



Landmoth Hall, Kirby Sigston, Northallerton, North Yorkshire

Tree-ring Analysis of Timbers from the East Range

Alison Arnold and Robert Howard

Discovery, Innovation and Science in the Historic Environment



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Research Report Series 55-2015

**LANDMOTH HALL,
KIRBY SIGSTON, NORTHALLERTON,
NORTH YORKSHIRE**

TREE-RING ANALYSIS OF TIMBERS FROM THE EAST RANGE

Alison Arnold and Robert Howard

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SUMMARY

Dendrochronological analysis was undertaken on two of the three samples obtained from the remaining timbers in the ruin of Landmoth Hall. This analysis was unsuccessful and hence the two samples remain undated.

CONTRIBUTORS

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ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to thank the owners of Landmoth Hall, Mr and Mrs Jones, for their enthusiasm and help with this programme of analysis and for their cooperation during sampling. We must also thank Shahina Farid and Cathy Tyers (Historic England Scientific Dating Team) for commissioning this programme of tree-ring dating, and for providing information and advice throughout this analysis, as well as Jenny Lee (Historic England Heritage at Risk Projects Officer) for helping to arrange access to the building. Finally, we would like to thank Colin Briden, consulting buildings archaeologist, for the use of his survey plans in this report.

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INTRODUCTION

Landmoth Hall lies approximately 2.5km south-south-east of Kirby Sigston, near Northallerton (Fig 1a/b) and is the site of the medieval manor of Landmoth-cum-Catto which is mentioned in the Domesday Survey of AD 1086. Today, along with modern farm buildings, the site comprises a late nineteenth-century brick-built farmhouse with sandstone footings which are likely to incorporate the foundations of the mostly demolished sixteenth-century structure (Fig 2).

Separate, although immediately adjacent, is the East Range with its attached byers. The East Range, which is also on the Heritage at Risk register, appears to date to the sixteenth century as well and is significant as few domestic dwellings of this date survive in North Yorkshire. The East Range is constructed of squared sandstone but is currently a shell of semi-standing walls. The walls, however, retain a small number of *in situ* timbers which are thought to be associated with the original construction. The house, the East Range, and the earthworks form part of a Scheduled Ancient Monument, the structures recently being the subject of a Historic Buildings Assessment (Briden 2015).

SAMPLING

A dendrochronological survey of the timbers at Landmoth Hall was requested by Zoe Kemp (Historic England Heritage at Risk Architect/Surveyor) to provide independent dating evidence for the surviving timbers which are thought to be potentially associated with the original construction of Landmoth Hall. It was hoped that this information would help inform a plan for repair and protection of the ruins within the Historic England Repair Grants for Heritage at Risk programme.

The assessment of dendrochronological potential undertaken prior to sampling concluded that although the timbers were only three in number, thus providing somewhat fewer than the recommended minimum of 8–10 required from a single phase or area, they generally appeared to have high numbers of rings and, although a little decayed due to exposure to the elements, they might be successfully cored. Thus from the timbers available a total of three samples was obtained, but due to decay, the core from the third timber fragmented into a series of disarticulated pieces and was thus unusable. Each sample was given the code LMT-A (for Landmoth site 'A') and numbered 01–03 (Table 1). The locations of the sampled timbers are shown on the plan, Figure 3, as well as in the annotated photographs Figures 4a–c.

ANALYSIS AND RESULTS

The two useable core samples obtained were prepared by sanding and polishing to clearly reveal the annual growth rings, and the widths of these were measured. The data of these measurements is 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 extant timbers at Landmoth Hall has, in this instance, failed to produce any cross-matching or dating evidence. The samples certainly have sufficient numbers of rings for successful analysis, so the lack of success is likely to be due to a number of factors. Individual samples can occasionally be dated successfully but this is often much more difficult than with groups of samples where the data is well replicated. In addition Landmoth Hall is located in an area that is known to be problematic with respect to successful dendrochronological analysis and hence the network of local reference chronologies is relatively sparse compared with other areas of the country.

BIBLIOGRAPHY

Briden, C, 2015 Landmoth Hall, Landmoth-cum-Catto, North Yorkshire; Historic Building Assessment

TABLES

Table 1: Details of tree-ring samples from Landmoth Hall, Kirby Sigston, North Yorkshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
LMT-A01	Tiebeam, west wall	177	h/s	-----	-----	-----
LMT-A02	Wall plate west wall	86	h/s	-----	-----	-----
LMT-A03	Wall beam, south wall	nm	---	-----	-----	-----

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

nm = sample not measured

FIGURES

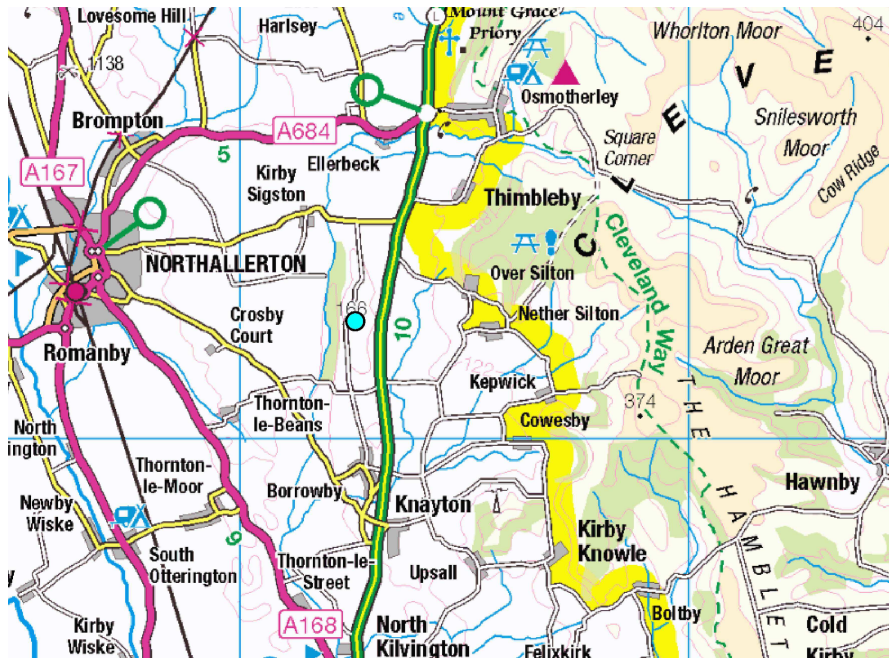


Figure 1a: Map to show the approximate location of Landmoth Hall. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

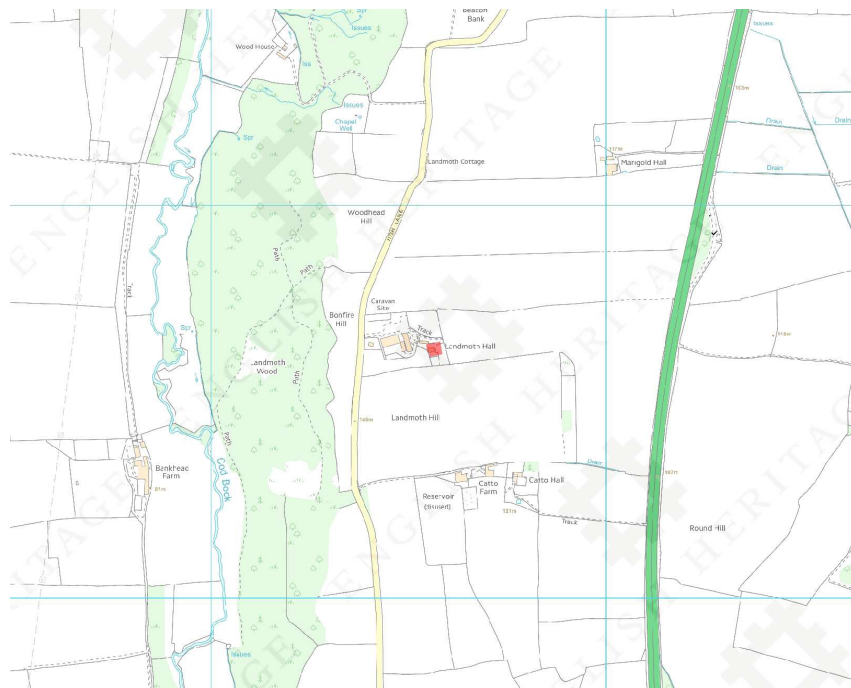


Figure 1b: Map to show the detailed location of Landmoth Hall. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

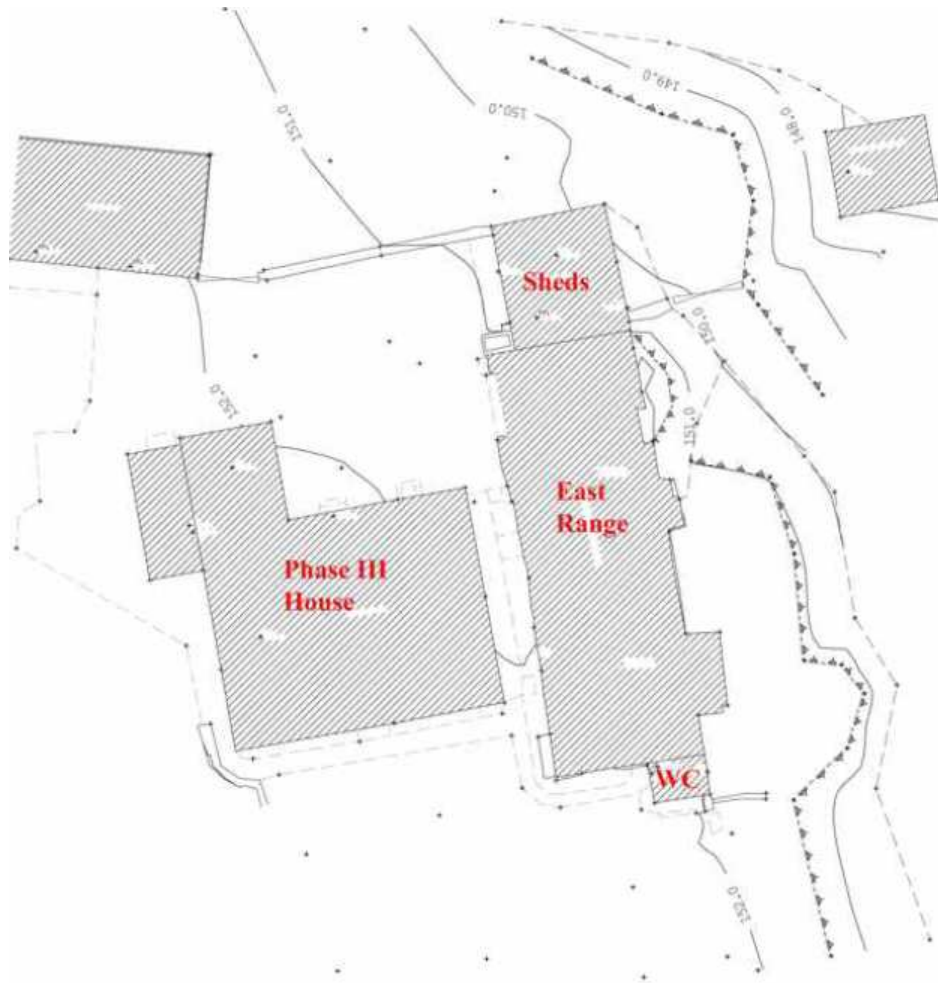


Figure 2: Plan of the Landmoth Hall site to show the layout and arrangement of the buildings (after Colin Briden)

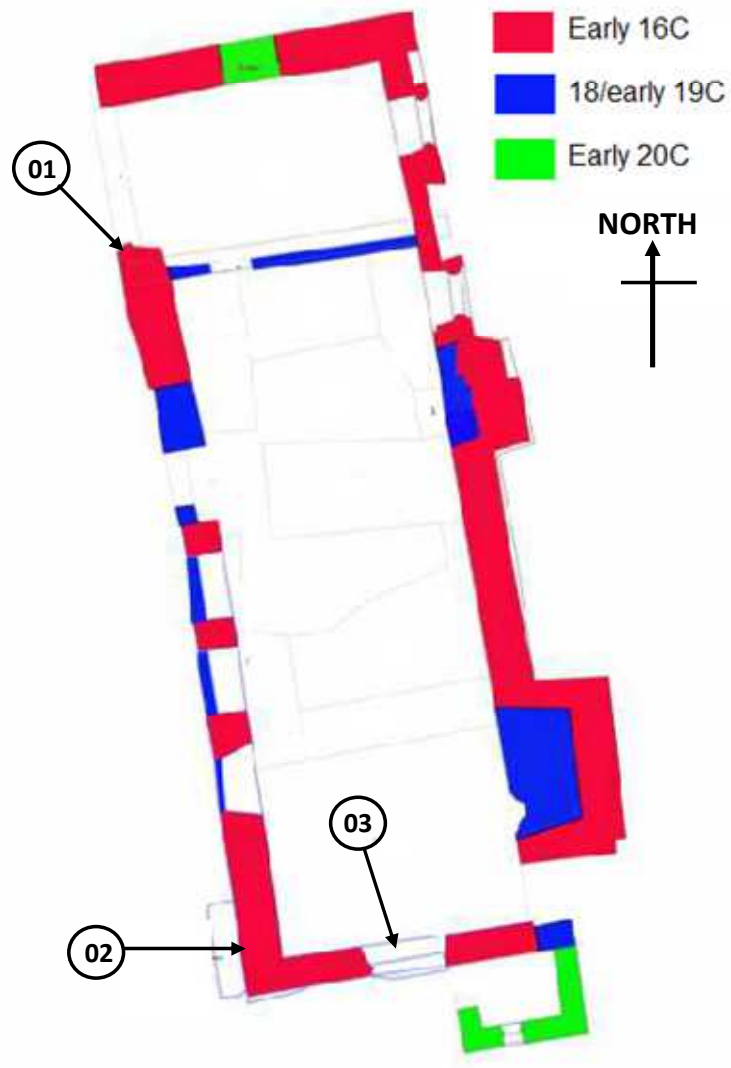


Figure 3: Plan of the East Range at Landmoth Hall to show the phasing of the structure and the approximate positions of the sampled timbers (after Colin Briden)



Figure 4a: View to help locate sampled timber - north wall, outer face (photograph Robert Howard)



Figure 4b: View to help locate sampled timber - west wall, outer face (photograph Robert Howard)



Figure 4c: View to help locate sampled timber - south wall, inner face (photograph Robert Howard)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

LMT-A01A 177

131 121 148 161 114 148 192 238 162 196 173 210 164 167 123 111 159 142 176 180
188 156 117 92 84 72 75 56 52 61 50 63 50 46 72 88 135 67 97 65
60 96 85 100 101 82 68 74 67 65 107 113 85 105 95 78 96 93 123 139
113 101 98 145 143 128 124 126 81 59 68 89 76 101 134 93 116 87 56 76
95 110 89 89 92 117 115 84 85 83 81 78 78 101 82 67 70 84 103 128
113 139 125 133 105 140 157 128 96 76 81 85 112 109 78 106 121 151 106 153
139 109 103 140 110 158 181 134 119 133 184 181 187 198 175 145 196 123 176 156
116 121 118 125 139 147 127 109 93 106 102 111 186 134 122 103 108 113 93 118
73 91 92 75 99 143 97 90 112 128 112 87 109 109 126 112 106

LMT-A01B 177

131 113 159 150 122 144 195 235 175 201 158 211 163 176 117 134 153 153 166 172
178 157 99 83 81 78 63 60 58 53 46 66 53 45 69 85 122 71 88 67
57 103 85 92 118 89 75 74 57 74 108 103 91 112 105 80 95 98 123 142
109 111 102 139 142 132 139 120 84 71 57 89 76 90 137 93 125 78 68 75
80 106 92 81 86 110 103 109 78 85 85 76 82 103 90 67 60 98 106 132
114 129 148 118 104 137 167 128 89 73 82 87 111 114 79 103 123 146 106 165
134 112 128 135 118 159 184 147 124 130 179 149 194 159 158 134 209 115 191 145
110 136 118 129 117 147 131 109 86 104 114 100 202 126 113 100 119 103 100 112
81 109 81 86 103 131 90 98 109 140 109 81 109 87 164 100 102

LMT-A02A 86

250 247 271 284 304 182 170 178 303 217 244 282 158 189 188 141 160 235 148 128
164 157 153 228 202 287 191 239 218 189 146 109 134 162 151 148 121 143 129 120
143 146 165 132 123 179 135 192 146 184 198 150 152 157 151 150 137 132 112 89
150 145 153 160 157 134 126 137 174 191 97 82 94 176 142 112 159 141 119 165
170 110 98 111 112 147

LMT-A02B 86

252 243 279 288 310 179 162 180 300 217 248 294 141 190 181 139 167 234 144 125
170 158 164 232 200 307 172 230 235 191 137 96 151 160 157 146 131 148 141 122
145 146 168 135 123 189 145 192 148 187 203 153 154 142 143 164 143 118 123 79
154 147 157 167 150 130 135 131 175 194 91 66 83 188 135 113 164 137 134 175
168 113 109 112 112 148

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 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

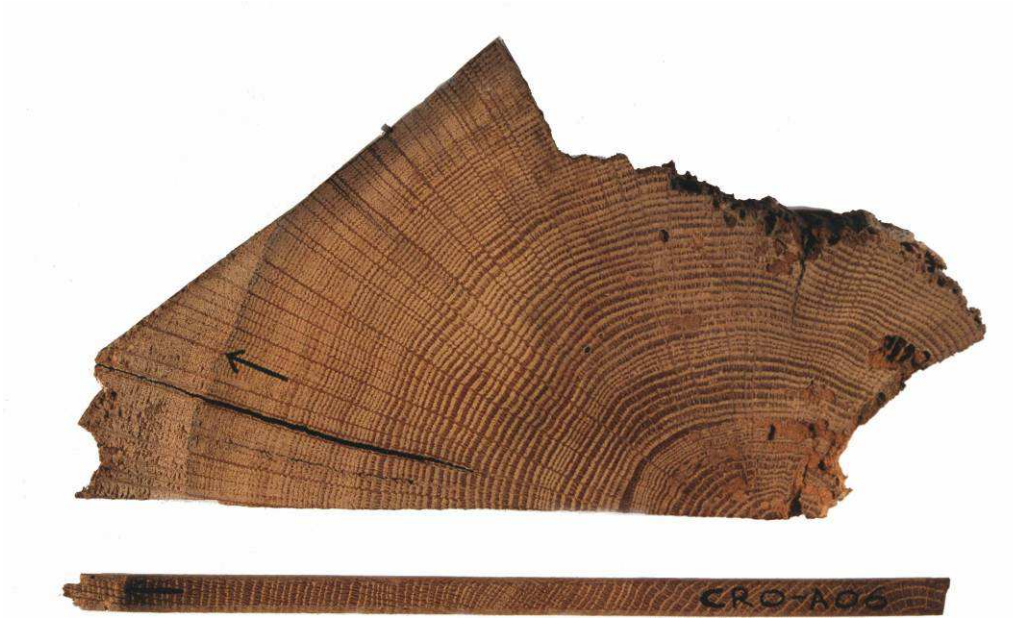


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil



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 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

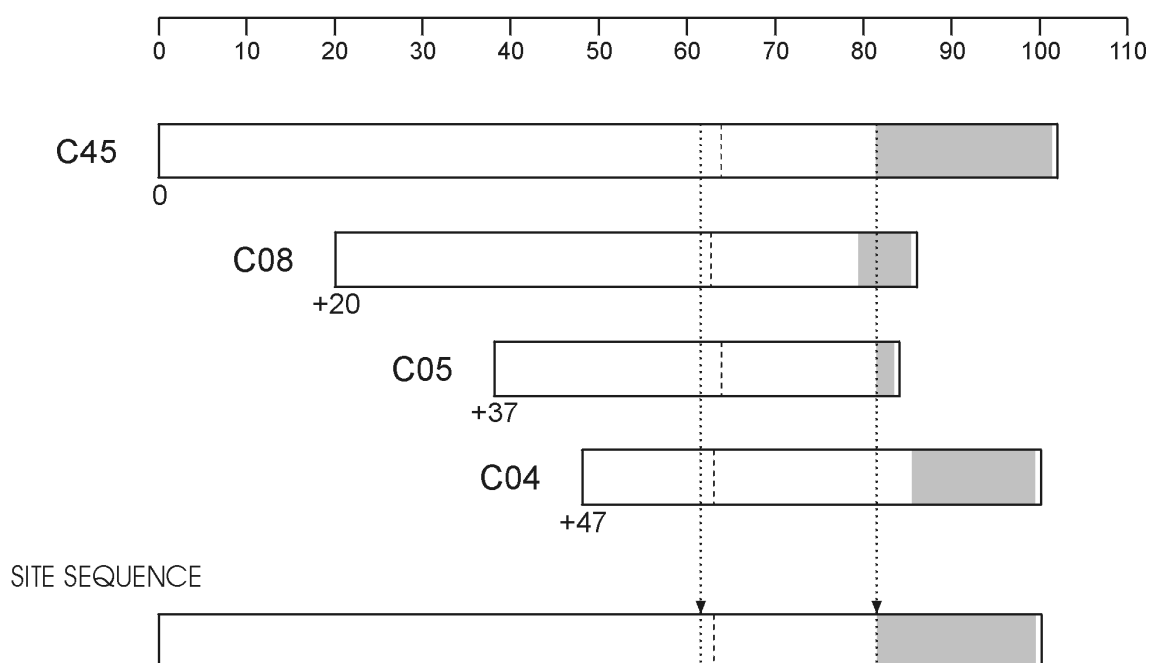


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

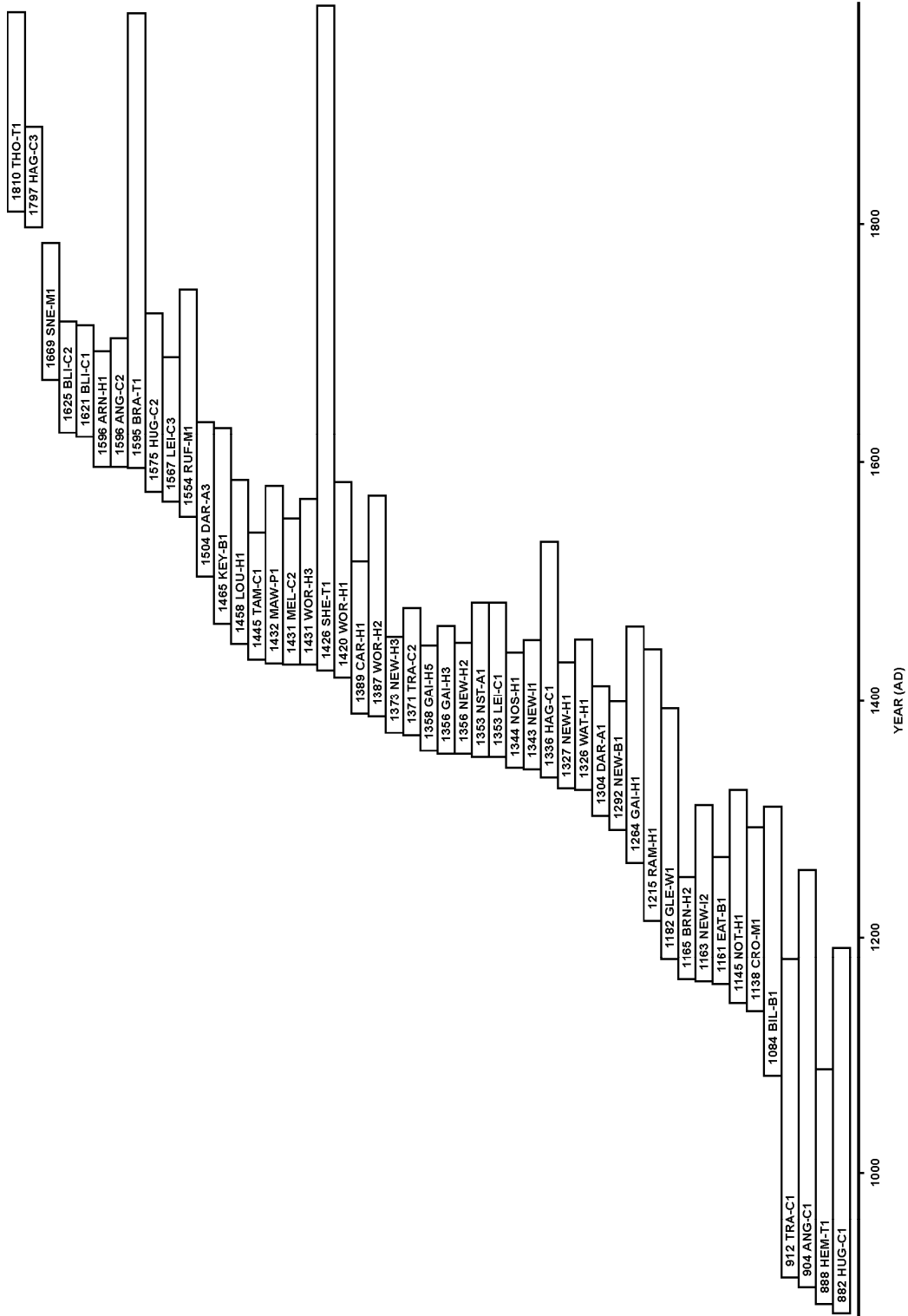
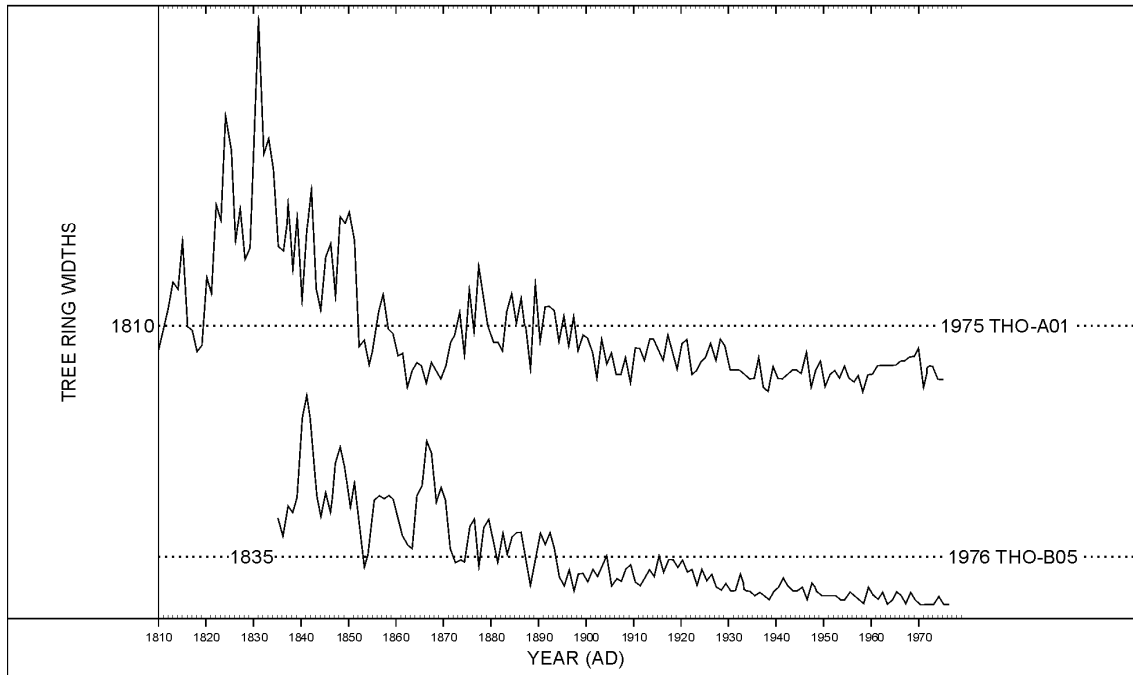


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

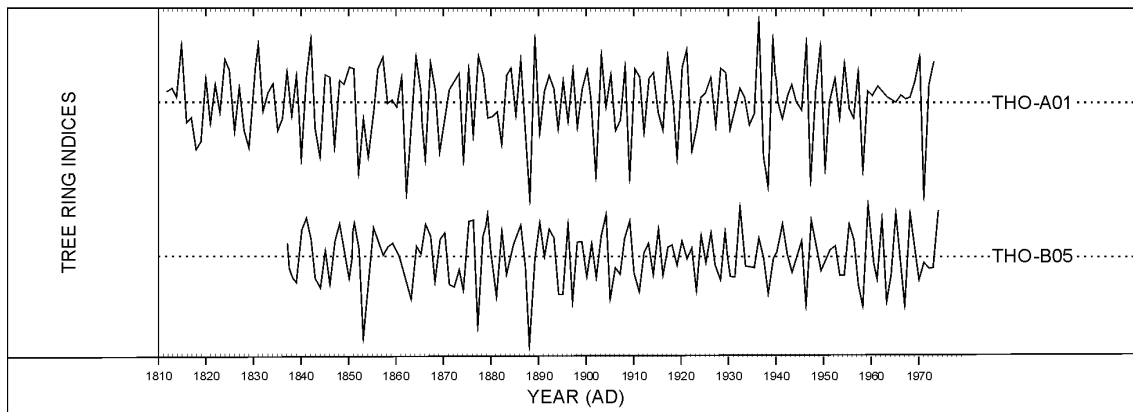


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

References

- Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, **33**, 7–14
- English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **15–26**
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 17 - Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in the East Midlands, *Vernacular Architect*, **23**, 51–6.
- Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25–35
- Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III
- Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90–8
- Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7
- Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*, **18**, 29–40
- Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, **28**, 40–56
- Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London
- Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



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