



Church of All Saints, Church Street, Wath Upon Dearne, South Yorkshire

Tree-ring Analysis of Timbers

Alison Arnold and Robert Howard

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CHURCH STREET, WATH UPON DEARNE,
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TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

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SUMMARY

Dendrochronological analysis was undertaken on two of the three samples obtained from corbels, removed due to decay, from the nave of All Saints Church, Wath upon Dearne. This analysis was unsuccessful and hence the samples remain undated.

CONTRIBUTORS

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INTRODUCTION

The Church of All Saints, Wath upon Deame, is a Grade I listed Place of Worship located to the north of Church Street (Figs 1a/b). The listed building entry indicates that the north arcades and the lower part of the tower date to the twelfth century. The nave and chancel were rebuilt and added to in the thirteenth and fourteenth centuries and the tower was heightened in the fourteenth or fifteenth century. The first clock was apparently installed in the tower when the original spire was replaced by the present one in 1714, and major restoration was conducted in 1868. Twentieth century restoration projects have continued since a fire in 1917.

The church is also on the Heritage at Risk register due to the roofs, high level masonry, and the rainwater goods being in poor condition and a current programme of repairs is being funded under the old Places of Worship grant scheme. Works have been undertaken on the roof where the lead covering has been particularly interesting with very good examples of graffiti dating from the 1700s to the present day being found. It has been during this phase of work that a number of severely decayed elements of the historic timbers have been replaced, including three corbel braces which were removed from the nave roof and stored at the church (Figs 2a/b).

SAMPLING

A dendrochronological survey of these corbels was requested by Zoe Kemp (Historic England Heritage at Risk Architect/Surveyor) to obtain, if possible, precise independent dating for the *ex situ* historic timbers. It was hoped that, if successful, this information would inform and enhance the understanding of the development of the church leading towards its eventual removal from the Heritage at Risk register.

The assessment of dendrochronological potential undertaken immediately prior to sampling concluded that the few available timbers were of borderline suitability because of low numbers of rings as well as being in a state of decay. However, given their potential significance the decision was taken, following discussion with relevant parties, to proceed with sampling. Thus, from the timbers available a total of three samples was obtained from the *ex situ* corbels with a chainsaw. Each sample was given the code WTH-B (for Wath upon Deame, site 'B') and numbered 01–03 (Table 1).

ANALYSIS AND RESULTS

Each of the three samples obtained was prepared by first being reduced to radial slices, and then by sanding and polishing to clearly reveal the annual growth rings. It was seen at this time that one sample, WTH-B03, had less than the 40 rings deemed necessary for reliable dating here, and so it was rejected from this programme of analysis. The annual growth ring widths of the remaining two samples were measured, the data of these measurements being given at the end of this report.

These data were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), but there was no cross-matching between them and hence a combined site chronology could not be created. The two measured samples were then compared individually to the full corpus of reference data, but again there was no cross-matching and the two samples must, therefore, remain undated.

INTERPRETATION AND CONCLUSION

Analysis by dendrochronology of two of the three *ex situ* corbels has, in this instance, failed to produce any cross-matching or dating evidence. This is possibly due to both the low number of samples obtained (the usual requirement being a minimum of 8–10 samples per phase/area) and the relatively low number of rings on at least one of the measured samples (WTH-B02). While such samples can occasionally be dated this is often much more difficult than with groups of samples where the data is well replicated. It is also noticeable that although sample WTH-B01 has 68 rings, it has two bands of very narrow rings (Fig 3) which might have been brought about by some non-climatic input on the growth of the tree such as pollarding or other forms of woodland management. This will also have had a negative impact on the potential for cross-matching and successful dating.

TABLES

Table 1: Details of tree-ring samples from All Saints Church, Wath upon Dearne, South Yorkshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
WTH-B01	Corbel	68	h/s	-----	-----	-----
WTH-B02	Corbel	48	4	-----	-----	-----
WTH-B03	Corbel	nm	---	-----	-----	-----

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

nm = sample not measured

FIGURES



Figure 1a/b: Maps to show the location of Wath upon Dearne (top) and All Saints Church (bottom). © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900



Figure 2a/b: View of the nave roof (top) and one of the corbels (bottom) (photographs Robert Howard)



Figure 3: View of the sliced samples, WTH-B01 (left) and WTH-B02 (right) (photograph Robert Howard)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

WTH-B01A 68

312 213 461 174 306 499 405 343 468 560 329 442 489 453 596 413 425 374 331 375
357 576 481 360 415 331 325 396 414 492 412 209 85 58 63 98 81 148 248 235
218 285 281 162 103 91 104 112 151 185 156 181 291 359 233 146 111 148 123 234
161 153 112 214 214 193 127 197

WTH-B01B 68

308 209 451 193 336 503 400 380 466 544 333 459 476 454 602 401 407 373 314 487
338 600 448 340 420 345 328 403 404 495 403 201 84 62 60 98 81 150 248 227
234 287 271 153 98 87 112 110 148 196 136 178 309 397 262 140 100 148 109 235
168 146 116 239 206 208 120 155

WTH-B02A 48

86 134 201 187 112 171 285 206 334 412 280 293 219 314 403 383 402 385 303 282
214 175 189 144 141 88 125 165 163 195 168 153 146 187 204 135 151 198 135 196
175 157 129 139 142 125 150 171

WTH-B02B 48

88 128 208 177 108 175 301 200 306 380 327 296 232 312 382 393 410 382 299 279
214 185 185 128 151 82 128 164 190 179 148 157 131 157 190 164 164 212 126 210
176 162 120 135 132 115 161 162

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

I. 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

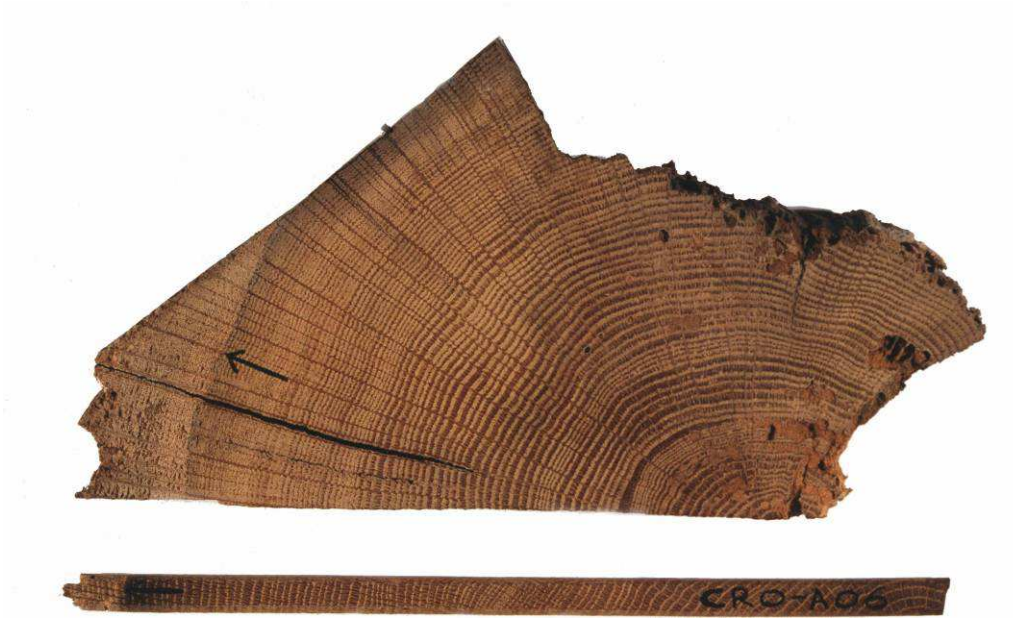


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil



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 35 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.

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

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

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

t-value/offset Matrix

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

Bar Diagram

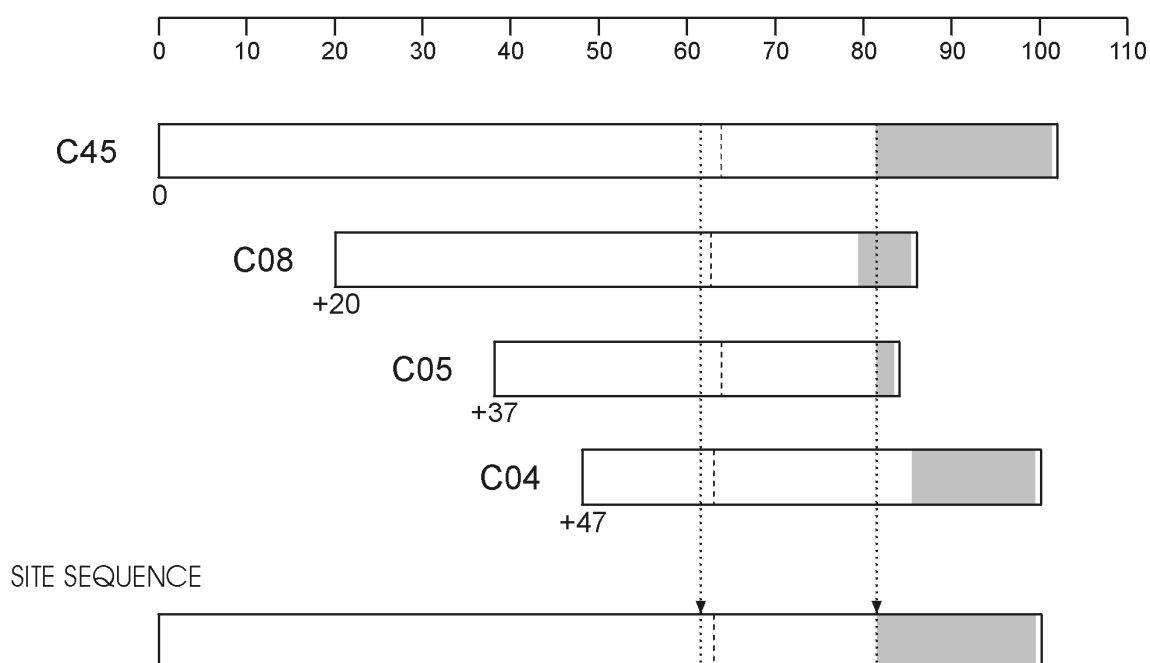


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

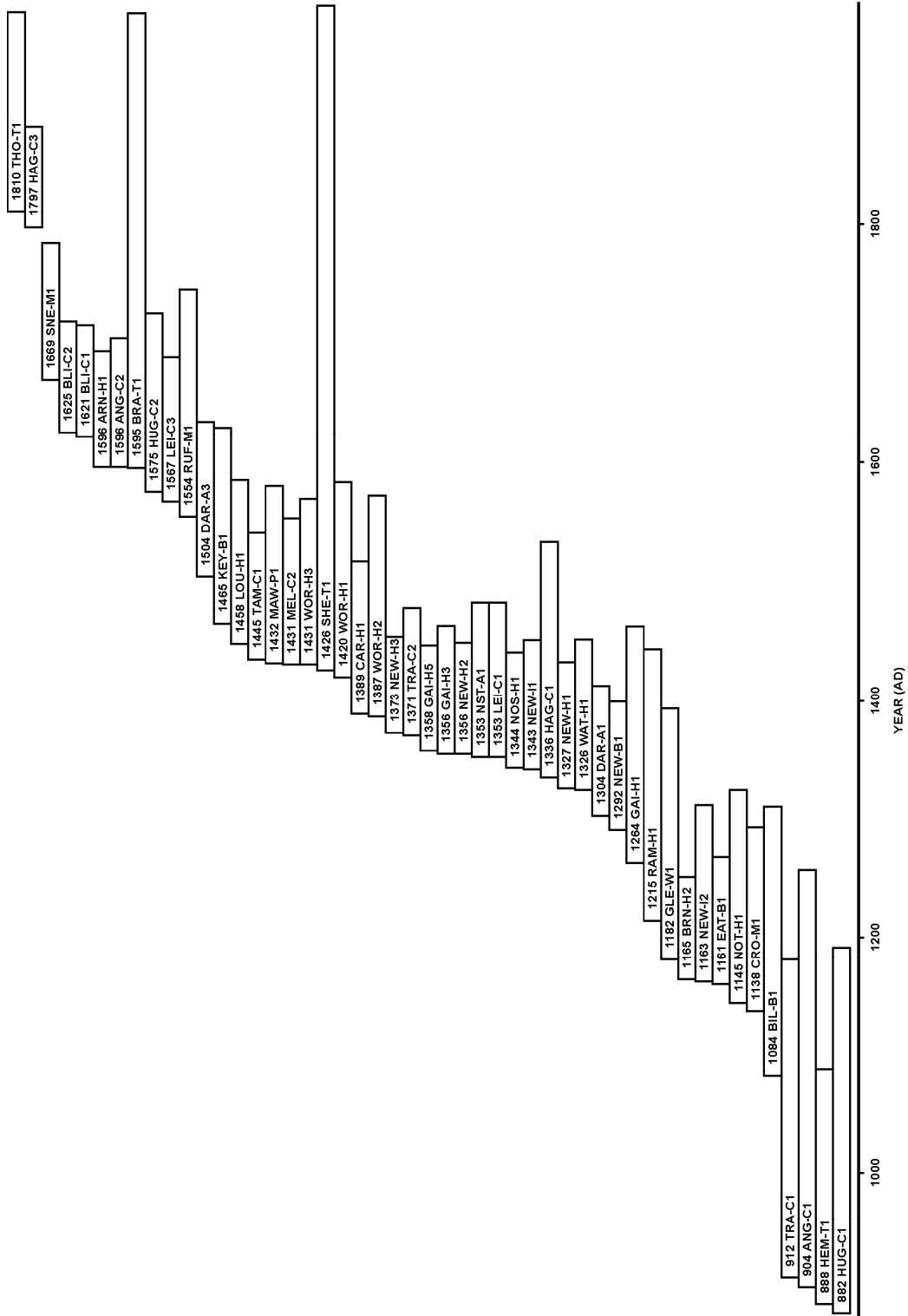
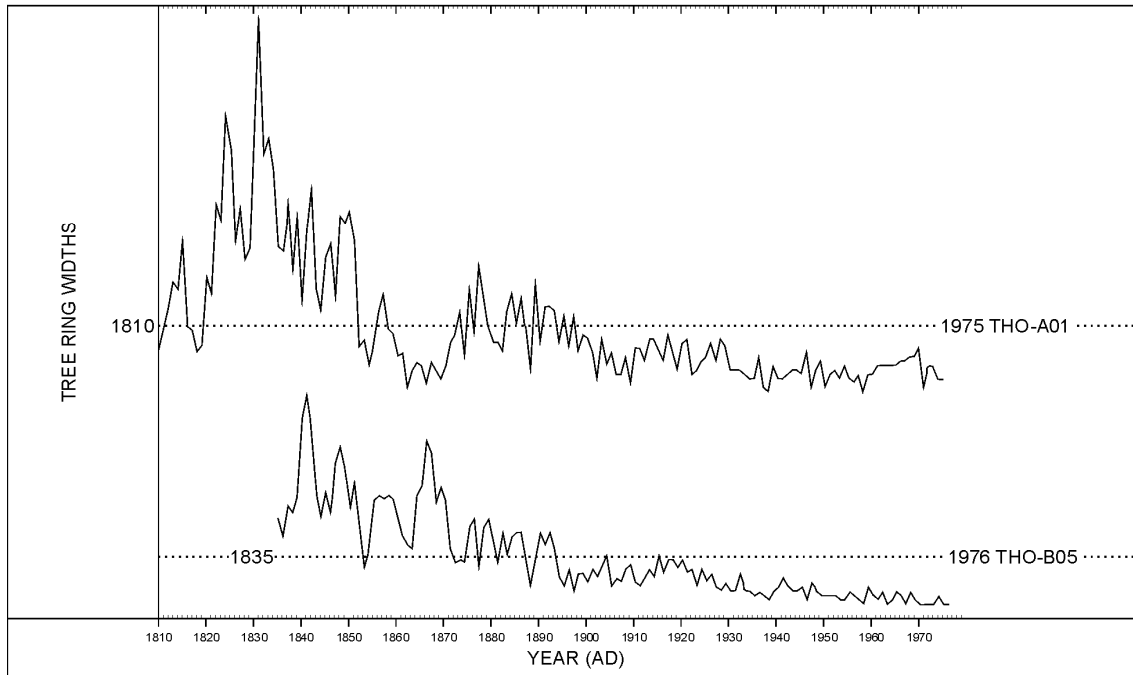


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

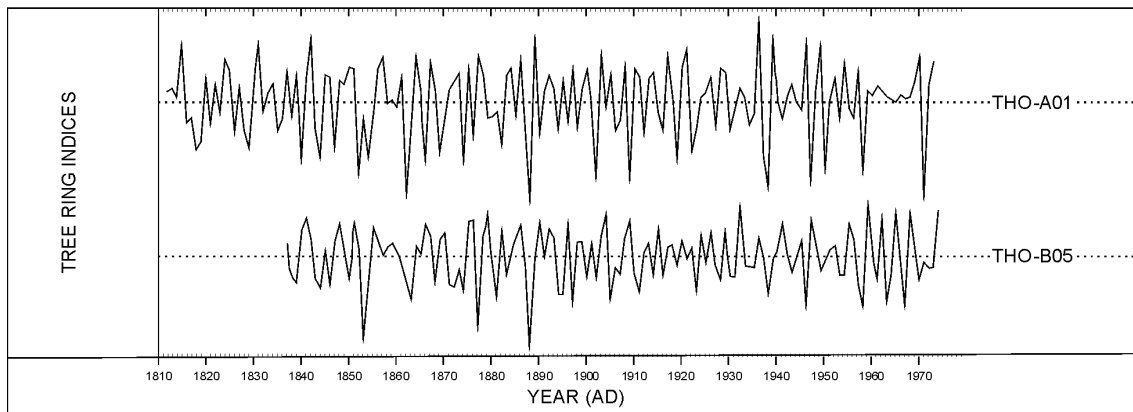


Figure A7 (a): *The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

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

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

The growth trends have been removed completely

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