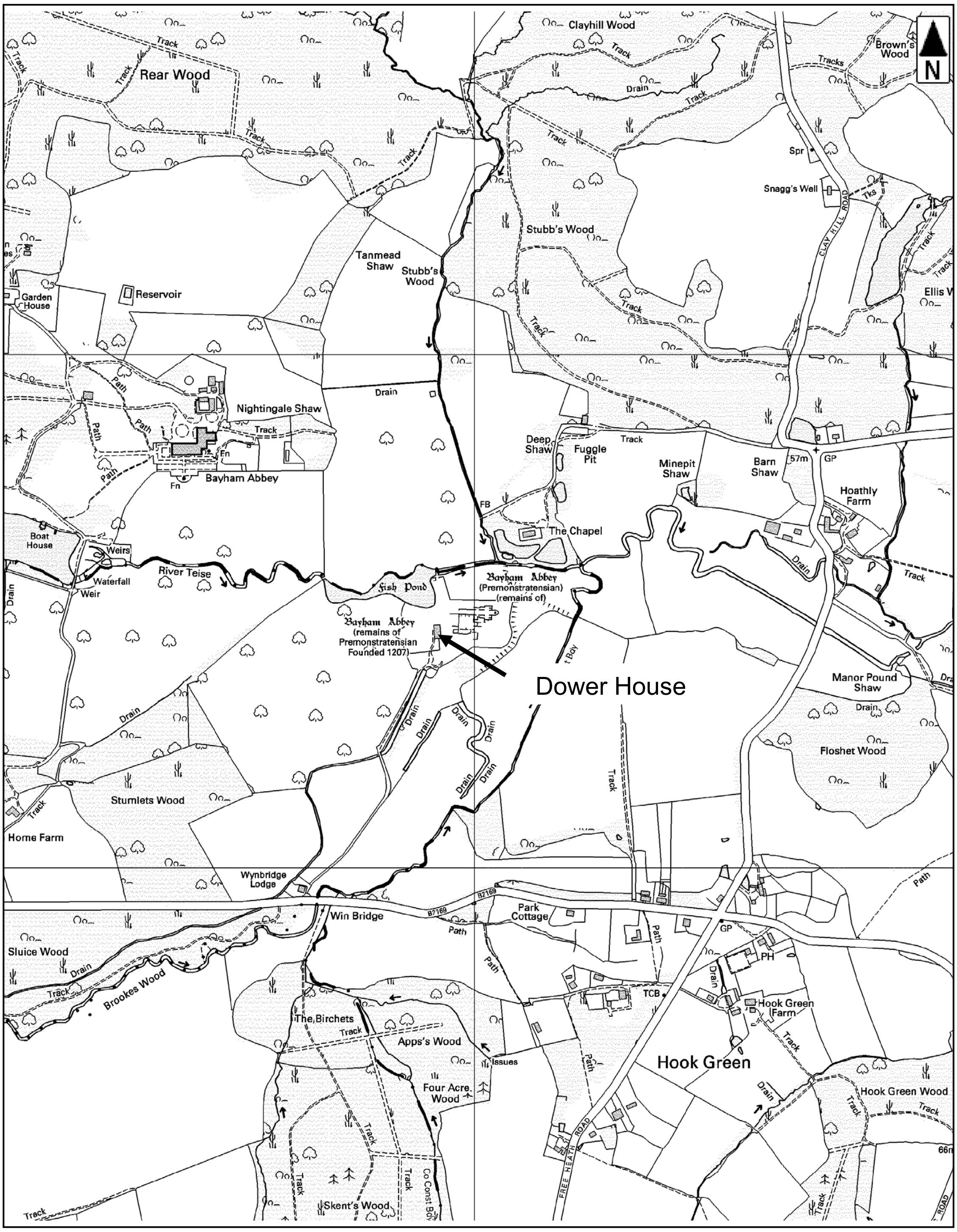


Figure 2: Map to show the location of The Dower House

Figure 3: The Dower House, taken from the north-east

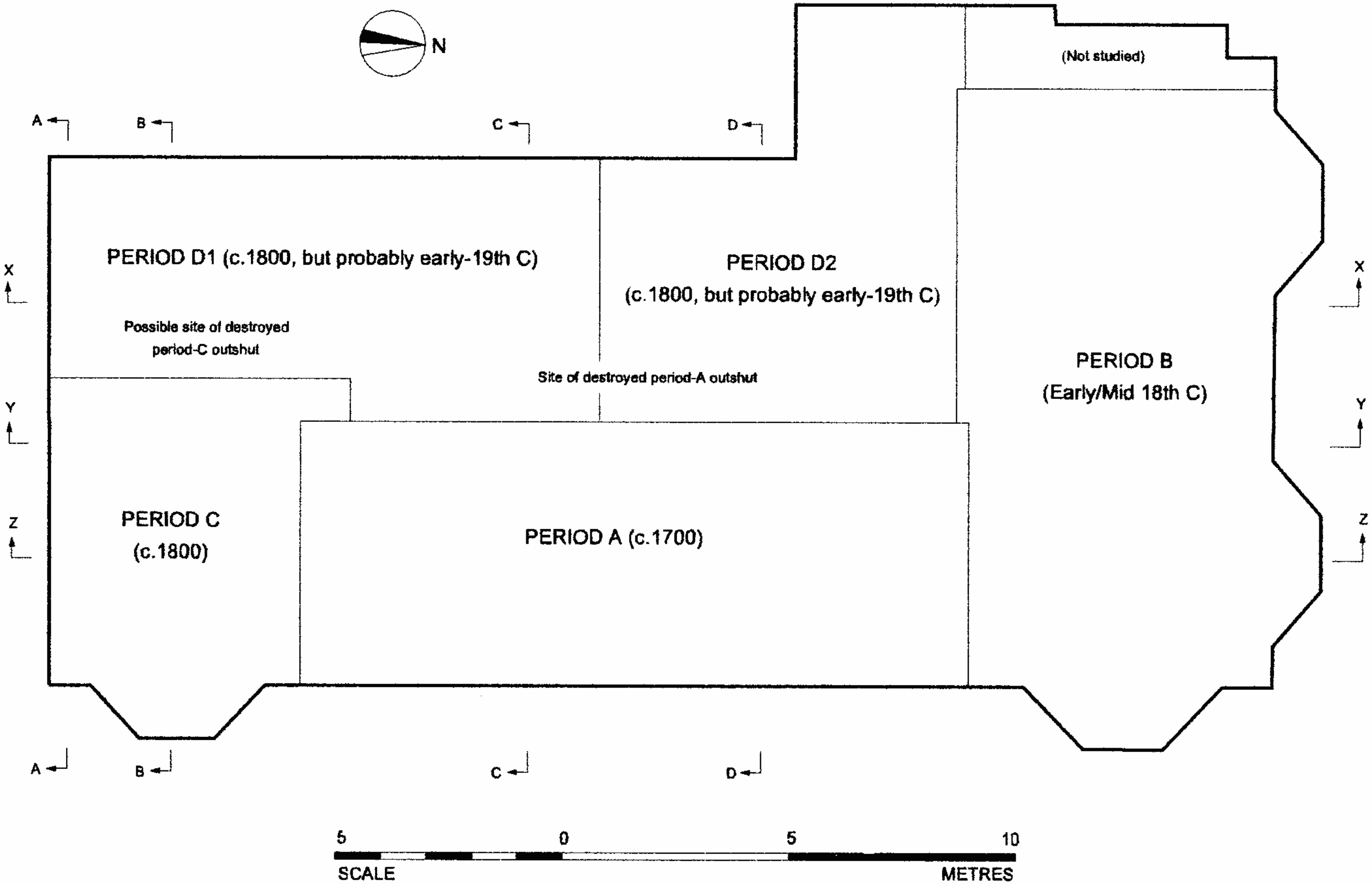


Figure 4: Outline plan showing the sequence of development of the house as suggested by the roof structure (Archaeology South-East)

Figure 5: The north-wing roof

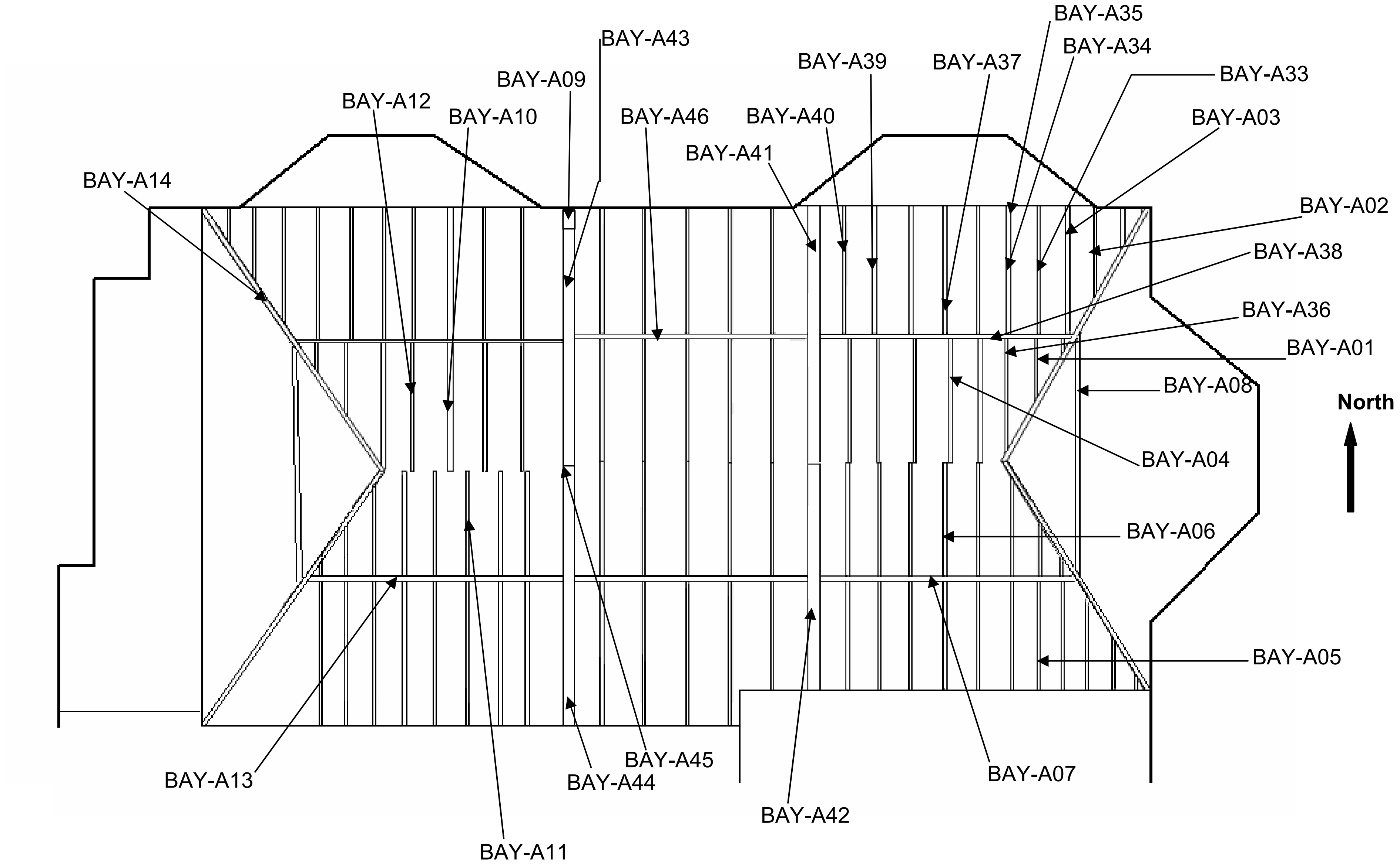


Figure 6: Sketch plan of the north-wing roof timbers, showing the location of samples BAY-A01–14 and BAY-A33–46

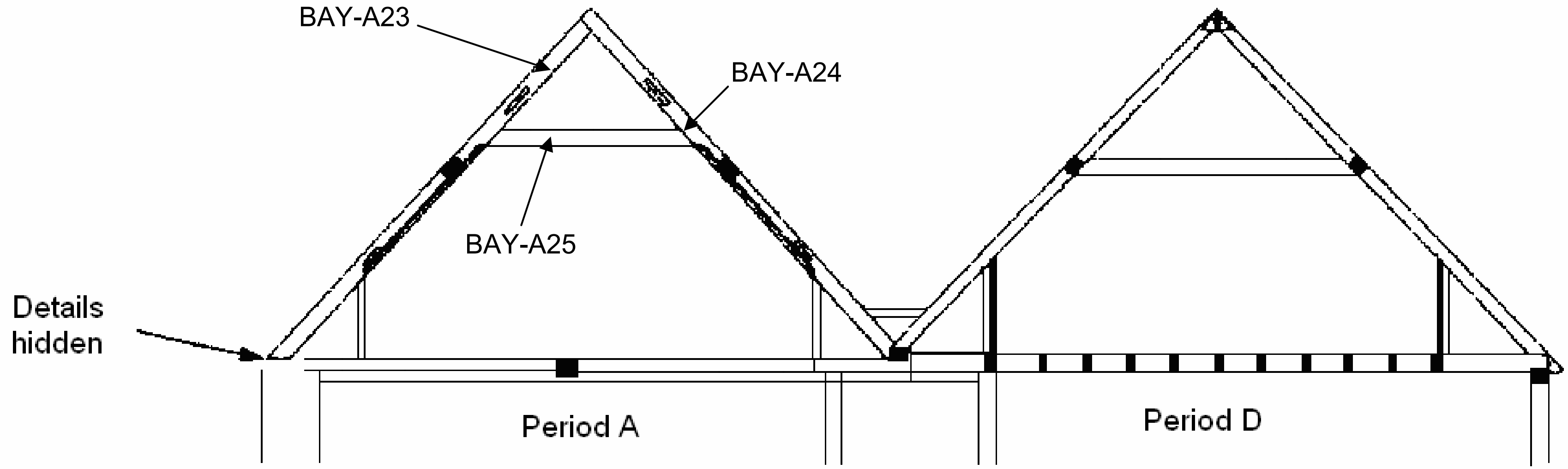


Figure 7: Section C–C (truss 13) looking south, showing the location of samples BAY-A23–5 (Archaeology South-East)

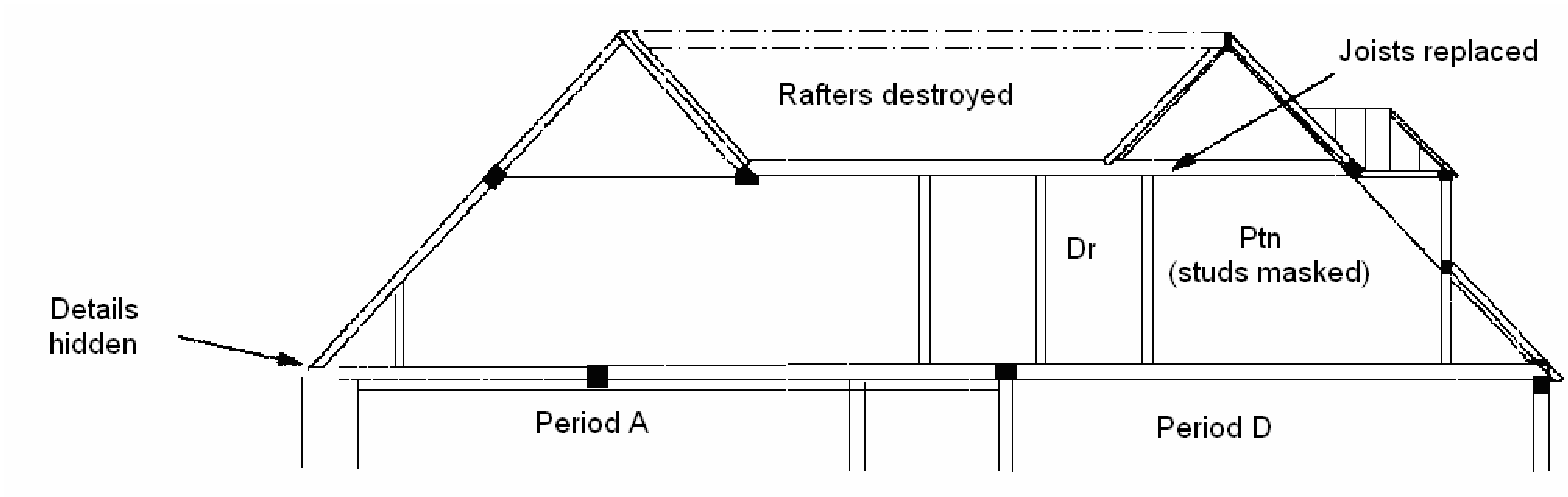


Figure 8: Section D–D (Truss 14) looking south (Archaeology South-East)

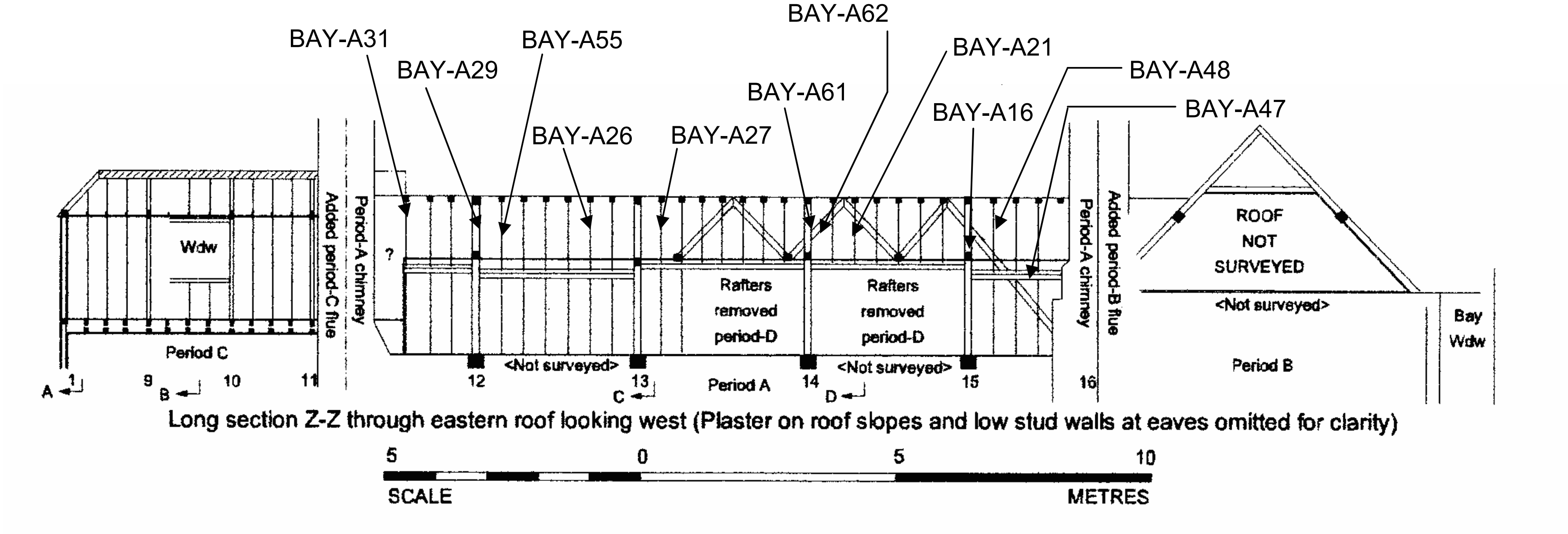


Figure 9: Long section Z–Z looking west, showing the location of samples BAY-A16, BAY-A21, BAY-A26–7, BAY-A29, BAY-A31, BAY-A47–8, BAY-A55, and BAY-A61–2 (Archaeology South-East)

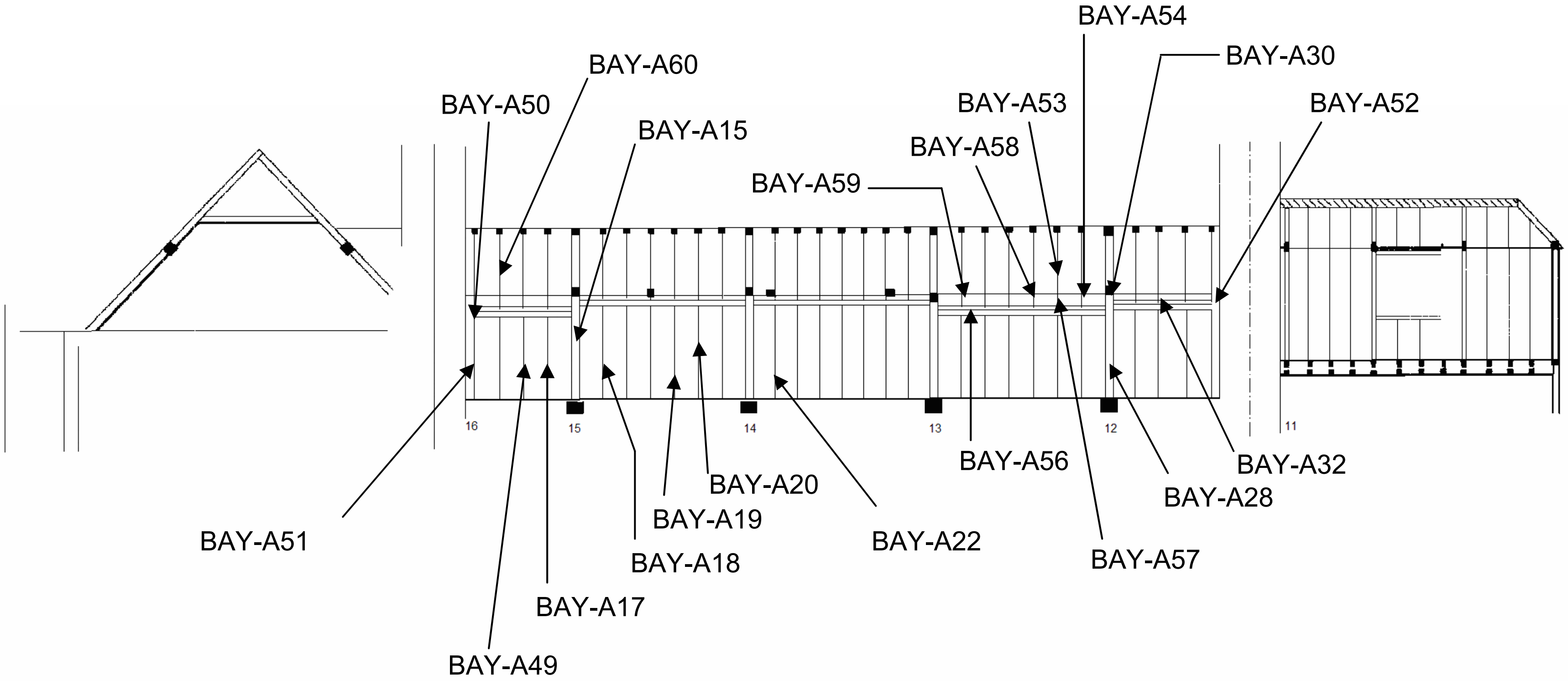


Figure 10: Long section, looking east, showing the location of samples BAY-A15, BAY-A17–20, BAY-A22, BAY-A28, BAY-A30, BAY-A32, BAY-A49–54, and BAY-A56–60 (based on Archaeology South-East)

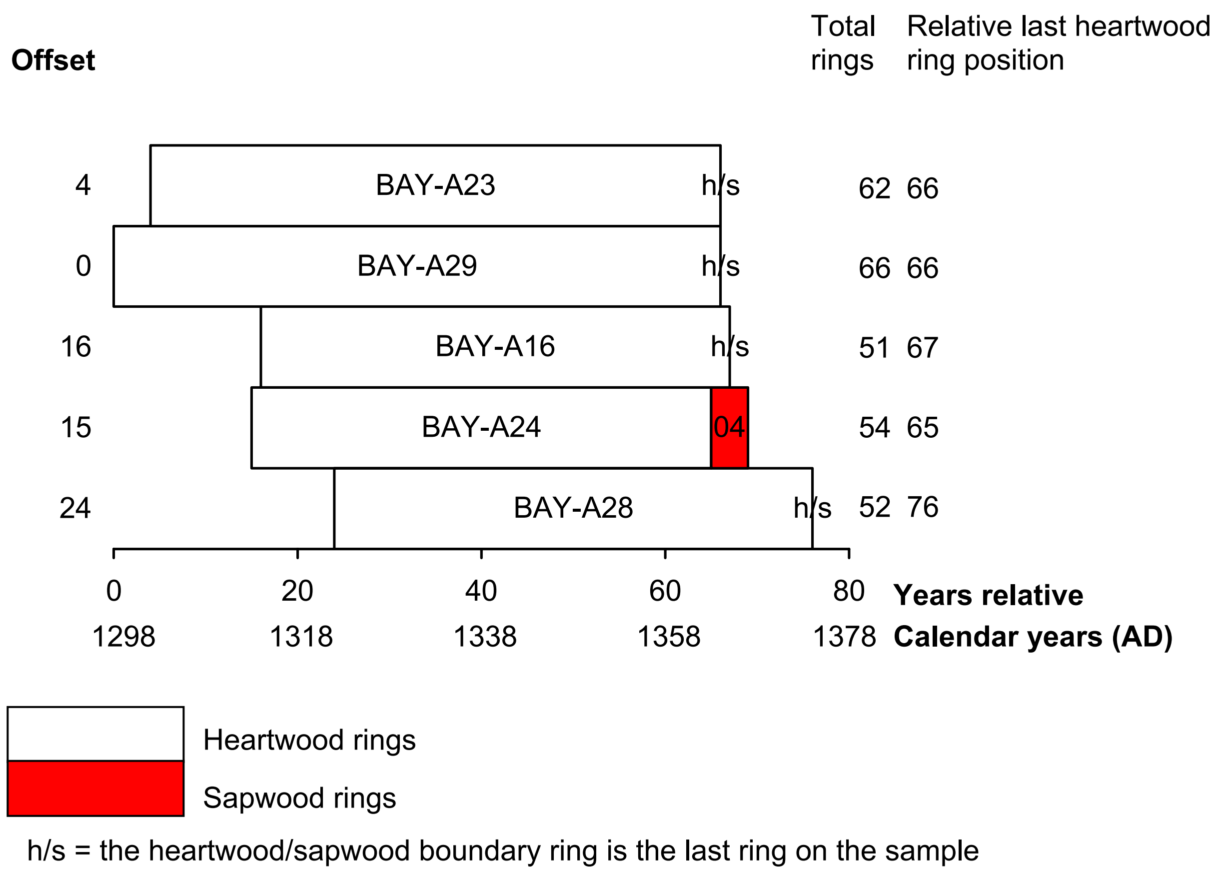


Figure 11: Bar diagram of samples in site sequence BAYASQ01

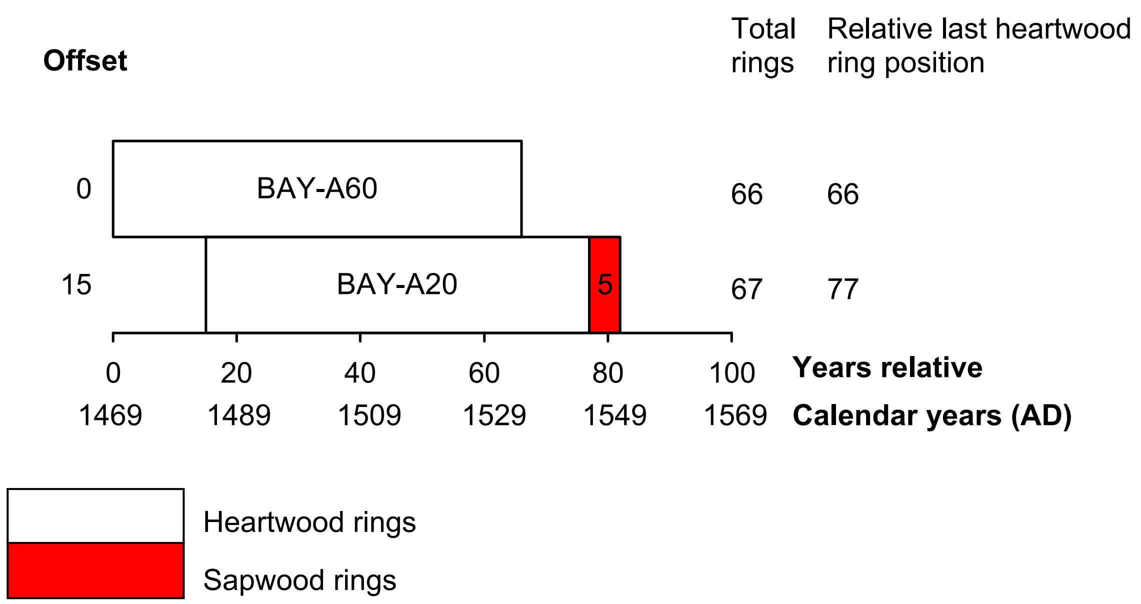
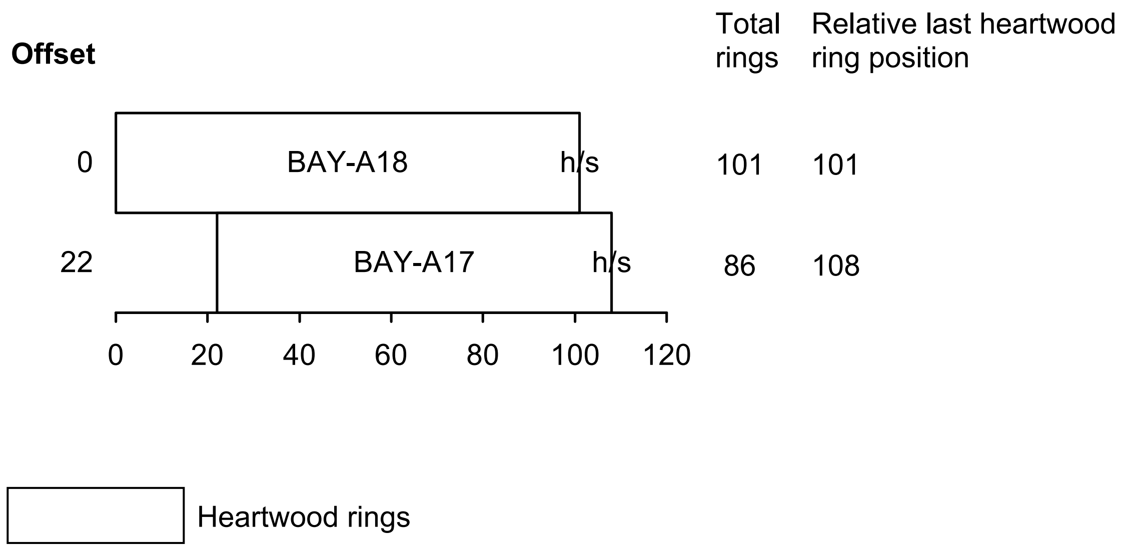
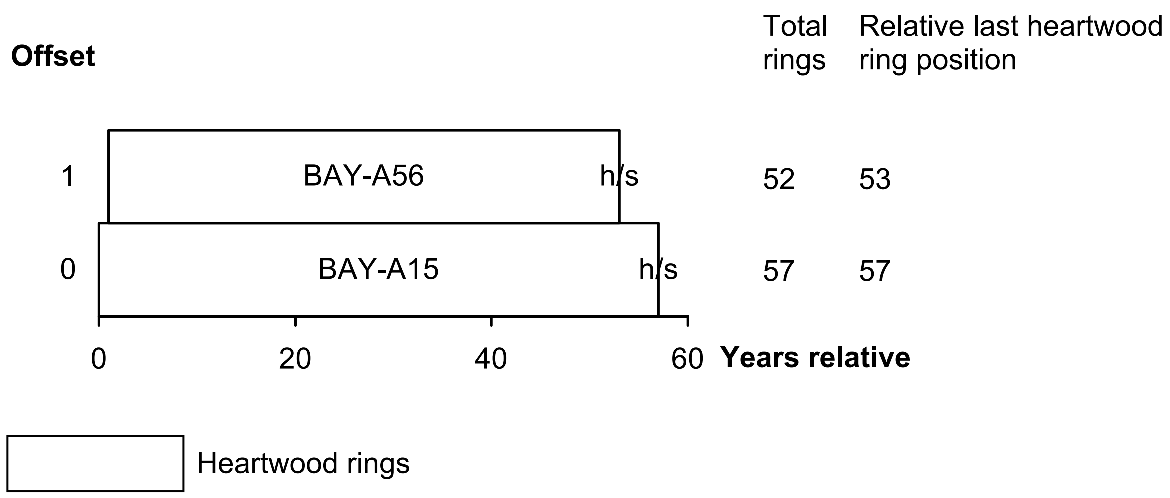


Figure 12: Bar diagram of samples in site sequence BAYASQ02



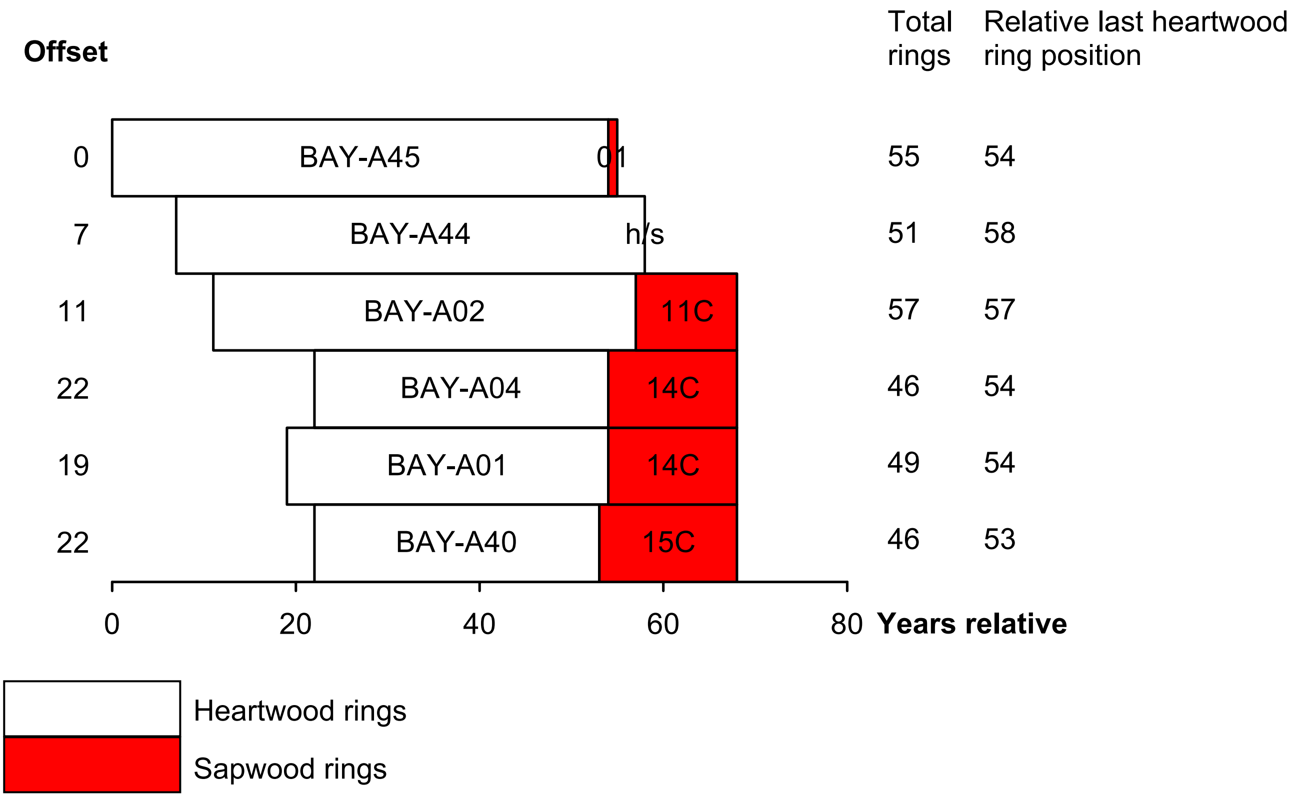
h/s = the heartwood/sapwood boundary ring is the last ring on the sample

Figure 13: Bar diagram of samples in site sequence BAYASQ03



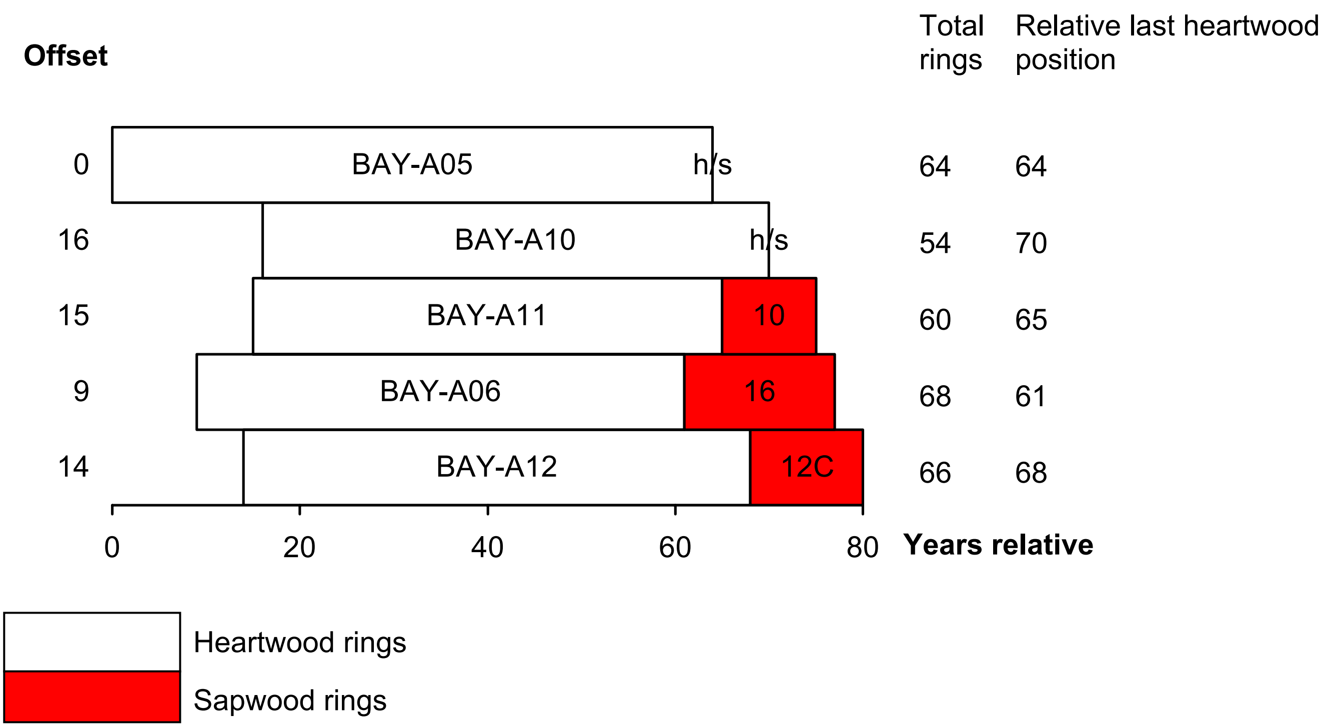
h/s = the heartwood/sapwood boundary ring is the last ring on the sample

Figure 14: Bar diagram of samples in site sequence BAYASQ04



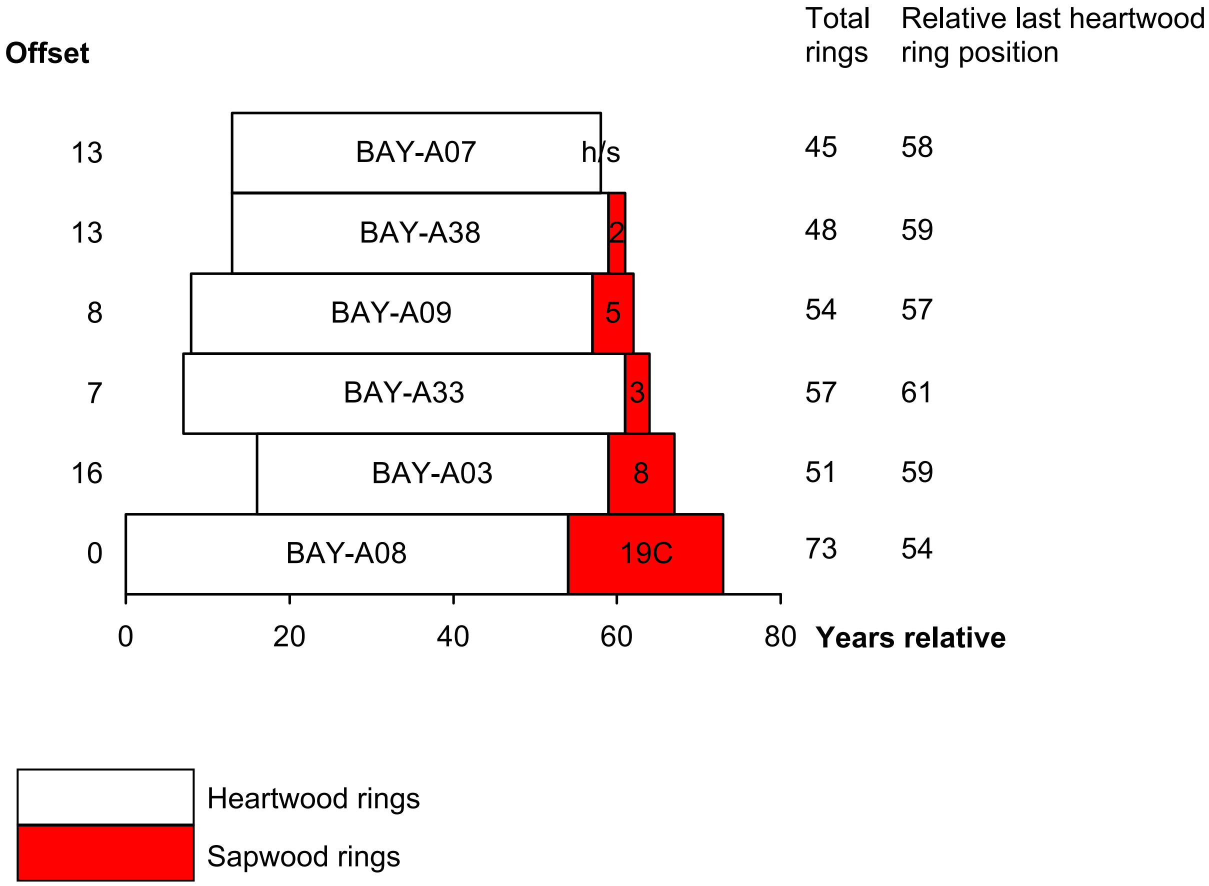
h/s = the heartwood/sapwood boundary ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Figure 15: Bar diagram of samples in site sequence BAYASQ05



h/s = the heartwood/sapwood boundary ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Figure 16: Bar diagram of samples in site sequence BAYASQ06



h/s = the heartwood/sapwood boundary ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Figure 17: Bar diagram of samples in site sequence BAYASQ07

Data of measured samples – measurements in 0.01mm units

BAY-A01A 49
162 247 275 306 331 216 151 115 79 103 111 122 114 100 160 155 212 229 230 194
148 154 193 151 421 368 145 144 115 168 170 178 204 160 225 286 271 235 244 171
81 73 43 46 39 69 74 95 88
BAY-A01B 49
145 244 281 323 315 213 148 108 89 101 113 124 113 96 162 154 209 229 237 195
152 149 195 144 417 367 144 141 114 166 173 175 213 157 232 272 290 235 225 166
86 63 37 57 32 69 69 84 106
BAY-A02A 57
168 135 131 139 173 191 169 186 252 195 200 214 328 191 126 107 76 90 110 156
112 80 108 119 162 182 159 131 88 98 113 83 212 239 116 73 57 104 94 119
127 83 139 147 177 100 313 197 116 132 72 75 83 105 109 127 107
BAY-A02B 57
162 135 130 143 165 187 166 181 250 193 198 211 318 193 120 110 73 84 108 156
110 79 107 116 164 180 157 130 96 88 110 85 212 237 106 79 56 102 83 130
121 87 135 156 165 105 302 203 122 141 63 62 85 111 98 107 111
BAY-A03A 51
247 201 206 174 133 93 120 87 107 124 65 58 210 310 225 172 118 113 116 105
102 117 122 148 182 189 190 198 215 221 216 212 334 457 352 264 218 224 188 193
182 167 176 187 191 204 163 144 152 97 123
BAY-A03B 51
168 211 204 167 127 106 121 93 97 121 59 60 210 322 234 185 129 101 117 107
105 117 131 150 176 189 186 197 220 221 211 217 336 455 350 270 223 213 173 197
194 170 169 192 186 205 163 120 152 100 128
BAY-A04A 46
282 497 317 238 157 134 158 143 159 125 129 150 166 229 220 244 234 204 231 317
235 558 333 116 129 98 140 173 180 193 181 208 252 250 190 226 179 114 84 53
40 50 83 75 111 106
BAY-A04B 46
252 500 321 237 153 127 151 145 166 122 98 133 159 197 212 239 241 201 223 316
226 564 339 118 123 104 143 171 193 196 177 207 260 243 194 226 177 112 82 46
43 51 72 88 105 113
BAY-A05A 64
379 340 225 92 70 75 135 201 179 293 184 310 266 168 156 252 255 184 185 195
221 161 108 69 54 73 50 56 60 73 121 206 342 167 184 246 135 144 139 91
79 96 91 120 270 187 151 148 179 190 194 139 92 81 149 112 112 78 67 55
72 105 121 116
BAY-A05B 64
413 343 219 88 69 86 163 216 178 289 182 318 271 178 150 253 241 177 186 190
249 161 101 81 63 69 56 59 43 81 127 205 345 163 189 232 139 145 144 88
81 92 91 113 273 191 157 148 184 180 188 141 87 90 147 109 110 72 70 57
63 108 124 117
BAY-A06A 68
335 233 404 303 166 179 335 246 214 218 218 250 137 86 69 52 60 61 69 87
141 251 284 313 152 151 159 99 85 106 55 47 50 45 53 117 122 90 83 100
128 125 119 83 87 178 164 222 176 137 131 127 179 159 125 86 81 88 99 98
92 67 96 113 112 57 124 92
BAY-A06B 68
359 240 447 314 182 166 342 256 205 242 199 249 145 90 68 59 59 64 66 78
155 254 287 323 148 138 138 98 88 103 51 58 45 40 53 125 112 82 77 105
128 115 125 79 85 189 151 221 171 142 134 135 178 160 127 95 87 86 107 97
83 71 96 112 130 54 116 86

BAY-A07A 45
409 479 459 281 234 170 169 200 155 148 164 141 189 77 87 198 239 131 123 123
102 111 75 68 77 60 69 77 86 108 130 130 132 185 118 233 352 251 244 150
137 121 146 117 137
BAY-A07B 45
369 475 480 287 244 170 151 219 156 146 146 148 190 78 78 200 248 149 109 129
102 114 77 67 59 73 69 80 86 104 129 127 141 181 134 227 353 251 256 150
129 127 146 128 129
BAY-A08A 73
194 288 264 163 248 220 178 153 165 150 139 157 162 197 160 159 197 176 225 178
256 270 311 305 315 354 197 167 253 269 264 213 165 196 218 239 173 247 244 255
269 261 223 205 180 169 218 144 237 172 130 134 113 125 171 154 115 126 131 143
175 165 141 162 97 74 61 36 57 60 75 89 95
BAY-A08B 73
186 300 271 204 207 224 173 161 163 148 145 152 167 193 157 164 192 189 234 177
255 279 307 302 319 345 185 166 263 253 271 219 173 184 240 229 188 261 229 282
258 284 209 194 179 191 213 151 240 182 121 138 114 127 168 154 111 138 121 123
170 177 128 162 95 84 56 50 60 55 86 78 104
BAY-A09A 54
278 317 219 299 272 252 241 336 294 245 181 120 110 75 79 68 96 120 108 118
190 295 214 194 159 160 163 116 111 109 126 129 109 129 119 121 135 123 123 120
184 215 167 209 164 146 181 179 175 177 196 180 228 174
BAY-A09B 54
271 308 222 337 277 255 240 336 290 254 176 121 112 85 77 60 106 124 109 126
181 307 205 197 158 165 169 128 107 118 138 123 125 134 135 128 144 143 134 145
179 204 170 204 167 154 190 171 176 171 203 185 230 180
BAY-A10A 54
261 283 314 299 241 116 86 73 62 73 70 70 81 105 105 158 236 93 95 119
84 99 90 74 57 71 50 64 145 146 128 108 153 230 235 191 160 135 154 108
171 165 151 139 126 185 199 256 220 177 160 169 193 151
BAY-A10B 54
227 280 304 270 236 120 101 65 65 66 60 70 77 106 112 146 221 92 94 115
93 100 106 66 63 62 60 65 142 163 138 121 165 238 229 191 138 147 155 130
161 159 153 142 128 176 184 249 234 172 183 164 188 184
BAY-A11A 60
183 275 227 206 210 294 195 234 163 148 131 114 122 109 161 158 203 317 198 220
214 127 129 117 79 87 69 60 73 151 121 91 93 98 96 109 109 97 88 151
139 145 132 137 106 105 157 162 155 90 100 113 113 128 98 69 99 106 86 64
BAY-A11B 60
195 275 229 208 211 294 195 233 159 156 120 114 124 111 156 169 197 311 209 211
215 127 120 125 73 84 66 65 79 145 122 91 86 96 95 101 120 93 93 155
148 137 138 124 116 110 157 159 151 108 90 108 117 122 97 72 101 97 108 58
BAY-A12A 66
259 326 219 227 254 236 332 282 134 107 112 76 41 71 57 172 196 228 359 116
129 135 121 106 139 100 100 97 93 111 262 230 226 166 171 228 264 195 130 151
194 181 246 227 224 167 209 258 275 332 229 180 174 242 303 266 130 170 135 111
69 95 97 145 166 162
BAY-A12B 66
278 314 212 224 255 243 324 266 141 112 106 79 45 63 67 179 208 227 342 120
115 142 112 119 131 103 106 87 90 110 255 218 240 166 172 235 255 193 129 147
200 187 258 226 216 182 214 265 258 336 229 190 171 244 292 259 141 178 136 116
74 88 98 137 161 153
BAY-A15A 57
150 97 290 349 221 309 223 273 223 288 319 234 213 214 367 319 249 264 312 214
160 179 224 201 232 176 121 146 157 172 143 131 110 125 112 99 98 75 77 77
95 94 89 82 69 67 52 101 90 78 96 91 64 83 64 78 61

BAY-A15B 57
132 112 245 337 236 325 214 265 218 293 277 221 200 234 366 298 248 256 327 208
161 181 226 201 216 175 111 158 153 173 136 126 106 125 114 94 98 73 75 81
93 90 92 79 62 84 64 97 85 90 85 90 70 80 68 73 68
BAY-A16A 51
228 318 214 215 245 276 277 239 205 213 180 136 131 135 132 151 158 111 134 179
232 206 217 200 211 220 163 134 63 53 79 108 60 54 92 72 86 121 91 115
83 92 93 85 62 97 83 88 84 109 95
BAY-A16B 51
235 317 213 207 236 294 283 242 197 209 157 135 130 125 129 169 143 122 121 189
237 224 211 193 220 215 145 123 66 55 82 101 65 54 90 77 89 116 94 108
88 75 107 71 61 98 79 91 79 103 111
BAY-A17A 86
116 120 120 113 125 107 101 118 128 103 92 112 106 126 131 155 101 124 115 97
109 101 123 124 108 96 91 99 106 123 85 100 67 83 88 93 93 129 100 100
95 118 112 102 105 79 82 86 124 86 63 84 88 78 119 78 90 125 105 88
110 108 111 87 88 105 70 78 91 97 83 79 106 61 66 54 60 89 56 89
72 101 82 73 76 87
BAY-A17B 86
120 120 120 114 127 108 107 110 121 106 91 116 101 121 132 158 102 117 119 97
111 97 127 118 109 98 91 102 107 122 90 92 73 76 97 84 97 129 98 95
88 124 103 107 104 77 82 87 117 85 70 88 79 77 121 74 99 115 109 88
114 109 114 96 83 119 70 78 95 103 80 75 106 62 67 58 58 72 65 97
64 98 97 64 73 73
BAY-A18A 101
84 109 104 103 88 96 89 72 96 79 58 70 61 81 111 87 50 60 60 77
75 67 67 76 95 84 111 88 91 88 100 100 96 118 101 159 149 178 173 125
139 98 127 113 142 149 166 143 129 148 118 154 126 132 121 99 128 101 133 135
109 111 110 134 107 101 105 108 117 118 162 98 68 89 94 75 93 83 81 114
91 87 113 99 110 69 98 121 64 78 111 113 87 93 105 67 71 51 58 74
80
BAY-A18B 101
94 112 101 101 84 98 84 81 97 82 54 69 66 79 102 88 53 51 67 78
81 72 62 86 86 86 113 67 78 83 105 109 93 114 108 150 147 186 162 138
129 98 122 94 162 136 145 143 115 130 129 150 132 126 118 97 109 112 132 138
114 119 95 121 123 84 92 105 120 119 182 94 57 68 77 88 91 74 83 108
100 82 102 92 98 86 90 124 69 71 98 106 100 88 101 60 72 49 59 73
74
BAY-A19A 128
288 357 204 253 240 201 178 166 195 173 163 168 169 205 178 187 171 128 117 123
86 87 112 108 103 150 165 135 128 147 114 107 55 61 67 83 80 68 88 89
94 75 61 61 50 53 51 56 52 69 59 48 32 38 36 29 34 61 43 46
46 52 50 44 29 35 30 28 33 27 41 54 38 44 48 53 49 24 30 32
32 34 18 48 47 45 40 32 35 47 43 45 34 47 53 58 41 51 36 29
35 28 21 36 44 50 59 39 41 40 46 48 46 63 56 55 62 63 77 75
55 40 64 59 58 66 54 50
BAY-A19B 128
294 357 208 254 237 197 174 170 194 159 150 167 177 203 175 192 174 131 116 117
89 89 101 118 106 158 168 139 126 147 109 113 54 54 67 75 84 79 90 81
95 75 66 65 48 48 47 61 52 52 64 37 42 44 30 26 35 63 39 41
48 52 51 45 33 32 31 25 30 27 52 52 33 38 58 48 36 34 24 37
34 35 27 51 37 41 44 37 42 36 44 41 39 48 56 48 42 47 37 35
31 23 36 28 47 57 72 35 45 47 45 37 48 61 54 54 63 64 82 73
56 47 62 59 57 54 58 58

BAY-A20A 67
161 217 236 267 226 200 197 158 157 193 223 193 239 217 155 161 151 191 180 167
166 223 160 146 155 136 142 149 175 174 158 167 142 104 155 171 139 136 194 127
193 158 200 153 170 139 153 202 209 173 130 146 130 131 126 135 133 156 101 144
153 166 107 127 100 128 129
BAY-A20B 67
160 214 235 267 227 211 198 173 164 184 231 177 253 210 159 161 161 187 179 169
163 186 166 145 141 143 144 148 173 178 163 164 148 107 159 171 142 150 180 137
193 153 200 167 170 133 160 208 217 164 147 130 139 133 134 128 129 161 114 133
156 154 113 123 93 112 90
BAY-A21A 92
277 361 239 142 155 115 86 80 63 70 69 44 60 56 34 38 36 72 90 147
122 83 89 66 48 42 45 111 124 97 76 84 105 70 45 82 86 131 100 121
166 207 155 152 119 180 187 174 153 131 132 208 167 139 96 67 54 97 75 46
41 30 45 47 59 69 141 117 168 67 34 59 73 83 62 140 118 85 47 58
56 48 45 24 33 31 44 33 34 44 37 40
BAY-A21B 92
270 342 234 145 154 116 81 73 67 64 85 46 56 59 37 29 33 78 86 152
91 80 84 70 57 34 76 117 138 82 61 93 95 85 65 112 82 127 110 109
164 205 165 156 120 184 185 178 155 133 126 211 172 142 96 59 66 75 83 50
45 29 49 46 48 70 142 124 166 64 39 63 63 88 49 139 111 86 48 61
55 44 51 28 29 27 36 40 48 38 31 33
BAY-A23A 62
212 135 150 202 256 461 460 277 273 288 330 282 289 349 236 202 155 164 153 144
138 151 154 151 171 168 182 181 122 98 144 151 182 200 189 159 167 148 135 123
114 66 90 107 66 82 103 93 90 160 122 157 162 124 116 93 76 82 71 94
101 106
BAY-A23B 62
185 137 147 198 268 489 471 272 288 283 350 280 272 311 250 201 164 174 150 166
143 165 154 146 172 166 181 178 125 90 147 148 170 198 213 155 158 151 144 124
115 67 81 104 61 86 97 100 91 159 129 161 173 115 118 91 77 72 84 94
103 109
BAY-A24A 54
379 411 445 426 250 255 278 264 356 338 359 252 177 120 216 175 202 103 103 137
111 247 200 106 112 201 152 132 99 77 56 74 100 86 107 100 64 98 96 136
121 97 51 87 87 69 87 83 76 88 160 159 98 68
BAY-A24B 54
378 410 446 424 249 257 279 266 353 330 355 251 190 118 217 187 202 97 106 137
109 254 195 109 124 190 153 128 107 69 64 90 90 89 112 94 70 90 106 129
122 104 65 69 100 58 86 79 86 83 158 163 112 80
BAY-A26A 48
279 500 625 244 172 180 203 251 254 336 260 267 249 214 223 291 244 298 149 183
163 146 178 144 264 239 224 278 259 271 215 220 224 146 206 130 407 265 168 318
325 258 309 404 221 241 273 305
BAY-A26B 34
188 206 170 145 161 138 230 231 227 244 213 257 212 206 204 132 214 139 394 279
186 370 357 366 394 423 229 215 248 278 273 280 299 71
BAY-A28A 52
233 270 257 245 235 245 310 331 213 195 198 174 217 207 217 133 167 158 147 129
101 84 126 130 110 126 141 86 121 183 152 134 84 117 148 99 119 141 168 172
123 188 202 166 140 126 158 139 101 87 158 162
BAY-A28B 52
229 271 248 245 247 277 293 320 207 195 222 179 247 182 199 130 167 159 137 145
108 72 150 150 104 133 133 103 111 173 144 142 94 103 140 125 103 145 155 167
136 180 205 157 148 118 159 128 107 83 170 145

BAY-A29A 66
555 444 433 480 346 356 362 367 328 396 454 353 315 251 253 235 214 218 168 160
143 148 128 153 135 163 136 106 93 122 125 154 133 88 87 113 147 147 137 116
142 210 129 113 76 64 98 107 62 101 134 94 118 113 91 149 122 73 104 120
56 55 69 78 67 128
BAY-A29B 66
557 445 401 462 352 337 363 350 320 403 428 328 304 250 233 249 207 221 170 180
134 147 127 146 145 161 139 106 100 117 125 160 139 84 93 116 153 149 145 113
142 208 126 113 73 65 93 111 60 103 138 90 112 115 97 154 126 81 107 104
57 65 66 75 58 130
BAY-A30A 211
74 38 84 151 174 224 146 157 113 88 138 118 135 141 80 124 93 81 122 118
99 66 75 93 73 69 67 78 87 47 55 78 127 73 84 58 72 49 79 65
101 84 82 69 65 64 82 111 55 97 79 79 82 95 85 84 71 65 77 56
51 65 43 39 38 47 54 68 56 60 58 66 55 68 69 65 87 78 90 59
65 72 49 42 41 31 42 62 75 46 48 47 44 35 48 75 56 68 67 68
80 63 60 83 70 53 65 51 56 73 63 71 61 63 66 56 55 56 57 83
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81 97 133 85 72 83 81 83 83 69 80 94 107 121 73 107 104 114 161 100
123 123 101 93 97 102 97 108 98 75 102 92 99 98 103 82 101 118 81 114
114 139 114 113 102 113 107 103 81 77 78 97 119 97 118 119 108 108 80 70
59 86 77 113 96 122 87 97 91 76 93
BAY-A30B 211
87 32 75 156 156 236 146 136 124 95 129 119 140 136 74 132 88 85 114 113
108 61 80 84 73 73 71 73 90 46 64 81 123 82 74 58 76 58 82 66
104 79 86 72 68 65 75 102 67 85 83 77 73 89 79 78 85 65 78 54
54 63 54 36 39 44 49 71 57 65 52 66 54 67 72 64 84 80 91 62
60 68 60 34 33 30 48 67 70 56 45 45 46 46 37 70 65 67 75 68
78 51 66 83 71 57 64 54 51 75 57 65 68 65 63 51 60 53 56 67
69 62 59 79 73 76 71 70 73 82 109 98 97 124 83 82 73 92 63 99
87 106 129 74 66 100 69 76 73 57 82 79 95 112 85 97 93 109 146 99
130 117 97 94 82 105 75 115 109 63 112 102 119 89 105 72 91 110 75 126
113 115 120 111 100 105 103 119 72 81 70 102 107 103 106 120 120 107 85 66
61 86 80 102 99 109 96 87 86 76 96
BAY-A31A 77
157 135 134 132 100 147 169 168 176 155 182 141 170 126 161 116 210 200 139 193
158 167 192 179 109 113 119 101 102 113 177 178 195 135 118 116 127 114 146 103
114 149 85 97 135 141 190 159 212 224 175 210 197 137 169 112 116 153 164 191
180 188 171 134 154 62 99 95 102 118 138 159 188 120 148 115 98
BAY-A31B 77
154 134 135 126 102 151 168 167 173 157 178 143 169 129 159 115 211 194 142 186
162 174 192 171 114 114 118 100 101 119 179 177 202 126 119 122 123 118 143 104
124 155 72 107 144 143 172 141 201 237 164 219 188 136 166 123 109 152 162 197
177 183 160 140 154 70 110 86 106 110 138 158 177 146 144 107 105
BAY-A32A 68
350 399 293 346 310 245 309 326 229 321 250 261 380 267 295 290 104 126 150 152
163 116 153 112 97 83 112 121 118 80 77 55 64 90 61 64 48 54 48 47
42 40 42 45 30 31 38 28 28 37 64 52 60 66 57 86 40 40 60 54
57 69 100 82 64 55 52 46
BAY-A32B 68
349 401 287 347 312 247 302 316 216 314 260 252 377 272 287 289 108 121 148 149
171 124 153 105 104 77 114 126 122 81 62 65 62 96 51 64 46 59 48 48
48 44 26 46 32 36 43 23 24 39 65 51 62 68 51 98 32 38 63 58
49 71 106 76 71 45 65 50

BAY-A33A 57
164 172 115 139 186 113 204 167 240 208 128 87 51 45 27 37 58 111 139 70
104 223 310 182 137 118 129 145 180 132 170 152 211 265 299 286 254 225 217 280
174 219 230 169 227 162 205 230 246 298 225 222 257 313 288 208 161
BAY-A33B 57
169 164 127 146 183 113 210 166 238 206 133 90 52 44 28 40 62 107 139 73
103 219 309 188 135 116 125 153 173 138 164 155 206 268 314 295 252 224 217 277
174 231 239 170 219 166 202 237 243 298 209 213 238 305 266 229 199
BAY-A34A 55
147 179 159 161 114 141 143 120 178 130 149 105 90 68 54 35 34 30 66 140
177 93 106 164 200 196 148 123 112 131 129 123 145 178 163 229 237 288 314 216
213 310 217 329 385 284 265 201 202 207 214 191 151 141 197
BAY-A34B 55
145 195 156 168 108 150 141 126 182 120 167 105 95 63 57 36 41 26 59 142
169 93 107 163 203 192 148 129 110 139 123 124 144 177 162 231 233 295 310 214
223 301 223 331 392 281 269 199 201 210 215 189 163 150 206
BAY-A38A 48
331 404 266 177 167 107 73 81 75 95 94 167 168 108 92 196 283 248 270 188
181 197 186 132 162 172 162 185 210 227 229 165 105 138 114 223 500 251 243 136
125 141 152 198 218 209 137 174
BAY-A38B 48
260 343 272 173 171 97 71 79 73 99 101 150 159 105 98 182 270 247 266 191
186 190 190 123 161 172 157 191 210 225 223 164 105 129 117 220 488 254 244 137
124 140 154 200 222 214 141 162
BAY-A40A 46
131 525 291 227 184 175 189 161 131 136 118 137 138 148 152 184 145 121 119 159
142 220 299 129 166 162 169 159 177 163 143 164 185 211 171 209 157 99 118 70
59 86 90 127 100 86
BAY-A40B 46
71 564 296 223 187 179 191 164 133 133 121 134 143 144 158 178 156 116 143 158
144 219 288 127 158 166 175 163 166 165 131 168 187 211 169 208 158 98 110 75
57 84 99 123 107 81
BAY-A43A 48
131 451 256 269 283 201 163 149 168 153 132 142 276 210 162 127 95 103 93 115
137 141 179 251 178 241 241 255 242 156 121 139 131 126 94 92 130 171 173 206
183 141 144 197 233 129 253 242
BAY-A43B 48
137 450 259 268 277 201 168 132 167 146 130 142 273 207 162 121 101 89 107 118
128 138 196 252 186 234 249 259 236 153 131 141 131 119 101 82 133 167 170 201
189 140 150 195 220 135 266 258
BAY-A44A 51
219 315 450 251 230 159 120 158 142 132 163 206 216 245 243 227 287 268 223 248
262 295 278 199 157 154 152 231 221 272 253 258 169 183 250 154 288 378 208 244
218 239 288 234 302 238 241 265 315 340 220
BAY-A44B 51
222 316 465 262 226 159 127 146 133 141 167 222 224 269 280 251 285 263 218 253
266 292 280 199 156 148 165 221 236 259 249 258 172 179 254 155 285 375 213 243
222 234 285 235 305 238 228 274 316 348 210
BAY-A45A 55
201 234 292 237 193 225 248 237 274 238 119 110 98 71 82 110 109 111 120 135
186 215 208 263 270 201 160 207 250 235 138 192 155 169 249 178 219 197 192 147
164 286 132 307 361 143 144 91 117 117 166 224 106 164 189
BAY-A45B 55
214 226 301 235 210 208 227 231 264 238 121 126 87 84 87 109 115 106 118 122
187 207 204 272 270 191 163 208 256 221 148 191 157 163 245 178 218 202 198 146
166 272 140 311 361 144 131 99 126 110 165 222 110 162 209

BAY-A48A 57
130 110 176 176 136 185 246 233 211 217 223 151 315 205 135 170 210 184 119 191
174 217 199 272 287 233 267 238 251 224 134 127 99 120 156 167 197 191 168 187
182 233 211 184 263 227 209 173 135 138 100 127 171 200 144 175 161
BAY-A48B 57
157 108 168 161 134 185 237 223 214 215 202 157 300 204 134 151 226 180 121 197
177 216 197 271 257 210 259 256 263 252 163 128 94 125 161 178 216 197 179 175
181 220 202 200 269 231 210 178 131 142 103 133 167 202 140 178 153
BAY-A49A 140
126 130 134 106 113 123 71 95 92 120 142 119 61 60 84 86 127 176 172 133
112 125 104 82 36 54 30 51 48 53 55 54 47 46 43 36 34 33 29 40
58 58 54 93 53 54 45 51 56 46 53 42 47 36 60 50 40 72 47 56
72 45 55 57 57 62 63 51 34 51 50 59 42 59 36 44 51 71 68 50
58 40 38 40 46 38 41 61 55 50 47 40 45 43 49 56 62 93 77 51
48 40 60 71 62 70 68 41 57 62 40 55 49 47 40 41 34 51 59 58
58 58 57 50 34 39 61 50 81 80 74 103 65 110 122 107 123 121 134 99
BAY-A49B 140
139 123 131 108 112 123 71 102 94 114 145 114 66 59 76 94 122 176 172 131
116 122 103 70 43 56 38 40 39 62 54 46 51 54 40 23 29 38 35 44
48 59 54 93 58 56 45 55 61 49 58 46 38 46 51 50 41 72 59 68
65 42 51 56 58 62 61 46 37 50 54 54 34 52 44 39 48 81 74 59
55 47 32 42 46 41 37 61 57 49 51 33 49 43 53 55 61 87 80 50
44 46 63 67 58 62 66 48 51 68 48 48 54 45 43 45 39 46 64 55
59 65 51 55 38 43 61 49 71 90 87 96 76 102 121 105 127 132 133 116
BAY-A50A 53
210 258 269 271 292 278 297 304 183 220 314 157 156 172 127 158 170 155 147 126
162 148 154 168 102 119 107 92 61 110 95 60 100 108 101 94 155 117 119 62
88 58 61 62 54 40 65 46 59 40 51 48 65
BAY-A50B 53
194 256 263 267 286 274 299 306 184 210 337 170 166 192 121 167 184 153 131 112
163 143 161 160 103 131 92 96 65 112 80 69 96 110 103 100 166 119 112 67
82 62 67 56 54 45 64 56 50 36 46 47 79
BAY-A51A 90
152 165 125 141 150 156 177 210 164 153 162 158 161 212 198 196 210 197 140 169
183 171 130 199 232 176 172 167 160 164 196 130 82 190 132 133 135 163 181 281
240 194 184 117 62 67 58 79 99 104 148 144 93 80 89 82 56 60 77 61
87 72 54 57 62 84 87 92 68 76 82 67 100 87 87 83 76 75 52 40
51 58 89 53 63 51 53 66 72 86
BAY-A51B 90
139 177 125 138 158 152 184 199 165 157 166 156 162 201 198 197 203 189 135 179
184 172 123 195 232 187 159 160 160 158 195 128 85 192 133 131 130 159 196 273
244 208 169 118 67 68 59 79 100 102 141 143 94 82 86 83 47 68 71 70
85 76 55 58 62 82 90 91 70 76 84 68 101 83 87 76 75 69 53 43
57 58 95 56 61 53 59 56 75 95
BAY-A54A 49
269 359 256 325 233 251 214 193 218 187 223 208 282 261 206 183 231 158 139 163
154 150 128 169 145 130 133 133 159 108 135 157 121 183 132 88 103 129 89 168
123 136 140 161 129 190 140 80 39
BAY-A54B 49
277 356 262 329 225 229 199 215 211 183 219 208 281 256 204 186 216 159 147 170
158 145 131 157 143 138 126 134 156 107 138 167 119 189 142 95 112 118 113 180
129 135 136 162 117 197 138 91 39
BAY-A56A 52
340 528 455 294 299 202 321 329 274 260 155 73 164 315 339 283 384 404 291 191
205 310 253 305 208 126 181 215 188 219 231 222 216 229 155 144 98 63 92 91
79 115 86 82 84 48 69 79 85 83 82 49

BAY-A56B 52
291 520 454 300 293 211 302 321 297 254 147 72 168 305 340 284 366 407 279 182
195 311 248 310 208 125 183 211 187 218 227 216 214 217 155 127 92 64 80 84
77 112 78 85 81 78 60 76 72 66 76 41
BAY-A57A 82
117 96 89 67 81 122 137 108 116 154 116 105 125 101 115 65 71 61 74 60
74 81 114 93 97 108 102 109 98 125 116 98 95 121 105 92 155 126 110 92
91 116 122 104 110 78 60 64 72 63 89 85 72 77 68 79 83 93 89 65
53 55 61 73 76 72 72 66 39 36 55 66 51 61 91 69 113 112 61 55
91 80
BAY-A57B 82
122 93 92 64 84 111 147 107 114 153 125 102 123 112 109 59 64 61 68 62
73 83 116 95 108 96 103 109 101 127 111 93 101 111 112 89 153 125 110 93
93 116 117 107 106 82 55 64 65 67 92 73 85 80 62 88 79 98 83 71
46 58 71 56 88 65 78 70 36 39 52 71 54 59 77 78 115 107 66 56
94 69
BAY-A58A 61
122 155 178 198 164 292 304 204 123 143 160 226 241 244 180 136 145 185 226 241
205 236 182 143 112 129 175 150 118 102 129 124 142 123 116 136 98 91 103 73
51 59 57 66 66 57 66 52 62 87 114 96 64 55 75 69 45 52 44 69
62
BAY-A58B 61
125 157 178 201 169 292 304 205 125 142 160 233 236 244 177 136 152 185 226 255
202 226 174 149 121 124 168 165 105 109 130 120 148 132 114 131 111 98 96 74
65 56 55 76 66 59 79 58 62 88 110 103 67 49 77 72 39 54 63 53
75
BAY-A59A 80
373 368 273 264 218 184 171 168 163 180 138 167 140 152 225 306 217 169 162 146
204 207 221 152 103 111 167 108 110 71 129 100 114 130 111 76 93 123 134 72
88 40 61 83 51 46 68 75 44 93 118 65 45 72 65 50 37 38 45 53
38 41 41 32 56 46 34 34 22 44 35 39 48 52 57 46 38 27 28 24
BAY-A59B 80
384 358 274 258 206 187 173 154 162 180 121 162 132 155 213 306 234 166 162 146
201 205 221 148 99 112 172 106 108 71 120 108 116 123 111 75 86 128 118 81
78 45 57 76 52 46 68 70 37 95 108 67 53 73 65 52 47 37 43 53
27 53 34 38 50 44 36 31 25 37 37 40 46 57 50 40 26 33 30 26
BAY-A60A 66
299 246 210 228 152 213 252 211 165 132 212 263 242 153 187 253 195 171 164 205
178 181 144 128 167 182 150 163 146 121 149 121 131 110 109 145 171 137 148 153
149 152 136 114 137 119 129 114 118 181 166 159 177 191 119 149 165 212 151 166
126 176 192 142 142 112
BAY-A60B 66
302 238 210 240 147 213 250 203 153 130 239 273 231 161 188 254 189 181 164 194
185 171 145 120 159 176 144 165 156 124 151 130 131 120 101 142 174 143 150 149
171 156 144 117 134 107 116 115 104 163 183 158 170 190 123 152 181 210 157 142
148 175 194 148 129 109
BAY-A62A 67
151 253 183 107 105 138 82 102 54 101 81 57 66 105 65 80 77 83 107 117
131 127 164 183 164 172 177 202 169 199 339 265 173 227 154 178 255 220 190 122
128 118 129 136 122 162 174 174 161 140 159 113 119 129 164 113 116 116 108 120
147 212 348 290 237 219 163
BAY-A62B 67
151 242 185 110 109 131 84 101 66 94 86 49 57 109 75 74 66 90 96 125
134 118 155 183 170 166 191 211 160 203 331 254 167 230 155 175 266 219 180 128
117 113 130 136 112 138 164 174 176 145 167 117 110 134 170 97 122 118 116 124
151 198 344 308 234 224 163

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building'* (Laxton and Litton 1988) and*, Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 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 1, 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 2 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 to 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 2; it is about 15cm long and 1cm 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 1: 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 2: Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Figure 3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure 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 4: 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 2. 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 3).

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 4). 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 5 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 5. 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 5 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 straight forward 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. Actually it could be the year after if it had been felled in the first three months 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 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 Fig 6 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 Fig 6. 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 Fig 7. 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

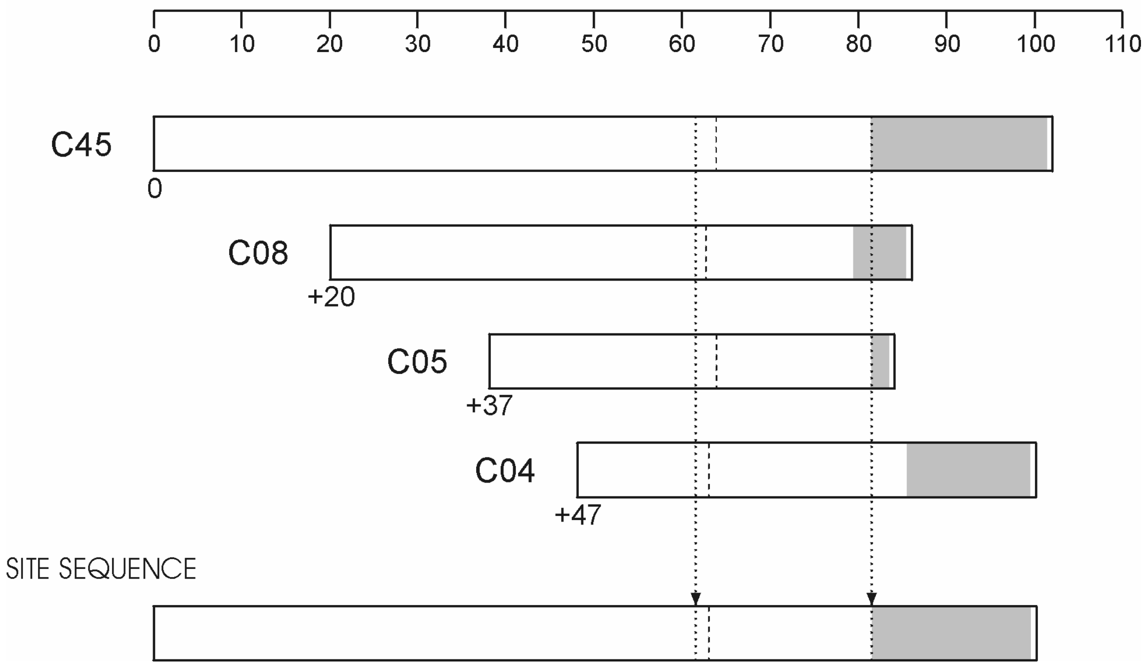


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

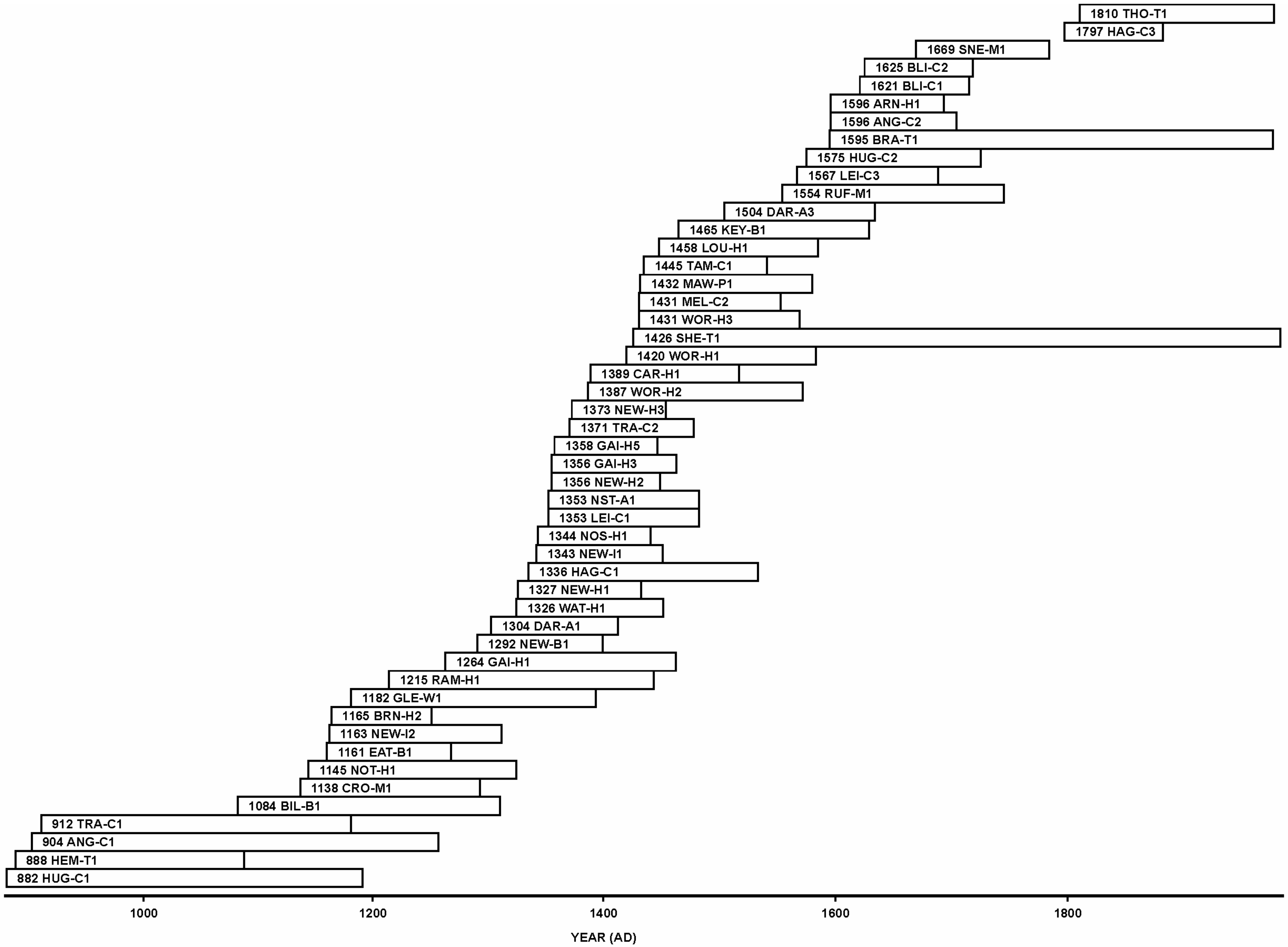
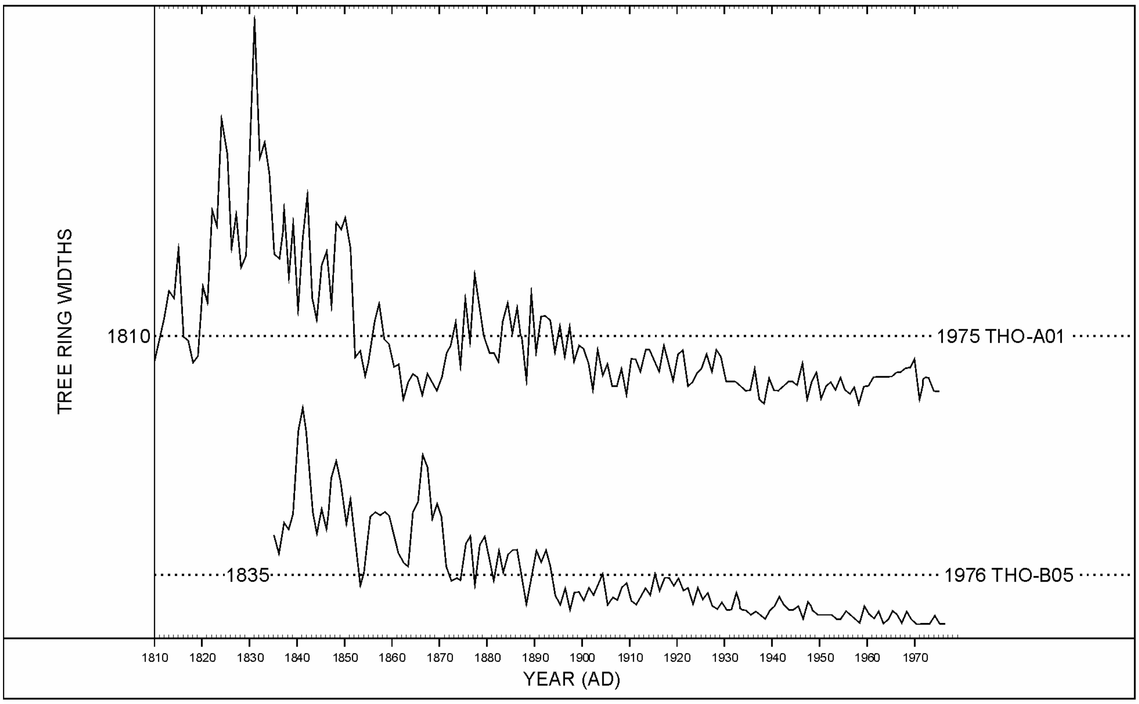


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

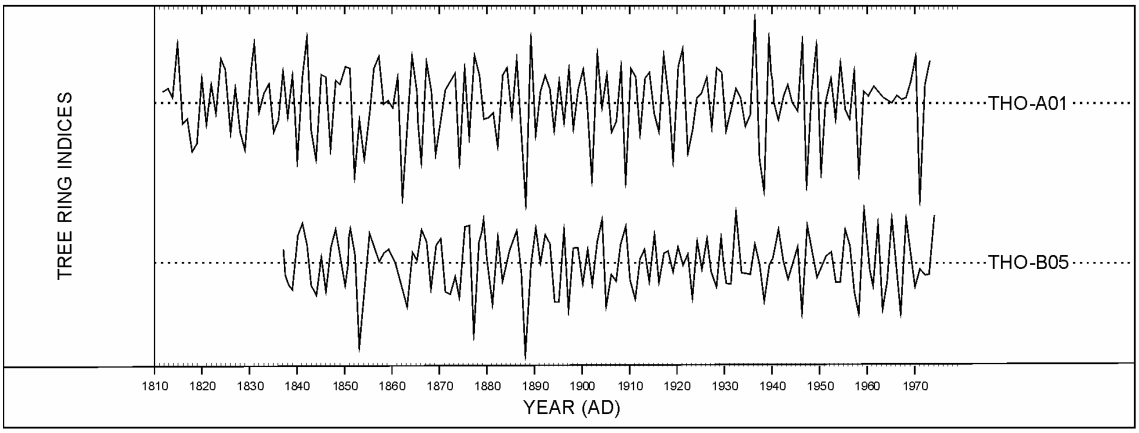


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Figure 7 (b): The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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