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Codnor Castle, Castle Lane, Codnor, Derbyshire

Tree-ring Analysis of Oak Timbers from the Farmhouse and Barn

Alison Arnold and Robert Howard

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SUMMARY

Analysis undertaken on samples from timbers in the farmhouse and barn at Codnor Castle resulted in the successful dating of 36 timbers.

The floor of the primary section of the farmhouse has been dated to the late AD 1530s, whilst the roof and floor of the southern extension of the farmhouse are slightly later, dating to AD 1560–85 and AD 1560–78 respectively.

The roof of the barn contains timber representing several different fellings in AD 1538–63, AD 1560–85, and the late AD 1720s, with both groups of sixteenth-century timbers thought to be reused. The floor-frame of this barn is constructed of timber felled in AD 1617–39 and AD 1727, again with the earlier timbers potentially representing reused timbers. The barn thus appears to date to the early-eighteenth century.

CONTRIBUTORS

Alison Arnold and Robert Howard

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INTRODUCTION

The Codnor Castle complex, located approximately 1.7km east of the village of Codnor (Figs 1–2), consists of the ruinous remains of a substantial medieval residence, made up of two ‘courts’, with associated earthworks and is thought to date back to the eleventh century. The upper court is a Scheduled Monument and it is on the Heritage at Risk register, despite the previous owners of the site, UK Coal, having undertaken extensive consolidation works. The lower court lies outside of the scheduled area but includes a range of grade II listed buildings including the farmhouse and a barn.

Farmhouse

Located adjacent to the castle is the Grade II listed farmhouse (Fig 3). This five bay house is of two storeys, plus basement, and is built from ashlar coursed squared stone (possibly salvaged from the castle) and red brick with stone dressings. The roof is plain tiled. The oldest part, the northern section, has previously been thought to date to the seventeenth century, with the southern extension a later addition. However recent observations of the timbers have led to the suggestion that much of the timberwork may be sixteenth century. It is also believed that there are alterations dating to the eighteenth and nineteenth centuries.

Primary building

The northern section of the farmhouse is believed to represent the original, or primary, building (Fig 4). The roof over this part of the house consists of two visible principal rafter and tiebeam trusses with the southernmost one (truss 2) being closed with ‘herringbone’ style framing and the central one (truss 1) having raking struts and king post (Fig 5). The first-floor frame is exposed at ground-floor level in the living room (Fig 6) and the entrance hall and comprises a main east-west beam from which runs a single main north-south beam, which in turn holds the common joists.

Southern extension

The roof over this section of the farmhouse is of three trusses, with the first truss of this phase (truss 3) set immediately adjacent to truss 2 in the northern older section. All trusses have principal rafters, tiebeams, king posts, and raking struts (Fig 7). There are a single set of purlins between the trusses. The first-floor frame of the southern extension is also visible at ground-floor level. There is an east-west main beam immediately adjacent to the east-west beam of the primary building from which runs a north-south main beam which holds the common joists (Fig 8).

Barn

Situated approximately 20m to the south-west of the farmhouse is what is believed to be a late-eighteenth century barn, comprising four bays, thought to have originally been stables with a loft above. Central steps on the west elevation give access to the upper floor. It is constructed of red brick with a plain tiled roof and rendered raised gables.

The roof comprises of two principal rafter and tiebeam trusses, two bays being separated by a wall only, with raking struts from the tiebeams to the principals. There are two purlins to each slope in the southern two bays (a single set in the northern two bays) with straight braces running from the upper purlins to the principal rafters (Fig 9). The northern two bays only have a single set of purlins though. It is noticeable that many of the timbers show clear signs of reuse. The first-floor frame is exposed at ground-floor level and comprises four east-west main beams, carrying north-south joists (Fig 10). The joists of bay 3 do not sit in the original housings.

SAMPLING

A dendrochronological survey was requested by Tim Allen, Historic England Inspector of Ancient Monuments, to enhance understanding of the historic development of this complex and hence inform significance of these two buildings located in the lower court. It was hoped that this would elucidate the relationship between the scheduled upper court and unscheduled lower court, thereby potentially supporting a review of the current designated area and securing a future for the complex.

A total of 54 timbers from the floors and roofs of the farmhouse and barn was sampled by coring. Each sample was given the code COD-C and numbered 01–54. The location of all samples was noted at the time of sampling and has been marked on Figures 11–15. Further details relating to the samples can be found in Table 1. Trusses and floor beams have been numbered from north to south in both the barn and the farmhouse, with other timbers being numbered on an east-west basis as appropriate.

Assessment of the dendrochronological potential of the timbers in the roof of the oldest northern section of the farmhouse, indicated that fast grown, young, trees had been utilised. The timbers therefore contained insufficient numbers of rings for secure analysis and so this roof was rejected and excluded from this programme of dendrochronological analysis. Additionally, although sampling would have required Scheduled Monument Consent, a single timber within the castle remains was assessed but this was also clearly unsuitable and hence excluded from this analysis.

ANALYSIS AND RESULTS

Ten samples (three from the farmhouse and seven from the barn) were, following initial preparation in the laboratory, found to have too few rings for secure analysis and so were discarded prior to measurement. The remaining 44 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 36 samples matching to form four groups.

Two samples from the roof over the southern section of the farmhouse matched each other and were combined at the relevant offset positions to form CODCSQ01, a site sequence of 123 rings (Fig 16). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1430–1552. The evidence for this dating is given in Table 2.

Twenty-five samples from the roof and floor-frame of the southern section of the farmhouse, the floor-frame of the northern section of the farmhouse, and the roof of the barn, grouped to form CODCSQ02, a site sequence of 179 rings (Fig 17). This was compared to a series of relevant oak reference chronologies and successfully dated as spanning the period AD 1381–1559 (Table 3).

Five samples taken from the floor-frame of the barn, matched each other and were combined to form CODCSQ03, a site sequence of 109 rings (Fig 18). Attempts to date this site sequence by comparing it against the reference chronologies resulted in it being dated with a first-measured ring date of AD 1508 and a last-measured ring date of AD 1616. The evidence for this dating is given in Table 4.

Finally, four samples from the roof and floor-frame of the barn were grouped and combined to form CODCSQ04 (Fig 19), a site sequence of 80 rings. Following comparison with reference chronologies, this site sequence was found to span the period AD 1648–1727 (Table 5).

Attempts to match the remaining eight ungrouped samples by comparing them individually against the four site chronologies and reference chronologies were unsuccessful and thus all remain undated.

INTERPRETATION

Tree-ring analysis has resulted in the successful dating of 36 timbers from both the barn and farmhouse. To aid interpretation each area is dealt with separately below and illustrated in Figure 20. Felling date ranges have been calculated using the estimate that mature oak trees in this region have 15–40 sapwood rings (95% confidence range).

Farmhouse

Primary building – floor frame

Eight of the samples taken from the floor frame of the primary building have been dated. Two of these (COD-C06 and COD-C07) representing common joists have complete sapwood (ie the last ring of growth before felling is present) and a last-measured ring of AD 1538, the felling date of the two timbers represented. Two further samples (COD-C01 and COD-C02) were taken from common joists that had complete sapwood but a small number of the outermost rings were lost during the sampling procedure due to the fragile nature of sapwood. A note was made of the amount in millimetres of sapwood lost and this was then used to estimate how many rings may have been lost. Thus it appears that sample COD-C01 has lost *c* 3 rings and COD-C02 *c* 2 rings which when added to the last-measured ring dates of these samples indicates that they were felled in *c* AD 1539 and *c* AD 1537, respectively.

Sample COD-C08, also from a common joist, has a heartwood/sapwood boundary ring date of AD 1515, giving an estimated felling date within the range AD 1531–55 (allowing for this sample to have a last-measured ring date of AD 1530 with incomplete sapwood). This is clearly consistent with the timber also having been felled in the late AD 1530s.

The other three dated samples from this floor, representing two joists and the main north-south beam, do not have the heartwood/sapwood boundary ring date but with last-measured ring dates of AD 1494 (COD-C14), AD 1516 (COD-C23), and AD 1483 (COD-C24) these have a *terminus post quem* for felling of AD 1509, AD 1531, and AD 1498, respectively, not inconsistent with these timbers also having been felled in, or around, AD 1538. This interpretation is supported by the overall level of similarity between the eight dated individual samples, with COD-C23 and COD-C24 matching with a *t*-value of 11.2 suggesting that they may be derived from the same-tree.

Southern extension - roof

Eight of the samples taken from the roof over this part of the farmhouse have been dated, six of which have the heartwood/sapwood boundary ring. In all cases this is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1545, allowing an estimated felling date to be calculated for the six timbers represented (three principal rafters, two king posts, one raking strut) to within the range AD 1560–85. Although the other two samples, COD-C15 and COD-C16, do not have the heartwood/sapwood boundary ring date, the level of similarity seen between them and the other dated roof samples suggest these were also felled in AD 1560–85 (Table 6). Indeed, as sample COD-C15 matches COD-C20 at a value of t = 15.5, it is quite possible that these two timbers were cut from the same tree.

Southern extension – floor frame

Six of the samples, all representing commons joists in the floor of this extension have been dated, but only one of these has the heartwood/sapwood boundary. Sample COD-C03 has a heartwood/sapwood boundary ring date of AD 1538 which, allowing for this sample having a last-measured ring date of AD 1559, provides an estimated felling date range of AD 1560–78.

The other five dated samples from this floor do not have the heartwood/sapwood boundary and so estimated felling dates cannot be calculated for them. However, with the last-measured ring dates ranging from AD 1503 (COD-C04) to AD 1542 (COD-C09), these produce a *terminus post quem* for felling ranging from AD 1518 to AD 1557. Again the level of similarity between the samples suggests that this is a coherent group and that all six dated common joists were probably felled in the range AD 1560–78.

Barn

Roof

Eight of the roof timbers of this building have been successfully dated. Seven samples have the heartwood/sapwood boundary which suggests three separate fellings.

The earliest relates to sample COD-C34, representing a raking strut, with a heartwood/sapwood boundary of AD 1523, giving an estimated felling date range of AD 1538–63. Three others, COD-C35, COD-C36 and COD-C38 representing a wall plate and two purlins, have slightly later heartwood/sapwood boundary rings, the average of which is AD 1545, giving an estimated felling date range of AD 1560–85. All three of these latter samples were taken from timbers which showed clear signs of reuse. The dated sample COD-C37, representing a purlin, does not have the heartwood/sapwood boundary ring date but with a last-measured ring date of AD 1493 this has a *terminus post quem* for felling of AD 1508, making it likely that this timber was also felled in either AD 1538–63 or AD 1560–85.

Two other samples (COD-C28 and COD-C29) were taken from a tiebeam and principal rafter with complete sapwood but the outer *c* 2mm of sapwood was lost during the sampling procedure. As above this suggests the loss of a single ring for both samples giving them felling dates of *c* AD 1727 (COD-C28) and *c* AD 1728 (COD-C29). A third sample, COD-C40 from a tiebeam, has a similar heartwood/sapwood boundary ring to COD-C28 and COD-C29, making it likely that this timber was also felled in the late AD 1720s.

Floor frame

Six of these samples have been dated, five of which have the heartwood/sapwood boundary ring which suggests two separate fellings.

The earliest of these fellings is represented by four samples (COD-C47, COD-C48, COD-C49, and COD-C52) from joists. The average heartwood/sapwood boundary ring date of AD 1599 gives an estimated felling date for these joists of AD 1617–39. This allows for sample COD-C49 having a last-measured ring date of AD 1616 with incomplete sapwood. Sample COD-C50, also from a joist, does not have the heartwood/sapwood boundary ring and so an estimated felling date range cannot be calculated for it, except to say that with a last-measured ring date of AD 1576 the timber represented has a *terminus post quem* for felling of AD 1591. Whilst it could in theory represent the inner section of a long-lived tree felled in AD 1727 (see below), it appears far more likely that it was felled in the early-seventeenth century. This interpretation is supported by the overall level of similarity between it and the other early-seventeenth century timbers from this floor frame. Four of these dated joists are from bay 3 where the joists do not sit in the original housing in the main beam.

A final dated sample representing a main beam in this floor frame has complete sapwood and the last-measured ring date of AD 1727, the felling date of the timber represented.

DISCUSSION

The earliest extant timbers identified are in the floor of the northern section of the farmhouse, thought to represent the oldest part of the farmhouse. This group of samples, representing common joists, joists and a main beam with no evidence of reuse, have been dated as being felled in the late AD 1530s. This suggests that the primary construction of the farmhouse potentially occurred somewhat earlier than the seventeenth century date indicated in the listing and supports recent observations that the timberwork may have been of sixteenth century origin. It is unfortunate that the roof over this northern section of the farmhouse was unsuitable for dendrochronological analysis as the provision of independent dating evidence for this element would have provided further evidence for the sixteenth-century origins.

The southern extension of the farmhouse is now known to incorporate timbers in the floor frame that were felled in the range AD 1560–78 and in the roof that were felled in the range AD 1560–85. The similarity in the felling date ranges calculated for the floor frame and roof suggests the timber utilised in both elements was felled as part of a single felling programme in the second half of the sixteenth century. Further evidence to support this interpretation is the potential same tree match identified between a joist (COD-C11) and a principal rafter (COD-C18); these samples match each other at a value of $t = 10.3$.

Timbers dating to the sixteenth century were also identified in the roof of the barn with timbers now known to have been felled in AD 1538–63 and AD 1560–85, the former being broadly coeval with the primary construction of the farmhouse and the latter being broadly contemporary with the floor-frame and roof timbers in the southern extension of the farmhouse. Four of these roof timbers showed clear evidence of reuse and it appears possible that these timbers may have been reused from another building, or buildings, on-site that were of similar date to the two phases of construction identified in the farmhouse. Several common joists from the floor-frame in the barn were dated as being felled in AD 1614–39 but several of these joists did not actually sit in the original housings of their associated main beam. It is therefore suggested that these seventeenth century timbers represent a significantly later repair or modification, reusing timbers from another building. The latest dated timbers from the barn, three roof timbers and a main floor beam were felled in the late AD 1720s and it is thought likely that construction of the barn occurred very shortly after their felling. The barn has previously been stylistically dated to the late-eighteenth century but the results of this analysis suggest a slightly earlier construction, utilising a significant amount of reused sixteenth century timbers in the roof and at some point during repairs or modifications incorporating reused material in the floor-frame dating to the seventeenth century.

Site sequences CODCSQ01 and CODCSQ02 can be seen to match each other at the significant value of $t = 5.8$ which might suggest the same or adjacent woodland sources were utilised for the timber represented by the samples in these site sequences. It can be seen that both of these site sequences match most closely those reference chronologies from sites in the north-west and Derbyshire (Tables 2 and 3). Site sequence CODCSQ03 has low but noteworthy matches against both CODCSQ01 ($t = 4.1$) and CODCSQ02 ($t = 3.1$) and again can be seen to match most highly against sites in the north-west and the Midlands. Site sequence CODCSQ04 is somewhat later than the others; the reference chronologies against which it has dated most highly against are in Leicestershire and Lincolnshire (Table 5), to the south of Codnor Castle. This might suggest a change in woodland source or may simply be a result of reference chronologies held for that period. Although it is not possible to determine exactly where the woodland source/s were they are likely to have been relatively local.

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TABLES

Table 1: Details of samples from Codnor Castle, Castle Lane, Derbyshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Farmhouse						
Floor – primary (or northern section)						
COD-C01	East common joist 4	111	19c(+*c*3 lost)	1426	1517	1536
COD-C02	East common joist 6	96	14c(+*c*2 lost)	1440	1521	1535
COD-C06	West common joist 4	99	13C	1440	1525	1538
COD-C07	West common joist 5	85	12C	1454	1526	1538
COD-C08	West common joist 6	150	15	1381	1515	1530
COD-C14	North-south beam (north)	99	--	1396	----	1494
COD-C23	Entrance - Joist 1	111	--	1406	----	1516
COD-C24	Entrance - Joist 2	81	--	1403	----	1483
COD-C25	Entrance - Joist 3	NM	--	----	----	----
COD-C26	Entrance - Joist 4	70	h/s	----	----	----
COD-C27	Entrance - back plate/beam	48	h/s	----	----	----
Floor - southern extension						
COD-C03	East common joist 1	121	21	1439	1538	1559
COD-C04	East common joist 2	89	--	1415	----	1503
COD-C05	East common joist 5	63	--	1460	----	1522
COD-C09	West common joist 1	75	--	1468	----	1542
COD-C10	West common joist 2	98	--	1444	----	1541
COD-C11	West common joist 3	78	--	1437	----	1514
COD-C12	West common joist 4	NM	--	----	----	----
COD-C13	Main east-west beam (south)	NM	--	----	----	----
Roof – southern extension						
COD-C15	East principal rafter, truss 3	94	--	1415	----	1508
COD-C16	West principal rafter, truss 3	120	--	1411	----	1530
COD-C17	King post, truss 3	120	h/s	1433	1552	1552
COD-C18	West principal rafter, truss 4	110	01	1438	1546	1547

Table 1 (cont)

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
COD-C19	King post, truss 4	112	h/s	1430	1541	1541
COD-C20	East principal rafter, truss 5	117	h/s	1431	1547	1547
COD-C21	West principal rafter, truss 5	120	h/s	1426	1545	1545
COD-C22	West raking strut, truss 5	81	h/s	1460	1540	1540
Barn						
Roof						
COD-C28	Tiebeam truss1	69	12c(+*c*1 lost)	1658	1714	1726
COD-C29	West principal rafter, truss 1	53	12c(+*c*1 lost)	1675	1715	1727
COD-C30	East principal rafter, truss 1	56	13	----	----	----
COD-C31	East raking strut, truss 1 - reused	85	--	----	----	----
COD-C32	West principal rafter, truss 2	51	09C	----	----	----
COD-C33	East principal rafter, truss 2	NM	--	----	----	----
COD-C34	East raking strut, truss 2	69	h/s	1455	1523	1523
COD-C35	West plate - reused	73	h/s	1468	1540	1540
COD-C36	West purlin, truss 1 to north extension - reused	131	h/s	1422	1552	1552
COD-C37	East purlin, north extension - reused	73	--	1421	----	1493
COD-C38	East purlin, truss 1 to north extension - reused	133	h/s	1412	1544	1544
COD-C39	East upper purlin, truss 2 to south wall	77	h/s	----	----	----
COD-C40	Tiebeam, truss 2	66	h/s	1648	1713	1713
Floor						
COD-C41	Beam 1	72	13	----	----	----
COD-C42	Beam 2	58	11C	1670	1716	1727
COD-C43	Beam 3	71	18C	----	----	----
COD-C44	Joist 9, bay 1	NM	--	----	----	----
COD-C45	Joist 5, bay 2	NM	--	----	----	----
COD-C46	Joist 8, bay 2	NM	--	----	----	----
COD-C47	Joist 4, bay 3	77	h/s	1528	1604	1604
COD-C48	Joist 6, bay 3	88	h/s	1509	1596	1596
COD-C49	Joist 9, bay 3	109	12	1508	1604	1616

Table 1 (cont)

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
COD-C50	Joist 10, bay 3	50	--	1527	----	1576
COD-C51	Joist 3, bay 4	NM	--	----	----	----
COD-C52	Joist 9, bay 4	70	h/s	1524	1593	1593
COD-C53	Joist 9, bay 5	NM	--	----	----	----
COD-C54	Joist 7, bay 5	NM	--	----	----	----

NM = not measured
h/s = heartwood/sapwood boundary is the last-measured ring
c(+*cx* lost) = complete sapwood on timber, all or part lost in sampling, estimated number of lost rings in brackets
C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence CODCSQ01 and relevant reference chronologies when the first-ring date is AD 1430 and the last-measured ring date is AD 1552

Reference chronology	*t*-value	Span of chronology	Reference
Headlands Hall, Liversedge, West Yorkshire	6.9	AD 1388–1487	Tyers 2001
2–4 Church Street, Leek, Staffordshire	6.6	AD 1406–1512	Arnold and Howard 2009 unpubl
Ordsall Hall, Salford, Greater Manchester	6.1	AD 1385–1512	Howard *et al* 1994a
Dandra Garth, Garsdale, Cumbria	6.0	AD 1373–1635	Arnold and Howard 2014
Crag House Farm Barn, Cookridge, Leeds, Yorkshire	5.9	AD 1416–1602	Arnold and Howard 2012
Howley Hall Farm, Morley, West Yorkshire	5.9	AD 1415–1635	Arnold and Howard 2013
St Martin's Church, Alfreton, Derbyshire	5.8	AD 1413–1560	Arnold and Howard 2008

Table 3: Results of the cross-matching of site sequence CODCSQ02 and relevant reference chronologies when the first-ring date is AD 1381 and the last-measured ring date is AD 1559

Reference chronology	*t*-value	Span of chronology	Reference
Wakelyn Old Hall, Hilton, Derbyshire	11.5	AD 1415–1573	Arnold *et al* 2008a
Ightfield Hall Barn, Shropshire	10.9	AD 1341–1566	Groves 1997
Howley Hall Farm, Morley, West Yorkshire	10.8	AD 1415–1635	Arnold and Howard 2013
Black Ladies, near Brewood, Staffordshire	9.5	AD 1372–1671	Tyers 1999
Kingsbury Hall, Kingsbury, Warwickshire	9.4	AD 1391–1564	Arnold and Howard 2006
Sinai Park, Burton on Trent, Staffordshire	9.4	AD 1227–1750	Tyers 1997
Woodseats Hall Barlow, Derbyshire	9.3	AD 1417–1535	Howard *et al* 1996

Table 4: Results of the cross-matching of site sequence CODCSQ03 and relevant reference chronologies when the first-ring date is AD 1508 and the last-measured ring date is AD 1616

Reference chronology	*t*-value	Span of chronology	Reference
Stoneleigh Abbey, Stoneleigh, Warwicks	5.5	AD 1398–1658	Howard *et al* 2000
Stubley Farm, Morley, West Yorkshire	5.4	AD 1508–1662	Tyers *pers comm*
Teversal Manor Garages, Sutton in Ashfield, Nottinghamshire	5.2	AD 1522–1581	Arnold *et al* 2003
Bolsover Castle (Riding House), Bolsover, Derbyshire	5.0	AD 1494–1744	Howard *et al* 2005
Upper Hall, Hartshorne, Derbyshire	5.0	AD 1448–1611	Arnold *et al* 2008a
Bentley Hall, Derbyshire	5.0	AD 1444–1675	Arnold *et al* 2009
Hipper Hall, Walton, Derbyshire	4.9	AD 1478–1632	Howard *et al* 1994b

Table 5: Results of the cross-matching of site sequence CODCSQ04 and relevant reference chronologies when the first-ring date is AD 1648 and the last-measured ring date is AD 1727

Reference chronology	*t*-value	Span of chronology	Reference
St John the Baptist Church, Grimstone, Leicestershire	6.6	AD 1674–1754	Arnold *et al* 2005
Church Farm, Bringhurst, Leicestershire	6.0	AD 1664–1781	Groves *et al* 2004
Shenton Dovecote, Leicestershire	5.9	AD 1606–1719	Arnold *et al* 2008b
St Firmin Church, Thurlby, Lincolnshire	5.9	AD 1599–1792	Arnold and Howard 2010
New Hall, Eaton under Heywood, Shropshire	5.9	AD 1606–1752	Worthington and Miles 2004
Green's Mill, Snenton, Nottinghamshire	5.4	AD 1664–1787	Laxton *et al* 1982
Bretby Hall, Derbyshire	5.1	AD 1494–1719	Howard *et al* 1999

Table 6: Matrix to show the level of cross-matching, as indicated by the t-values, and the relevant offsets between dated samples from the farmhouse roof; values of t=10.0+ may represent timbers cut from the same tree; – indicates either no overlap or a not statistically significant t-value between samples

	COD-C15	COD-C16	COD-C17	COD-C18	COD-C19	COD-C20	COD-C21	COD-C22
COD-C15	*	4	--	-23	--	-16	-11	--
COD-C16	10.6	*	--	-27	-19	-20	-15	-49
COD-C17	--	--	*	--	3	--	--	--
COD-C18	10.4	8.2	--	*	8	7	12	-22
COD-C19	--	2.8	18.8	3.1	*	--	--	-30
COD-C20	15.5	9.9	--	9.3	--	*	5	--
COD-C21	6.3	6.3	--	7.1	--	5.4	*	--
COD-C22	--	3.3	--	3.1	5.1	--	--	*

FIGURES

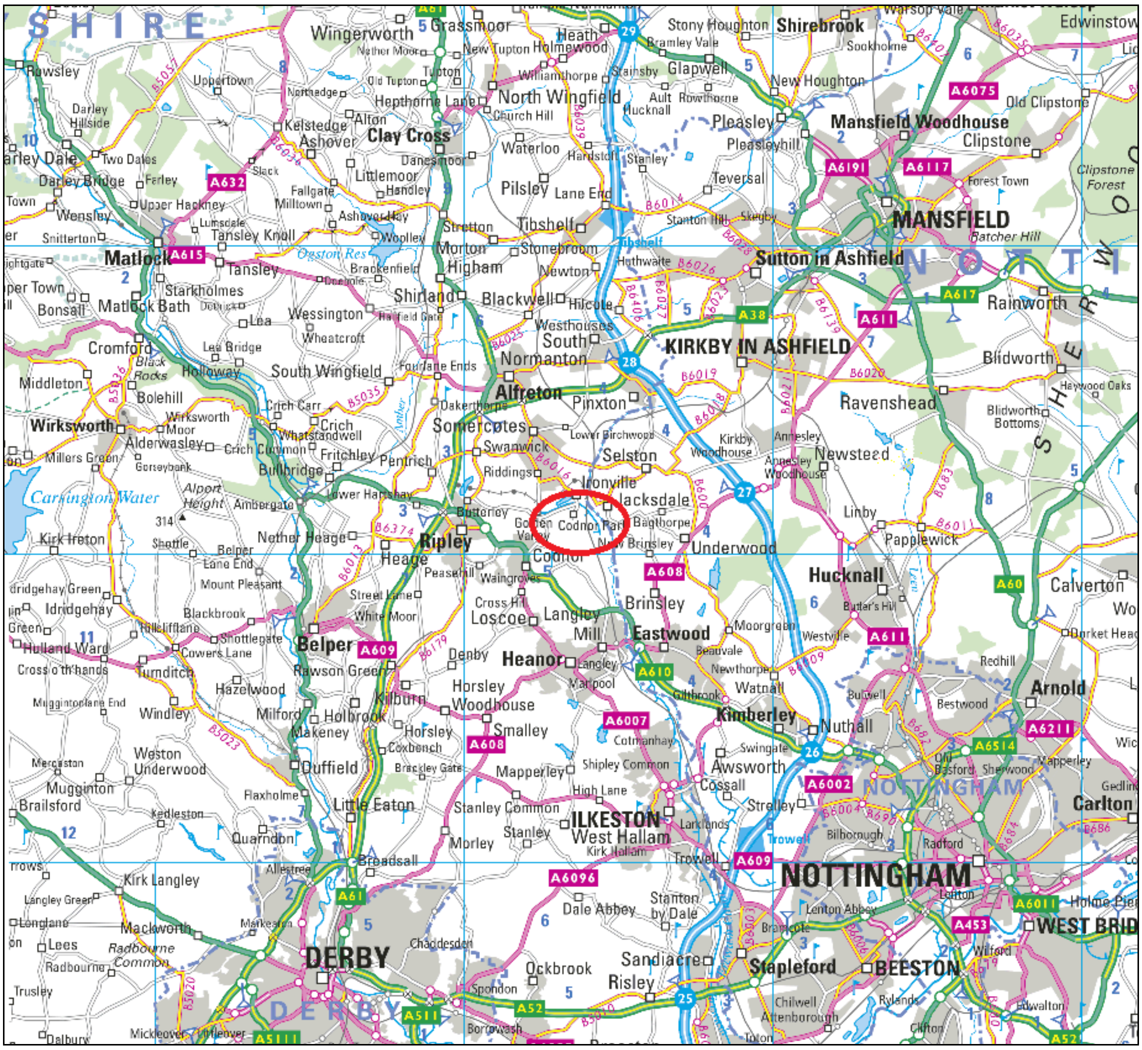

Figure 1: Map to show the general location of Codnor, circled. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

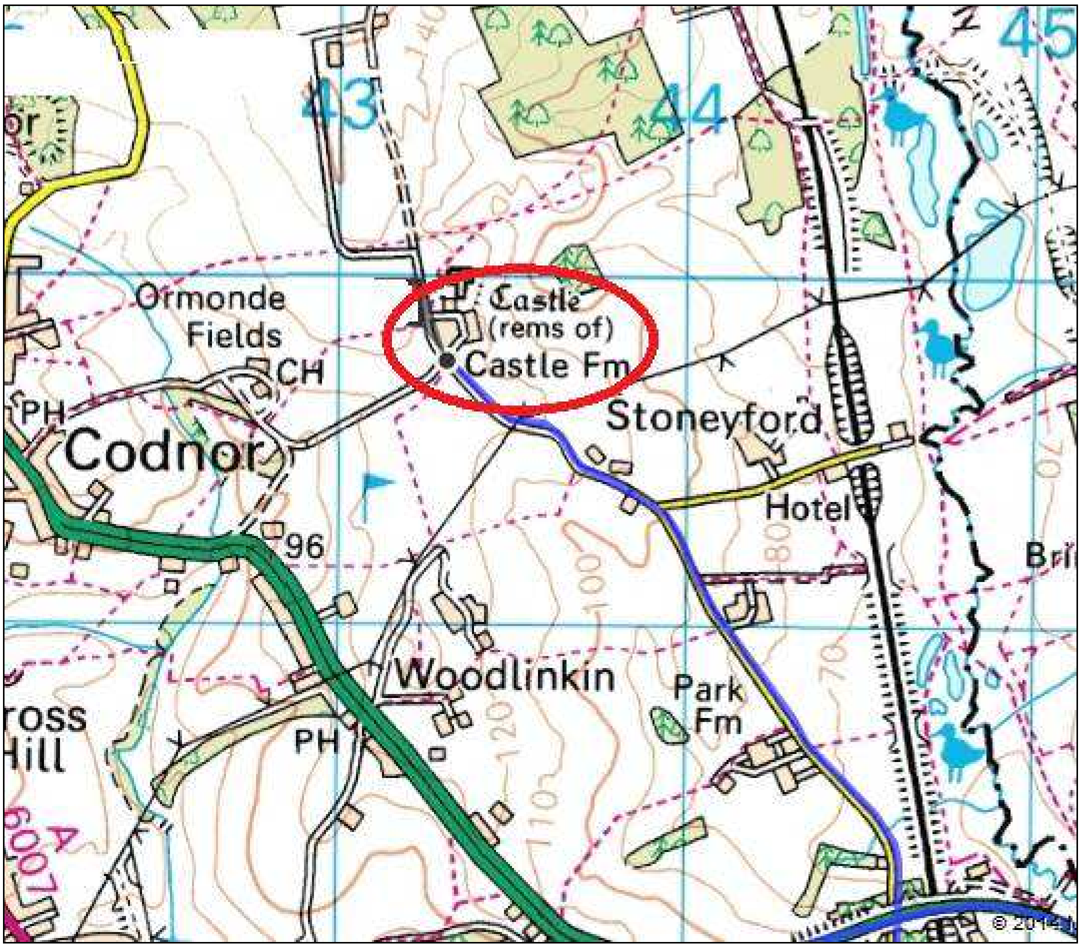

Figure 2: Map to show the general location of Codnor Castle, circled. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: Map to show the location of Codnor Castle farmhouse (black hashing) and barn (red hashing). © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

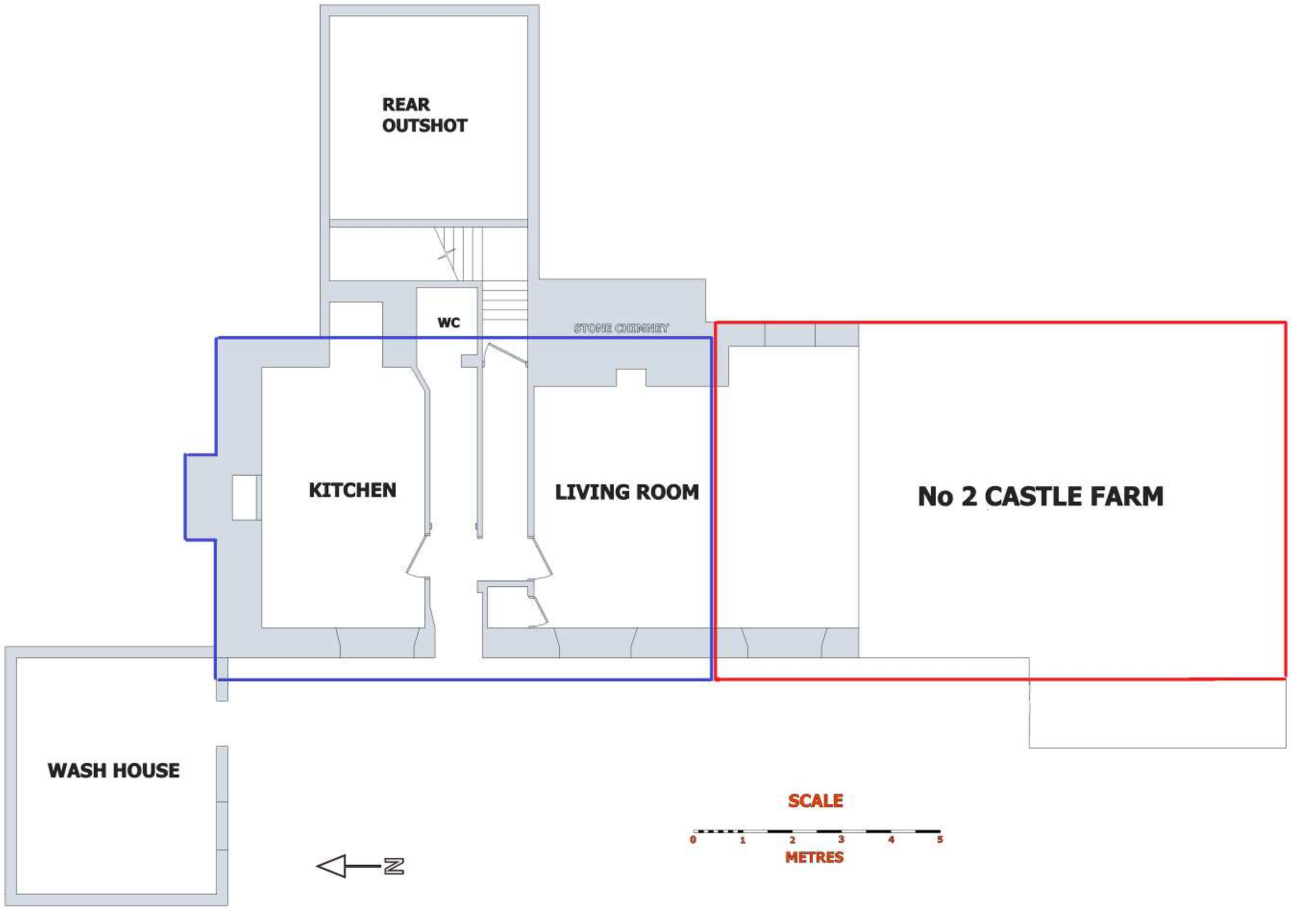

Figure 4: Farmhouse, ground-floor plan, showing the primary building (outlined in blue) and southern extension (outlined in red) (after Charles Glenn)

Figure 5: Farmhouse, primary roof, truss 1, photograph taken from the south (Robert Howard)

Figure 6: Farmhouse, primary floor frame (left of photograph), photograph taken from the north-west (Robert Howard)

Figure 7: Farmhouse, southern extension roof, truss 4 in foreground, photograph taken from the south (Robert Howard)

Figure 8: Farmhouse, southern extension floor frame (left of photograph), photograph taken from the south-east (Robert Howard)

Figure 9: Barn, truss 2, photograph taken from the north (Robert Howard)

Figure 10: Barn, floor frame with beam 2 and bay 3 in the foreground; it can be seen that the joists of bay 3 do not sit in the original housings, photograph taken from the north (Alison Arnold)

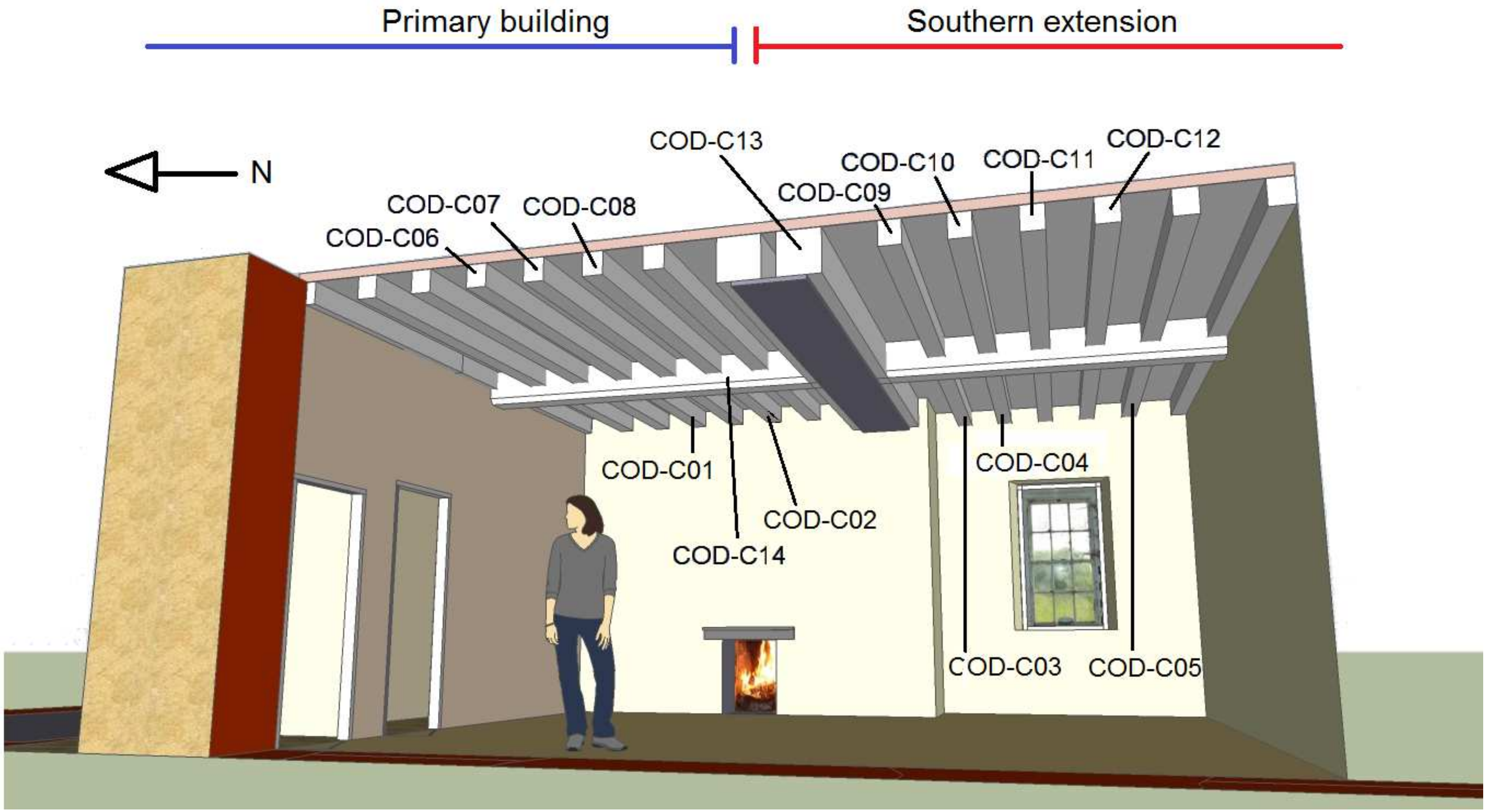

Figure 11: Illustration of the farmhouse showing the location of samples COD-C01–14 (after Charles Glenn)

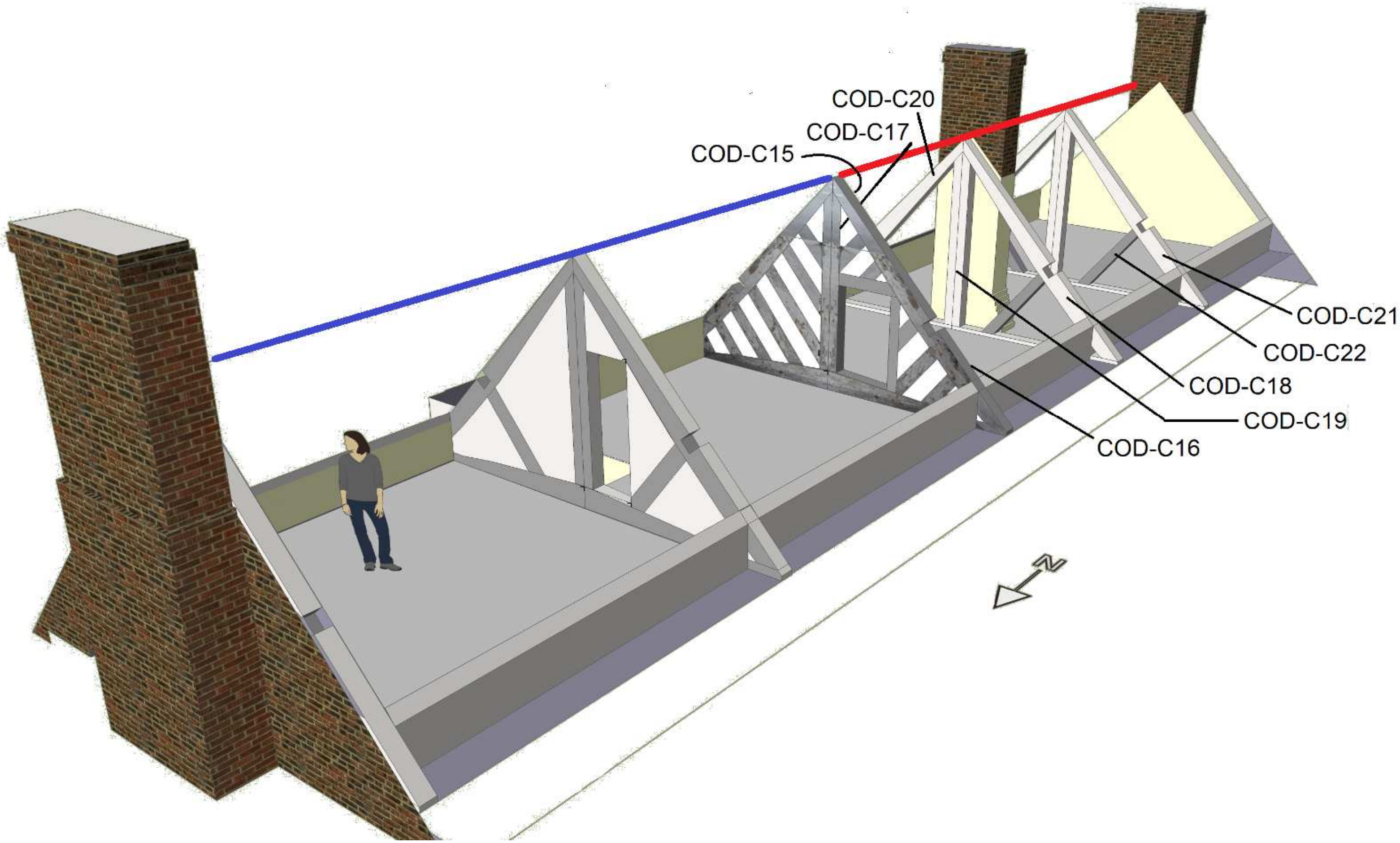

Figure 12: Illustration of the farmhouse showing the location of samples COD-C15–22 (after Charles Glenn)

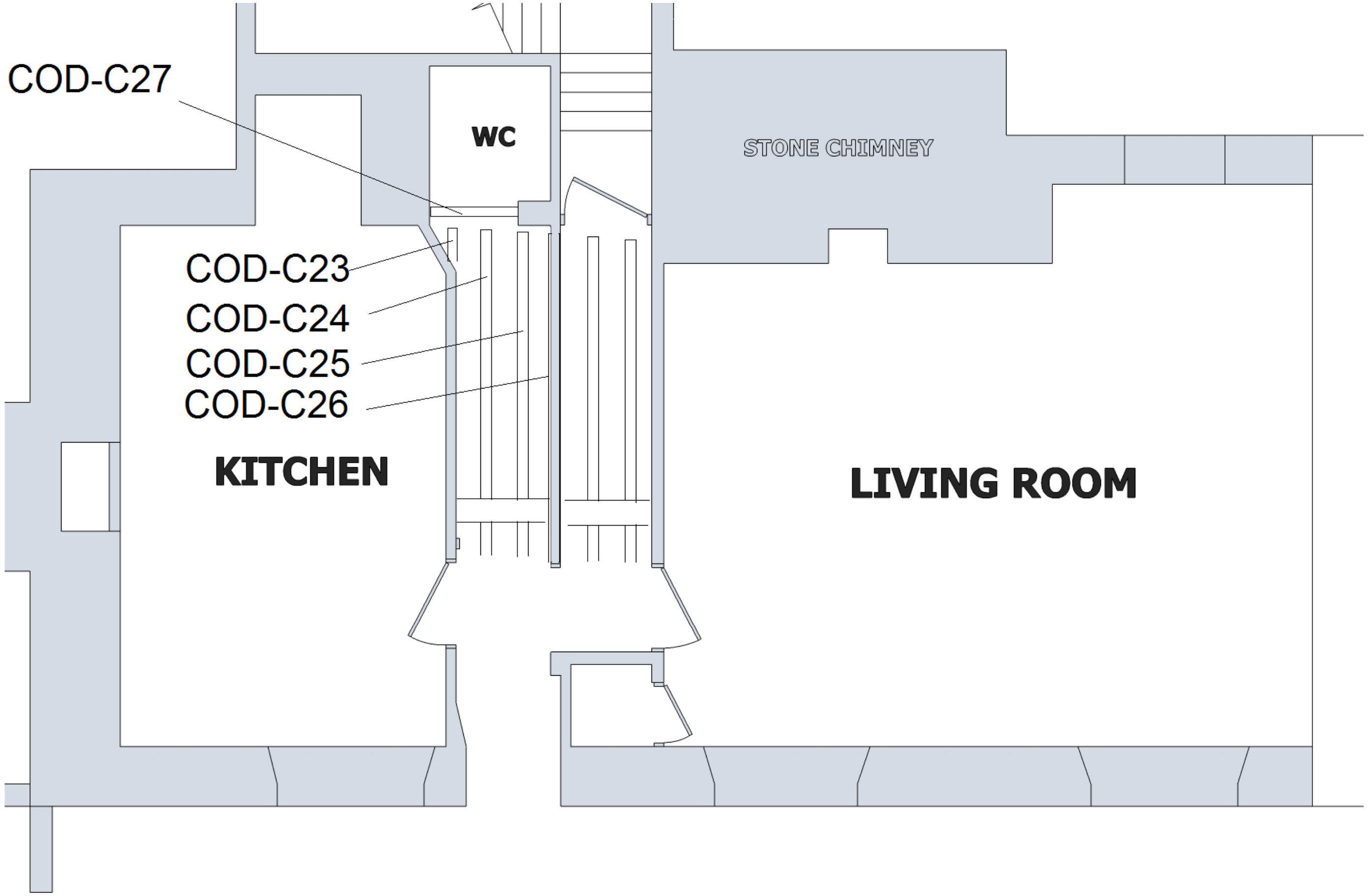

Figure 13: Ground-floor plan of the farmhouse, showing the location of samples COD-C23–7 (after Charles Glenn)

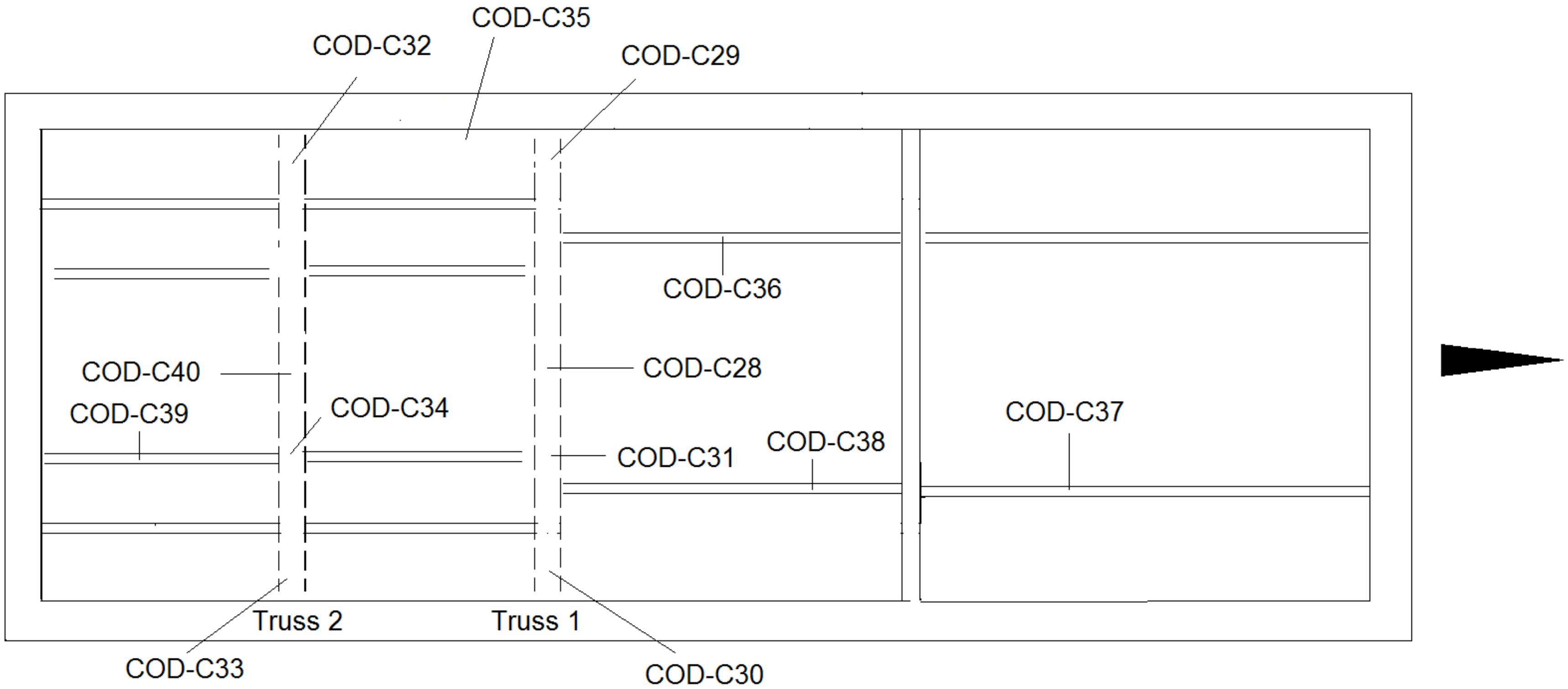

Figure 14: Sketch plan of the roof of the barn, showing the location of samples COD-C28–40

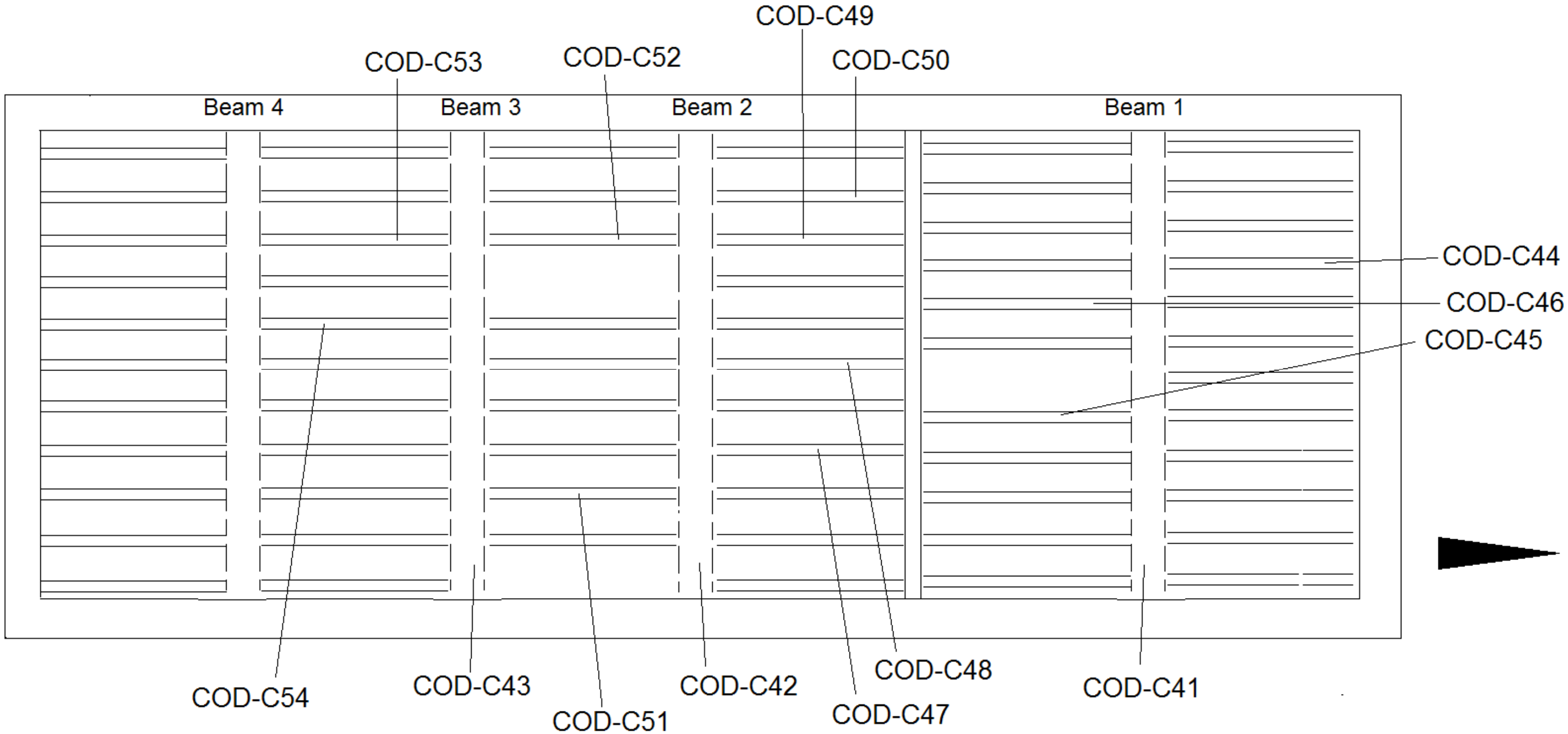

Figure 15: Sketch plan of the first-floor frame of the barn, showing the location of samples COD-C41–54

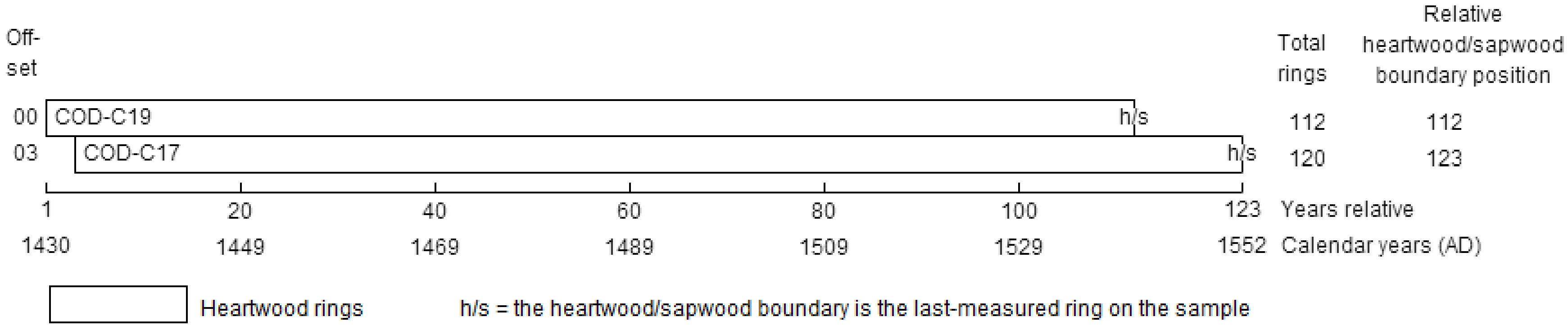

Figure 16: Bar diagram to show the relative position of samples in site sequence CODCSQ01

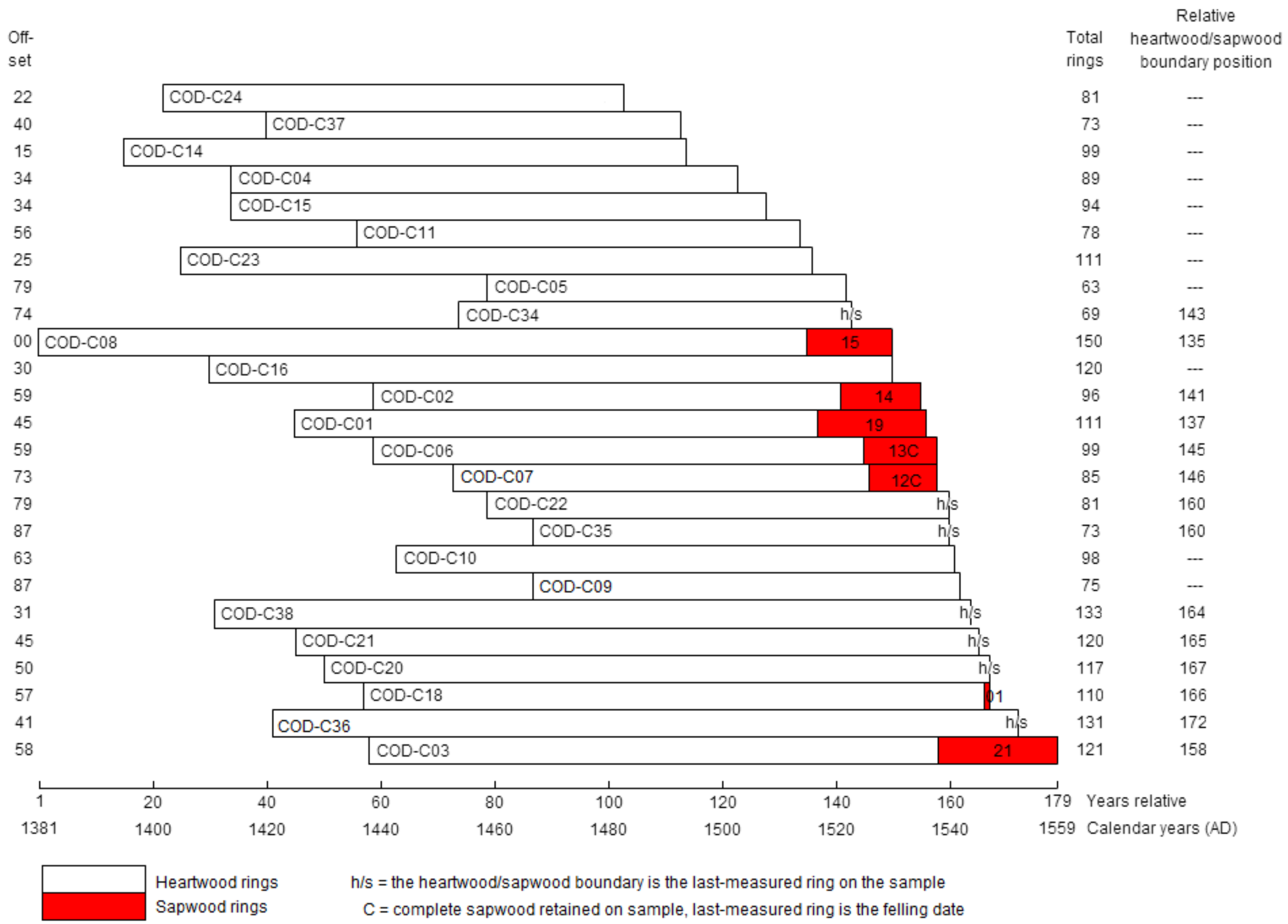

Figure 17: Bar diagram to show the relative position of samples in site sequence CODCSQ02

Figure 18: Bar diagram to show the relative position of samples in site sequence CODCSQ03

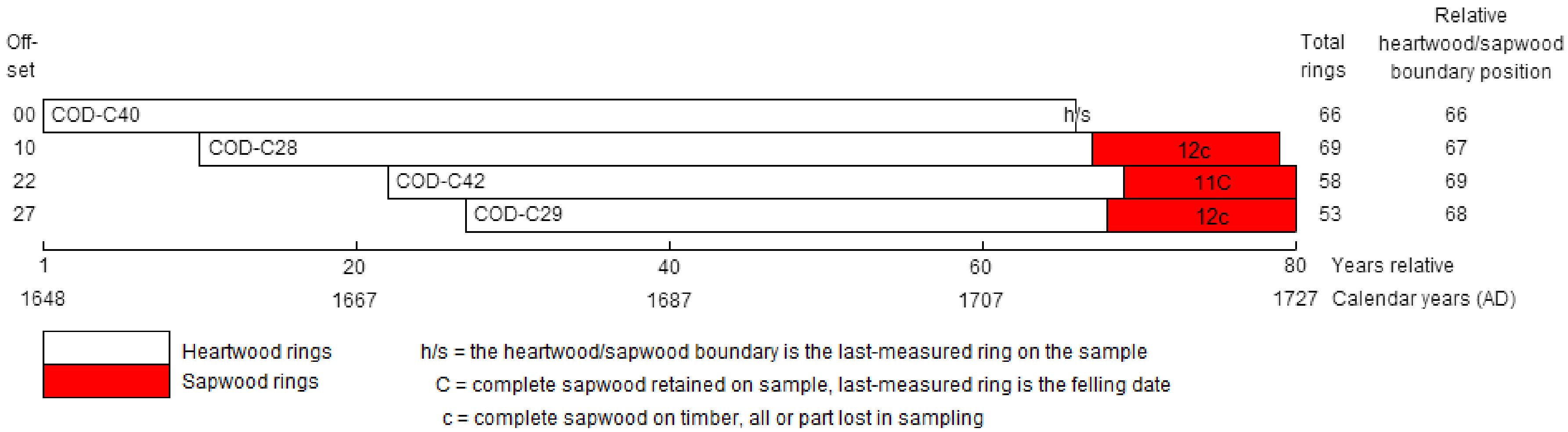

Figure 19: Bar diagram to show the relative position of samples in site sequence CODCSQ04

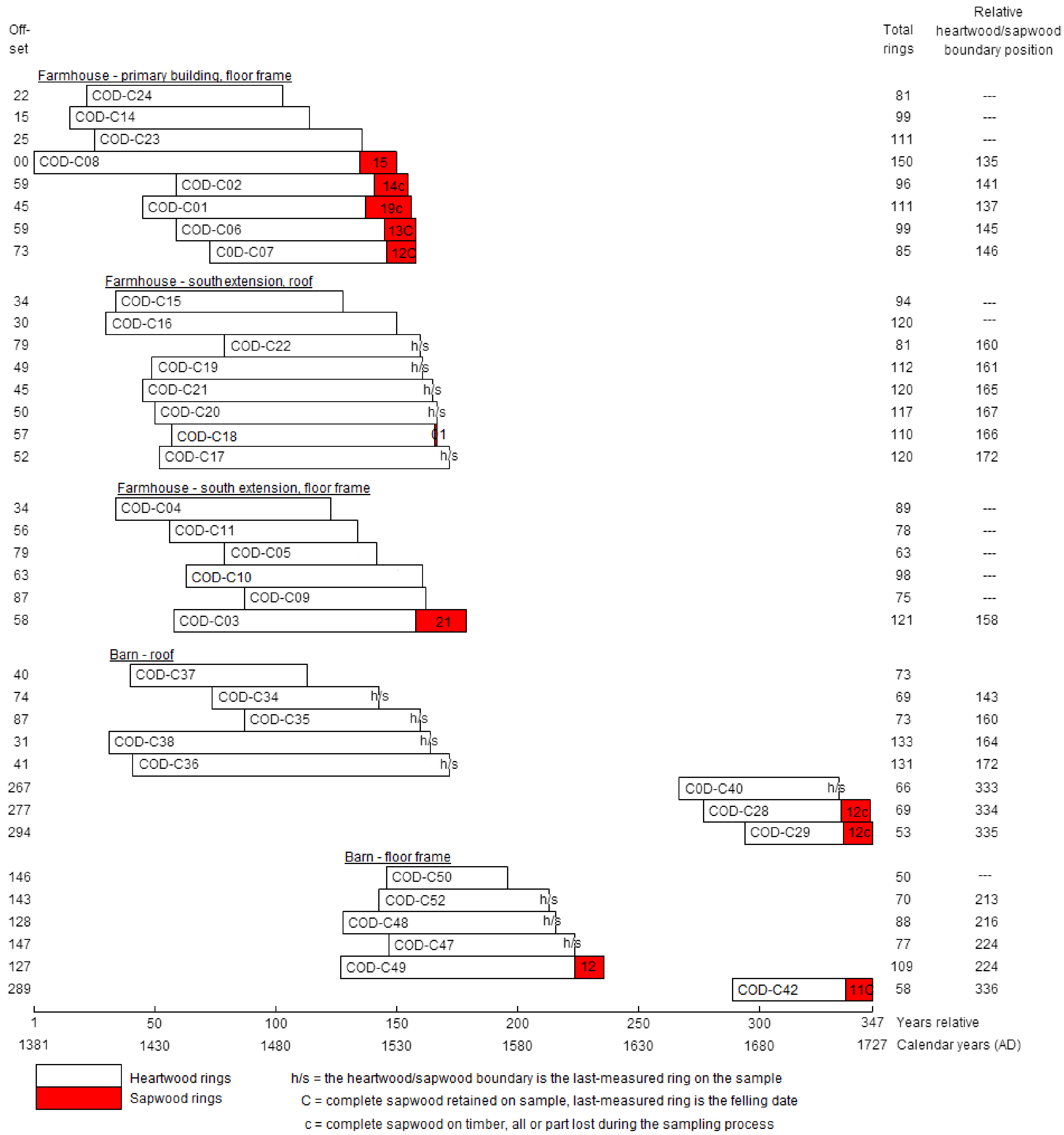

Figure 20: Bar diagram of all dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

COD-C01A 111
464 429 583 579 205 234 206 125 127 141 116 139 129 103 120 123 148 208 205 156
121 133 110 173 160 237 215 148 112 138 157 141 129 95 122 137 166 128 91 135
144 147 162 154 141 135 67 76 68 75 75 55 58 58 51 86 69 105 142 213
249 332 264 248 186 175 200 282 266 228 290 206 149 174 119 5 57 108 143 136
144 143 93 130 130 165 135 170 166 141 148 184 145 177 143 175 136 143 157 84
86 104 152 145 117 184 123 182 160 112 121
COD-C01B 111
468 438 586 589 206 220 205 129 131 140 113 142 131 99 128 119 159 207 203 156
124 120 120 166 165 229 211 151 121 155 161 156 124 114 107 139 154 125 87 139
138 159 157 157 156 127 72 70 70 75 79 57 57 52 63 82 77 103 137 207
254 334 264 248 197 171 225 273 275 242 287 223 162 172 116 79 61 105 137 137
179 110 94 132 127 170 138 173 160 146 149 183 144 169 150 175 136 145 157 81
90 95 146 156 108 185 148 155 161 111 122
COD-C02A 96
167 218 174 294 274 188 125 100 117 116 128 152 166 145 138 202 185 158 191 153
215 186 204 182 151 206 214 192 219 222 191 190 151 126 165 254 183 113 133 149
115 148 104 127 136 138 166 237 172 160 135 109 153 212 221 215 243 207 142 180
148 92 117 146 223 273 204 115 93 107 93 164 132 178 156 173 165 231 197 199
158 166 180 185 219 147 145 204 211 179 173 257 186 280 274 214
COD-C02B 96
164 217 166 301 279 192 119 108 108 109 128 160 169 145 139 205 184 157 192 154
217 185 196 183 151 202 204 190 221 227 188 189 150 126 170 253 181 120 129 143
119 156 98 127 142 138 166 237 180 163 139 113 159 223 228 219 249 209 143 186
154 100 121 158 252 285 198 121 102 95 92 165 132 175 158 167 171 235 189 204
157 169 171 180 215 151 147 208 221 183 172 233 216 269 268 222
COD-C03A 121
209 230 217 177 188 199 158 133 165 251 233 200 300 235 220 334 322 282 199 312
247 243 236 171 209 198 176 206 215 214 211 154 173 141 151 161 197 228 190 167
164 217 291 208 185 199 255 218 327 221 163 268 210 228 225 186 197 275 212 166
207 229 190 121 80 81 72 59 40 41 46 39 41 27 31 35 29 38 38 39
46 43 69 72 83 67 73 70 76 67 56 49 73 78 74 94 121 107 117 94
111 109 144 114 148 137 112 112 99 161 173 190 159 127 155 119 138 120 117 108
148
COD-C03B 121
203 235 211 172 187 196 154 135 167 248 240 194 291 236 209 334 324 281 188 294
252 239 235 175 201 193 174 200 212 219 227 150 173 138 150 150 205 218 177 151
179 218 284 209 191 205 249 220 312 224 171 275 218 228 222 191 197 284 215 161
190 220 188 123 67 77 75 59 41 42 55 37 46 36 24 29 30 42 36 41
59 46 60 75 81 67 72 69 85 71 50 53 66 81 72 99 118 105 112 95
111 108 144 114 149 137 103 115 100 158 174 192 158 132 139 136 135 116 118 104
140
COD-C04A 87
167 234 212 172 60 172 148 142 187 245 300 292 254 257 242 217 237 250 140 217
171 173 196 169 187 225 212 182 255 210 239 210 201 231 217 207 262 223 198 220
193 224 195 226 162 245 204 109 113 178 171 146 220 224 222 220 198 203 196 239
282 293 277 216 186 215 200 178 155 203 180 167 181 154 129 140 127 127 146 175
165 156 41 64 54 48 35

COD-C04B 89
153 239 212 175 49 175 141 151 213 260 252 279 270 244 243 248 238 254 135 207
178 169 217 201 161 194 214 173 259 207 233 201 204 229 217 206 259 210 194 220
202 221 189 229 168 236 213 111 110 181 166 145 205 218 222 225 198 207 203 244
268 272 271 211 178 201 216 180 169 188 169 178 181 150 142 143 132 122 138 164
152 151 59 52 52 57 50 49 51
COD-C05A 63
845 748 772 994 627 212 159 320 509 367 293 189 163 200 214 531 554 297 271 341
339 386 281 248 253 320 358 460 383 142 64 81 76 87 109 171 370 237 174 252
130 79 51 57 89 93 81 73 81 110 106 118 98 109 114 104 104 124 124 123
125 178 133
COD-C05B 63
848 683 776 989 628 211 161 304 474 416 314 183 157 248 239 528 550 294 260 358
356 390 350 319 240 326 369 498 391 133 72 82 70 93 110 168 383 235 171 233
147 80 59 54 85 95 83 64 81 102 99 115 104 108 111 109 103 124 124 123
134 173 137
COD-C06A 99
513 424 362 460 511 408 253 362 363 344 293 246 266 179 240 197 272 254 270 197
165 246 262 73 52 136 166 165 175 70 68 68 96 119 152 138 113 77 85 106
122 134 191 177 208 253 152 241 191 171 323 223 218 109 159 174 184 147 149 152
153 91 162 190 212 296 278 187 193 325 291 181 80 69 78 101 104 136 163 129
126 187 204 201 283 178 207 269 330 314 323 494 362 350 212 78 138 112 135
COD-C06B 99
516 422 377 457 508 400 262 362 365 348 285 251 267 201 249 204 297 257 300 206
170 239 258 70 54 96 104 132 172 85 80 77 86 113 150 136 114 78 84 102
118 132 187 180 209 252 158 251 201 173 323 227 223 118 148 160 183 147 144 152
151 100 156 184 221 304 275 188 193 317 306 175 82 71 74 98 102 137 161 131
123 186 208 197 290 172 204 263 338 314 308 504 383 353 202 83 119 134 134
COD-C07A 85
389 327 398 279 234 225 264 245 263 178 121 127 138 172 164 152 153 159 142 157
166 176 141 94 96 130 128 175 218 265 226 288 226 355 277 247 313 229 173 92
114 195 234 180 175 231 184 129 192 229 279 332 415 301 265 332 379 157 75 89
80 106 148 157 187 181 145 168 201 197 214 150 164 227 343 450 375 466 468 396
259 103 87 149 184
COD-C07B 85
284 321 387 270 228 231 240 249 254 172 119 130 125 162 149 152 145 138 124 137
156 174 150 92 92 119 138 211 204 258 219 288 211 355 265 253 292 235 174 89
117 200 222 179 172 235 197 124 198 221 283 326 398 303 276 324 381 161 79 83
92 110 157 136 175 153 125 192 203 194 225 153 171 248 356 425 357 566 416 430
245 102 91 126 130
COD-C08A 150
222 272 252 235 246 228 223 224 183 178 151 140 108 109 113 160 156 235 226 255
291 242 254 250 190 221 187 213 227 233 197 167 153 98 99 100 122 121 98 114
120 96 87 78 51 50 66 60 67 66 80 79 56 69 63 69 99 108 85 163
204 151 203 239 187 147 174 173 180 176 189 122 111 133 146 167 150 143 115 108
116 123 115 108 122 134 152 162 130 126 61 34 50 38 72 91 79 82 79 82
120 104 102 122 147 134 178 169 134 119 112 137 161 184 175 195 182 166 177 156
115 106 130 147 164 144 100 75 60 56 58 66 79 80 93 96 104 120 112 85
116 132 121 135 121 132 131 111 133 109
COD-C08B 150
208 264 257 226 250 221 202 227 187 184 153 158 119 108 110 164 151 234 224 253
284 243 253 242 186 220 190 217 226 237 197 167 148 96 103 99 126 120 97 111
119 95 84 80 57 46 64 64 61 65 86 79 59 67 56 67 110 101 88 166

203 150 201 242 183 150 184 168 184 175 187 129 109 132 156 181 162 153 119 117
115 119 139 111 120 130 141 150 135 120 77 31 48 44 60 92 82 80 87 75
117 100 106 126 152 133 181 164 133 126 115 122 171 178 176 203 179 159 170 158
115 109 123 151 159 149 99 71 56 63 57 64 81 83 94 95 104 141 103 74
117 123 117 132 128 118 143 142 98 110
COD-C09A 75
352 336 391 280 244 246 244 399 303 246 178 228 217 257 211 228 167 217 232 278
254 182 173 161 135 146 197 229 256 221 185 185 203 69 67 59 87 118 101 84
90 120 103 120 101 104 131 121 112 114 145 142 116 161 169 187 164 175 159 209
151 134 143 174 148 181 156 175 182 191 217 200 227 203 131
COD-C09B 75
324 317 387 300 237 244 246 352 286 235 171 223 208 255 225 227 171 220 228 269
237 192 180 148 145 148 178 216 276 234 190 205 209 72 53 51 81 103 93 81
91 104 100 123 113 102 104 119 106 112 130 145 113 152 163 229 164 161 141 190
154 140 119 177 178 171 178 185 206 183 229 178 219 200 112
COD-C10A 98
403 292 279 192 208 171 141 287 235 237 278 235 284 192 96 145 240 160 164 150
167 203 171 204 149 187 235 206 166 144 193 304 234 234 181 301 310 271 196 203
164 153 148 250 157 131 109 91 92 113 104 160 173 181 126 143 87 60 48 32
54 53 66 43 59 59 62 94 89 79 94 94 116 107 108 125 118 151 174 143
87 83 91 93 121 102 96 128 134 118 133 125 156 124 148 107 164 213
COD-C10B 98
386 292 219 205 213 164 144 277 231 245 286 230 289 198 89 175 234 190 195 153
155 190 173 204 167 185 227 196 163 150 203 276 239 233 183 297 310 267 199 204
165 157 149 247 161 121 122 89 88 108 107 159 173 183 130 148 92 54 48 38
39 63 64 47 52 67 72 94 78 80 92 103 113 100 109 121 120 160 156 148
90 83 86 101 101 95 88 124 124 114 123 128 140 129 142 111 162 131
COD-C11A 78
256 344 336 334 309 292 441 370 383 316 312 347 316 341 403 401 285 338 277 349
304 334 238 310 289 225 213 204 155 175 185 216 181 204 190 197 172 200 200 220
207 188 131 201 234 234 219 224 240 215 261 218 179 165 195 157 195 225 224 241
170 175 209 201 108 170 150 191 161 192 138 151 190 179 187 165 175 151
COD-C11B 78
261 350 337 335 305 292 436 372 392 318 303 350 320 338 398 404 286 337 278 343
298 333 249 302 284 239 212 210 161 188 191 210 186 203 188 190 171 201 202 217
207 181 133 199 238 223 233 226 234 212 261 218 185 158 197 156 198 233 219 241
174 172 214 209 105 182 160 188 162 199 130 153 189 181 182 171 174 159
COD-C14A 99
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413 459 444 426 907 723 640 798 724 795 765 538 591 609 501 698 406 289 264 243
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310 223 181 137 129 167 130 88 88 100 83 162 198 126 157 139 180 242 243 360
364 324 221 272 224 251 155 173 194 194 207 269 203 176 153 67 85 139 305
COD-C14B 99
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413 444 449 428 832 747 610 866 755 824 766 538 591 607 517 677 423 290 278 242
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366 323 222 267 223 249 155 182 189 200 207 271 210 170 157 78 87 145 258
COD-C15A 94
252 308 298 342 187 353 270 227 320 257 285 246 348 320 293 223 294 316 203 269
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233 263 121 102 108 112 60 106 89 118 109 110 101 90
COD-C15B 94
237 308 305 352 183 357 268 228 304 258 286 271 337 305 298 227 250 319 203 272
216 214 251 240 238 181 229 215 319 299 259 212 239 301 262 229 327 227 204 205
194 233 210 214 148 215 152 117 75 64 190 131 121 107 116 124 127 137 172 194
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237 266 122 115 106 112 60 105 89 118 101 124 96 95
COD-C16A 120
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431 460 296 366 305 288 328 319 240 225 291 228 338 317 309 273 261 292 222 231
325 231 181 245 197 229 197 171 147 178 151 133 54 91 112 102 133 140 152 148
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168 154 162 156 170 213 145 126 143 130 77 115 98 147 127 135 106 128 131 140
144 108 137 120 110 106 99 148 138 90 127 144 150 142 157 152 191 136 113 95
COD-C17A 120
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255 341 246 334 274 188 202 262 193 183 206 190 235 224 220 214 234 243 253 248
COD-C17B 120
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196 216 204 302 247 294 310 343 433 426 444 418 163 144 186 201 195 219 209 188
179 220 238 309 196 128 131 134 118 110 150 126 143 139 197 150 149 168 151 233
217 232 280 211 244 242 245 123 100 117 138 179 173 189 151 191 217 228 240 122
95 109 101 145 134 120 117 141 161 207 181 239 209 219 229 225 208 196 281 274
264 324 243 333 273 186 193 266 190 182 212 185 232 215 214 222 240 221 248 241
COD-C18A 110
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COD-C18B 110
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168 126 176 270 207 207 202 185 189 247 256 198 171 211 177 188 200 199 245 151
145 172 162 77 156 122 171 141 188 129 153 181 174 192 182 176 159 137 137 151
184 130 135 162 152 150 174 160 131 183 125 127 145 169 156 173 155 173 162 152
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COD-C19A 112
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158 178 212 212 339 365 464 463 450 361 393 481 538 478 409 211 148 150 137 132

142 125 134 131 170 207 248 126 67 59 65 80 61 99 90 116 105 206 187 192
174 168 259 222 310 344 319 360 333 307 155 111 149 175 193 198 224 163 201 224
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229 283 241 266 222 207 283 239 213 243 307 147
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149 124 123 137 167 206 249 126 62 59 69 78 66 95 85 112 116 196 187 186
173 167 259 212 316 337 317 361 320 306 149 111 141 178 196 197 229 174 201 211
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165 131 155 147 178 216 142 129 153 136 65 119 94 113 94 123 101 109 125 154
171 125 130 125 135 130 79 143 135 121 127 133 159 136 111 123 164 124 101 121
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164 134 145 154 176 216 147 127 150 133 71 115 93 115 101 123 102 104 128 154
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161 299 357 166 138 146 145 136 171 157 195 84 53 52 41 48 60 60 106 125
121 108 103 186 192 145 125 113 111 122 147 136 200 165 127 144 165 148 205 150
173 196 137 117 130 163 131 140 133 169 131 127 119 142 156 145 124 113 82 107
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113 129 147 104 110 126 120 155 175 218 189 187 132 149 140 225 209 220 211 192
166 296 352 171 139 145 141 137 165 160 192 75 60 50 34 52 62 66 105 122
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172 187 139 123 131 167 119 141 136 166 127 119 126 155 160 145 123 116 75 110
COD-C22A 81
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323 76 55 57 73 73 75 66 85 122 144 150 145 152 147 142 136 168 185 189
170 266 263 256 230 220 184 233 130 146 152 180 127 160 175 128 132 138 136 164
180
COD-C22B 81
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57 52 51 83 85 136 118 205 180 184 188 184 202 208 288 209 292 290 281 355
325 75 54 54 65 83 72 62 89 123 148 155 145 147 148 146 137 165 184 195
166 259 269 244 233 217 189 192 170 141 148 182 130 155 178 136 129 143 138 164
175
COD-C23A 111
355 362 452 591 391 222 235 120 102 151 187 207 220 127 175 259 178 227 182 201

385 365 431 144 41 45 65 56 32 49 43 58 57 42 100 124 136 167 244 196
110 97 58 59 70 91 123 91 96 117 159 131 144 109 128 134 142 118 83 117
152 199 201 204 312 214 124 87 73 109 139 142 123 135 135 288 315 238 297 259
287 384 285 242 200 137 170 232 262 292 285 288 163 190 115 85 59 91 105 146
93 56 36 69 76 89 111 111 83 79 91
COD-C23B 111
301 353 444 594 393 219 239 119 98 156 182 201 229 122 196 257 173 228 177 202
377 369 435 137 49 35 61 49 36 47 34 50 69 52 96 124 134 175 233 184
112 97 66 62 73 95 126 93 102 119 156 115 139 97 129 130 144 120 81 117
162 206 201 201 317 212 123 87 71 110 138 144 130 128 134 283 289 264 310 267
280 396 309 238 197 141 175 228 261 289 283 290 166 190 112 83 61 96 94 144
95 52 46 71 75 90 106 113 84 83 92
COD-C24A 81
657 723 461 461 374 430 494 350 196 156 89 62 137 138 159 184 100 154 226 173
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321 398 296 185 163 137 156 126 188 221 183 242 323 314 196 193 168 214 172 174
185 171 234 264 284 316 274 250 239 133 138 151 241 241 170 184 258 231 294 214
266
COD-C24B 81
629 709 463 451 359 383 483 341 180 154 86 62 131 133 156 157 106 142 234 164
256 181 196 283 300 307 93 47 43 60 50 32 50 55 53 65 105 210 221 194
304 391 281 200 147 143 142 124 167 234 177 244 305 319 177 184 185 190 164 177
171 174 236 264 279 323 303 225 220 136 121 143 240 238 163 177 272 217 294 223
261
COD-C26A 70
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69 76 58 46 42 45 72 99 232 254 140 199 257 237 155 135 105 150 123 140
185 181 143 122 95 133 122 136 117 111 129 156 184 145 177 139 142 168 211 149
143 123 107 108 167 118 126 126 111 88
COD-C26B 70
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67 71 59 46 41 57 83 103 198 249 144 208 257 237 159 129 106 154 124 125
156 179 142 127 99 132 125 131 117 114 122 156 186 158 154 142 157 154 205 150
139 126 109 105 165 123 121 120 107 91
COD-C27A 48
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253 299 347 250 122 115 210 244 268 185 220 297 326 217 279 459 366 361 243 81
154 170 169 225 226 292 343 370
COD-C27B 48
423 297 255 201 198 167 223 170 176 252 262 291 213 266 220 177 111 207 201 184
257 296 333 256 136 126 195 240 268 188 220 302 322 218 281 463 376 372 261 72
165 188 149 232 227 298 344 393
COD-C28A 69
533 579 488 541 724 759 425 287 380 417 516 448 757 670 513 556 541 292 413 550
545 626 572 435 699 605 383 271 449 477 469 451 216 277 254 255 203 208 187 165
160 173 162 176 154 228 313 156 202 221 295 266 180 267 229 353 207 258 236 279
193 272 212 168 132 125 188 208 250
COD-C28B 69
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530 621 587 430 688 605 381 251 452 481 458 447 207 284 254 254 203 201 191 171
159 166 166 168 161 232 319 148 203 219 294 265 171 276 250 328 213 205 285 287
206 267 207 174 127 103 185 200 241
COD-C29A 53

437 439 605 589 565 615 417 571 467 432 415 583 636 533 458 335 530 335 287 426
323 301 257 234 173 135 183 234 258 413 222 285 348 197 193 112 88 142 230 183
117 118 127 109 149 139 222 264 213 363 179 286 217
COD-C29B 53
448 431 609 593 561 610 443 560 446 431 425 580 630 531 458 341 536 326 284 425
314 298 266 219 178 124 195 236 250 425 222 284 366 195 194 111 88 141 231 189
117 117 121 115 150 132 217 263 221 356 181 287 215
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414 232 271 258 211 243 214 203 157 155 201 185 203 224 180 195 265 241 208 156
217 203 257 88 46 85 70 63 79 80 135 124 131 161 130 253
COD-C30B 56
542 485 528 541 498 481 533 523 526 645 447 536 501 396 301 520 545 409 307 306
417 231 272 267 211 239 200 194 155 152 193 181 198 225 176 198 255 246 212 152
215 189 266 87 47 82 68 68 75 84 131 126 134 161 133 251
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90 72 76 84 58 81 116 95 183 131 100 139 66 124 120 181 166 79 99 84
75 85 92 109 120 100 151 157 101 92 91 41 60 81 83 143 112 93 55 64
70 74 77 71 98 101 91 88 79 63 41 56 66 46 59 60 69 70 67 72
61 60 67 44 58
COD-C31B 85
109 178 111 113 132 126 101 72 59 87 91 141 115 112 98 118 120 99 60 98
89 69 73 88 65 74 112 98 181 139 104 130 60 116 119 150 180 80 72 82
68 94 83 121 124 93 153 163 92 90 86 46 67 89 90 154 144 98 53 63
72 70 75 80 92 97 95 81 87 67 30 62 61 52 56 58 68 71 71 67
52 71 64 44 64
COD-C32A 51
429 333 296 379 233 494 388 365 276 426 560 419 495 553 670 403 85 60 71 95
80 151 178 250 369 335 446 541 299 244 439 290 254 246 393 400 464 292 258 363
319 342 399 456 556 521 290 398 369 476 280
COD-C32B 51
427 353 300 398 248 504 392 349 308 434 535 426 484 535 681 391 85 77 68 98
85 143 185 250 370 334 444 545 300 259 452 280 249 246 392 392 445 306 261 359
339 349 409 471 552 500 347 393 332 486 237
COD-C34A 69
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156 152 140 113 168 158 215 286 233 250 233 145 344 245 263 257 243 240 243 289
264 449 269 216 238 254 203 195 209 261 207 247 193 123 105 80 77 49 73 81
73 77 105 161 125 124 172 159 133
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159 155 133 112 169 158 214 279 233 251 230 150 350 241 264 250 244 235 251 284
271 451 265 218 236 257 183 193 209 269 199 239 202 128 107 83 77 58 69 88
74 75 106 155 133 120 163 168 148
COD-C35A 73
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310 391 358 323 297 280 259 199 167 134 145 119 97 67 65 37 49 50 40 65
44 47 41 42 43 49 40 53 70 68 74 109 64
COD-C35B 73
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454 144 91 99 102 130 179 456 689 524 393 542 496 287 457 392 458 640 508 284

304 391 348 317 296 280 254 199 171 128 148 125 86 74 62 34 48 46 48 54
48 43 47 39 46 53 36 49 67 70 71 105 63
COD-C36A 71
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164 188 152 145 129 162 187 193 180 193 211 186 135 212 214 129 170 113 151 170
179 158 166 149 244 265 332 198 156 167 219 219 285 390 335 170 204 215 236 267
216 221 220 276 240 255 162 137 148 109 136
COD-C36B 84
212 134 198 251 235 284 410 346 173 232 225 245 268 220 211 222 283 237 271 167
148 140 116 143 100 74 46 53 56 50 66 53 55 52 69 67 73 68 70 65
77 76 53 41 71 59 63 70 76 83 77 61 107 90 65 77 59 64 82 99
103 64 49 42 48 63 53 59 78 69 78 110 129 70 91 92 94 87 107 108
139 124 128 113
COD-C37A 73
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203 174 193 216 225 184 228 220 208 170 299 268 212 256 221 242 175 161 146 193
195 190 210 185 234 256 350 325 254 202 183 178 164 153 238 231 176 150 124 182
198 165 187 191 170 182 288 168 133 139 118 143 89
COD-C37B 73
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204 175 195 210 226 181 233 219 202 168 300 266 218 241 216 246 167 160 144 183
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190 165 180 194 175 181 277 171 127 143 118 139 88
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170 114 152 235 242 154 106 152 187 164 157 203 207 263 340 398 258 156 89 55
88 93 149 180 150 170 85 103 139 125 128 109 115 161 130 119 90 103 135 127
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118 55 52 59 73 63 76 98 112 100 88 73 73
COD-C38B 133
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264 149 254 250 305 248 233 178 210 164 189 230 147 105 73 116 131 123 111 118
177 115 150 236 239 146 111 148 186 163 152 174 218 258 350 392 260 158 83 56
85 76 153 179 151 177 85 105 134 127 127 109 118 161 132 114 72 123 133 129
130 109 94 107 103 54 38 47 54 76 81 68 93 84 117 136 93 85 96 92
119 47 54 65 67 67 69 104 114 96 89 72 72
COD-C39A 77
177 214 297 265 308 245 199 187 181 174 207 190 158 113 187 221 261 299 271 242
218 225 347 294 228 262 185 156 189 242 242 280 278 184 205 228 200 191 241 223
199 239 195 146 123 92 91 135 131 126 108 106 111 143 117 125 140 114 127 125
106 89 95 104 76 84 89 59 48 55 49 54 52 56 79 62 67
COD-C39B 77
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219 218 341 293 229 258 187 161 190 236 240 281 284 193 200 226 196 196 235 217
196 229 187 145 124 88 97 133 125 131 104 104 112 136 127 113 149 109 131 128
93 99 88 110 85 86 81 59 57 43 51 61 42 62 71 58 84
COD-C40A 66
258 129 208 108 188 170 284 225 102 135 142 143 93 144 167 156 126 108 72 108
93 101 136 141 115 156 102 60 106 226 169 180 111 117 247 162 160 107 155 222
264 274 126 179 93 124 73 76 97 126 137 124 147 185 149 235 259 166 213 279

447 437 196 285 275 280
COD-C40B 66
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249 249 131 176 98 127 77 85 100 131 135 117 149 192 144 236 273 169 212 266
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COD-C41A 72
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513 395 164 85 147 96 156 151 146 117 151 106 133 133 134 131 154 180 228 131
198 187 145 134 165 217 298 229 191 422 669 202
COD-C41B 72
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636 341 559 494 342 278 495 391 322 579 266 640 311 252 236 337 498 555 448 288
484 380 160 87 119 96 147 132 133 107 150 97 126 141 129 137 144 182 232 129
196 189 140 139 158 223 286 232 192 423 666 200
COD-C42A 58
356 664 600 620 368 207 194 258 285 354 434 537 825 538 563 398 399 439 481 468
365 525 412 296 357 347 375 320 398 251 224 277 259 324 331 213 258 281 281 270
144 169 254 270 216 280 252 271 190 190 260 298 242 244 382 227 354 315
COD-C42B 58
351 643 583 616 376 202 193 259 287 377 469 551 815 540 579 401 396 440 487 465
366 535 404 301 360 352 378 320 398 254 227 271 259 303 335 221 258 285 270 263
147 173 244 274 207 286 252 271 190 191 255 292 239 237 375 233 341 313
COD-C43A 71
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280 261 223 299 476 342 334 391 210 186 209 159 141 156 141 149 127 99 160 158
219 137 145 142 91 78 70 69 72 113 122
COD-C43B 71
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256 242 241 242 272 229 249 201 170 154 112 151 237 297 388 475 497 403 453 355
273 261 219 312 478 358 323 381 197 198 194 151 156 149 134 136 147 95 150 160
224 131 144 130 93 78 69 58 80 119 116
COD-C47B 77
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242 190 218 337 332 373 267 390 273 158 92 98 95 105 122 107 100 101 206 260
205 164 230 250 230 232 125 85 170 173 124 140 239 117 125 124 167 81 63 42
40 42 58 105 114 126 106 128 61 65 100 132 143 202 118 171 197
COD-C47B 77
141 65 73 103 129 202 219 131 174 231 228 211 288 188 83 87 81 102 157 164
229 176 237 351 304 405 267 400 281 153 97 92 103 112 119 116 96 102 215 291
208 139 230 229 218 234 130 78 179 168 116 137 257 117 116 137 156 85 56 39
50 33 68 93 117 131 109 129 55 73 91 133 156 187 122 166 212
COD-C48A 88
424 600 598 546 495 550 240 308 243 191 239 235 343 341 279 291 147 194 226 127
57 35 80 64 63 63 43 87 106 215 125 99 74 67 110 92 143 82 116 113
106 113 162 151 192 108 127 93 82 77 89 85 102 115 102 97 98 84 109 132
101 120 87 96 95 76 72 111 168 132 137 188 128 125 126 146 66 50 45 47
34 37 32 44 50 72 67 70
COD-C48B 88
456 609 594 546 496 551 247 304 243 191 236 247 315 325 278 288 151 189 233 126
54 40 74 62 57 60 58 87 111 229 127 99 70 66 113 96 133 95 113 112

101 116 159 151 190 111 124 98 81 68 90 86 101 115 98 99 94 78 104 127
101 136 94 89 100 82 79 107 160 130 138 190 130 121 121 158 70 55 41 51
43 34 41 43 44 73 66 75
COD-C49A 109
206 218 327 467 297 105 63 54 65 89 87 111 126 315 259 142 253 148 193 340
104 62 55 139 128 145 200 98 193 218 220 173 179 119 59 77 57 99 103 126
141 89 129 201 230 251 194 223 156 116 94 107 124 109 137 142 87 66 130 151
127 108 220 189 157 134 100 73 113 142 99 164 261 129 139 158 198 99 76 48
47 51 75 111 123 100 96 121 59 71 111 121 109 109 76 132 163 111 146 225
141 146 166 116 123 82 89 131 106
COD-C49B 109
217 226 312 462 308 118 75 45 71 79 93 110 131 319 260 140 259 144 194 349
97 69 56 133 130 151 200 101 199 208 234 167 182 115 51 75 61 102 118 121
148 92 129 191 223 254 210 218 162 112 92 114 118 118 141 150 86 66 130 144
129 103 214 186 161 123 100 76 115 153 97 161 264 128 135 160 200 89 73 49
47 54 74 112 117 104 95 119 58 70 110 120 106 111 77 129 162 124 140 231
143 143 178 108 123 87 96 128 96
COD-C50A 50
350 142 103 82 194 247 332 445 240 338 275 248 313 480 353 103 104 104 108 193
271 522 386 431 373 518 455 280 362 276 228 100 173 223 130 103 93 71 77 171
258 219 88 187 147 236 187 151 124 165
COD-C50B 50
353 131 103 87 165 262 290 447 223 355 275 236 322 530 361 96 102 102 115 209
278 547 444 379 399 566 430 260 338 204 140 101 183 198 164 87 105 66 70 169
282 196 121 172 127 223 191 172 129 112
COD-C52A 70
259 151 186 311 96 59 70 98 104 84 119 72 212 185 196 153 209 134 60 102
110 135 120 118 147 85 131 128 143 179 154 154 162 143 53 93 94 107 127 138
108 84 117 187 135 123 148 165 156 171 118 111 177 260 212 260 282 205 201 233
326 144 93 67 54 52 74 100 141 126
COD-C52B 70
274 171 179 292 97 55 73 100 94 95 121 60 210 179 175 153 195 139 75 60
76 144 135 118 146 100 133 126 130 192 151 152 160 144 65 101 96 103 127 133
102 82 119 165 155 126 192 174 159 163 113 111 181 259 225 252 289 209 196 240
324 149 81 69 59 54 71 105 135 130

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

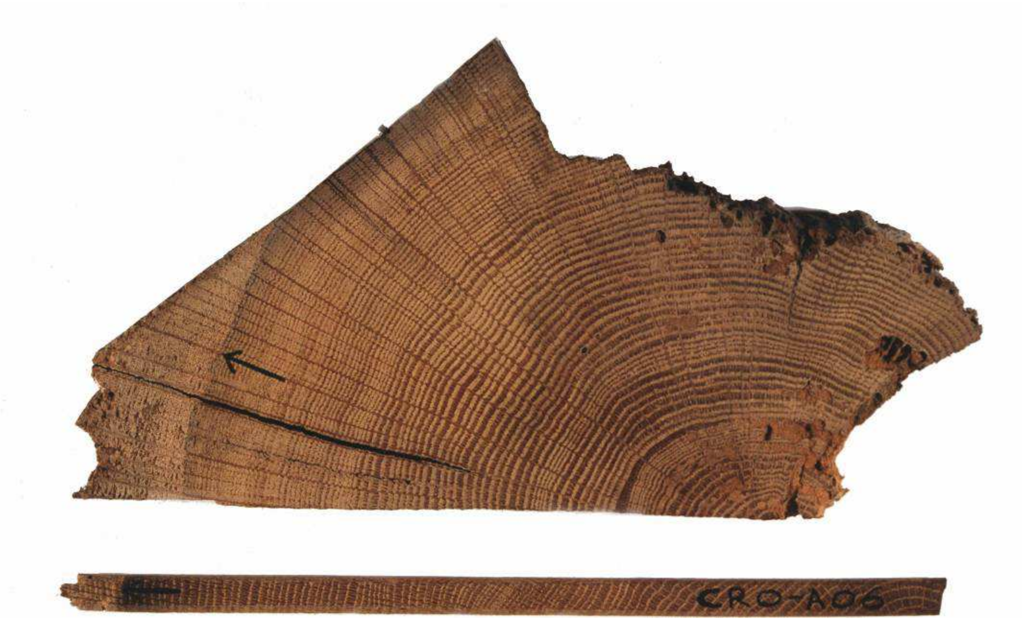


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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 Figure A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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 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

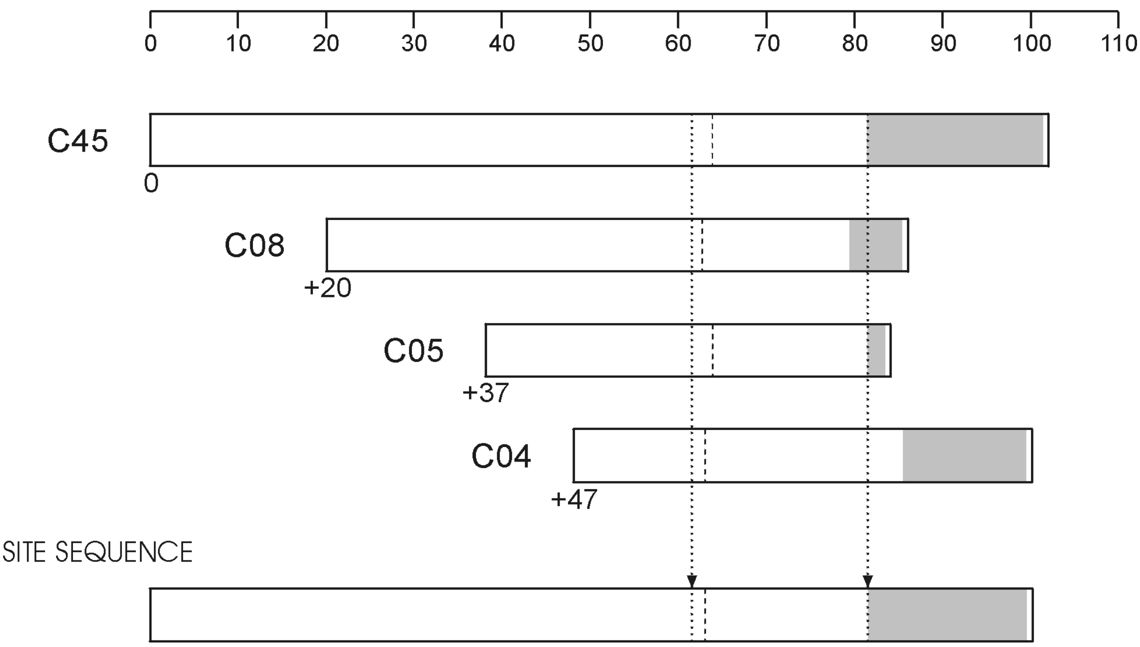


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

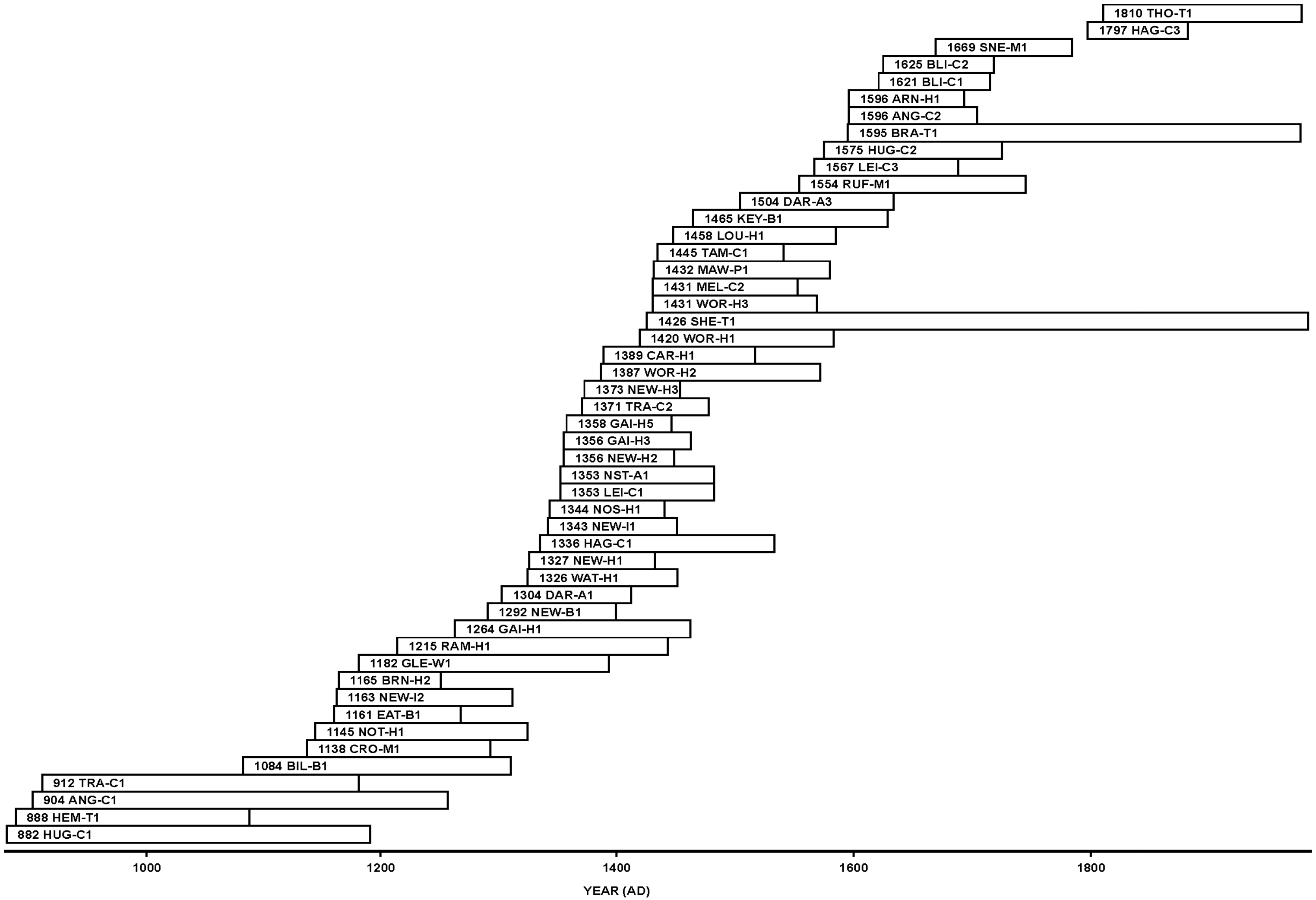
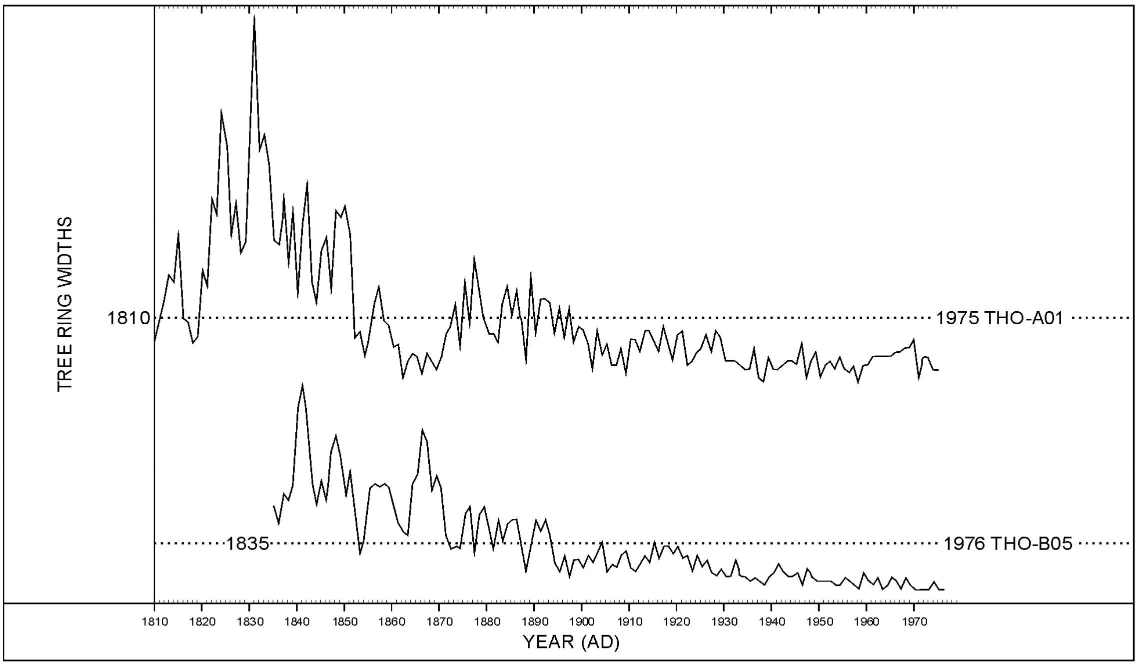


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

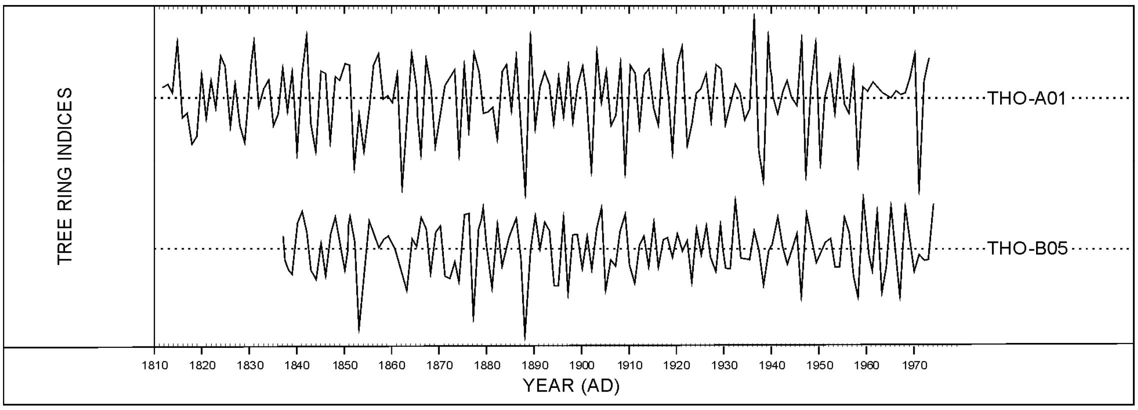


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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