Research Report Series 86/2024

Yarmouth Castle, Quay Street, Yarmouth, Isle of Wight

Tree-ring Analysis of Oak Lintels to two Gabled Windows of the Master Gunner's Attic

Alison Arnold and Robert Howard

Scientific Dating

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National Grid Reference: SZ 35388 89774

Print: ISSN 2398-3841
Online: ISSN 2059-4453

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Summary

Dendrochronological analysis was undertaken on core samples from lintels over the two gabled dormer windows to the Master Gunner's Attic, on the second-floor north elevation (adjacent to the room known as the Long Room), at Yarmouth Castle, these timbers being exposed during opening-up works to investigate suspected timber defects. This analysis produced a single site chronology comprising both samples, this site chronology being 66 rings long overall. These 66 rings were dated as spanning the years AD 1711–76. It is not certain that either sample retains the heartwood/sapwood boundary (the surfaces of the timbers possibly having been denuded by rot and decay), and as such, and taking into account the last extant heartwood ring on each sample, it is felt probable that the east window lintel was not felled before AD 1791, while the west window lintel is unlikely to have been felled before AD 1778. Both may be coeval though, and hence neither felled before AD 1791.

Contributors

Alison Arnold and Robert Howard (Nottingham Tree-ring Dating Laboratory).

Acknowledgements

We would firstly like to thank Nicola Dyer, English Heritage Properties Curator, for her support in requesting and promoting this programme of tree-ring analysis. Luke Bonwick, English Heritage Building Conservation Manager, is thanked for his help in gaining access to this building, and for his assistance on the day of sampling. Finally, we would like to thank Shahina Farid, Historic England Scientific Dating Coordinator, for commissioning this programme of tree-ring analysis and both Shahina Farid and Cathy Tyers, Historic England Dendrochronologist, for their valuable contributions to this report.

Front cover image

Yarmouth Castle on the Isle of Wight [© Historic England Archive Reference: DP068836]

Archive location

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

Historic Environmental Record

Isle of Wight Historic Environment Record, Westridge Centre, Brading Road, Isle of Wight, PO33 1QS

Date of investigation

2024

Contact details

Historic England, Cannon Bridge House, 25 Dowgate Hill, London EC4R 2YA
customers@historicengland.org.uk

Alison Arnold and Robert Howard, Nottingham Tree-ring Dating Laboratory, Mayfield Cottage, Tattle Hill, Dale Abbey, Ilkeston, Derbyshire DE7 4RR
roberthoward@tree-ringdating.co.uk,
alisonarnold@tree-ringdating.co.uk

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Introduction

Yarmouth Castle lies at the mouth of the River Yar on the northwest coast of the Isle of Wight (Fig 1). The following information is summarised from English Heritage (2024). The castle was constructed *c*. AD 1547, towards the end of a period of intensive defence construction ordered by King Henry VIII. The castle at Yarmouth shared qualities with the earlier Henrician constructions, including relatively low walls able to carry guns, but it also incorporated the latest defensive architecture, most notably in the form of an arrow-head bastion and square plan. The castle retains many of the military features of its original construction, alongside significant adaptations.

The interior of the castle formed a central courtyard but this appears to have been adapted within 20 years of construction by the introduction of a platform in the northern half which pushed the courtyard south. The courtyard was also reduced in size due to the construction of the Master Gunner's House, which is located in the southeast corner of the castle and was originally of two storeys. The ground floor was used as a hall, parlour and kitchen/service wing. A stone staircase, potentially replacing an original timber staircase, lies within the south wall rising to the upper floor from the hall. The first floor comprises a single large chamber above the courtyard, with a seventeenth-century fireplace, and a further chamber within the bastion. A further attic storey is only accessible via the platform and connects directly with the Gunner's lodgings to the west. It is the lintels over the gable windows of this room, in the east and west ends of the north elevation, which are the subject of this programme of tree-ring analysis (Fig 2).

Figure 1: Maps to show the location of Yarmouth Castle on the Isle of Wight, marked in red. Scale: top right 1:13,000; bottom: 1:1,650. [© Crown Copyright and database right 2024. All rights reserved. Ordnance Survey Licence number 100024900]

Figure 2: General exterior view of the gabled windows, taken from the gun platform looking south. [photograph Robert Howard]

Sampling

This programme of tree-ring analysis was prompted by issues identified with the windows following the loss of a facing stone forming part of an external course of dressed stone over the east timber mullion window. Initially, it was hoped that the issues related to the loss of timber beading around the window opening, which appeared to offer some structural support to the lintel above. However, following a subsequent inspection and report from the Historic England Structural Engineering Team, concerns were raised in relation to the structural integrity of the lintel and hence, the need for works to be undertaken to establish the extent of decay.

The opening-up works exposed single timber lintels to each of the windows, for which dendrochronological investigation was requested to help inform further repair and conservation works to the windows.

Thus, core samples were obtained from the two lintels. Each sample was given the code YAR-C (for Yarmouth Castle) and numbered 01–02. The location of the sampled timbers are located on a survey drawing (Fig. 3), with individual timbers being further identified in annotated photographs shown here as Figures 4 and 5. Details of the samples are given in Table 1.

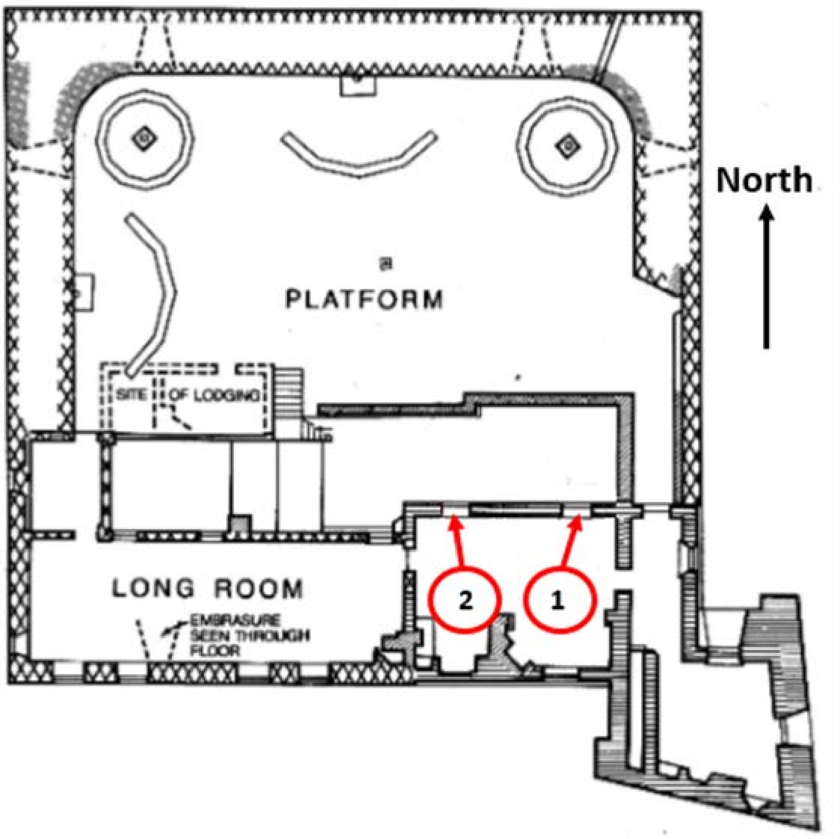

Figure 3: Plan at first-floor level to help locate sampled timbers. [© English Heritage: Guidebook 2012]

Figure 4: Sampled timber to the east gable window. [photograph Robert Howard]

Figure 5: Sampled timber to the west gable window. [photograph Robert Howard]

Table 1: Details of tree-ring samples from the window lintels to the Master Gunner's Attic, Yarmouth Castle, Yarmouth, Isle of Wight

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
YAR-C01	East window lintel	45	no h/s	1732	------	1776
YAR-C02	West window lintel	53	no h/s	1711	------	1763

no h/s = there is no heartwood/sapwood boundary on the sample, the outermost ring present is heartwood

Analysis and results

Both the samples obtained from the window lintels were prepared by sanding and polishing and their growth ring widths were measured, these measured data being given at the end of this report. The two measured series were then compared with each other and produced a value of *t*=7.2, albeit for a short (32 year) overlap, as illustrated in Figure 6.

The two samples were combined at their indicated offset positions to form YARCSQ01, a site chronology with an overall length of 66 rings. Site chronology YARCSQ01 was then compared with an extensive range of reference chronologies for oak, this indicating a repeated series of cross-matches when the date of its first ring is AD 1711 and the date of its latest ring is AD 1776 (Table 2). In addition, bearing in mind the short overlap between the two samples, both were compared individually to the reference chronologies to confirm the validity of the short overlap. This process being successful as both individual samples produced secure dating evidence at the dates expected.

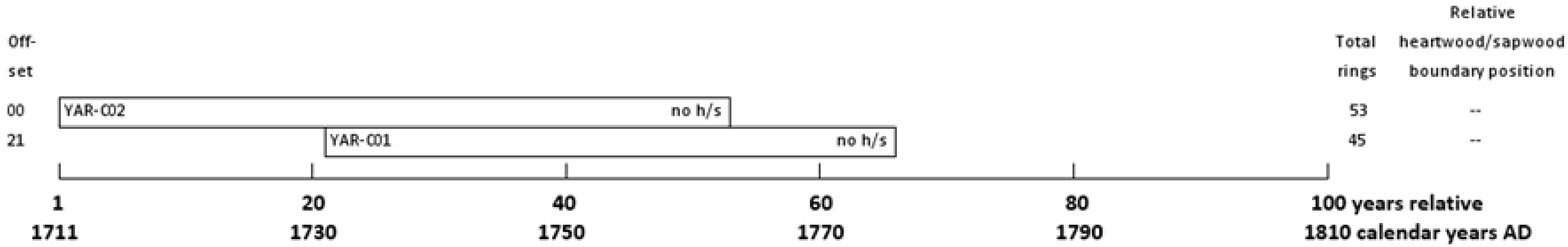

Figure 6: Bar diagram of samples in site chronology YARCSQ01. White bars = heartwood rings; no h/s = there is no heartwood/sapwood boundary on the sample, the outermost ring present is heartwood

Table 2: Results of the cross-matching of site sequence YARCSQ01 and relevant reference chronologies when the first-ring date is AD 1711 and the last-ring date is AD 1776

Reference chronology	Span of chronology	*t*-value	Reference
England South East regional	AD 435 – 1811	6.5	I Tyers pers comm 2004
Blagrave Farm Barns, Oxfordshire	AD 1705 – 1806	5.9	Haddon-Reece, Miles, Munby and Fletcher 1989 unpubl
The Dovecote, Breakspear House, Hillingdon, London	AD 1695 – 1769	5.8	Arnold and Howard 2011
Tilbury Fort, Essex	AD 1678 – 1777	5.5	Groves 1993
Bradgate Trees, Bradgate, Leicestershire	AD 1595 – 1975	5.4	Laxton and Litton 1988
St John the Baptist Church, Bishopstone, Wiltshire	AD 1705 – 1798	5.4	Bridge 1999
Step Cottage, Mapledurham, Oxfordshire	AD 1688 – 1809	5.4	Miles and Worthington 1998
St Mary's Church, Saffron Walden, Essex	AD 1701 – 1789	5.2	Bridge 2001
The Hovel, Ludgershall, Buckinghamshire	AD 1671 – 1811	5.2	Miles and Worthington 1999
Cobham Hall, Cobham, Kent	AD 1656 – 1774	5.2	Arnold et al. 2003
Ty-fry, Penrhyndeudraeth, Gwynedd, Wales	AD 1637 – 1755	5.1	Miles et al. 2007

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Interpretation

As may be seen from Table 1 and Figure 6, both samples in site chronology YARCSQ01 are comprised of heartwood only and thus, do not retain the outermost rings of the trees from which they were originally derived, to bark edge. Both timbers have suffered significant degradation making it difficult to determine with certainty, if the outermost extant ring indicates the heartwood/sapwood boundary. On balance, in both cases, it appears unlikely to be, which indicates that the timbers have lost, not only all of their sapwood rings, but a number of heartwood rings as well, during conversion from tree to element. As such, given that both trees could have continued growing for a number of years after their last extant heartwood rings, it is not possible to give a precise felling date or a felling date range within which it is likely that the timbers were felled.

It could be said, however, that with a last extant heartwood ring date of AD 1776, and allowing for a minimum of 15 sapwood rings (the lower limit of the 95% confidence interval for the number of sapwood rings oak trees generally have), it is unlikely that the tree represented by sample YAR-C01, from the east window lintel, was felled before AD 1791. Similarly, with a last extant heartwood-ring date of AD 1763, and again allowing for a minimum of 15 sapwood rings, it is unlikely that the tree represented by sample YAR-C02, from the west window lintel, was felled before AD 1778. It is possible, given the high level of similarity between the overlapping sections of the two ring-width series, that the two lintels are coeval and hence, neither was felled before AD 1791.

Discussion and conclusion

Tree-ring analysis has thus provided dates for the extant rings on both lintels from the two windows to the Master Gunner's Attic. Interpretation of the results suggests that the source trees were probably both felled no earlier than the late-eighteenth century. As such, it is perhaps possible that these relate to repairs undertaken during the early years of the Napoleonic Wars.

Woodland sources

In some programmes of tree-ring analysis it is possible to suggest the region or general locality from which the dated timbers used in a particular building might have been sourced. This is usually intimated by any site chronology created during analysis, although having been compared with reference material from all over England, tending to show the highest levels of similarity with reference chronologies from a particular region or area rather than elsewhere. However, as may be seen in Table 2 for site chronology YARCSQ01, the reference chronologies listed show a relatively wide geographical distribution, and apart from a possible general 'southern England' influence, no particular locality or regional trend can be discerned. This lack of geographic trend is possibly due to site chronology YARCSQ01 being composed of only two samples, this providing insufficient distinct geographic climate data.

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Data of measured samples

Units of 0.01mm

YAR-C01A 45
225 211 210 194 170 177 258 220 197 160 135 187 216 266 228 236 216 164 155 244
258 172 183 187 183 157 199 182 157 115 91 104 103 89 146 106 132 151 119 87
67 76 101 83 183

YAR-C01B 45
223 213 225 183 187 170 256 221 208 142 137 176 191 262 234 231 226 161 149 243
237 176 189 221 210 163 189 181 158 110 99 103 107 103 136 104 143 159 125 99
68 92 106 84 167

YAR-C02A 53
185 238 260 171 134 143 131 152 156 187 242 201 189 212 148 164 237 257 273 241
205 251 264 303 198 194 172 259 199 202 167 152 185 197 246 256 259 170 107 117
196 220 166 203 206 210 204 262 259 235 192 177 198

YAR-C02B 53
204 239 263 180 153 150 132 150 156 196 222 193 181 226 160 160 261 284 264 238
203 250 248 278 198 191 178 253 192 204 176 155 174 212 235 255 263 154 112 120
204 225 159 206 196 212 215 287 270 234 192 171 211

Appendix: Tree-Ring Dating

The Principles of Tree-Ring Dating

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

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

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

1. Inspecting the Building and Sampling the Timbers.

Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

2. Measuring Ring Widths.

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

3. Cross-Matching and Dating the Samples.

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

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

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

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

4. Estimating the Felling Date.

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

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

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

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

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

5. Estimating the Date of Construction.

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

6. Master Chronological Sequences.

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

Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. Ring-Width Indices.

Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

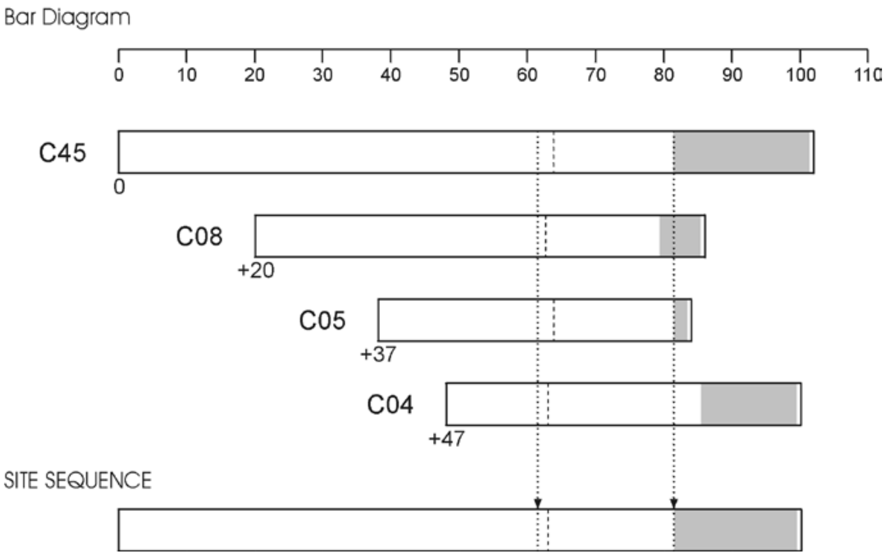


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

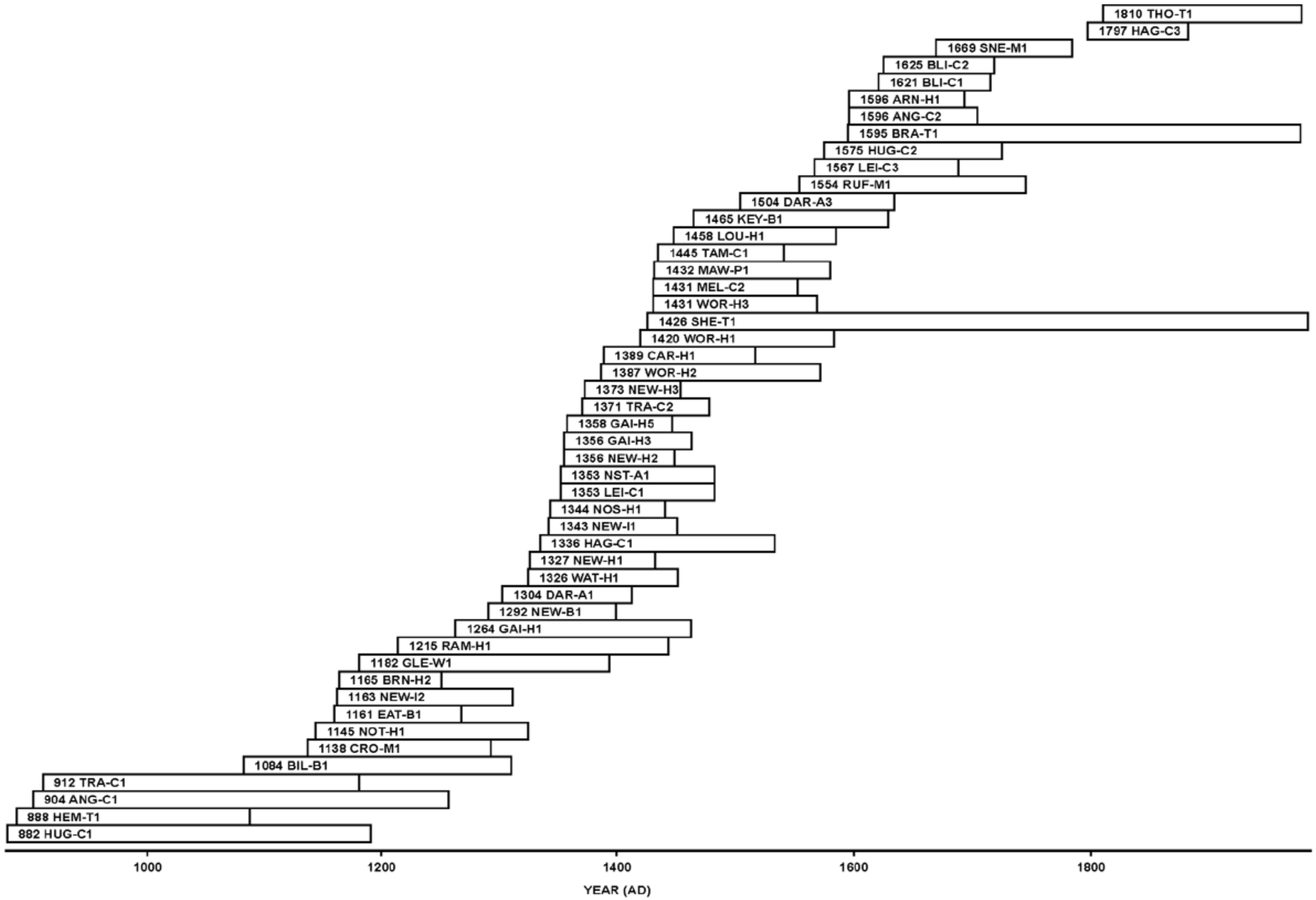
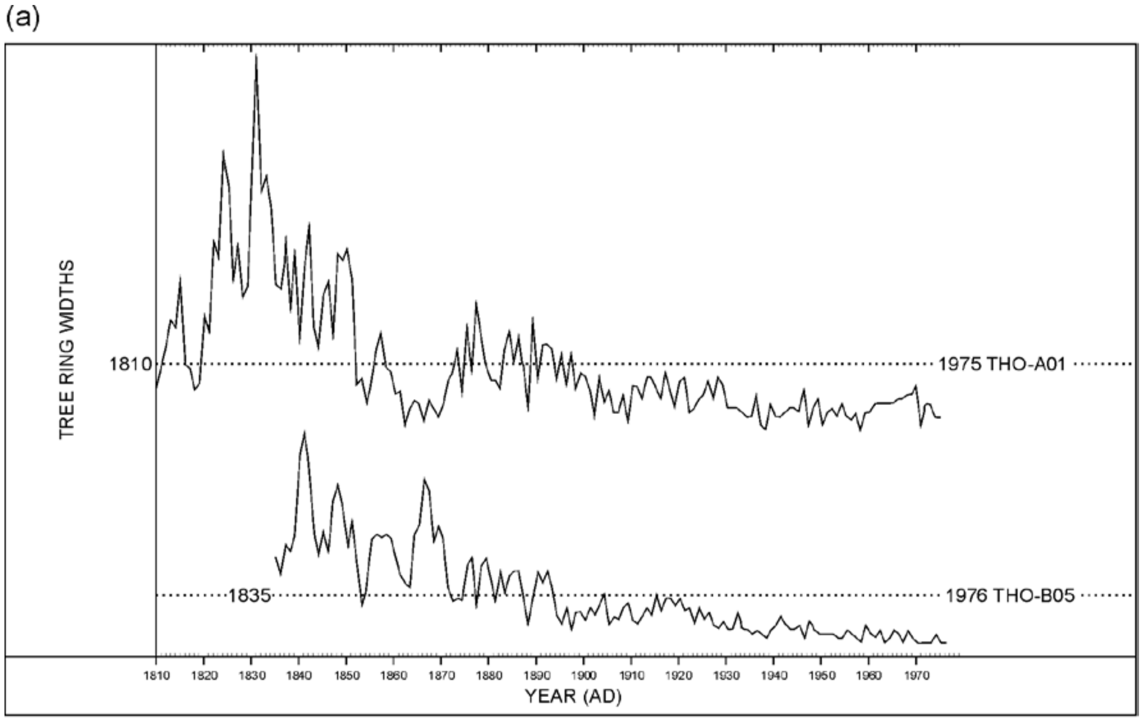


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



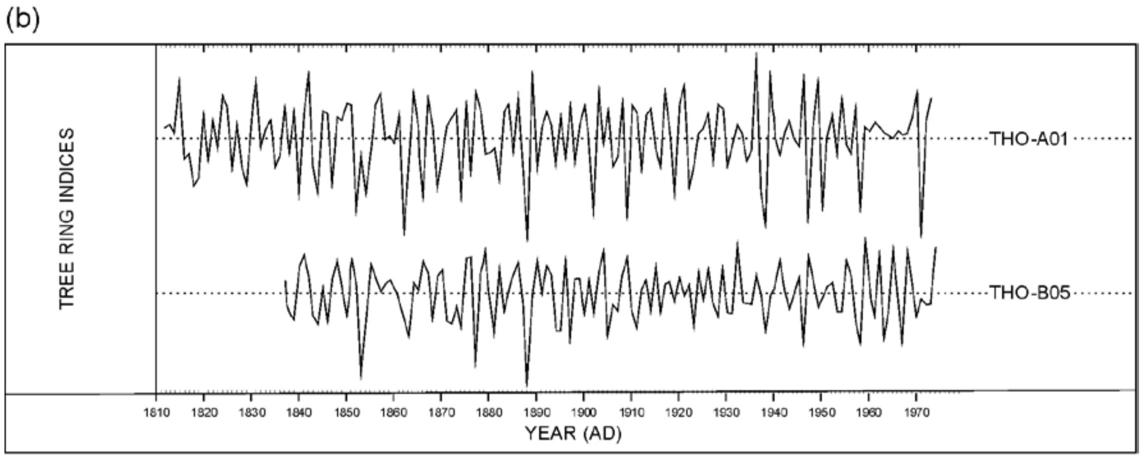


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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ISSN 2398-3841 (Print)
ISSN 2059-4453 (Online)