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# Fair View, 11 West Street, Dunster, Somerset

## Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard and Cathy Tyers


Scientific Dating

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# Summary

Tree-ring analysis undertaken on the roof of the front range of this property resulted in the successful dating of three timbers. All three timbers are broadly coeval and date to the second half of the fourteenth century but are not necessarily the product of a single felling event. Three other timbers appear to be coeval but remain undated, as do the remaining ungrouped samples.

## Contributors

Alison Arnold, Robert Howard, and Cathy Tyers

## Acknowledgements

This property was one of a series included in the Early Fabric in Historic Towns: Early Dunster project and we would like to thank the owner for kindly agreeing to sampling being undertaken. Mary Ewing, of the Somerset Archaeology and Natural History Society (SANHS) Historic Buildings Committee, is thanked for arranging access and supplying background information and drawings used in the report, these resulting from the research and survey work undertaken by Mary and the volunteer members of the SANHS West Somerset Building Research Group (WSBRG). Thanks, are also given to Shahina Farid (Historic England Scientific Dating Team) for commissioning this work and for her advice and assistance throughout the production of this report and to Rebecca Lane (Historic England Senior Architectural Investigator) who coordinated this project.

## Front cover image

The front elevation of Fair View, 11 West Street. [© Historic England. Photograph Alison Arnold]

## Archive location

Historic England, The Engine House, Fire Fly Avenue, Swindon, SN2 2EH

## Historic environment record

Exmoor National Park Historic Environment Record, Exmoor National Park Authority, Exmoor House, Dulverton, Somerset, TA22 9HL

## Date of survey/research/investigation

The Early Fabric in Historic Towns: Early Dunster Project was awarded to Somerset Archaeology and Natural History Society (SANHS) in 2017. Buildings for dendrochronology were identified in 2019 and sampled at different properties over the following 5 years (extended due to the COVID pandemic) A dendrochronology assessment was undertaken at Fairview, 11 West Street in 2019, sampled in 2020, with the final report published online in 2025.

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# Introduction

The Early Fabric in Historic Towns: Voluntary Group Projects, funded by Historic England, have been developed in the recognition and acknowledgement of the excellent work being undertaken by local vernacular groups in the study of local architectural trends and fabrics. The project's intention is to encourage this type of study through the provision of support and to facilitate training of more people in building analysis and recording. The local projects were coordinated by Rebecca Lane (Historic England Senior Architectural Investigator).

## Understanding Early Dunster

The West Somerset Building Research Group (WSBRG), under the auspices of the Somerset Archaeological and Natural History Society (SANHS), was set up in 2013 to complement the village studies and other detailed work by the Somerset Vernacular Buildings Research Group which has focussed mainly on the south and east of the county. Whilst there is a corpus of research on Dunster (e.g. Hancock 1905, Lyte 1909, Gathercole 2002; Jordan 2007; Siraut 2023), including reports produced by SANHS Historic Buildings Committee from the 1970s and 1980s on a number of buildings, there has until recently been a relative paucity of systematic research on the extant historic buildings in this substantially intact medieval market town in spite of the apparent extensive survival of early fabric. The *Unearthing Dunster* project, which commenced in 2012 and was undertaken by Time Team Digital Dig Ventures, has significantly enhanced understanding of the origins and development of Dunster, including highlighting the presence of extant medieval fabric in a number of buildings. The Historic England supported *Understanding Early Dunster* project was established by the WSBRG in order to further explore the development of Dunster during the medieval and post-medieval periods through targeted desktop research combined with relevant building surveys, thus enhancing the understanding of the architectural development and the degree of survival of early fabric in Dunster.

The WSBRG identified a number of properties for a programme of comprehensive investigation, this subsequently being increased following the extent of early fabric identified during the initial investigations. Twenty of these properties were assessed primarily for their suitability for ring-width dendrochronology and those found to contain timbers potentially suitable for analysis were sampled. The potential of timbers for radiocarbon analysis and oxygen isotope dendrochronology was also considered during this assessment stage, as well as when ring-width dendrochronology failed to provide secure dating evidence. A limited programme of analysis was undertaken using complementary scientific dating techniques during the *Early Dunster* project but further exploitation of the potential for the use of complementary scientific dating techniques on this challenging material was outside of the aims and objectives of this project.

The results of the *Early Dunster* project will be published in SANHS Proceedings, whilst the reports produced on the historic buildings surveyed as part of this project will be deposited in the South West Heritage Centre and the Exmoor National Park Historic Environment Record. The primary archive reports for each individual building sampled for scientific dating as part of this project are accessible through the Historic England website (https://research.historicengland.org.uk/).

## Fair View, 11 West Street

The Grade II listed Fair View, 11 West Street, (National Heritage List Entry 1057586; https://historicengland.org.uk/listing/the-list/list-entry/1057586), is located in the historic core of Dunster (Fig. 1). The two-storey building is of four bays and is of cross passage plan with hall and inner room fronting on to West Street and an extension to the rear. The main front range is aligned broadly north-east to south-west (north-south for the purposes of this report) running parallel with West Street (Fig. 2). The roof over the main range consists of a true cruck truss (Fig. 3) and jointed cruck trusses (Figs 4–6) with further trusses extending over the adjacent property at 13 West Street. There are remnants of another jointed cruck within the rear extension. Fair View was refronted in the eighteenth century and has later alterations.

 

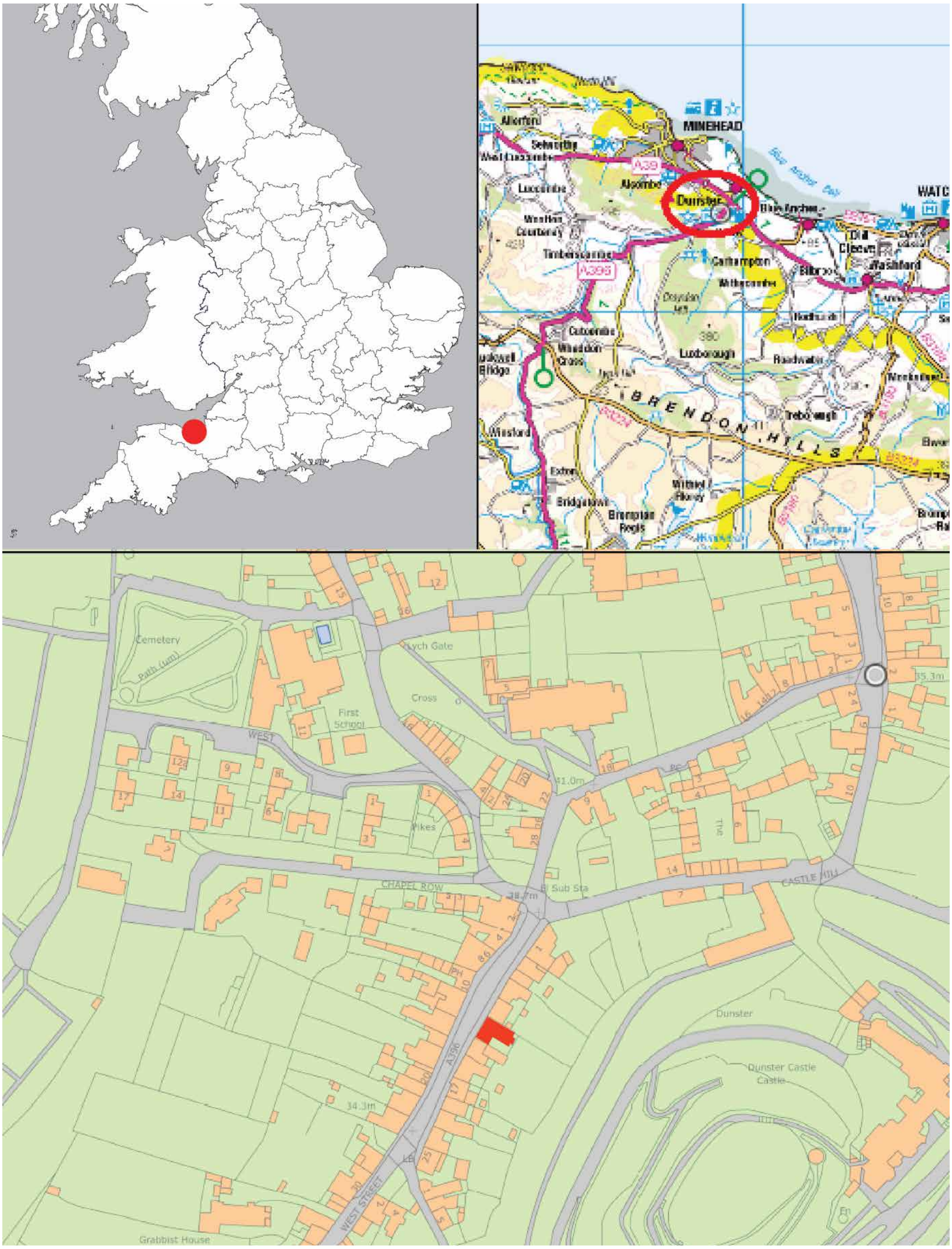


Figure 1: Maps to show the location of Fairview, 11 West Street in Dunster (marked in red). Scale: top right 1:150,000; bottom 1:1,900. [© Crown Copyright and database right 2025. All rights reserved. Ordnance Survey Licence number 100024900]

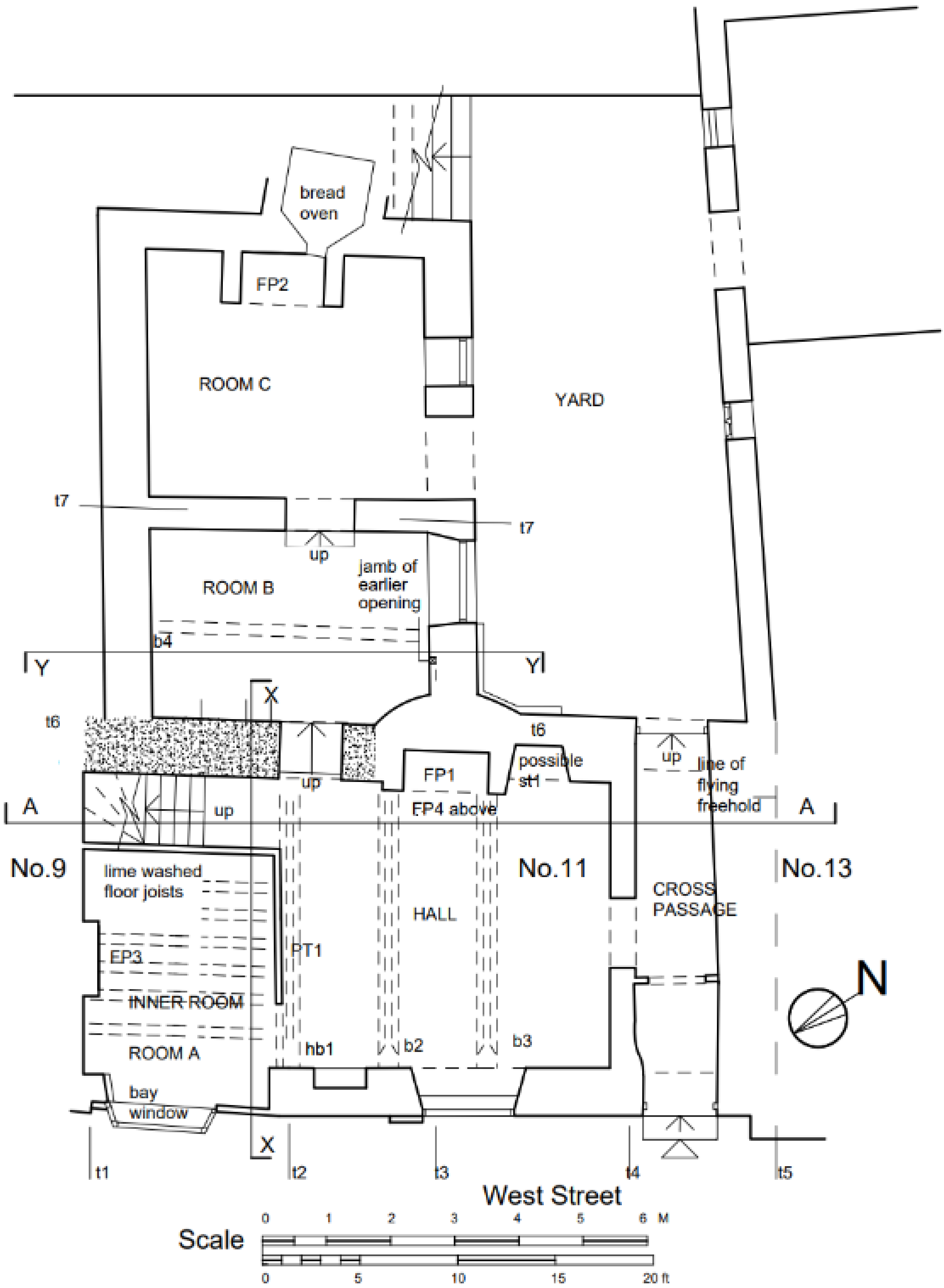


Figure 2: Plan of 11 West Street, showing truss numbering and location of sections. [Somerset Archaeology and Natural History Society]. Trusses are numbered t1–t5 in the main range and t6–t7 in the rear range


Figure 3: T1 is a true cruck. Sampled timber marked DUN-C01, photograph taken from the south. [Alison Arnold]

Figure 4: T2 is a jointed cruck, photograph taken from the north. [Alison Arnold]


Figure 5: T3 is a jointed cruck. Sampled timbers marked DUN-C08 and DUN-C09, photograph taken from the north. [Alison Arnold]


Figure 6: T4 is a jointed cruck truss. Sampled timber marked DUN-C06, photograph taken from the north. [Alison Arnold]

# Sampling

Nine oak (*Quercus* sp.) timbers from the roof over the main range were cored, with each sample being given the code DUN-C and numbered 01–09. Further details relating to these samples can be found in Table 1. The location of sampled timbers has been indicated on Figures 3, and 5–8. Trusses have been numbered from site north to south following the numbering system used by SANHS (Fig. 2). The number of suitable timbers available for sampling was, unfortunately, quite limited, with the timbers of t2 being a mixture of elm and very fast grown oak (as confirmed by sample DUN-C03 having only 33 rings). The cruck blades of t4 and floor beams, previously identified as being of interest, were also found to be of elm and, therefore, unsuitable. Visible timbers in the rear range were positioned in such a way as to prevent appropriate sampling.

Table 1: Details of tree-ring series from Fair View, 11 West Street, Dunster, Somerset

| Sample number | Sample location | Total rings | Sapwood rings | First measured ring date (AD) | Last heartwood ring date (AD) | Last measured ring date (AD) |
|---|---|---|---|---|---|---|
| DUN-C01 | West cruck blade, t1 | 113 | 01 | ---- | ---- | ---- |
| DUN-C02 | East lower purlin, t1–t2 | 121 | h/s | ---- | ---- | ---- |
| DUN-C03 | Middle post, t2 | 33 | -- | ---- | ---- | ---- |
| DUN-C04 | East lower purlin, t2–t3 | 77 | h/s | 1270 | 1346 | 1346 |
| DUN-C05 | East cruck blade, t3 | 126 | -- | 1209 | ---- | 1334 |
| DUN-C06 | Collar, t4 | 90 | h/s | ---- | ---- | ---- |
| DUN-C07 | East cruck blade, t1 | 218 | 47C | ---- | ---- | ---- |
| DUN-C08 | West cruck blade, t3 | 131 | 02 | 1234 | 1362 | 1364 |
| DUN-C09 | Collar, t3 | 126 | h/s | ---- | ---- | ---- |

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

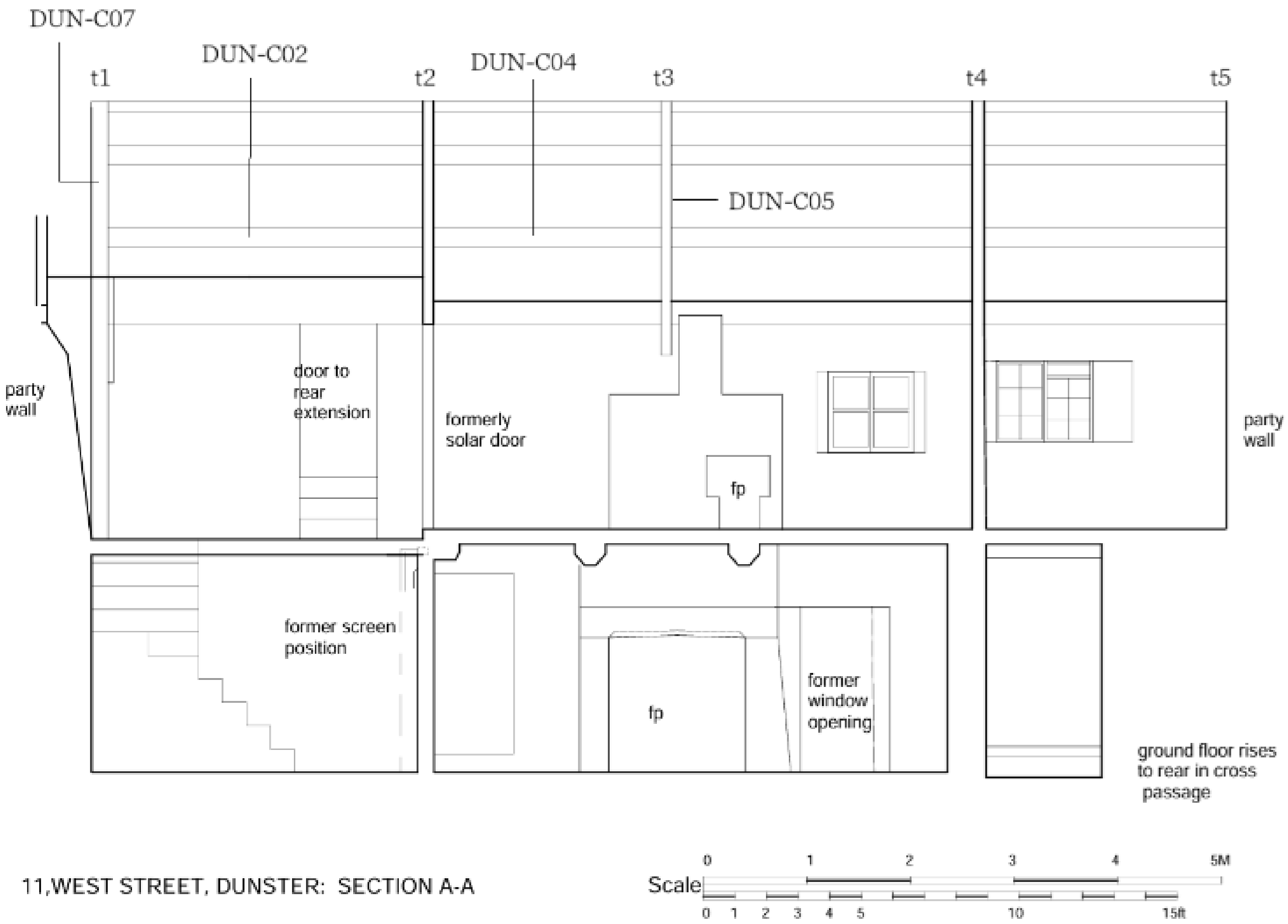


Figure 7: Section A–A, showing location of sampled timbers DUN-C02, DUN-C04–05, and DUN-C07. [Somerset Archaeology and Natural History Society]

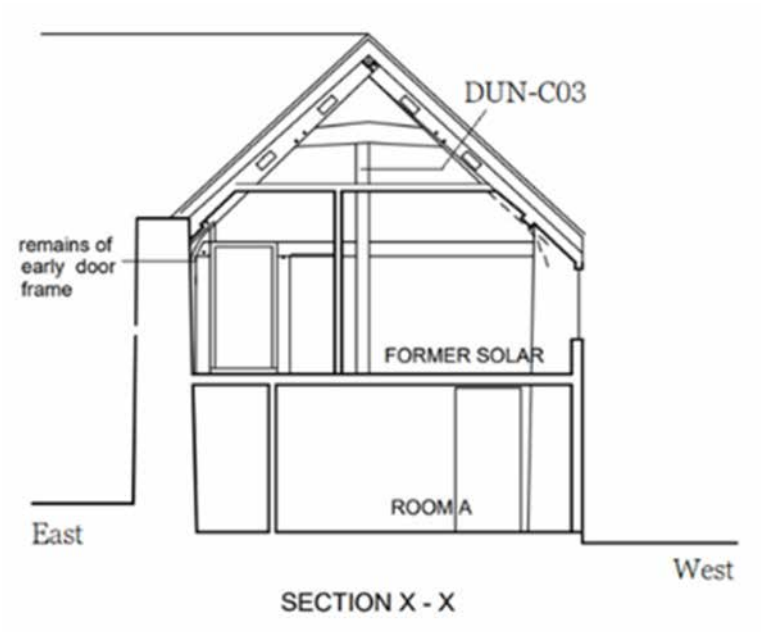


Figure 8: Section X–X, showing the location of sample DUN-C03. [Somerset Archaeology and Natural History Society]

# Analysis and results

As noted above, sample, DUN-C03, taken from the post of t2, only has 33 rings but given samples of this length were measured and formed a site sequence at 3 Mill Lane, Dunster (Arnold et al. 2025) the decision was made to include this sample in the analysis. Additionally, due to problems experienced during sampling (breaking of cores and distorted rings) duplicate cores were taken from the east cruck blades of trusses 1 and 3 and the collar of truss 1 with, in each case, both cores being measured, matched and averaged to maximise the length of growth ring series for these timbers. All 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. All measurements were then compared with each other, by the Litton/Zainodin grouping programme (see Appendix), resulting in samples from six timbers matching to form two groups.

Firstly, three samples matched each other at a minimum *t*–value of 6.5 and were combined at the relevant offset positions to form DUNCSQ01, a site sequence of 156 rings (Fig. 9). This site sequence was compared against an extensive corpus of reference material. It matched consistently and securely at a first-measured ring date of AD 1209 and a last-measured ring date of AD 1364 (Table 2).

Three other samples also matched each other, at a minimum value of $t$ = 7.5, and were combined at the relevant offset positions to form DUNCSQ02, a site sequence of 218 rings (Fig. 10). Comparison of this site sequence, and the remaining ungrouped samples, against the reference chronologies failed to identify consistent and secure dating evidence and thus all remain undated.

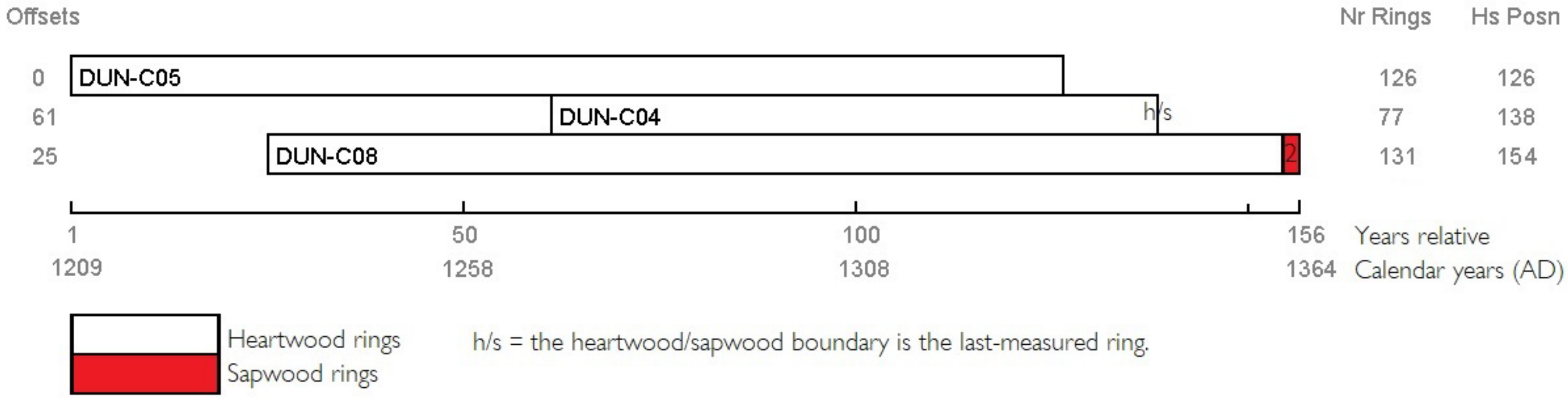


Figure 9: Bar diagram of samples in site sequence DUNCSQ01. Nr Rings = total number of rings; Hs Posn = relative year of heartwood/sapwood boundary

Table 2: Results of the cross-matching of site sequence DUNCSQ01 and example reference chronologies when the first ring date is AD 1209 and the last-measured ring date is AD 1364

| Site reference | | *t* – value | Span of chronology | Reference |
|---|---|---|---|---|
| Exeter Cathedral, Devon | | 7.1 | AD 1132–1337 | Arnold et al. 2003a |
| Muchelney Abbey, Muchelney, Somerset | | 7.0 | AD 1148–1498 | Bridge 2002 |
| The Deanery, Exeter Cathedral, Devon | | 6.5 | AD 1233–1403 | Howard et al. 2000 |
| Kingswood Abbey Gatehouse, Gloucestershire | | 6.5 | AD 1307–1428 | Arnold et al. 2003b |
| Wadhayes, Awliscombe, Devon | | 6.4 | AD 1179–1331 | Tyers et al. forthcoming |
| The Granary, Bradford-on-Avon, Wiltshire | | 6.3 | AD 1167–1360 | Arnold and Howard 2016 |
| Ulverscroft Priory, Leicestershire | | 6.3 | AD 1219–1463 | Arnold et al. 2008 |
| Archdeacons House, Exeter, Devon | | 6.2 | AD 1186–1404 | Howard et al 1999 |
| Thame Park House, Thame, Oxfordshire | | 6.2 | AD 1234–1319 | Howard et al. 1993 |
| Upwich, Droitwich, Worcestershire | | 6.2 | AD 1178–1415 | Groves 1988 |

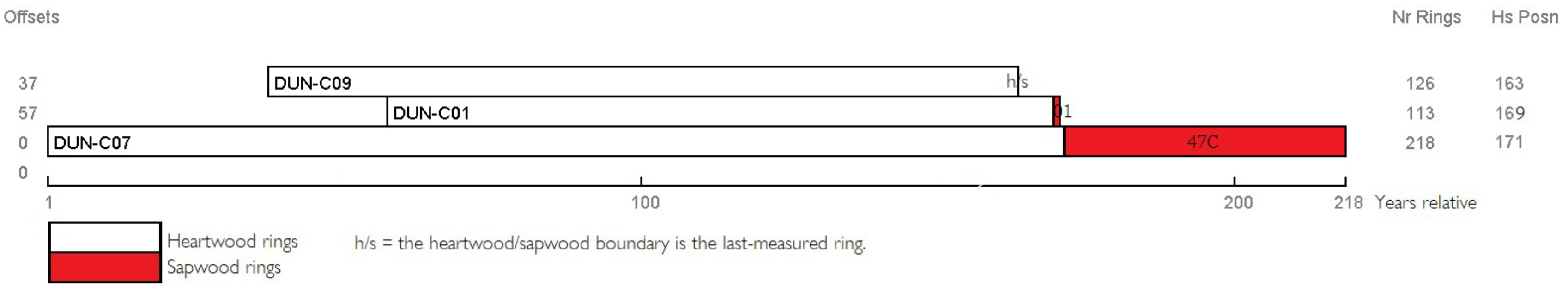


Figure 10: Bar diagram of samples in undated site sequence DUNCSQ02. Nr Rings = total number of rings; Hs Posn = relative year of heartwood/sapwood boundary

# Interpretation

Dendrochronological analysis has resulted in the successful dating of three samples (Fig. 9). Felling dates have been calculated using the estimate that 95% of mature oak trees have between 15 and 40 sapwood rings.

Two of the samples (DUN-C04 and DUN-C08) have the heartwood/sapwood boundary ring present which, by applying the sapwood estimate, indicate that the lower purlin running between t2 and t3 was felled during the period AD 1361–86 and the west cruck blade of t3 were felled during the period AD 1377–1402. These two felling date ranges clearly overlap indicating that the timbers are at least broadly coeval. However, if it is assumed that they represent a single felling event then, using the average date of the heartwood/sapwood boundary of AD 1354, an estimated felling date range of AD 1369–94 can be calculated for these two timbers.

The third dated sample (DUN-C05) does not have the heartwood/sapwood boundary and so a felling date range cannot be calculated but, with a last-measured heartwood ring date of AD 1334, it has a *terminus post quem* date for felling of AD 1349. Thus, the timber represented, the east cruck blade of t3, could have been felled at the same, or similar time, as the other two dated timbers, an interpretation that is supported by the high level of similarity between the ring-width series from this cruck blade and the dated purlin ($t$ = 9.4) and the other cruck blade ($t$ = 6.4).

# Discussion

Tree-ring analysis has demonstrated that three timbers in the main range roof are broadly coeval and may all have been felled in the latter decades of the fourteenth century, thus suggesting a potential construction date around that time, if these timbers are associated with the primary phase of construction. The caveat must be applied that the dated timbers are all associated with t3, in that it is both cruck blades from this truss and a purlin running between t2 and t3 that have been dated. However, from appearance and style, the roof timbers do appear to be largely coeval, and smoke blackening was extensive to the south of t2, so it is reasonable to assume that t3 is part of the primary structure (West Somerset Building Research Group pers. Comm.).

It is unfortunate that the second site sequence cannot be securely dated by ring-width dendrochronology at this point. This site sequence contains the samples from both cruck blades of t1 and the collar from t3 and, although undated, it is clear from the relative heartwood/sapwood boundary ring positions of the three samples represented (Fig. 10) that all were likely to have been felled at the same time.

It is relatively unusual for a long site chronology, such as DUNCSQ02, even with a sample depth of only three, to remain undated. Previous work undertaken in Dunster and other areas of the south-west peninsula has highlighted the on-going challenging nature of dendrochronology in certain areas, the underlying causes of which include natural environmental effects (e.g. highly varied topography) and anthropogenic effects (e.g. woodland management), as well as the potential for reuse of timber in areas where trees suitable for converting into major structural elements may be scarce. It should also be recognised that timber may have been imported from further afield in England or elsewhere in Europe, although this data was compared to reference chronologies from across the British Isles and elsewhere in Europe but to no avail. Documentary evidence points to strong links between the south-west peninsula of England and Ireland with additional supporting evidence coming from dendrochronological studies (e.g. Miles 2002a; Miles 2002b; Tyers 2021). This long site chronology may prove datable in the future as the local reference chronology network is enhanced through the successful dating of more buildings and also as scientific dating techniques are further developed.

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# Data of measured samples

Measurements in 0.01mm units

DUN-C01A 113
229 231 217 191 326 151 197 175 368 351 267 148 110 176 178 116 148 151 245 139 128 103
119 143 197 119 120 94 153 126 132 82 113 98 125 131 150 107 130 85
225 116 156 169 149 165 148 144 121 178 134 174 203 148 183 156 148 144 96 182
192 208 236 199 238 204 161 128 133 175 141 155 150 169 225 198 223 160 175 165
150 156 122 80 68 132 172 123 128 180 184 134 201 218 178 170 169 198 148 90
109 88 151 153 102 85 112 115 162 141 160 153 138
DUN-C01B 113
226 236 214 195 322 144 205 184 363 348 230 153 107 178 180 112 138 157 234 147
123 105 109 152 189 126 123 96 149 138 135 76 122 102 128 128 141 114 137 93
209 122 181 181 153 175 144 153 124 186 160 185 200 134 175 161 144 149 94 179
196 214 232 190 237 207 163 133 132 177 141 154 152 170 214 206 218 162 167 175
152 157 115 83 73 129 160 129 130 182 183 131 195 221 185 167 170 203 147 96
100 87 164 140 102 88 108 112 169 140 155 142 139
DUN-C02A 121
115 69 76 92 85 77 84 94 94 77 117 131 173 125 151 130 195 188 156 159
167 214 90 178 144 219 242 321 329 392 350 256 244 263 227 326 266 231 137 171
212 300 254 239 234 243 309 204 233 170 121 162 197 141 184 195 147 257 184 217
190 154 142 131 120 116 125 158 231 243 210 244 302 221 196 188 257 209 247 271
205 192 249 156 159 124 153 141 104 125 115 101 106 117 148 122 123 102 134 76
111 66 39 42 40 62 82 154 134 208 147 140 137 150 130 126 120 94 95 98
101
DUN-C02B 121
100 78 67 97 82 80 77 101 80 76 109 135 175 118 166 133 196 192 152 164
157 214 99 178 142 232 241 402 314 411 347 248 243 261 236 304 272 234 142 168
209 313 276 248 229 247 322 215 242 173 114 169 212 157 180 198 150 264 181 216
203 157 129 128 128 122 123 169 232 240 213 233 285 230 184 190 278 196 245 275
202 210 247 158 157 120 161 137 107 130 117 99 134 111 134 125 128 101 126 87
119 63 39 37 46 67 76 152 151 205 141 146 130 156 132 122 112 97 106 93
110
DUN-C03A 33
373 272 322 190 151 224 390 288 287 317 467 208 234 297 164 170 319 312 442 232
258 194 266 408 340 302 343 219 262 191 299 388 515
DUN-C03B 33
382 272 315 191 155 221 381 301 287 313 464 208 230 304 159 170 323 312 448 229
263 198 266 410 341 309 353 204 267 193 311 396 494
DUN-C04A 77
364 650 378 532 404 365 235 324 248 248 271 322 397 481 374 552 544 181 116 133
155 164 180 398 251 178 126 100 117 107 173 157 190 157 173 120 132 181 268 188
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102 103 139 145 142 199 146 128 104 173 136 143 197 176 192 236 155
DUN-C04B 77
365 654 361 509 393 404 244 332 255 240 288 329 386 474 373 553 556 176 111 146
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252 213 152 111 105 104 153 263 304 233 206 210 172 159 116 114 100 113 75 106
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135 98 117 85 97 86 182 108 112 119 161 103 144 136 88 82 92 128 127 200

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78 134 71 122 153 137 184 162 136 130 133 85 93 86 115 143 113 111 118 144
88 102 130 144 135 135 177 170 123 121 103 110 91 139 147 208 194 244 188 199
291 364 337 343 270 421 286 234 294 322 360 262 213 208 233 165 217 187 115 99
143 111 123 135 128 163 130 104
DUN-C06A 90
227 267 88 214 88 57 93 102 176 192 166 198 134 325 229 327 298 299 123 154
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DUN-C07A 166
96 104 121 98 91 97 94 114 92 117 131 129 103 104 106 165 150 167 133 95
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DUN-C09A 58

110 104 102 100 116 113 79 107 82 86 82 130 128 117 121 129 131 139 153 125
118 232 173 134 110 138 125 142 228 180 202 171 134 127 111 102 93 142 150 106
96 166 136 114 156 156 131 123 126 115 110 91 92 123 137 111 144 124
DUN-C09B 123
135 136 109 137 134 153 131 186 186 168 213 124 101 180 211 164 109 165 160 173
146 121 108 121 153 110 167 118 107 116 115 80 92 96 79 56 57 83 102 119
74 67 98 91 129 123 106 100 140 143 112 96 71 76 104 116 108 93 91 68
103 107 119 155 121 138 105 81 90 99 69 103 98 93 70 82 92 95 90 119
107 104 91 105 131 124 112 107 104 193 143 121 125 139 112 95 157 167 164 150
140 135 106 100 92 114 121 112 96 144 126 102 128 143 119 109 108 103 106 91
75 132 140

# Appendix: Tree-ring dating

## The Principles of Tree-Ring Dating

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

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

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

### 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.


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.

## 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).

## 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 (i.e. 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).

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; e.g. 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 Figure 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).

## 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, 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 complement 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.

## 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 (e.g. Baltic boards), then some allowance has to be made for this.

## 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.

## 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 AD 1810 is very apparent as is the smaller later growth from about AD 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in AD 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two-corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

*t*-value/offset Matrix

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

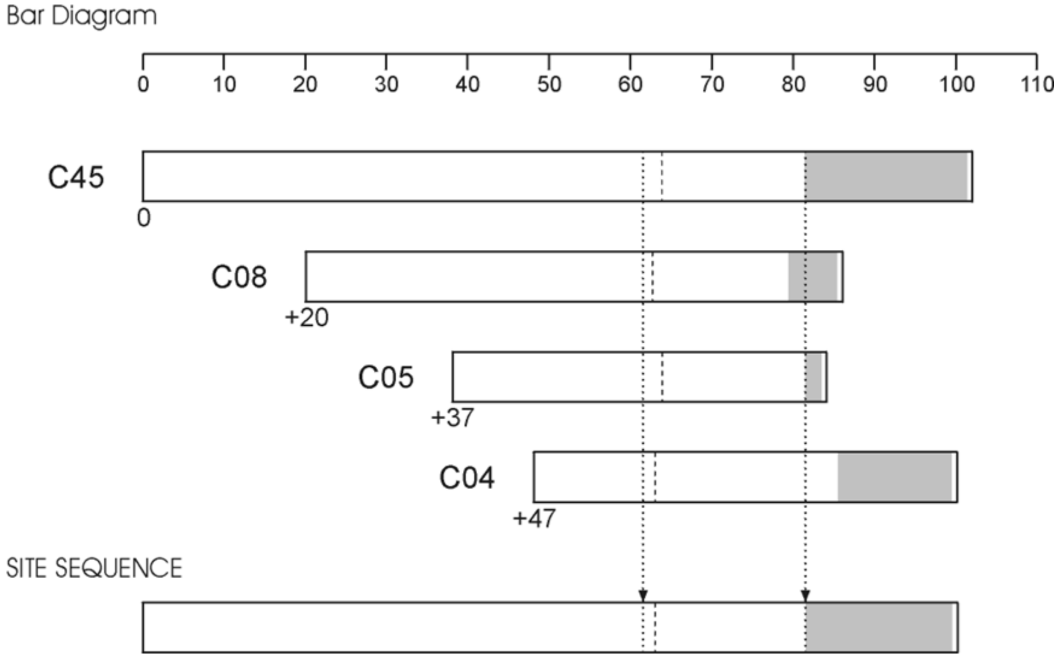



Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them. The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the t-values. The t-value/offset matrix contains the maximum t-values below the diagonal and the offsets above it. Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

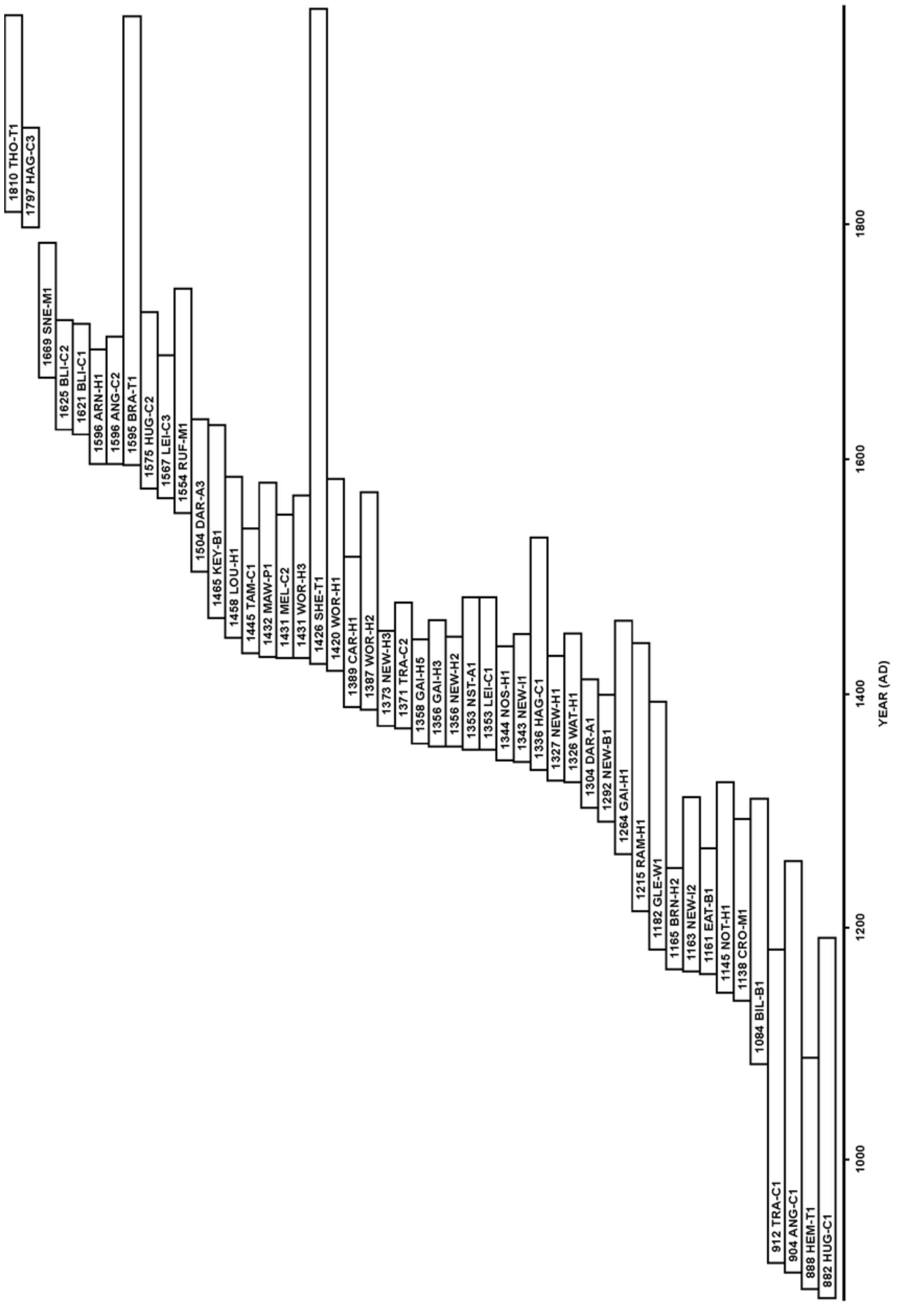
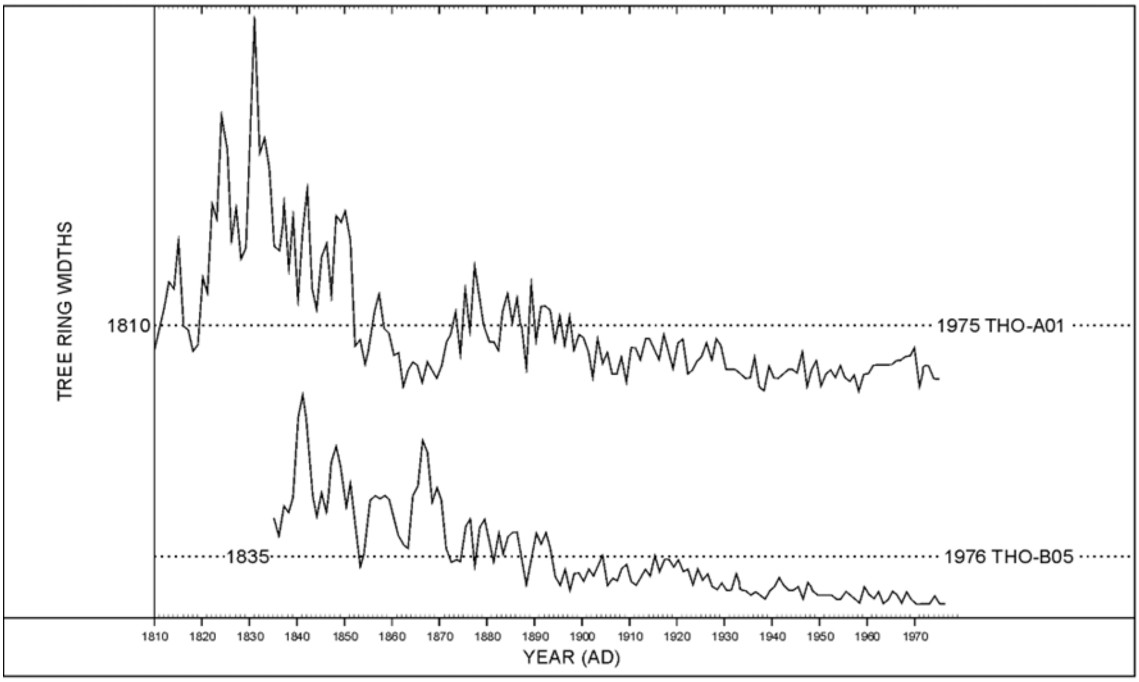



Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)




(b)

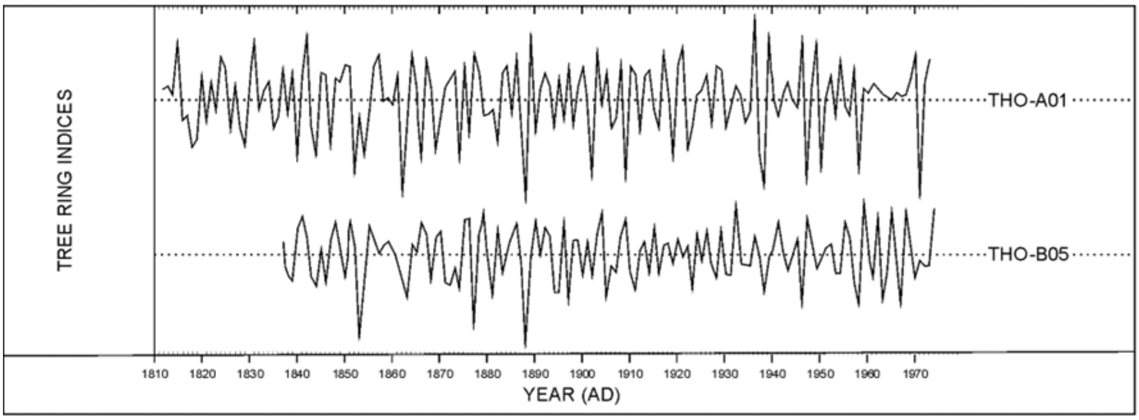



Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.
Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely.

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