THE OLD COACH HOUSE AND DOVECOTE, EASTCOTE HOUSE GARDENS, HIGH ROAD, EASTCOTE, HILLINGDON, LONDON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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NGR: TQ 107 888

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SUMMARY

Analysis by dendrochronology of 16 of the 20 samples from timbers in The Old Coach House has produced four site chronologies comprising six, four, two, and two samples each, of 88, 129, 101, and 107 rings respectively. The first three of these site chronologies can be dated, their rings spanning AD 1504–1591, AD 1569–1697, and AD 1720–1820, respectively.

Interpretation of the sapwood and the heartwood/sapwood boundary on the dated samples indicates that timbers representing several different felling dates are to be found here. Six timbers from the roof have an estimated felling date in the period AD 1592–1614. At least three timbers from the gallery floor frame have an estimated felling date in the range AD 1703–28, with a fourth joist also possibly felled at this time. A further floor joist from the gallery is unlikely to have been felled before AD 1827, and may be coeval with a stud from the west wall which has an estimated felling date in the range AD 1833–58.

The adjacent Dovecote was also assessed for potential tree-ring analysis but was deemed unsuitable for dating and no samples were taken.

CONTRIBUTORS

Alison Arnold and Robert Howard

ARCHIVE LOCATION

Greater London Historic Environment Record
English Heritage
1 Waterhouse Square
138–142 Holborn Place
London EC1N 2ST

DATE OF INVESTIGATION

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CONTACT DETAILS

Alison Arnold and Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
0115 960 3833
roberthoward@tree-ringdating.co.uk; alisonarnold@tree-ringdating.co.uk

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INTRODUCTION

Eastcote House and and a number of associated outbuildings, in Hillingdon, West London, dating at least in part to the early sixteenth century, were demolished in 1964. The Old Coach House and adjacent Dovecote (TQ 107 888, Figs 1 and 2) remain and now stand within the former gardens, these, and the garden walls, being grade II listed and on English Heritage's Heritage At Risk register (www.english-heritage.org.uk/publications/har-2011-registers/).

The listing for the Coach House describes it as being timber-framed and of early-seventeenth century date with later alterations. It is of two storeys beneath a tiled roof, with framing, in rectangular panels, to the upper levels only. Externally it would appear that original *in-situ* timber is only visible to the north gable wall, the framing to the west wall apparently having been extensively, though perhaps not entirely, replaced during later restoration; it is possible that a few original timbers remain or have been reused. It is also likely that the later timbers have been inserted in the same position as the timbers they have replaced, and in many cases an attempt at authenticity has been made by morticing and pegging some of them together. It would appear very likely, however, that several episodes of repair are to be found here. The timber-framed panels to both north and west walls are filled by brickwork, some of that to the west wall set herring-bone fashion, some with bricks on end, some in smaller rectangular sets being of particularly varied and decorative form. Externally there appear to be no timbers to the east wall or to the south gable wall, these now being entirely of brick.

Internally the building is divided into four bays by three principal rafter trusses and the two, lighter timber-framed, gable end walls (Fig 3). In addition to principal rafters and tiebeams, the trusses, which support two rows of purlins to each pitch of the roof, also have collars and queen struts (Fig 4a-c). There are braces from short wall posts to the tiebeams, and from the upper parts of the principal rafters to the upper purlins. The majority of these timbers appear to be integral with each other, being fully jointed and pegged, and to represent the primary phase of construction, there being no clear evidence for the reuse of older timber or for the insertion of later repair pieces. This is in contrast to the walls which appear to have had thick oak boards either applied to the inner faces of the timber frame, or inserted into the walls, in almost 'mock' timber-frame style not necessarily related to the original form.

The southern third of the building contains a first floor gallery supported on a close-set series of north/south joists of oak, these themselves being supported on two east-west softwood cross-beams (Fig 4d). Some of these oak joists show evidence of possible reuse in the form of redundant mortices. It is possible, however, that these mortices relate to some now removed internal fittings or structure. A short, narrow, brick-built, outshot projects to the east beneath a cat-slide roof, from what is now taken to be the rear of the building. This outshot contains timbers only to its roof.

The detached, brick-built, rectangular dovecote to the south of the Coach House is of two storeys beneath a roof hipped to all four sides. The roof comprises small, modern, probably late-twentieth century, softwood common rafters supported by purlins to each pitch. Internally there is a central vertical spindle post with a single arm off, the spindle fitting into a structure at its top made up of cross-beams

SAMPLING

Tree-ring analysis of timbers to both the Old Coach Hose and the Dovecote was requested by Kim Stabler and Will Reading, English Heritage London region. It was hoped that this would provide independent dating evidence for what appeared likely to be the primary timbers of the roof and wall-framing of the Old Coach House, if suitable, and for the timbers of the first floor gallery at its southern end, and of the roof timbers to the Dovecote. It was hoped that this would determine the original construction date of both buildings, and hence establish how much of the fabric might be original. In addition it was hoped to date the insertion of the gallery in the Old Coach House.

An initial assessment of the suitability of the timbers within both the Old Coach House and the Dovecote was made prior to sampling. It was clearly seen at this time that the timbers of the Dovecote, being of small scantling softwood, and having very few rings, were totally unsuitable to tree-ring analysis. It was also seen that the roof timbers of the brick-built outshot to the Coach House, although of oak, were again of small scantling and also derived from fast-grown trees. As such it was felt that they were unlikely to provide suitable samples for analysis. In addition many of the wall-frame timbers of the Coach House, although again of oak, appeared to be either relatively modern repair pieces, or to be reused timbers of uncertain origin. Finally, it was seen that the two cross-beams of the Coach House gallery floor were of softwood but, although they were large timbers, contained insufficient rings for dating. In view of this assessment, sampling was, therefore, restricted to the roof, the oak beams of the gallery floor, and a small number of potentially original wall timbers, of the Old Coach House.

Thus, from the material available, a total of 20 samples was obtained by coring. Each sample was given the code ECT-A (for Eastcote, site "A"), and numbered 01-20. A selection of joists to the first floor gallery was cored as samples ECT-A01-08. Samples ECT-A09-18 are from the roof, an attempt being made to obtain samples from as wide a range of locations within the roof as possible. The remaining two samples, ECT-A19 and A20, are from the west wall, the sampling of this being somewhat limited by the possible presence of multi-phase repair timbers.

The location of all samples was noted at the time of coring and marked on survey drawings made and provided by MRDA Ltd, Architects and Conservation Consultants, London. These are reproduced here as Figures 5a-e. Further details relating to the samples can be found in Table 1.

ANALYSIS

Each of the 20 samples obtained was prepared by sanding and polishing. It was seen at this time that four samples had fewer than the minimum of 50 rings here deemed necessary for reliable dating, and these were rejected from this programme of analysis. The annual growth-ring widths of the remaining 16 samples were, however, measured, the data of these measurements being given at the end of this report.

The data of the 16 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing four separate groups of cross-matching samples to be formed at a minimum value of t=4.5. These four groups account for 14 of the measured samples, the samples of each group cross-match with each other as shown in the bar diagrams, Figures 6a-d. The cross-matching samples of each group were combined at their indicated offset positions to form site chronologies ECTASQ01-SQ04.

Each of these four site chronologies was then compared to an extensive corpus of reference material for oak, this process resulting in the dating of three of them. The evidence for this dating is given in Tables 2–4. Each of the four site chronologies was then compared with the two remaining measured but ungrouped samples, but there was no further satisfactory matching. These two remaining ungrouped samples were then compared individually with the full range of reference chronologies for the oak, but there was no satisfactory cross-matching, and these samples must remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
ECTASQ01	6	88	1504–1591
ECTASQ02	4	129	1569–1697
ECTASQ03	2	101	1720–1820
ECTASQ04	2	107	undated
Ungrouped	2	---	undated
Unmeasured	4	---	---

INTERPRETATION AND DISCUSSION

Site chronology ECTASQ01

None of the six dated samples in site chronology ECTASQ01, all of them from the roof of the Old Coach House, retains complete sapwood and it is thus not possible to give a precise felling date for any of the timbers represented. All six samples, however, do retain some sapwood or at least the heartwood/sapwood boundary, that is, only the sapwood

rings are missing. It is thus possible to give an estimated likely felling date range for these timbers.

As may be seen from Table 1 and Figure 6a, the overall position of the heartwood/sapwood boundary varies by only 12 years. The earliest heartwood/sapwood boundary is at relative position 65 (AD 1568), on sample ECT-A11, with the latest heartwood/sapwood boundary being at relative position 77 (AD 1580) on sample ECT-A16. Such a limited variation is consistent with the timbers represented all probably cut in a single episode of felling. The average date of the boundary on the six samples in this site chronology is AD 1574. Using a 95% confidence limit of 15–40 rings for the amount of sapwood these trees had, and given that the latest sapwood ring of any sample (ECT-A11) is dated to AD 1591, would give the timbers represented an estimated felling date in the range AD 1592–1614.

Site chronology ECTASQ02

Likewise, none of the four dated samples in site chronology ECTASQ02, all of them from the gallery floor joists, retains complete sapwood, and hence it is again not possible to give a precise felling date for any of the timbers represented. Three of these samples do, though, retain either some sapwood or the heartwood/sapwood boundary.

As may be seen from Table 1 and Figure 6b, the overall position of the heartwood/sapwood boundary on the three samples in the group where it exists varies by only eight years, indicating that the timbers represented were all probably cut in a single episode of felling. In this case, the earliest heartwood/sapwood boundary is at relative position 117 (AD 1685), on sample ECT-A02, with the latest heartwood/sapwood boundary being at relative position 125 (AD 1693) on sample ECT-A07. The average date of the boundary on the three samples in this site chronology is AD 1688. Using a 95% confidence limit of 15–40 rings for the amount of sapwood these trees had would give the timbers represented an estimated felling date in the range AD 1703–28.

Allowing that the last extant heartwood ring on the fourth sample is dated to AD 1659, and allowing for a minimum of 15 sapwood rings, this timber is unlikely to have been felled before AD 1674. It is possible that the tree represented by this sample was felled at the same time as the three timbers discussed above. However, because this sample is without its heartwood/sapwood boundary it is also missing an unknown number of heartwood rings, and thus this cannot be proven.

Site chronology ECTASQ03

The two samples of the third site chronology, from a gallery floor joist and a stud post, are also without complete sapwood, but one of them, ECT-A20, retains its

heartwood/sapwood boundary, this being dated to AD 1818. Using the same sapwood estimate as above, 15–40 rings, would give the timber an estimated felling date in the range AD 1833–58.

It is possible that the tree represented by the other sample in this site chronology, ECT-A06, was felled at the same time as that represented by sample ECT-A20, but again the sample is without its heartwood/sapwood boundary and is missing an unknown number of heartwood rings. All that may be reliably said is that, allowing that its last extant heartwood ring is dated to AD 1812, and allowing for a minimum of 15 sapwood rings, the timber is unlikely to have been felled before AD 1827.

Site chronology ECTASQ04

The fourth and final site sequence is represented by two samples, both of them from gallery floor joists. Although the site sequence cannot be dated it is likely, given that the position of the heartwood/sapwood boundary on the two samples varies by only eight years, that the timbers represented were probably cut in a single episode of felling.

CONCLUSION

Analysis by dendrochronology of 16 of the samples taken only from timbers in The Old Coach House (the timbers of the Dovecote all being unsuitable) has produced four site chronologies, three of which can be dated. Interpretation of the sapwood and the heartwood/sapwood boundary on the dated samples indicates that timbers with different felling dates are to be found here.

The earliest material is represented by six timbers from the roof, these estimated to have been felled in the period AD 1592–1614. There is no obvious evidence that these timbers have been reused, and it is thus possible that these represent the primary construction phase of The Old Coach House.

An early-eighteenth century phase of felling is represented by a small group of joists from the gallery floor. It is unclear if the estimated felling date for these timbers, AD 1703–28, represents the construction of this feature or, given that one other gallery floor joist is unlikely to have been felled before AD 1827, the gallery is of nineteenth century date. There is, however, no physical, framed, connection between the two sets of timbers, and in theory it would be possible to insert the nineteenth century timber as a repair or alteration into an already existing eighteenth century gallery.

An early- to mid-nineteenth century phase of felling is represented by at least one other timber, this estimated to have been felled in the period AD 1833–58. This would appear to represent a repair phase to the front wall.

Two other samples, ECT-A08 and A09, a joist and a tiebeam respectively, remain ungrouped and undated, despite both of them having sufficient rings for reliable dating. Given that the building appears to have undergone periodic repair and alteration, it is possible that each of the unmatched timbers is of a different date, and from a different woodland source. This would, in effect, make them 'singletons'. While such samples can occasionally be dated it is often much more difficult than with groups of well replicated data. It is also possible that the timbers are from time periods and woodland sources not yet sufficiently well represented by the corpus of reference material to produce positive cross-matches, although this seems relatively unlikely given the location and period.

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TABLES

Table 1: Details of samples from the Old Coach House, Eastcote Manor, Eastcote, Hillingdon, West London

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
	Gallery floor joists					
ECT-A01	Joist 1 (from east)	91	no h/s	1569	------	1659
ECT-A02	Joist 4	87	h/s	1599	1685	1685
ECT-A03	Joist 5	100	10	------	------	------
ECT-A04	Joist 7	102	10	1596	1687	1697
ECT-A05	Joist 8	92	3	------	------	------
ECT-A06	Joist 13	93	no h/s	1720	------	1812
ECT-A07	Joist 14	101	h/s	1593	1693	1693
ECT-A08	Joist 15	87	h/s	------	------	------
	Roof and wall timbers					
ECT-A09	Tiebeam, truss 1 (from north)	66	14	------	------	------
ECT-A10	East principal rafter, truss 1	69	h/s	1504	1572	1572
ECT-A11	West principal rafter, truss 1	86	23	1506	1568	1591
ECT-A12	West principal rafter, truss 2	63	10	1526	1578	1588
ECT-A13	West queen strut, truss 2	79	15	1511	1574	1589
ECT-A14	West principal rafter, truss 3	nm	---	------	------	------
ECT-A15	Tiebeam truss 3	nm	---	------	------	------
ECT-A16	East principal rafter, truss 3	56	8	1533	1580	1588
ECT-A17	East queen strut, truss 3	55	16	1536	1574	1590
ECT-A18	West queen strut, truss 3	nm	---	------	------	------
ECT-A19	West wall post, truss 1	nm	---	------	------	------
ECT-A20	West stud post bay 4	90	2	1731	1818	1820

*nm = not measured; **h/s = the heartwood/sapwood ring is the last ring on the sample

Table 2: Results of the cross-matching of site chronology ECTASQ01 and relevant reference chronologies when first ring date is AD 1504 and last ring date is AD 1591

Reference chronology	Span of chronology	*t*-value	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	7.3	(Arnold and Howard forthcoming)
Dovebridge, Derbyshire	AD 1502–1617	7.3	(Howard *et al* 1998a unpubl)
Powcher's Hall, Ely Cathedral, Cambridgeshire	AD 1457–1609	7.1	(Arnold *et al* 2004)
Moyns Park, Birdbrook, Essex	AD 1431–1606	7.0	(Tyers 1999)
Cressing Temple Farmhouse, Essex	AD 1514–1608	6.8	(Tyers 1995)
Cobham Hall, Cobham, Kent	AD 1317–1662	6.7	(Arnold *et al* 2003)
Church of St Michael & St Mary, Melbourne, Derbyshire	AD 1509–1652	6.4	(Arnold and Howard 2009)
De Grey Mausoleum, Flitton, Bedfordshire	AD 1510–1726	6.2	(Arnold *et al* 2003a)

Table 3: Results of the cross-matching of site chronology ECTASQ02 and relevant reference chronologies when first ring date is AD 1569 and last ring date is AD 1697

Reference chronology	Span of chronology	*t-value*	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	7.9	(Arnold and Howard forthcoming)
Kibworth Harcourt post mill, Leicestershire	AD 1582–1773	6.8	(Arnold *et al* 2004)
Hill Hall, Theydon Mount, Essex	AD 1525–1681	6.4	(Bridge 1999)
Old Clarendon Building, Oxford	AD 1539–1711	6.4	(Worthington and Miles 2006)
De Grey Mausoleum, Flitton, Bedfordshire	AD 1510–1726	6.2	(Arnold *et al* 2003a)
Worcester Cathedral, Worcester	AD 1484–1772	5.9	(Arnold *et al* 2003b)
Church of St Peter and St Mary, Stowmarket, Suffolk	AD 1542–1671	5.9	(Howard *et al* 1994)
Castle House, Melbourne, Derbyshire	AD 1583–1720	5.7	(Arnold and Howard 2009 unpubl)

Table 4: Results of the cross-matching of site chronology ECTASQ03 and relevant reference chronologies when first ring date is AD 1720 and last ring date is AD 1820

Reference chronology	Span of chronology	*t-value*	Reference
Chicksands Priory, Chicksands, Bedfordshire	AD 1670–1814	8.7	(Howard *et al* 1998b)
Ely Cathedral, Cambridgeshire	AD 1678–1828	6.3	(Esling *et al* 1989)
Tilbury Fort, Essex	AD 1678–1777	5.5	(Groves 1993)
Jessops Riverside, Sheffield, South Yorkshire	AD 1709–1842	5.5	(Tyers pers comm 2001)
Kibworth Harcourt post mill, Leicestershire	AD 1582–1773	5.1	(Arnold *et al* 2004)
Wortley Forge, Stocksbridge, South Yorkshire	AD 1750–1823	5.1	(Hillam and Groves 1992)
Thaxted Church, Essex	AD 1644–1813	5.0	(Tyers 1990)
Church Farm, Bringhurst, Leicestershire	AD 1664–1781	4.8	(Groves *et al* 2004)

FIGURES
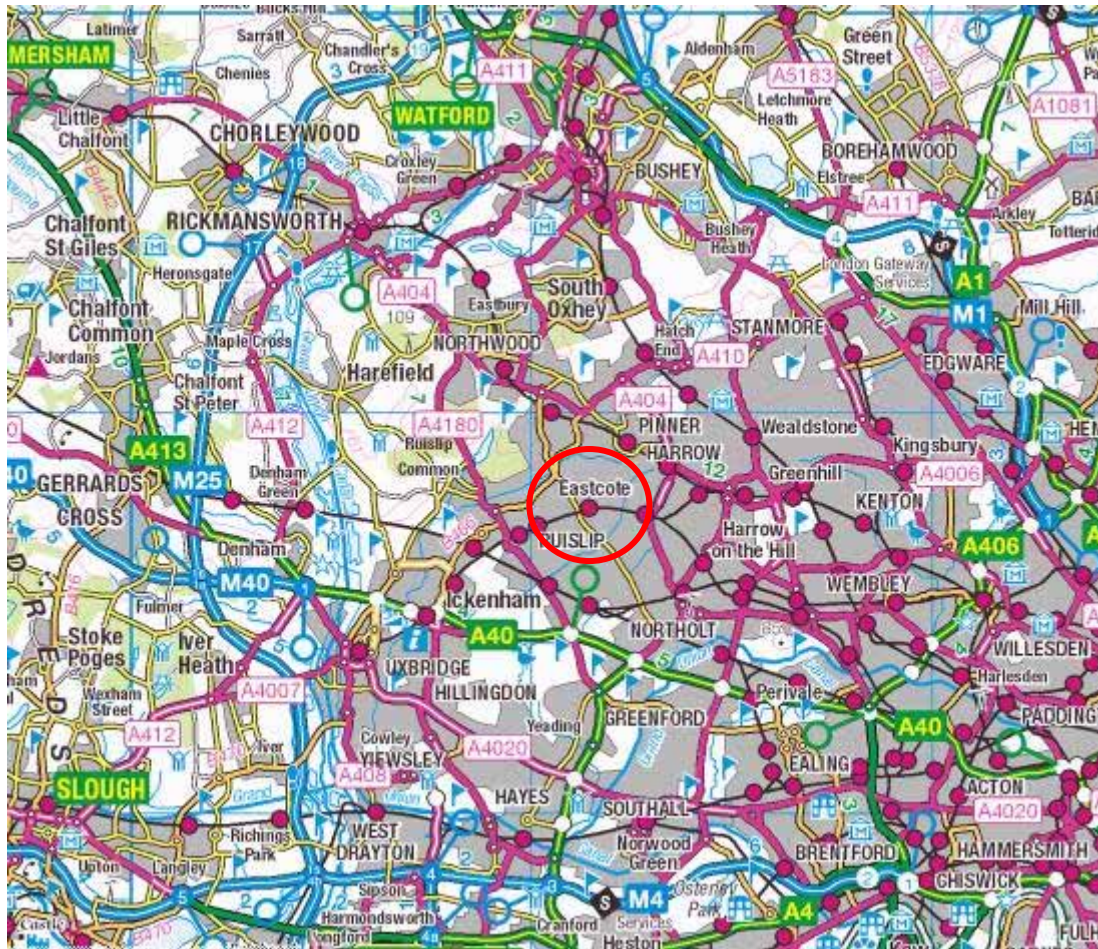
Figure 1: Map to show the general location of Eastcote Manor. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 2: Map to show the location of Eastcote Manor. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012
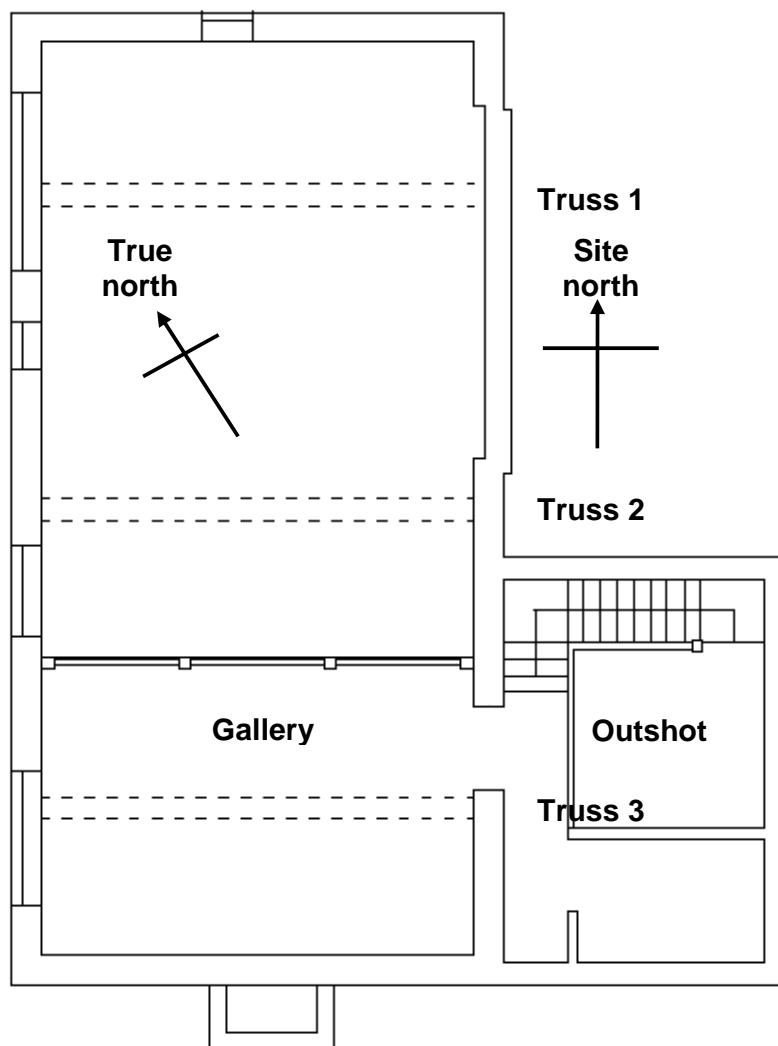
Figure 3: General plan of the Old Coach House

Figure 4a/b: General internal views of the Old Coach House, looking site north to south (top), and south to north (bottom)

Figure 4c/d: Views of the roof (top) and the beams of the gallery (bottom)
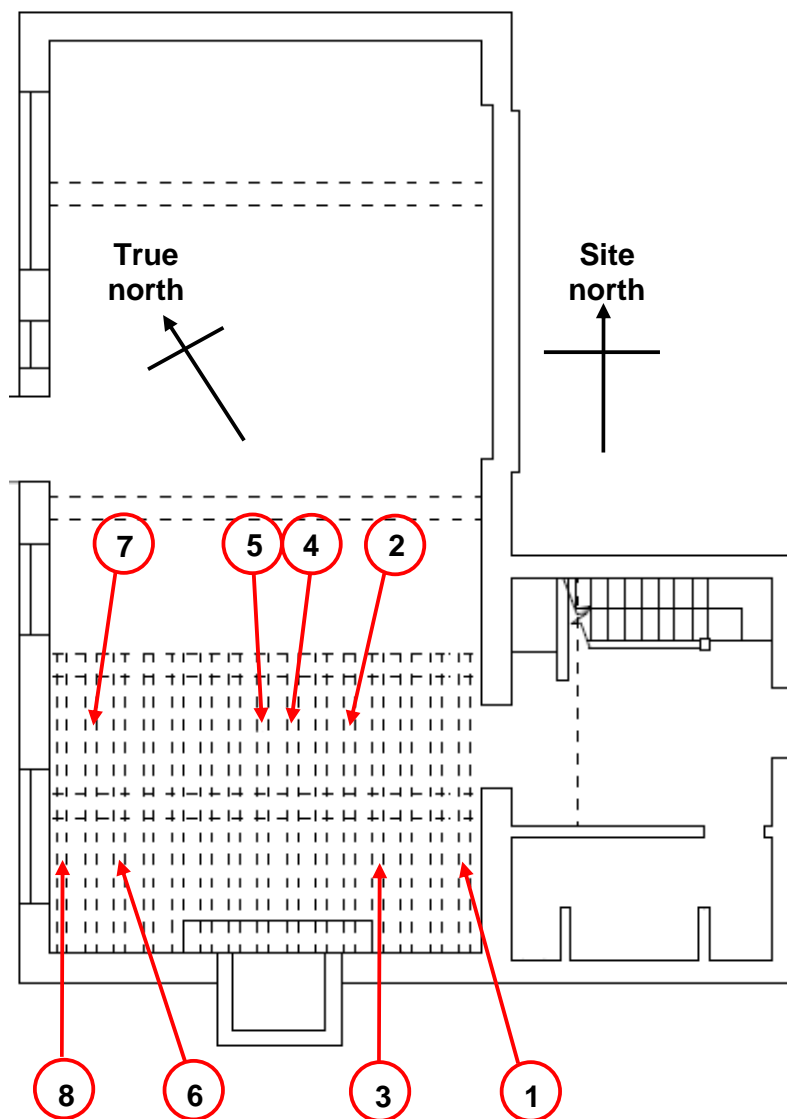
Figure 5a: Plan at ground floor level to show position of sampled timbers
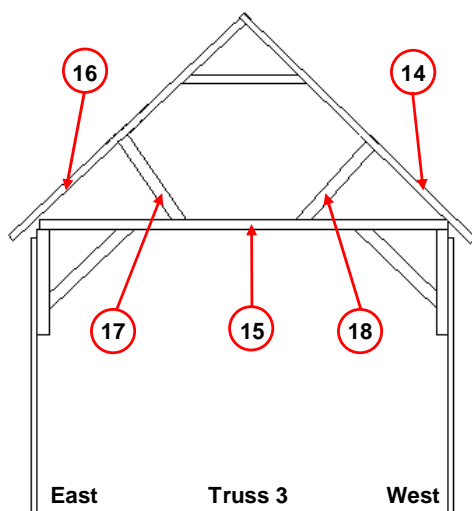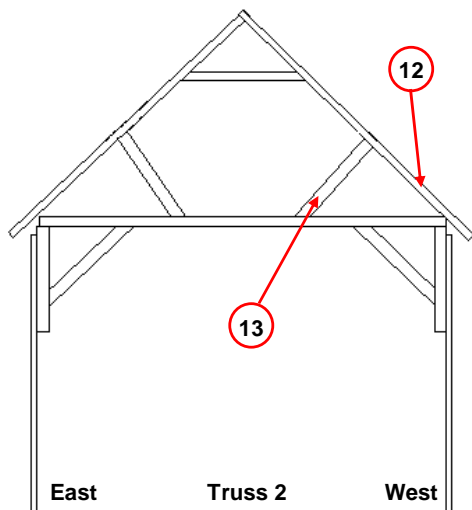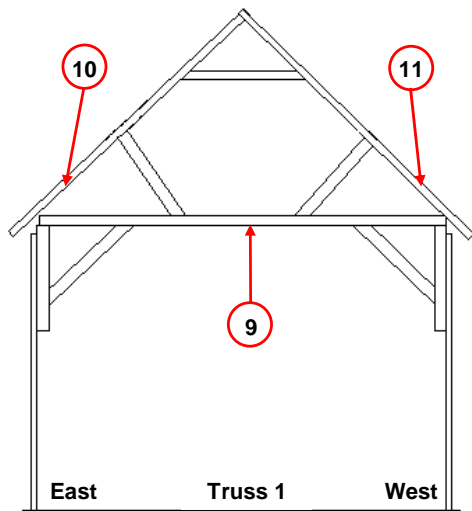
Figure 5b–d: Drawings of the trusses to show sampled timbers
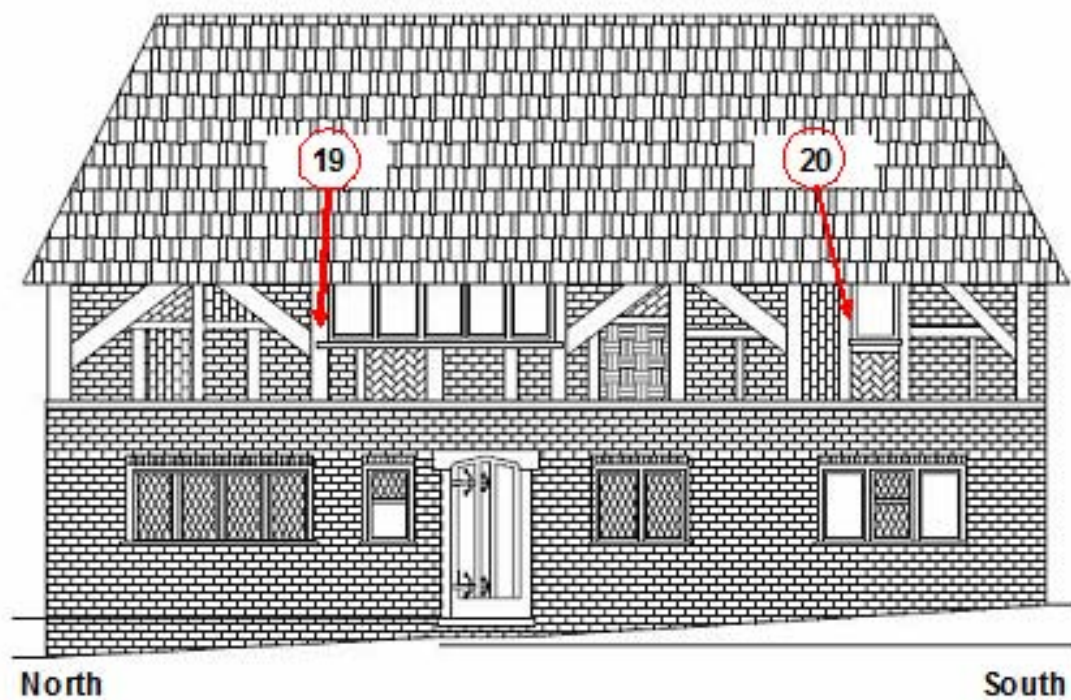
Figure 5e: Drawing to show sampled timbers
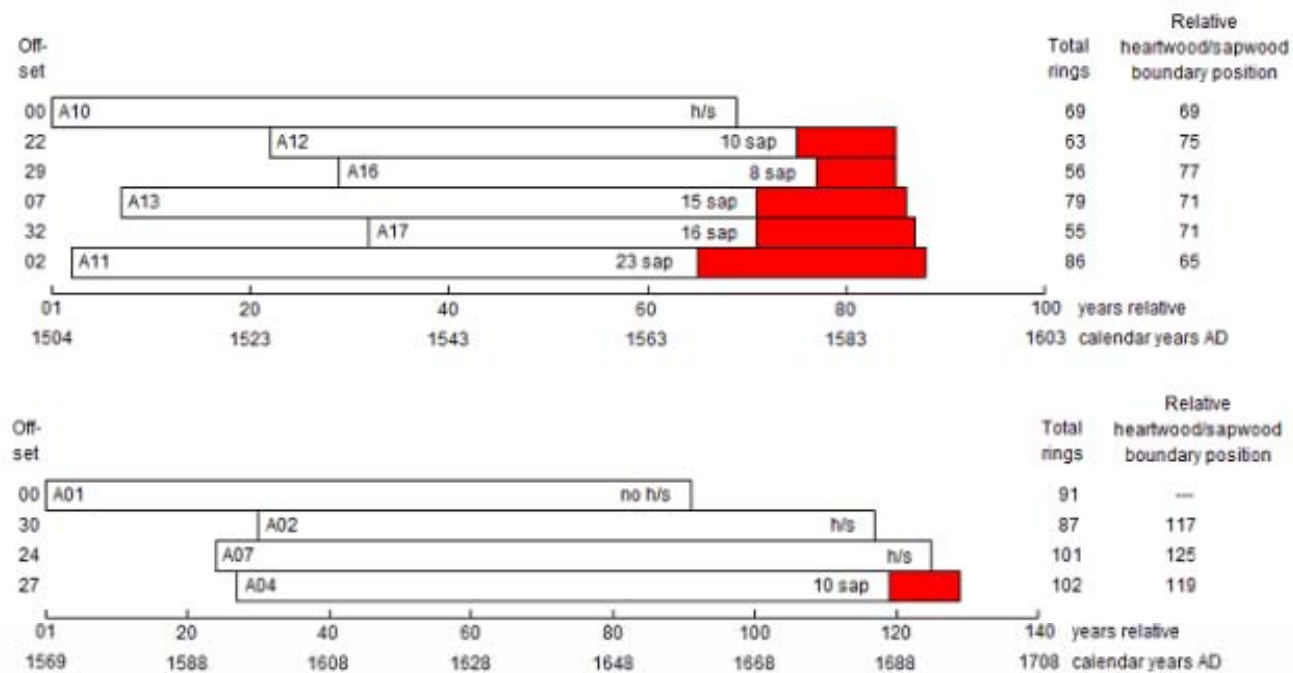
White bars =heartwood rings; Red bars = sapwood rings
h/s = the heartwood/sapwood ring is the last ring on the sample

Figure 6a/b: Bar diagram of the samples in site chronologies ECTASQ01 (top) and ECTASQ03 (bottom)
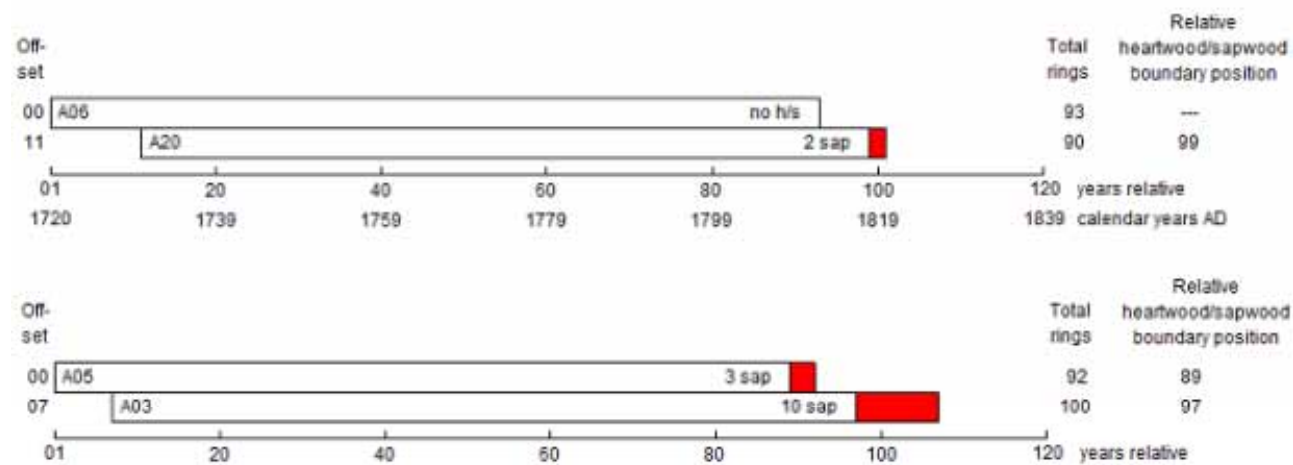
White bars =heartwood rings; Red bars = sapwood rings
h/s = the heartwood/sapwood ring is the last ring on the sample

Figure 6c/d: Bar diagram of the samples in site chronologies ECTASQ03 (top) and ECTASQ04 (bottom)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

ECT-A01A 91
 282 508 341 283 311 238 357 315 341 281 301 341 201 174 177 222 250 249 220 333
 265 204 200 193 208 284 291 337 234 280 238 216 168 155 178 190 160 277 239 194
 180 180 113 173 180 105 73 79 115 163 138 166 83 122 90 89 121 157 156 165
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ECT-A03B 100
 289 269 253 286 270 239 237 251 235 211 187 212 196 139 241 213 229 214 229 211
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229 243 155 135 140 275 264 228 301 331 284 334 204 181 229 252 322 266 304 235
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ECT-A16A 56
 244 313 391 334 224 609 586 670 681 504 451 454 493 353 370 393 446 321 369 354

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114 74 48 57 71 97 189 268 170 191 245 254 282 344 281 219
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building (Laxton and Litton 1988) and Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 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

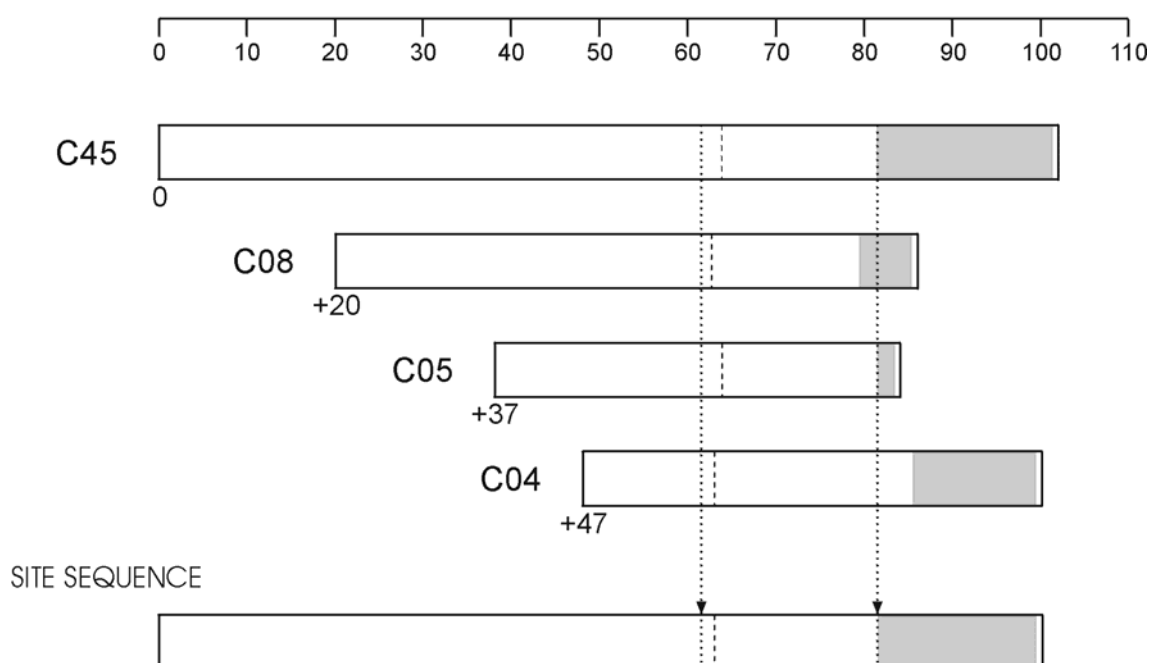|	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

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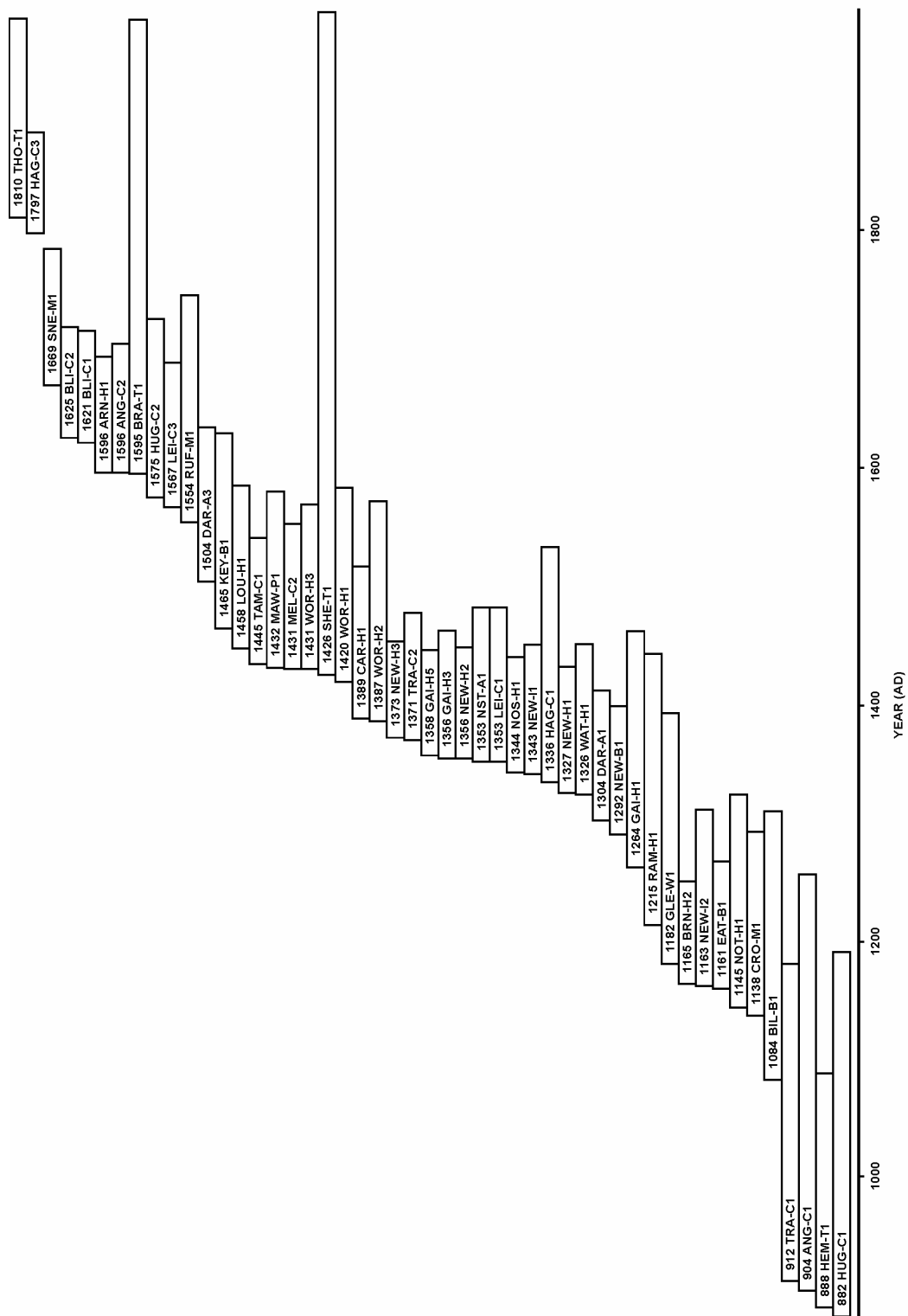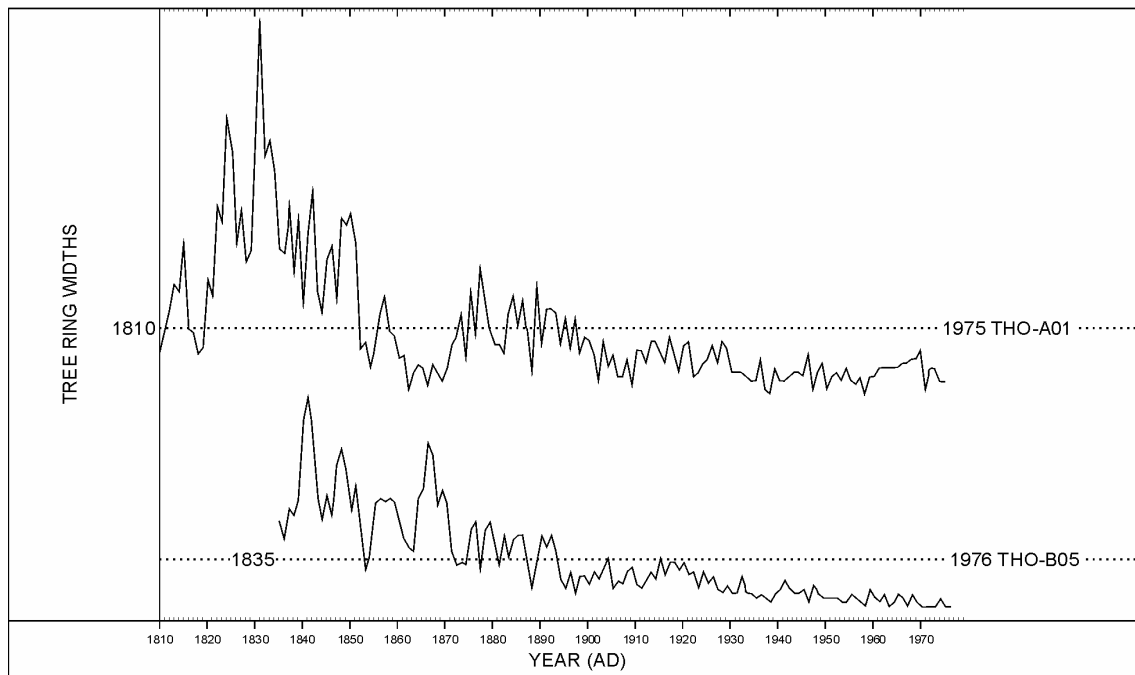
Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87
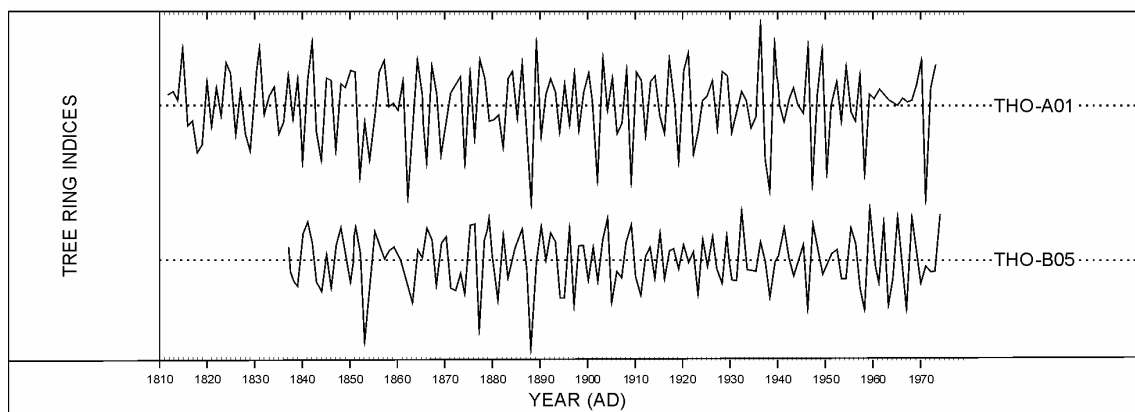
(a)

(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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ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

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The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

* Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
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* Imaging and Visualisation (including Technical Survey, Graphics and Photography)
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