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## Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

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Front Cover: Restoration work in progress at Ribbesford House in Bewdley, Worcestershire. Photograph by Timothy Cornah taken in June 2021

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SUMMARY
Dendrochronological analysis was undertaken on 54 of the samples obtained from 66 timbers located in different areas of the main house and an attached agricultural wing at Ribbesford House. This analysis produced five dated site chronologies accounting for 48 samples and dated a further sample individually, leaving a total of only five of the measured samples as ungrouped and undated. Interpretation of the dating evidence with respect to felling dates of the 49 dated samples shows that, although there is some variation, there are four main periods of felling activity represented in the first half of the sixteenth century, the mid-seventeenth century, the early eighteenth century, and the first half of the nineteenth century.

CONTRIBUTORS
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The Hive
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# INTRODUCTION

Ribbesford House stands just to the south of the hamlet of Ribbesford, near the west bank of the River Severn where the land rises up into Ribbesford woods (Fig 1). This Grade II* listed building (List Entry Number: 1329928), which is on the Heritage at Risk Register, has been largely unoccupied in recent times and has suffered through neglect for many years with substantial areas ending up open to the elements. A detailed description of the building, along with the phasing of various periods of construction and modification, can be found in the report by Worcestershire Archaeology (2019) from which the following information is summarised.

The estate was moated from the eleventh century, but the extant house is believed to be of mid-sixteenth century origin, potentially around the AD 1530s, following purchase of the manor by Sir Robert Acton. The main element of this house, the hall range, was aligned north-west to south-east (Fig 2a/b) with wings, originally at either end, projecting to the north-east creating a U-shaped courtyard to its rear. The hall range appears to retain this plan as originally built, although visible remains of this primary construction phase are limited, including some moulded decorative ground-floor ceiling beams.

Some works to the house is known to have been undertaken during the ownership of Sir Henry Herbert by AD 1669, but the extent of these works is unknown. In the early/mid-eighteenth century the house was extended at the north-west end by the addition of kitchen and service quarters, along with a long low wing, projecting to the north-east from this kitchen/service range, which was predominantly used for agricultural purposes (Fig 2a). Major structural changes were undertaken around AD 1800, following the acquisition of the property by Francis Ingram in AD 1787, including demolition of the original AD 1530s wings and the gatehouse. At this time the AD 1530s roofs were also dismantled to raise the walls, and the two turrets were rebuilt. The long agricultural wing also had its roof removed and part of it was raised. Much of the extant fenestration, render, and external detailing date to this major period of building activity, and the internal details are still largely of this period.

Subsequent minor alterations include the construction of a brick infill structure in the corner between the kitchen/service range and the agricultural wing, and the addition of a decorative structure with two towers to the south-east face of the agricultural wing later in the nineteenth century, whilst the addition of a single-storey structure on the north-west side of the building is dated to the first half of the twentieth century (Fig 2a), the latter thought to be associated with the of use of the building as an elite club at this time. The building was divided into flats after the Second World War and it remained in use as flats into the AD 1990s, with one flat remaining in use even later. As now seen, Ribbesford House comprises three floors of a main range aligned north-west to south-east with a wing to its north-west end, aligned north-east to south-west.

## SAMPLING

Dendrochronological analysis was requested by Nicholas Molyneux (Historic England Principal Inspector of Historic Buildings and Areas) with the aim of obtaining independent dating evidence to inform repairs and a management strategy for its future care and preservation leading to its removal from the Heritage at Risk register. It was hoped that tree-ring dating would enhance the understanding of the overall development of the building and inform its significance.

A total of 66 samples was obtained from the timbers accessible, or those that became accessible as opening-up and securing works proceeded, all of these being oak (*Quercus* sp.). Most timbers were sampled by the removal of cores, but a number of timbers that had been removed and not deemed suitable for reinstatement were sampled by the removal of cross-sectional slices. Each sample was given the code RIB-H (for 'Ribbesford House') and numbered 01–66 (Table 1). The sampling strategy targeted timbers thought to be associated with the original construction of each main element of the building, as well as timbers associated with possible later repairs and alterations. The areas sampled therefore, comprised the hall range, the kitchen/service range, and the agricultural wing with its ancillary buildings and cottage accommodation (Table 1; Figs 2 and 3a/b). The floor of the west turret appeared to be supported by modern softwood joists but was inaccessible during the various site visits for sampling purposes, thus only a single timber was sampled in the west turret. All sampled timbers have been located, approximately, on plans and drawings taken from the building report by Worcestershire Archaeology (2019) or on annotated photographs (Figures 4a–v) and for ease of reporting a site north has been imposed.

## ANALYSIS AND RESULTS

Each of the 66 samples was prepared by sanding and polishing. It was seen at this stage that 12 samples had fewer than the 40 rings here deemed necessary for reliable dating, and they were rejected from this programme of analysis, although the number of rings was noted, shown in Table 1. The annual growth ring-widths of the remaining 54 samples were measured, these data being given at the end of this report. The 54 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the production of five groups of cross-matching samples.

The first group comprises 12 samples, these being combined at their indicated offset positions to form RIBHSQ01 (minimum $t$-value of 3.0), a site chronology with an overall length of 170 rings (Fig 5). Site chronology RIBHBSQ01 was then compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match with a series of these when the date of its first ring is AD 1366 and the date of its last measured ring is AD 1535 (Table 2).

The second group comprises 14 samples, these also being combined at their indicated offset positions to form RIBHSQ02 (minimum $t$-value of 3.7), a site chronology with an overall length of 121 rings (Fig 6). Site chronology RIBHSQ02 was also compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1536 and the date of its last measured ring is AD 1656 (Table 3).

The third group also comprises 14 samples, these similarly being combined at their indicated offset positions to form RIBHSQ03 (minimum *t*-value of 3.8), a site chronology with an overall length of 92 rings (Fig 7). Site chronology RIBHSQ03 was also compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1727 and the date of its last measured ring is AD 1818 (Table 4).

The fourth group comprises six samples. These samples were likewise combined at their indicated offset positions to form RIBHSQ04 (minimum *t*-value of 3.0), a site chronology with an overall length of 69 rings (Fig 8). Site chronology RIBHSQ04 was also compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1640 and the date of its last measured ring is AD 1708 (Table 5).

The fifth and final group comprises two samples. These samples were also combined at their indicated offset positions to form RIBHSQ05 (minimum *t*-value of 6.2), a site chronology with an overall length of 78 rings (Fig 9). Being compared to the same extensive corpus of reference data, this site chronology matches consistently and repeatedly when the date of its first ring is AD 1438 and the date of its last measured ring is AD 1515 (Table 6)

Each of the six remaining measured but ungrouped series were then compared individually with the full corpus of reference chronologies for oak, this indicating a consistent and repeated match for sample RIB-H20 when its 220 rings span the years AD 1362–1581 (Table 7).

This analysis may be summarised thus:

| Site chronology/ sample | Number of samples | Length | Date span (where dated) |
|---|---|---|---|
| | | | |
| RIBHSQ01 | 12 | 170 | AD 1366–1535 |
| RIBHSQ02 | 14 | 121 | AD 1536–1656 |
| RIBHSQ03 | 14 | 92 | AD 1727–1818 |
| RIBHSQ04 | 6 | 69 | AD 1640–1708 |
| RIBHSQ05 | 2 | 78 | AD 1438–1515 |
| Dated individuals | 1 | 220 | AD 1362–1581 |
| Undated individuals | 5 | --- | --- |
| Unmeasured | 12 | --- | --- |

## INTERPRETATION

Analysis has produced five dated site chronologies, accounting for 48 samples, and dated a further sample individually (Fig 10) from the hall range, the kitchen/service range, and the agricultural wing. The following results are presented area by area and in Figures 5–9 and 11. In each case, where sapwood is not complete (ie the sample does not have the last ring produced before the tree was felled), the estimated felling date ranges is calculated on the basis of the 95% confidence interval for the amount of sapwood the trees are likely to have had which is 15–40 rings.

### Hall range

*Ground-floor ceiling (samples RIB-H01 – RIB-H14)*
Seven of 12 sampled timbers from rooms G2a-c and G4, in the hall, were dated (Figs 4a, 5, and 10). None of the dated samples retains the heartwood/sapwood boundary but, given the decorative nature of these timbers, it is possible that they have been relatively heavily trimmed during conversion from tree source to timber element. In addition, access was restricted to these timbers by them being deeply set into the ceilings, thus any trace of sapwood may have been hidden. The outermost measured heartwood rings on the samples range from AD 1432 (RIB-H10) to AD 1485 (RIB-H11) which, allowing for a minimum of 15 sapwood rings, produce felled-after dates ranging from AD 1447 (RIB-H10) to AD 1500 (RIB-H11). Given that these timbers appear integral to the primary construction phase, combined with the characteristic nature of the moulded decorative timbers, it is reasonable to assume that all seven dated timbers (five bridging joists and two common joists) are broadly coeval and all felled after AD 1500.

*Roofs (samples RIB-H25 – RIB-H35)*
All seven samples taken from timbers (four principal rafters, two king posts, and one queen post) in the roof over rooms S1 and S2 were dated (Figs 2b, 7, and 10). Five samples, RIB-H25, RIB-H28, RIB-H29, RIB-H30, and RIB-H31, retain complete sapwood. In each case, the last growth-ring, and thus the felling of the trees, is the same, being dated to AD 1818. The remaining two dated samples retain some sapwood, the average heartwood/sapwood boundary ring dating to AD 1801 which produces an estimate felling date range of AD 1816–41 for the two timbers represented. This encompasses the precise felling date of AD 1818 already identified and, taking account of the relative position of the heartwood/sapwood boundary rings on all seven samples, it seems likely that these two timbers were also felled in, or about, AD 1818.

The four samples taken from principal rafters in the hall roof over rooms S6a-c and S7 were dated (Figs 2b, 7, and 10). Although none of the samples have retained complete sapwood, all four retained some sapwood rings. The heartwood/sapwood boundary position ranges only four years from AD 1803 (RIB-H34) to AD 1808 (RIB-H33), indicating that these timbers are very likely coeval. The average heartwood/sapwood boundary ring dates to AD 1806, thus an estimated felling date range of AD 1821–46 is obtained.

*East and west turrets (samples RIB-H36 – RIB-H39 and RIB-H53 – RIB-H54)*
Three of the five samples obtained from timbers to the east turret were dated (Figs 2b, 5, and 9–10). In each case the outermost extant ring marks the heartwood/sapwood boundary, the date of which varies by only eight years from AD 1514 (RIB-H54) to AD 1522 (RIB-H37), indicating that the timbers represented are at least broadly coeval and may well represent a single felling event. The average heartwood/sapwood boundary date is AD 1517, which produces an estimated felling date in the range of AD 1532–57 for these timbers (a support beam, a floor beam, and a wall beam) from the east turret.

The only sample, RIB-H53, obtained from timbers in the west turret was dated (Figs 5 and 10). This sample has a last extant heartwood ring dating to AD 1504, which indicates that this support beam was felled after AD 1519.

## Kitchen/Service range

*Ground-floor ceilings (samples RIB-H15 – RIB-H19)*
All three sampled main ceiling beams in room G8 were dated (Figs 2a, 5, and 10). One of these, RIB-H15, retains complete sapwood, this meaning that it has the last growth-ring produced by the source tree before it was felled. This last sapwood ring, and thus the felling of the tree, is dated AD 1535. A second sample, RIB-H16, is from a timber from which the complete sapwood was lost during coring due to its soft and fragile nature. Given the last extant sapwood ring on the sample is dated to AD 1530, the amount of lost sapwood (approximately 2–3mm) would suggest that this timber was also felled in, or at least about, AD 1535. The third dated sample from this ceiling, RIB-H17, is without the heartwood/sapwood boundary, but with a last extant heartwood ring date of AD 1474, it was probably felled after AD 1489 and could, therefore, be coeval with the AD 1535 felling date identified.

Only the north beam (RIB-H18) of the two main ceiling beams sampled in the kitchen (rooms G9a/b), was dated (Figs 4a, 6, and 10). This sample is again without the heartwood/sapwood boundary. With a last extant heartwood ring date of AD 1627, and allowing for a minimum of 15 sapwood rings, it was probably felled after AD 1642.

*Roof (samples RIB-H40 – RIB-H52)*
A total of 13 samples from the roof over rooms S10–S14 were obtained, of which seven were dated indicating two different periods of felling activity (Figs 2b, 7–8, and 10).

Six timbers (four principal rafters and two common rafters) are clearly coeval, of which three of the samples, RIB-H41, RIB-H45, and RIB-H47, retain complete sapwood (Figs 8 and 10). In each case, this last growth-ring, and thus the time of felling of the trees is the same, being dated to AD 1708. Two other samples, RIB-H44 and RIB-H48, were taken from timbers with complete sapwood but both samples lost approximately 2–3mm of sapwood during coring. Both samples have a last extant sapwood ring dating to AD 1706 which, taking into account the lost sapwood, suggests that they were also felled in, or at least about, AD 1708.

A sixth sample, RIB-H43, has retained the heartwood/sapwood boundary. The relative position and date of the heartwood/sapwood boundary, as well as the presence of an unmeasured *c* 10mm section of sapwood rings, on this core would suggest that this timber was also felled at, or at least about, the same time in AD 1708.

The seventh dated sample from this roof, RIB-H40, has, however, a much later last extant sapwood ring dated to AD 1817, although the sapwood is not complete (Figs 7 and 10). With a heartwood/sapwood boundary date of AD 1804, an estimated felling date in the period AD 1819–44 is obtained for this common rafter.

### Agricultural wing (samples RIB-H20 – RIB-H24 and RIB-H55 – RIB-H66)

Sixteen of the of the 17 samples taken from timbers to the agricultural wing were dated, which appear to represent three distinct episodes of felling (Figs 2a, 6–7, and 10).

The earliest timber, represented by sample RIB-H20, is possibly originally a main bridging beam of a floor frame, reused here as a spine beam to one of the rooms to the southern end of this wing (Fig 10). This sample has a last measured ring date of AD 1581, this being at the heartwood/sapwood boundary. This timber, therefore, has estimated felling date in the range AD 1596–1621.

A further 13 samples, representing three *in situ* ground-floor ceiling beams in rooms G23 and G24, as well as a number of *ex situ* timbers potentially associated with the roof and a possible floor beam, appear coeval and likely to represent a single later episode of felling (Figs 6 and 10). Four samples, RIB-H61, RIB-H62, RIB-H63, and RIB-H64, retain complete sapwood. The last growth-ring, and thus the felling of the trees, is dated to AD 1655 on three of the samples and AD 1656 on the fourth sample. The remaining nine dated samples retain some sapwood or at least the heartwood/sapwood boundary, the average date of which is AD 1633. This produces an estimated felling date range of AD 1648–73 for these nine timbers, a date encompassing the known felling dates of AD 1655 and AD 1556. Taken overall, with the relative position and date of the heartwood/sapwood boundary on all 13 samples being very similar, varying by only 16 years from AD 1625 (RIB-H66) to AD 1641 (RIB-H60), it appears likely that all 13 of these timbers were felled in the mid-AD 1650s.

The latest phase of felling identified in this wing is represented by two samples, RIB-H23 and RIB-H24, obtained from the principal rafters of an *ex situ* roof frame originally located to the middle part of the agricultural wing (Figs 2a, 7, and 10). These samples have retained the heartwood/sapwood boundary, this being dated to AD 1807 in both cases. The two timbers represented, therefore, have an estimated felling date range of AD 1822–47

# DISCUSSION AND CONCLUSION

## Dating

Analysis by dendrochronology has dated 49 of the 66 timbers sampled from the hall range, the kitchen/service range, and the agricultural wing. The dated timbers appear to represent four major periods of felling, and hence building activity, although a further felling event was identified represented by a single timber (Figs 10 and 11).

The earliest felling activity identified is in the first half of the sixteenth century (Figs 10 and 11). Timbers to the ceiling of room G8 in the kitchen/service range were probably all felled in, or around, AD 1535. Timbers in the east turret to the hall range, with a felling date range of AD 1532–57, and the west turret to the hall range, with a felled after date of AD 1519, appear likely to have been felled at a similar time, also potentially in the mid-AD 1530s. The other group of timbers that appear likely to have been felled as part of this earliest episode of felling are the ceiling timbers from rooms G2a-c and G4 in the hall, which were all probably felled after AD 1500, this indicating the likelihood of a number of these timbers having lost not only the sapwood rings but also varying amounts of heartwood during their conversion from the original trees to decorative ceiling beams. It therefore appears likely that this series of timbers from ceiling beams in both the hall range and kitchen/service range, along with timbers from the two turrets, represent elements of the sixteenth-century primary phase of construction of Ribbesford House by Sir Robert Acton. It should be noted that the east and west turrets are thought to be early nineteenth-century rebuilds. The turret superstructures are, however, supported by timbers within the ceilings of the rooms below, most of which show evidence, by way of redundant mortices, peg holes, etc, of being reused in their present positions, apart from the softwood joists in the west turret. In addition to these known reused timbers in the turrets, it appears that the main ceiling beams in room G8, although showing no obvious signs of reuse, need to be reconsidered as these three dated timbers clearly pre-date the assumed early eighteenth-century construction date for the kitchen/service range.

A single timber (RIB-H20), reused as a spine beam in the agricultural wing, has been identified as being felled in the range AD 1596–1621 (Figs 10 and 11). This very late sixteenth- or early seventeenth-century timber is notable in that it is clearly derived from a slower-grown and much longer-lived tree, probably in excess of 250 years old at felling, than the rest of the timbers sampled here.

The next felling episode is in the mid-seventeenth century (Figs 10 and 11). A number of *in situ* ceiling beams and a series of *ex situ* timbers, thought likely to be roof timbers and a possible floor beam, all associated with the agricultural wing appear likely to have been felled in, or around AD 1655 and AD 1656. The other timber potentially felled at this time is the single dated main beam to the ceiling of rooms G9a and G9b in the kitchen/service range, which has a felled after date of AD 1642 and would thus have to have been rather heavily trimmed if it was to be associated with one of the later felling episodes identified. Whilst certainly not impossible that it was felled later, the level of cross-matching with a number of timbers from the agricultural wing suggests that a mid seventeenth-century felling is more likely for this ceiling beam. These timbers, therefore, all appear to be associated with works undertaken by Sir Henry Herbert who acquired Ribbesford House in AD 1627 before it passed to his son, also Henry Herbert, in AD 1673. Whilst works were known to have been completed by AD 1669, during Sir Henry Herbert's incumbency, the extent of these works remained very much an unknown. The series of timbers associated with the agricultural wing dating to the mid-AD 1650s, suggests that the construction of this wing within the development of this overall complex may need to be readdressed in the light of this evidence. The single likely mid seventeenth-century ceiling timber in rooms G9a and G9b pre-dates what is thought to be an early eighteenth-century date of construction of this kitchen/service range, thus this timber needs to be reassessed as potential reuse.

Just over half a century later, a group of timbers from the roof of the kitchen/service range were felled in, or at least about, AD 1708 (Figs 10 and 11). This coincides with the ownership of Ribbesford House by Henry Herbert, the grandson of Sir Henry Herbert, who is thought to have extended the house (hall range and original wings) to the north-west by the addition of the kitchen and service quarters.

The latest period of felling activity identified by this analysis dates to the first half of the nineteenth century (Figs 10 and 11). The series of timbers to the roof over rooms S1 and S2 in the hall range were all probably felled in AD 1818. The adjacent roof over the hall, above rooms S6a-c and S7, has timbers felled in the range AD 1821–46 and thus appears to be of a potentially slightly later date than the S1/S2 roof, an interpretation supported by the overall lower level of cross-matching seen between the S1/S2 roof timbers and the S6/S7 roof timbers. The other timbers included in this latest phase of felling are two principal rafters from an *ex situ* truss associated with the agricultural wing, with a felling date range of AD 1822–47, and a common rafter from the roof of the kitchen/service range, with a felling date range of AD 1819–44. Thus, these three latter timbers appear at least broadly coeval with the roof over the hall above rooms S6a-c/S7. These nineteenth-century timbers appear most likely to relate to the major structural changes that followed the purchase of the property by Thomas Ingram in AD 1787. This analysis suggests that at least some of this period of major rebuilding occurred slightly later than the *c* AD 1800 date previously attributed.

## Woodland sources

The level of cross-matching observed between some of the dated samples, from the hall range roof over rooms S1 and S2 for example, is high enough as to suggest that the trees represented grew in a single woodland source. Indeed, with some very high *t*-values, same-tree derivation is possible for some timbers (eg RIB-H29/RIB-H30 *t*-value = 11.0; RIB-H27/RIB-H28/RIB-H31 *t*-values > 10.0). Similarly high levels of cross-matching are also seen between samples from the *ex situ* timbers of the agricultural wing, including possible same-tree matches (eg RIB-H22/RIB-H57 *t*-value = 12.9; RIB-H60/RIB-H61 *t*-value = 11.1).

Although dendro-provenancing to any fine degree is highly problematic, as may be seen from Tables 2–7, there is a tendency for the Ribbesford House site chronologies to show the highest levels of similarity with reference chronologies comprised of timbers from other sites in the surrounding areas, rather than with those from further afield in England, such as Worcestershire, Herefordshire and other 'western' England sites appearing most frequently. This implies that the timbers used at Ribbesford House were likely to be of relatively local origin.

### Undated timbers

The dating of 49 of the 54 measured samples that were obtained represents a satisfactorily high success rate (just over 90%), with only five measured samples undated. As may be seen from Table 1, while two samples certainly do have sufficient numbers of rings for reliable tree-ring analysis, the others have ring numbers towards the lower limit of acceptability for reliable dating purposes. None of these undated samples show any compression or other disturbance to their growth patterns and the reason for the lack of dating remains unknown, although it should be noted that it is a feature of most programmes of tree-ring analysis that some samples remain undated, often for no apparent reason.

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# TABLES

*Table 1: Details of tree-ring samples, in numerical order, from Ribbesford House, Ribbesford, Bewdley, Worcestershire. Ground floor room numbers can be seen on Figure 2a; second floor room numbers can be seen on Figure 2b*

| Sample number | Sample location | Total rings | Sapwood rings | First measured ring date AD | Last heartwood ring date AD | Last measured ring date AD |
|---|---|---|---|---|---|---|
| | Hall range – ground-floor ceiling (rooms G2a-c and G4) | | | | | |
| RIB-H01 | North bridging joist, bay 2 | 47 | no h/s | 1435 | ------ | 1481 |
| RIB-H02 | North bridging joist, bay 1 | nm (34) | (no h/s) | ------ | ------ | ------ |
| RIB-H03 | Main north–south beam, bay 2 | nm (33) | (no h/s) | ------ | ------ | ------ |
| RIB-H04 | South bridging joist, bay 2 | 59 | no h/s | 1424 | ------ | 1482 |
| RIB-H05 | North bridging joist, bay 3 | nm (36) | (no h/s) | ------ | ------ | ------ |
| RIB-H06 | South bridging joist, bay 3 | 77 | no h/s | 1380 | ------ | 1456 |
| RIB-H07 | North bridging joist, bay 4 | 58 | no h/s | 1385 | ------ | 1442 |
| RIB-H08 | South bridging joist, bay 4 | 70 | no h/s | 1379 | ------ | 1448 |
| RIB-H09 | South common joist 5 (from east), bay 1 | nm (37) | (no h/s) | ------ | ------ | ------ |
| RIB-H10 | Middle common joist 2, bay 1 | 41 | no h/s | 1392 | ------ | 1432 |
| RIB-H11 | South common joist 4, bay 1 | 63 | no h/s | 1423 | ------ | 1485 |
| RIB-H12 | Middle common joist 3, bay 1 | nm (33) | (no h/s) | ------ | ------ | ------ |
| RIB-H13 | South common joist 3, bay 1 | nm (36) | (no h/s) | ------ | ------ | ------ |
| RIB-H14 | Middle common joist 4, bay 1 | nm (15) | (no h/s) | ------ | ------ | ------ |
| | | | | | | |
| | Kitchen/Service range – ground-floor ceiling (room G8) | | | | | |
| RIB-H15 | East main beam | 170 | 22C | 1366 | 1513 | 1535 |
| RIB-H16 | Middle main beam | 135 | 27c | 1396 | 1503 | 1530 |
| RIB-H17 | West main beam | 83 | no h/s | 1392 | ------ | 1474 |
| | | | | | | |
| | Kitchen/Service range – ground-floor ceiling (rooms G9a/b) | | | | | |
| RIB-H18 | North beam | 74 | no h/s | 1554 | ------ | 1627 |

| | | | | | | |
|---|---|---|---|---|---|---|
| RIB-H19 | South beam | 64 | h/s | ------ | ------ | ------ |
| | | | | | | |
| | Agricultural wing – *ex situ* timbers | | | | | |
| RIB-H20 | Spine beam | 220 | h/s | 1362 | 1581 | 1581 |
| RIB-H21 | Purlin | 55 | 1 | 1578 | 1631 | 1632 |
| RIB-H22 | Unknown timber | 64 | 8 | 1580 | 1635 | 1643 |
| RIB-H23 | *Ex situ* truss, right-hand principal rafter | 44 | h/s | 1764 | 1807 | 1807 |
| RIB-H24 | *Ex situ* truss, left-hand principal rafter | 51 | h/s | 1757 | 1807 | 1807 |
| | | | | | | |
| | Hall range – roof (over rooms S1 and S2) | | | | | |
| RIB-H25 | East principal rafter, truss 1 | 58 | 24C | 1761 | 1794 | 1818 |
| RIB-H26 | West principal rafter, truss 1 | 57 | 18 | 1759 | 1797 | 1815 |
| RIB-H27 | West queen post, truss 1 | 88 | 13 | 1727 | 1801 | 1814 |
| RIB-H28 | King post truss 1 | 78 | 18C | 1741 | 1800 | 1818 |
| RIB-H29 | East principal rafter, truss 2 | 73 | 22C | 1746 | 1796 | 1818 |
| RIB-H30 | West principal rafter, truss 2 | 61 | 21C | 1758 | 1797 | 1818 |
| RIB-H31 | King post truss 2 | 81 | 18C | 1738 | 1800 | 1818 |
| | | | | | | |
| | Hall range – roof (over rooms S6a-c and S7) | | | | | |
| RIB-H32 | North principal rafter, truss 3 | 52 | 7 | 1763 | 1807 | 1814 |
| RIB-H33 | South principal rafter, truss 3 | 42 | 7 | 1774 | 1808 | 1815 |
| RIB-H34 | North principal rafter, truss 4 | 66 | 9 | 1747 | 1803 | 1812 |
| RIB-H35 | South principal rafter, truss 4 | 68 | 8 | 1745 | 1804 | 1812 |
| | | | | | | |
| | Hall range - east turret | | | | | |
| RIB-H36 | East floor beam (reused) | nm (37) | (no h/s) | ------ | ------ | ------ |
| RIB-H37 | Middle floor beam (reused) | 94 | h/s | 1429 | 1522 | 1522 |
| RIB-H38 | West floor beam (reused) | nm (36) | (no h/s) | ------ | ------ | ------ |
| RIB-H39 | Wall beam (reused) | 78 | h/s | 1438 | 1515 | 1515 |
| | | | | | | |
| | Kitchen/Service range – roof (over rooms S11-14) | | | | | |
| RIB-H40 | South common rafter 13, bay 1 | 50 | 13 | 1768 | 1804 | 1817 |

| | | | | | | |
|---|---|---|---|---|---|---|
| RIB-H41 | North principal rafter, truss 1 | 50 | 15C | 1659 | 1693 | 1708 |
| RIB-H42 | South principal rafter, truss 1 | nm (30) | (h/s) | ------ | ------ | ------ |
| RIB-H43 | North principal rafter, truss 2 | 52 | h/s | 1640 | 1691 | 1691 |
| RIB-H44 | North common rafter 3, bay 3 | 67 | 15c | 1640 | 1691 | 1706 |
| RIB-H45 | North common rafter 4, bay 3 | 64 | 29C | 1645 | 1679 | 1708 |
| RIB-H46 | North common rafter 7, bay 3 | 40 | h/s | ------ | ------ | ------ |
| RIB-H47 | North principal rafter, truss 3 | 51 | 17C | 1658 | 1791 | 1708 |
| RIB-H48 | South principal rafter, truss 3 | 53 | 19c | 1654 | 1687 | 1706 |
| RIB-H49 | South common rafter 4, bay 4 | 64 | 3 | ------ | ------ | ------ |
| RIB-H50 | North common rafter 10, bay 4 | 49 | 17 | ------ | ------ | ------ |
| RIB-H51 | North principal rafter, truss 4 | nm (30) | (h/s) | ------ | ------ | ------ |
| RIB-H52 | South principal rafter, truss 4 | nm (30) | (h/s) | ------ | ------ | ------ |
| | | | | | | |
| | Hall range - west turret | | | | | |
| RIB-H53 | Support beam (reused) | 131 | no h/s | 1374 | ------ | 1504 |
| | | | | | | |
| | Hall range - east turret | | | | | |
| RIB-H54 | Support beam (reused) | 58 | h/s | 1457 | 1514 | 1514 |
| | | | | | | |
| | Agricultural wing – *ex situ* timbers | | | | | |
| RIB-H55 | Possible tiebeam | 51 | 2 | 1587 | 1635 | 1637 |
| RIB-H56 | Possible tiebeam | 72 | 4 | 1569 | 1636 | 1640 |
| RIB-H57 | Possible tiebeam | 67 | 12 | 1580 | 1634 | 1646 |
| RIB-H58 | Possible tiebeam | 64 | 6 | 1579 | 1636 | 1642 |
| RIB-H59 | Possible principal rafter | 72 | 14 | 1573 | 1630 | 1644 |
| RIB-H60 | Possible wall plate | 67 | 14C | 1589 | 1641 | 1655 |
| RIB-H61 | Possible wall plate | 71 | 15C | 1585 | 1640 | 1655 |
| RIB-H62 | Possible floor beam | 56 | h/s | 1581 | 1636 | 1636 |
| | | | | | | |
| | Agricultural wing – *in situ* timbers (rooms G23 and G24) | | | | | |
| RIB-H63 | Ground-floor ceiling beam 1 | 121 | 21C | 1536 | 1635 | 1656 |

| | | | | | | |
|---|---|---|---|---|---|---|
| RIB-H64 | Ground-floor ceiling beam 2 | 75 | 18C | 1581 | 1637 | 1655 |
| RIB-H65 | Ground-floor ceiling beam 3 | 48 | 19 | ------ | ------ | ------ |
| RIB-H66 | Ground-floor ceiling beam 4 | 64 | h/s | 1562 | 1625 | 1625 |

nm = sample not measured, number of rings and sapwood information in brackets
C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber represented
c = complete sapwood is found on the timber, but a portion of this has been lost from the sample in coring
h/s = the heartwood/sapwood ring is the last ring on the sample

*Table 2: Results of the cross-matching of site chronology RIBHSQ01 and relevant reference chronologies when the first-ring date is AD 1366 and the last-ring date is AD 1535*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Manor House, Lower Brockhampton, Herefordshire | AD 1304 – 1505 | 12.6 | (Arnold and Howard 2014a unpubl) |
| Bewdley, Worcestershire working master | AD 1258 – 1630 | 12.6 | (Arnold and Howard 2019 unpubl) |
| The Commandery, Worcester, Worcestershire | AD 1284 – 1473 | 12.0 | (Arnold and Howard 2006) |
| Village Hall, Cradley, Herefordshire | AD 1347 – 1530 | 11.4 | (Worthington and Miles 2004) |
| St John's Walk, Hereford Cathedral, Herefordshire | AD 1356 – 1504 | 10.6 | (Arnold and Howard 2015a unpubl) |
| Primrose Hill, Kings Norton, Birmingham | AD 1354 – 1593 | 10.6 | (Arnold and Howard 2008a) |
| Court House, Shelsley Walsh, Worcestershire | AD 1387 – 1575 | 10.5 | (Arnold *et al* 2008b) |
| Black Ladies, near Brewood, Staffordshire | AD 1372 – 1671 | 10.4 | (Tyers 1999a) |
| Cathedral Barn, Hereford, Herefordshire | AD 1359 – 1491 | 10.3 | (Tyers 1996) |
| Farmers Club, Widemarsh Street, Hereford, Herefordshire | AD 1313 – 1617 | 10.2 | (Tyers 1996) |

*Table 3: Results of the cross-matching of site chronology RIBHSQ02 and relevant reference chronologies when the first-ring date is AD 1536 and the last-ring date is AD 1656*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Worcester Cathedral, Worcester | AD 1484 – 1772 | 12.0 | (Arnold *et al* 2003c) |
| Buildwas Abbey, Ironbridge, Shropshire | AD 1563 – 1687 | 7.7 | (Miles 2002) |
| Sherborne House, Newland, Sherborne, Dorset | AD 1540 – 1670 | 7.3 | (Bridge 2014) |
| Alcester Town Hall, Alcester, Warwickshire | AD 1374 – 1625 | 6.7 | (Arnold and Howard 2014b unpubl) |
| 26 Westgate Street, Gloucester, Gloucestershire | AD 1399 – 1622 | 6.6 | (Howard *et al* 1998) |
| Old Hat Shop, Tewkesbury, Gloucestershire | AD 1484 – 1664 | 6.5 | (Nayling 2000) |
| 27 Wyre Hill , Bewdley, Worcestershire | AD 1314 – 1590 | 6.1 | (Arnold and Howard 2015b unpubl) |
| Church of St Mary, Stowmarket, Suffolk | AD 1542 – 1671 | 6.0 | (Howard *et al* 1994) |
| Church of St Mary bell tower, Pembridge, Herefordshire | AD 1559 – 1668 | 5.9 | (Tyers 1999b) |
| Church of St Mary the Virgin, Yatton, Somerset | AD 1564 – 1691 | 5.9 | (Wilson and Tyers 1999) |

*Table 4: Results of the cross-matching of site chronology RIBHSQ03 and relevant reference chronologies when the first-ring date is AD 1727 and the last-ring date is AD 1818*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Endcliffe Park wood, Sheffield, South Yorkshire | AD 1759 – 2003 | 9.4 | (Tyers 2004) |
| Sheffield, South Yorkshire | AD 1747 – 1830 | 6.8 | (Howard unpubl) |
| Bath modern, Somerset | AD 1754 – 1979 | 6.4 | (Pilcher and Baillie 1980) |
| Coombe Warren, Coventry, West Midlands | AD 1747 – 1830 | 5.9 | (Arnold and Howard 2015c unpubl) |
| Great Gransden windmill, Cambridgeshire | AD 1706 – 1836 | 5.9 | (Bridge 2015) |
| Whitewater Mill, Hook, Hampshire | AD 1755 – 1827 | 5.9 | (Moir 2017) |
| Kiln Farmhouse, Upper Basildon, Berkshire | AD 1692 – 1798 | 5.7 | (Miles and Bridge 2012) |
| Pitstone windmill, Ivinghoe, Buckinghamshire | AD 1729 – 1823 | 5.4 | (Miles *et al* 2004) |
| St Mary's Church, Saffron Walden, Essex | AD 1701 – 1789 | 5.3 | (Bridge 2001a) |
| Town Hall, Brackley, Northamptonshire | AD 1748 – 1881 | 5.3 | (Bridge and Miles 2016) |

*Table 5: Results of the cross-matching of site chronology RIBHSQ04 and relevant reference chronologies when the first-ring date is AD 1640 and the last-ring date is AD 1708*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Worcester Cathedral, Worcester | AD 1484 – 1772 | 9.5 | (Arnold *et al* 2003c) |
| Old Barn, Shottery, Warwickshire | AD 1591 – 1735 | 8.6 | (Howard *et al* 1996a) |
| Lydington Manor buildings, Lyddington, Rutland | AD 1607 – 1789 | 7.7 | (Arnold and Howard forthcoming) |
| De Grey Mausoleum, Flitton, Bedfordshire | AD 1510 – 1726 | 7.6 | (Arnold *et al* 2003b) |
| Royal Arsenal Woolwich, Greenwich, London | AD 1617 – 1782 | 7.4 | (Tyers 2000) |
| Court House, Shelsley Walsh, Worcestershire | AD 1580 – 1739 | 7.2 | (Arnold *et al* 2008b) |
| Ballingdon Bridge, Sudbury, Suffolk | AD 1617 – 1782 | 7.2 | (Tyers 2002) |
| The Commandery, Worcester, Worcestershire | AD 1608 – 1708 | 7.1 | (Arnold and Howard 2006) |
| Quenby Hall, Quenby, Leicestershire | AD 1648 – 1765 | 7.1 | (Arnold *et al* 2008a) |
| St Peter's Church, Oundle, Northamptonshire | AD 1642 – 1721 | 6.8 | (Arnold and Howard 2016 unpubl) |

*Table 6: Results of the cross-matching of site chronology RIBHSQ05 and relevant reference chronologies when the first-ring date is AD 1438 and the last-ring date is AD 1515*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Woodmanton Manor, Clifton-on-Teme, Worcestershire | AD 1413 – 1589 | 6.5 | (Tyers 2001) |
| Church of St Nectan, Stoke, Hartland, Devon | AD 1440 – 1697 | 6.2 | (Arnold and Howard 2013) |
| Lower House Farm, Tupsley, Herefordshire | AD 1425 – 1613 | 6.0 | (Tyers 1997) |
| Moyns Park, Birdbrook, Essex | AD 1431 – 1606 | 5.6 | (Tyers 1999c) |
| Lower Cil, Berriew, Powys | AD 1428 – 1583 | 5.4 | (Suggett *et al* 2007) |
| The Guildhall, Worcester, Worcestershire | AD 1361 – 1609 | 5.3 | (Arnold *et al* 2006) |
| Acton Manor, Ombersley, Worcestershire | AD 1350 – 1570 | 5.2 | (Arnold and Howard 2011 unpubl) |
| Forbury Chapel, Church Street, Leominster, Herefordshire | AD 1432 – 1520 | 5.2 | (Arnold *et al* 2003a) |
| Bishop's House, Norton Lane, Sheffield, West Yorkshire | AD 1399 – 1579 | 5.1 | (Arnold and Howard 2017 unpubl) |
| Broomfield House, Enfield, London | AD 1446 – 1562 | 5.1 | (Bridge 1997) |

*Table 7: Results of the cross-matching of sample RIB-H20 and relevant reference chronologies when the first-ring date is AD 1362 and the last-ring date is AD 1581*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Bewdley, Worcestershire working master | AD 1258 – 1630 | 9.2 | (Arnold and Howard 2019 unpubl) |
| Hoarstone Farm, Bewdley Worcestershire | AD 1350 – 1617 | 8.5 | (Tyers 2008) |
| Odda's Chapel, Deerhurst, Gloucestershire | AD 1352 – 1593 | 8.1 | (Bridge 2001b) |
| The Guildhall, Worcester, Worcestershire | AD 1361 – 1609 | 6.6 | (Arnold *et al* 2006) |
| Astley Castle, Warwickshire | AD 1495 – 1627 | 6.6 | (Howard *et al* 1997) |
| Lea Road Foundry Site, Church Street, Dronfield, Derbyshire | AD 1344 – 1526 | 6.5 | (Tyers 2003) |
| Alcester Town Hall, Alcester, Warwickshire | AD 1374 – 1625 | 6.4 | (Arnold and Howard 2014b unpubl) |
| 26 Westgate Street, Gloucester, Gloucestershire | AD 1399 – 1622 | 6.4 | (Howard *et al* 1998) |
| Mercer's Hall, Westgate Street, Gloucester, Gloucestershire | AD 1289 – 1541 | 6.3 | (Howard *et al* 1996b) |
| Black Ladies, near Brewood, Staffordshire | AD 1372 – 1671 | 6.3 | (Tyers 1999a) |

FIGURES

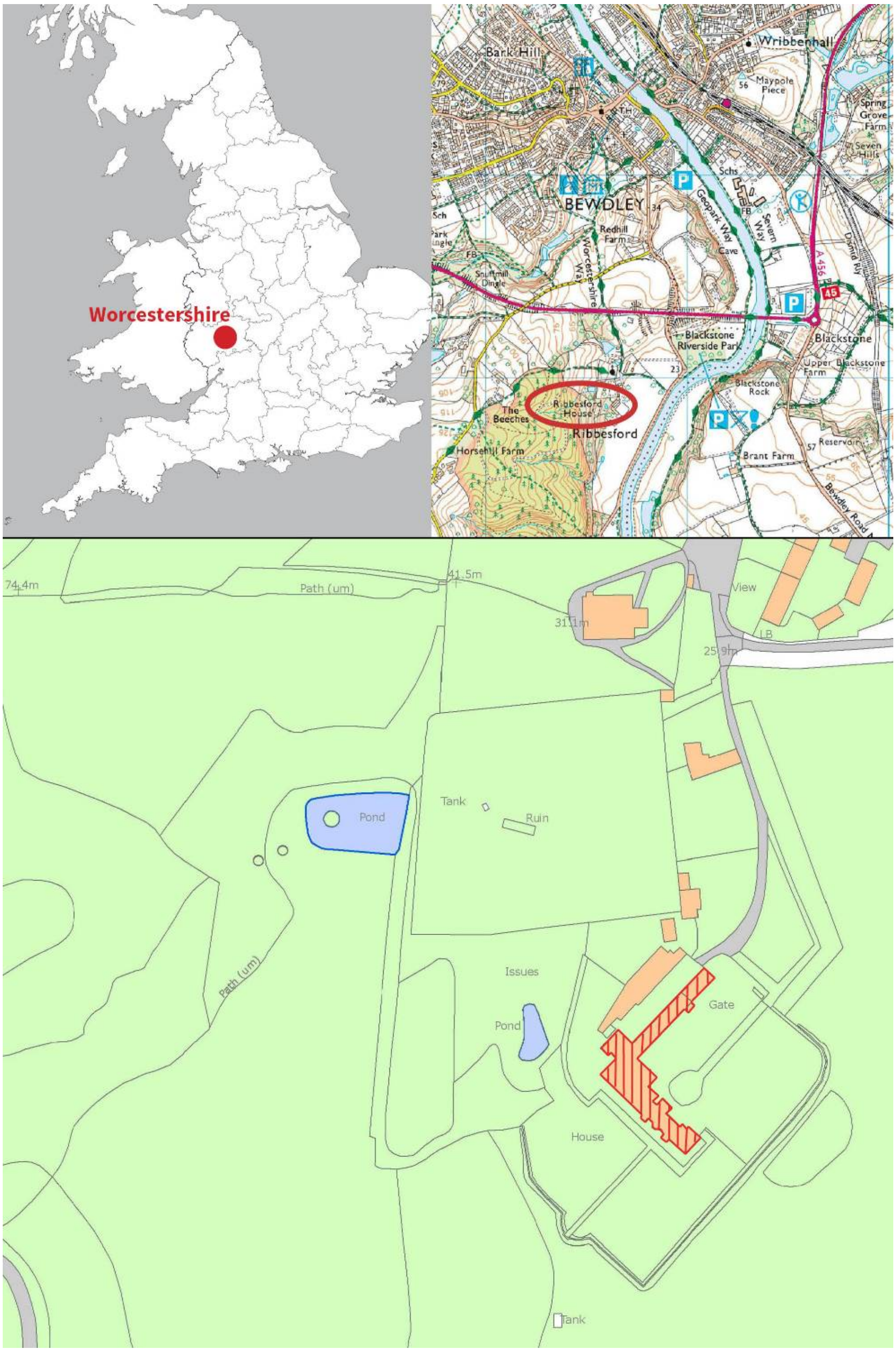



*Figure 1: Maps to show the location of Ribbesford House, Bewdley in Worcestershire, marked in red. Scale: top right 1:25000; bottom 1:2000. © Crown Copyright and database right 2021. All rights reserved. Ordnance Survey Licence number 100024900. © British Crown and SeaZone Solutions Ltd 2021. All rights reserved. Licence number 102006.006. © Historic England*

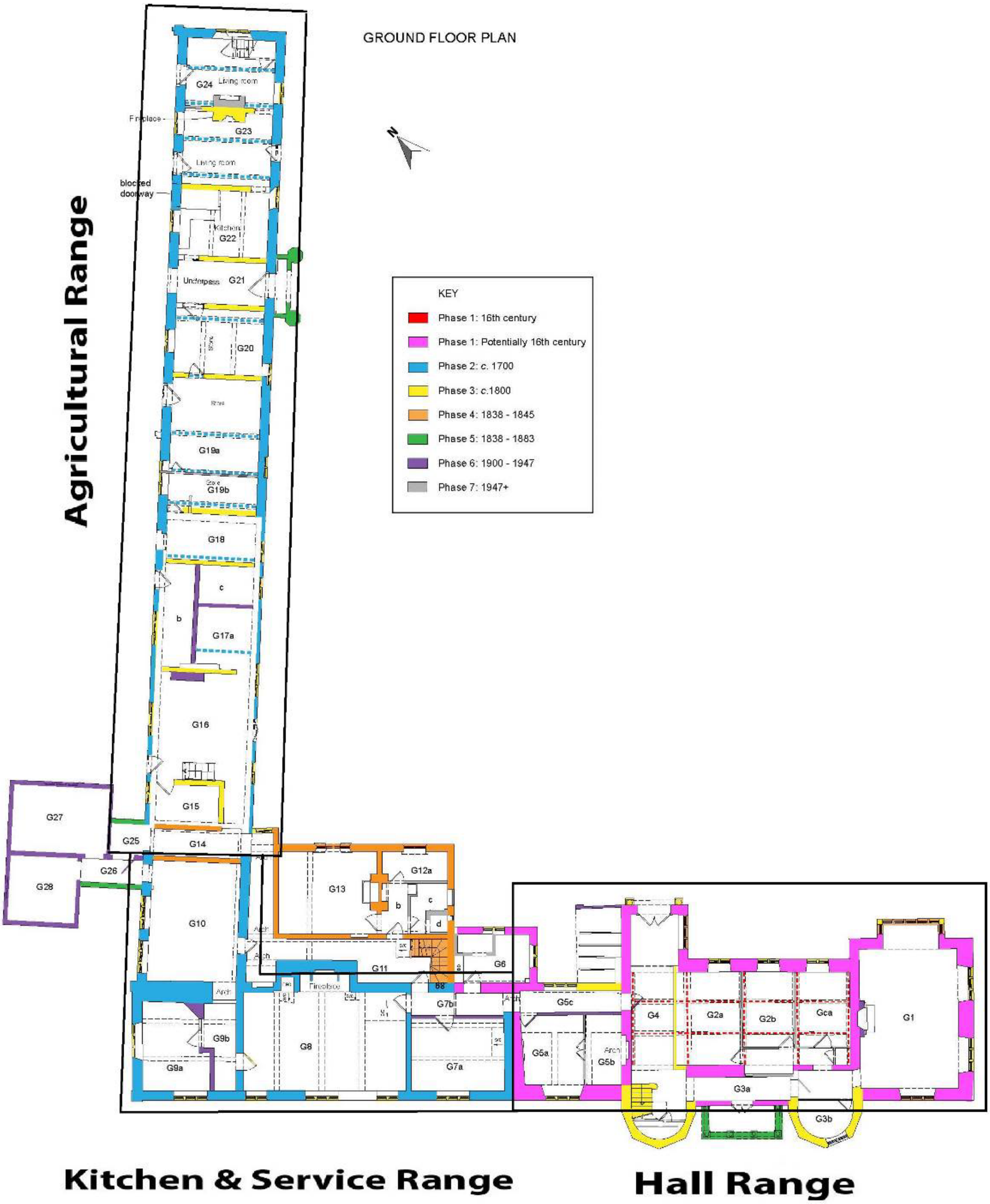



*Figure 2a: Ground-floor plan to show the layout of Ribbesford House and the room numbering scheme (Worcestershire Archaeology 2019)*

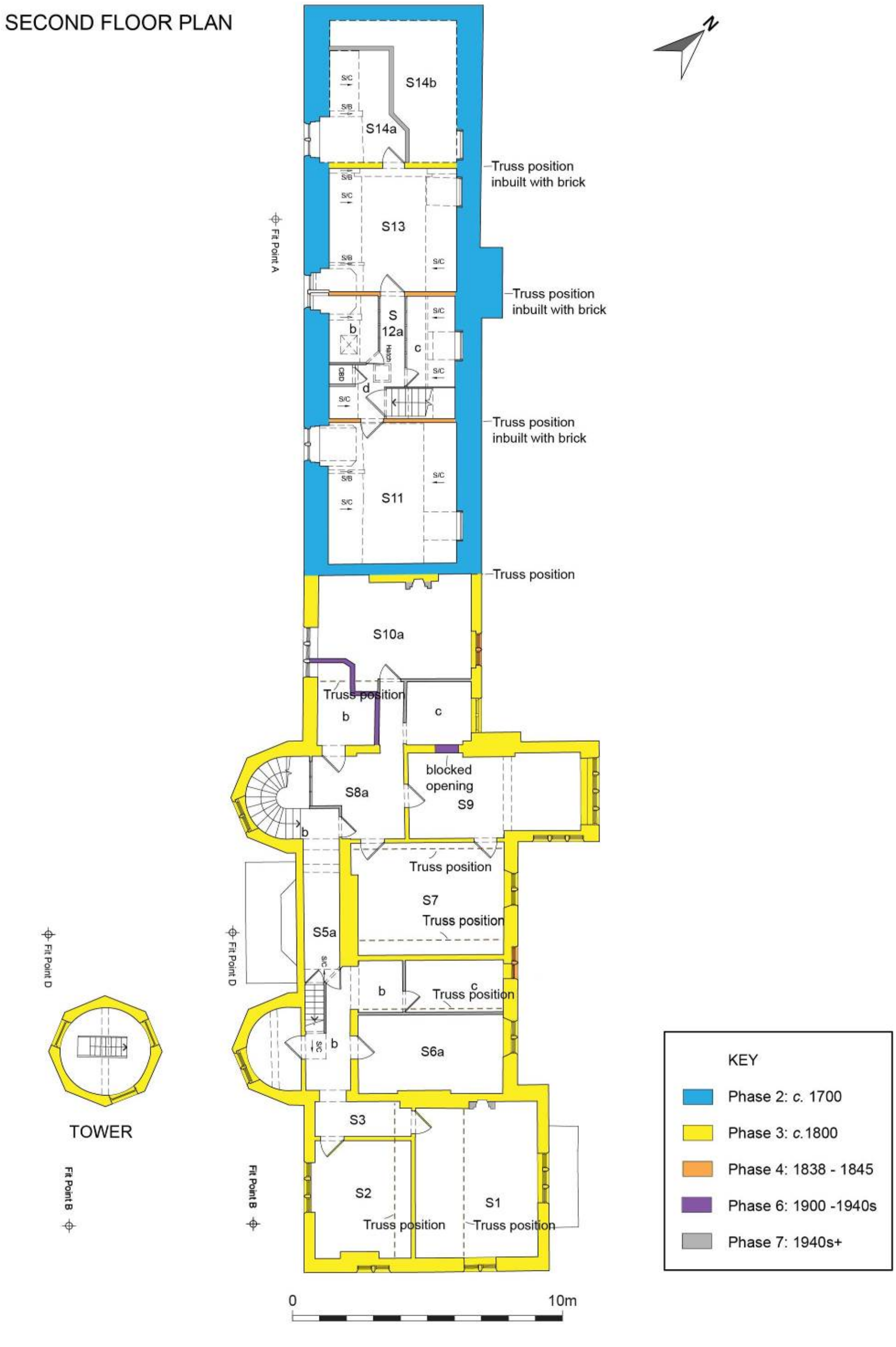



*Figure 2b: Second-floor plan to show the layout of Ribbesford House and the room numbering scheme (Worcestershire Archaeology 2019)*

*Figure 3a/b: Views of the ground-floor ceiling beams to the (top), and roof truss to the agricultural wing (bottom) (photographs Robert Howard)*

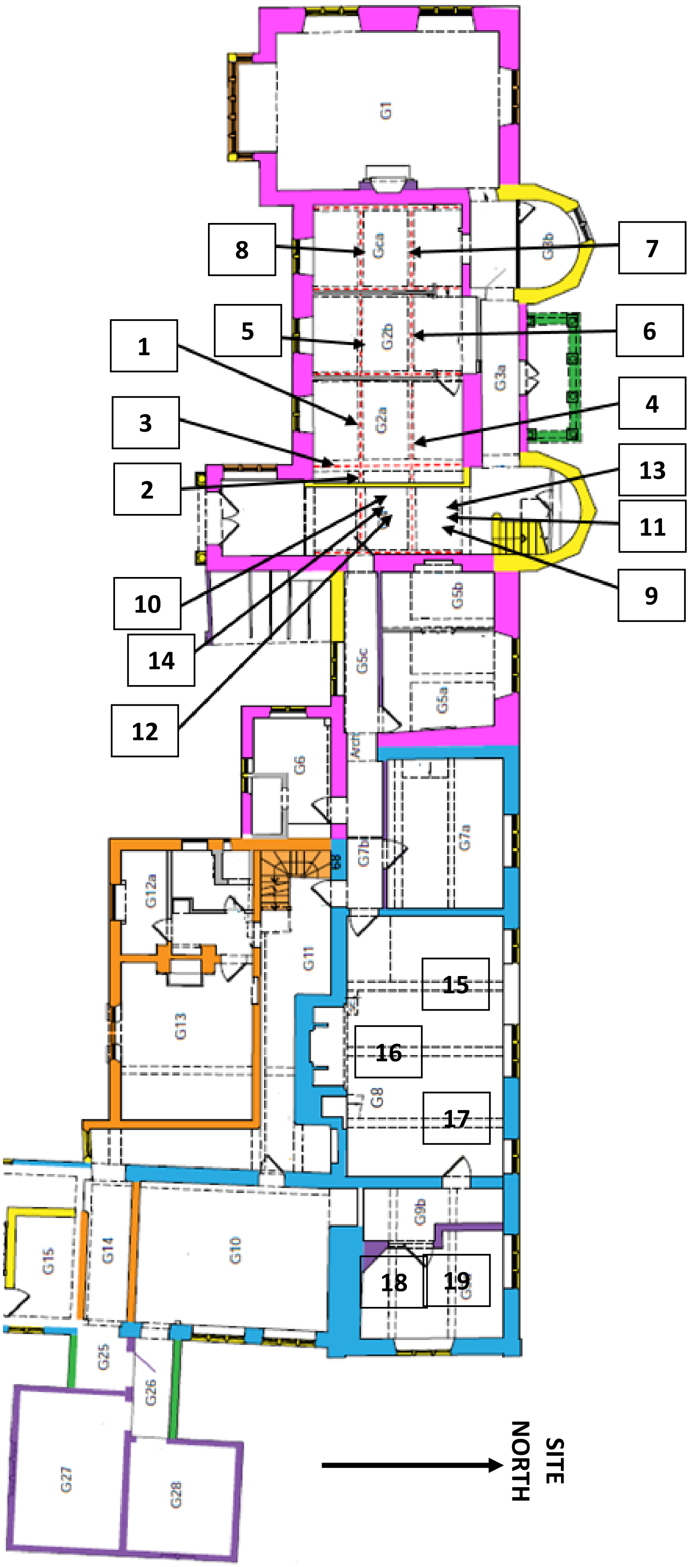



*Figure 4a: Ground-floor plan of the hall range and the kitchen/service range, including room numbers, to locate sampled timbers (after Worcestershire Archaeology 2019)*

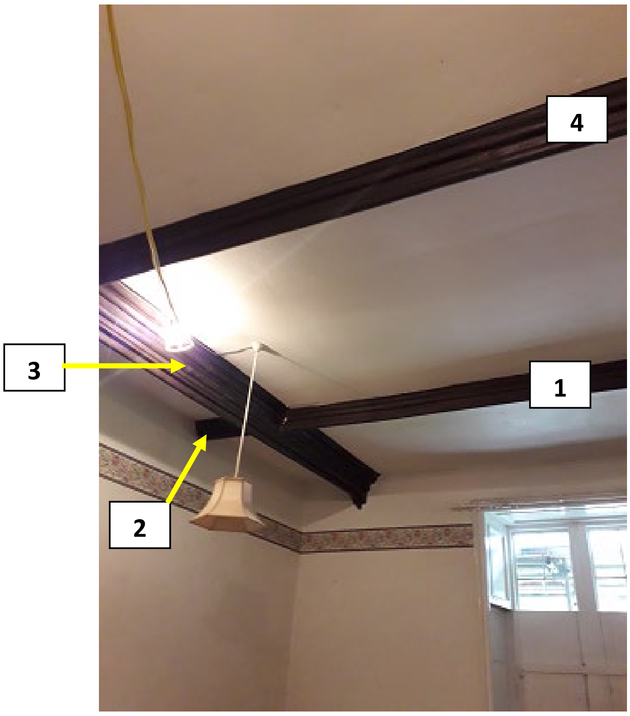




*Figure 4b/c: Annotated photographs identifying sampled timbers (photographs Robert Howard)*

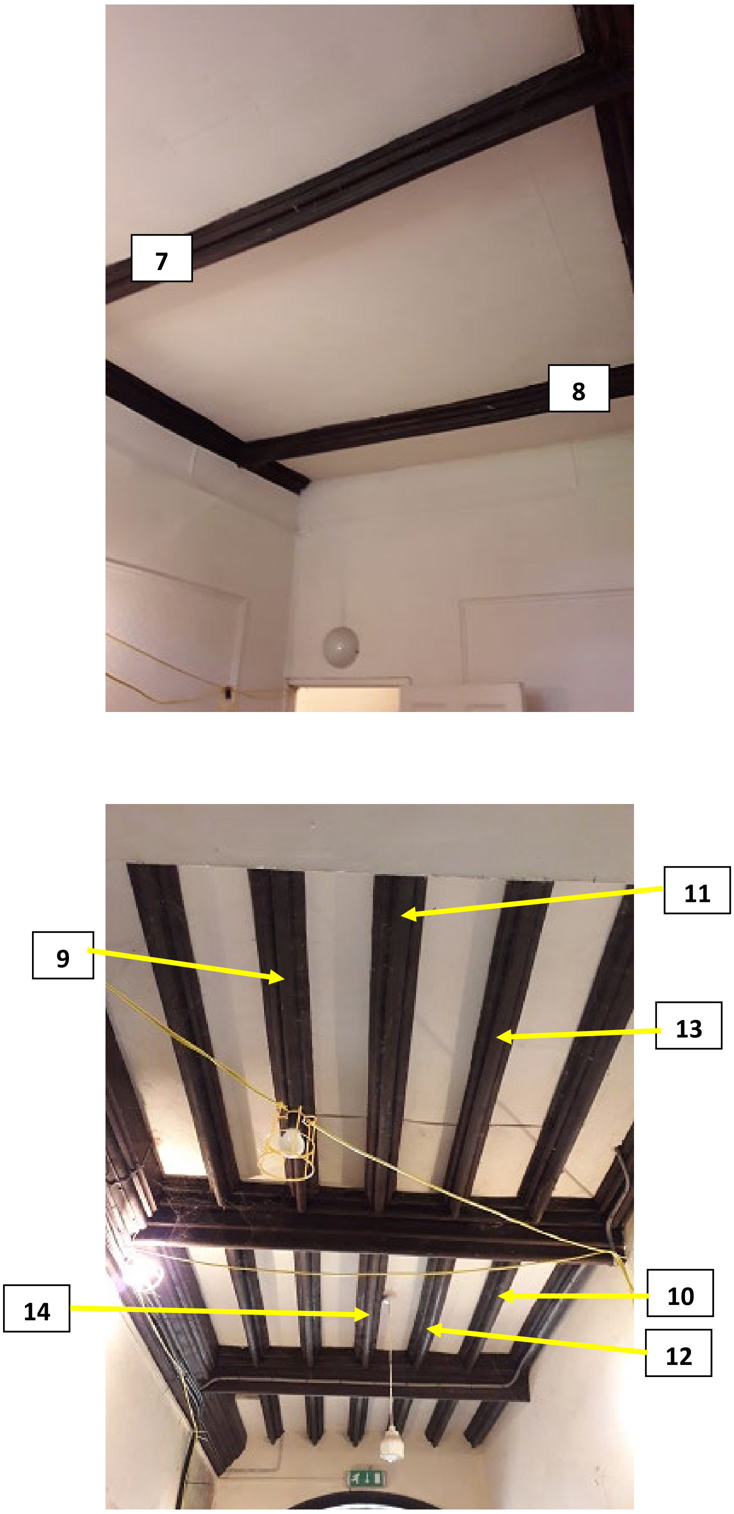



*Figure 4d/e: Annotated photographs identifying sampled timbers (photographs Robert Howard)*



*Figure 4f/g: Annotated photographs identifying sampled timbers (photographs Robert Howard)*



*Figure 4h/i: Annotated photographs identifying sampled timbers (photographs Robert Howard)*


*Figure 4j/k: Annotated photographs identifying sampled timbers (photographs Robert Howard)*

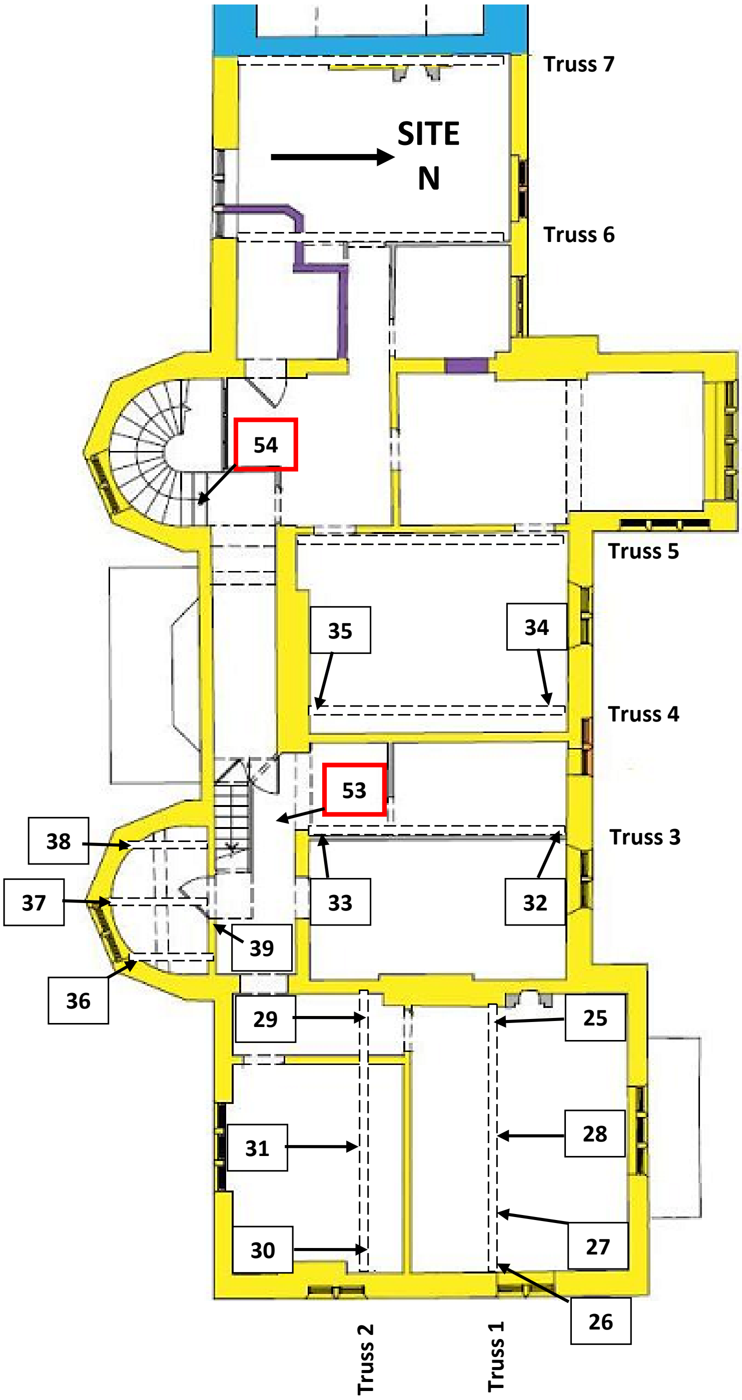



*Figure 4l: Second-floor plan of the hall range to locate sampled timbers (after Worcestershire Archaeology 2019)*

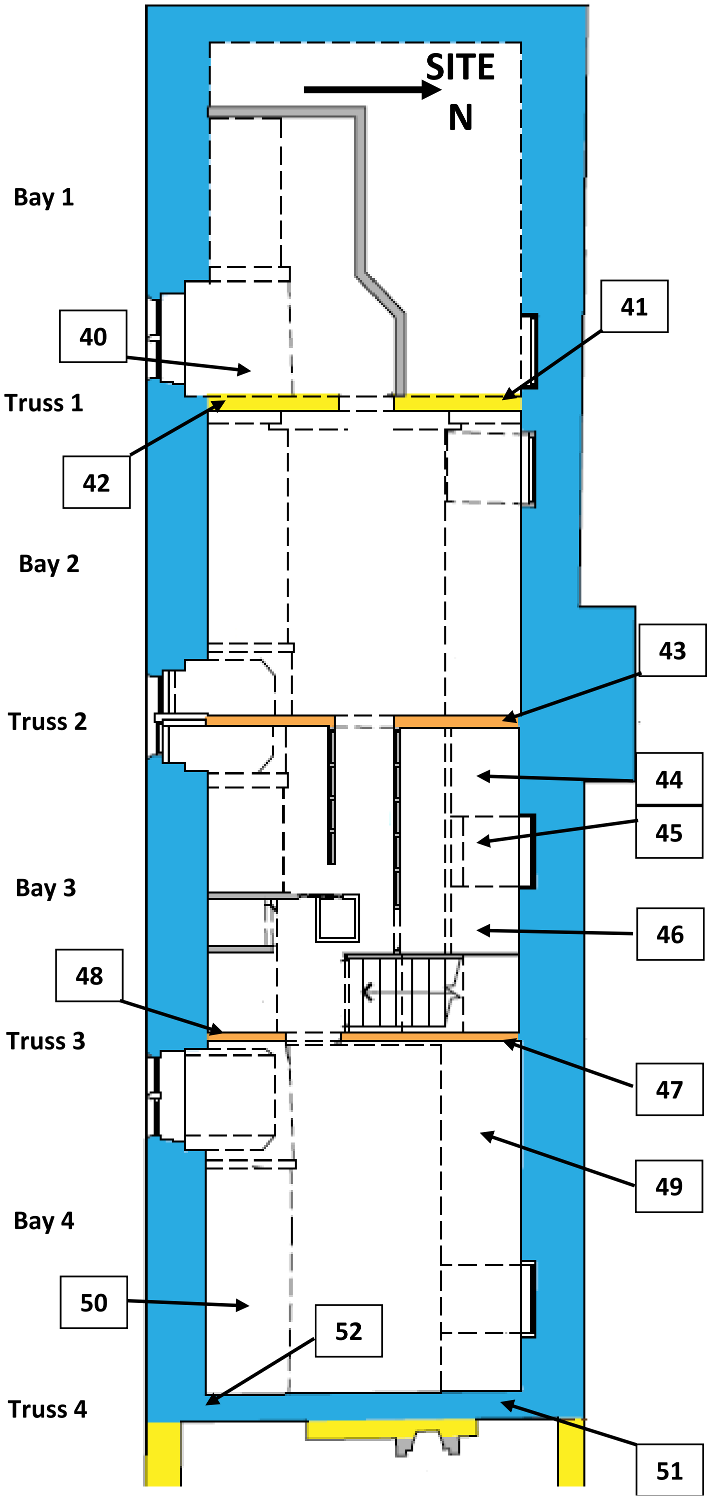



*Figure 4m: Second-floor plan of the kitchen/service range to located sample timbers (after Worcestershire Archaeology 2019)*



*Figure 4n/o: Annotated photographs identifying sampled timbers (photographs Robert Howard)*



*Figure 4p/q: Annotated photographs identifying sampled timbers (photographs Robert Howard)*



*Figure 4r/s: Annotated photographs identifying sampled timbers (photographs Robert Howard)*



*Figure 4t/u: Annotated photographs identifying sampled timbers (photographs Robert Howard)*

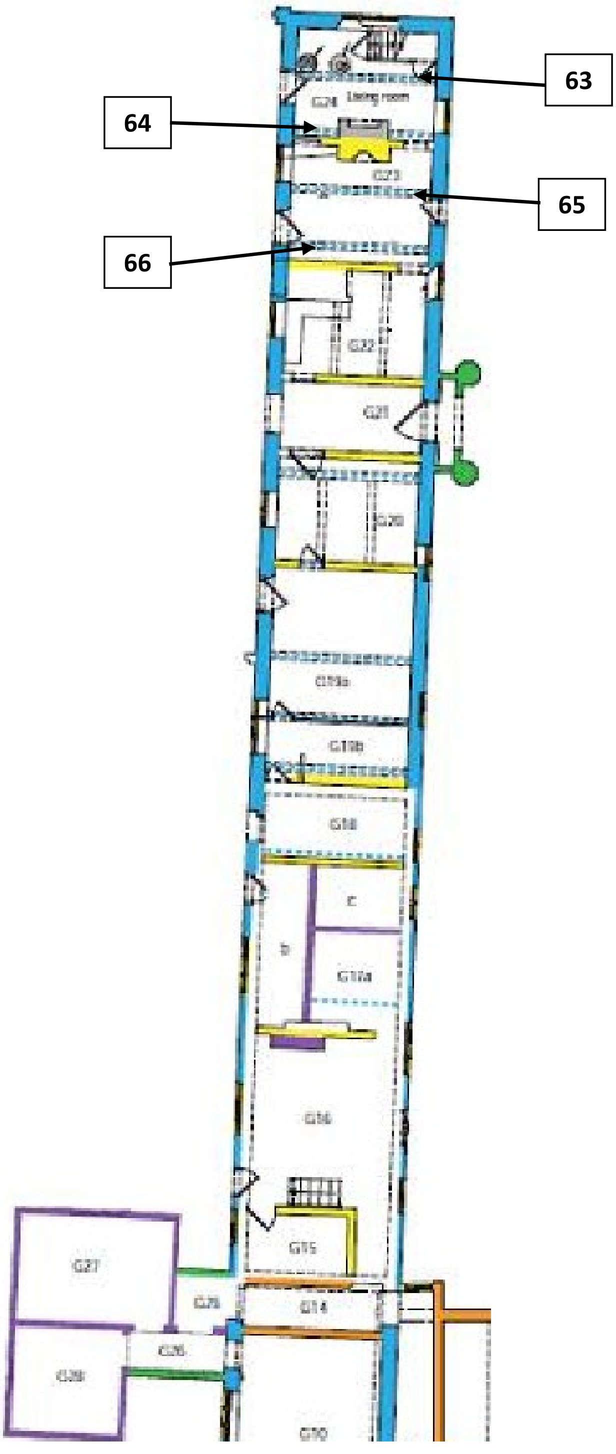
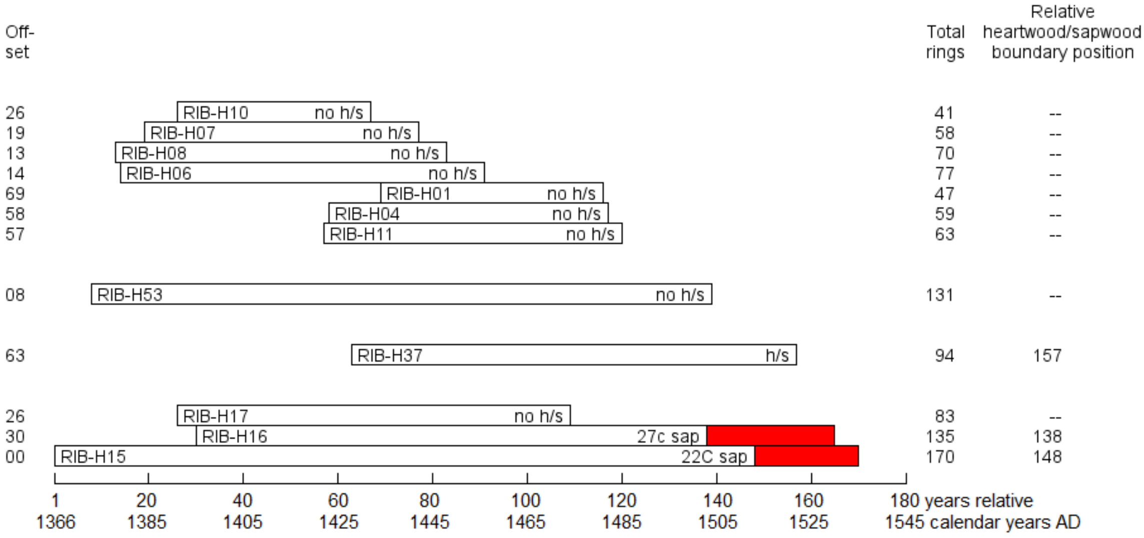
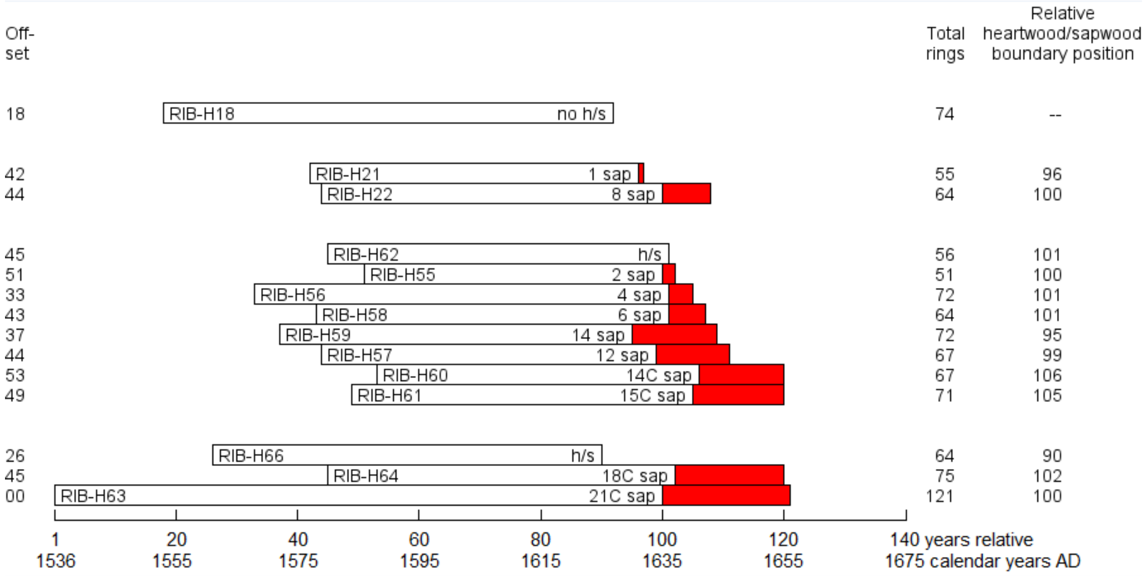



*Figure 4v: Ground-floor plan of the agricultural wing to locate sampled timbers (after Worcestershire Archaeology 2019*



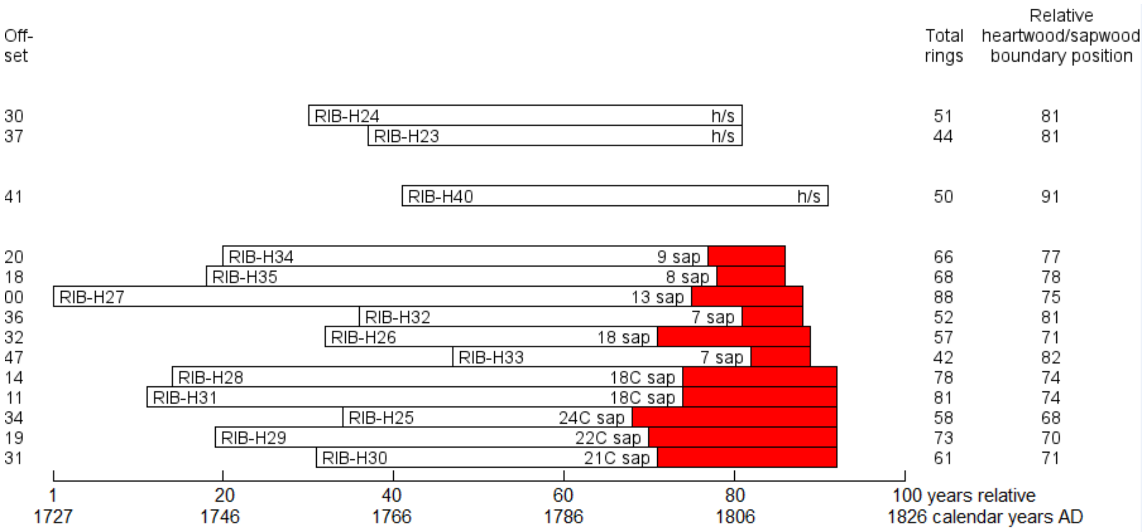

White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber represented; c = complete sapwood is found on the timber, but a portion has been lost from the sample in coring

*Figure 5: Bar diagram of the samples in site chronology RIBHSQ01*



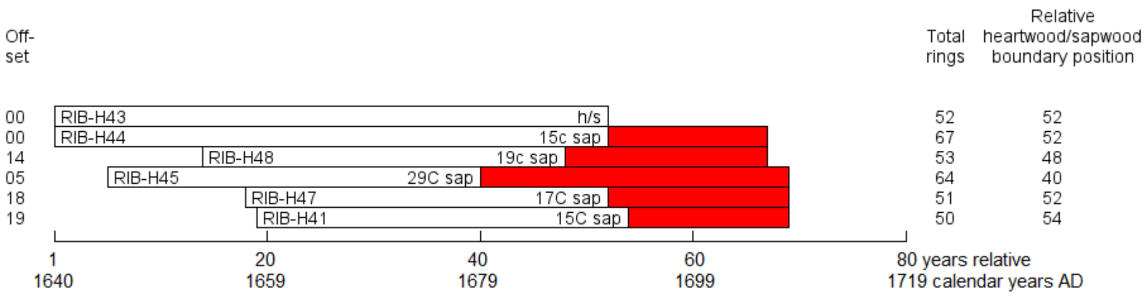

White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the timber represented

*Figure 6: Bar diagram of the samples in site chronology RIBHSQ02*



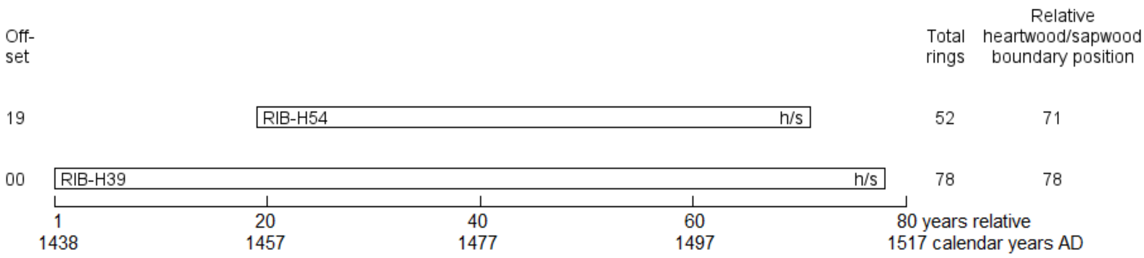

White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the timber represented

*Figure 7: Bar diagram of the samples in site chronology RIBHSQ03*



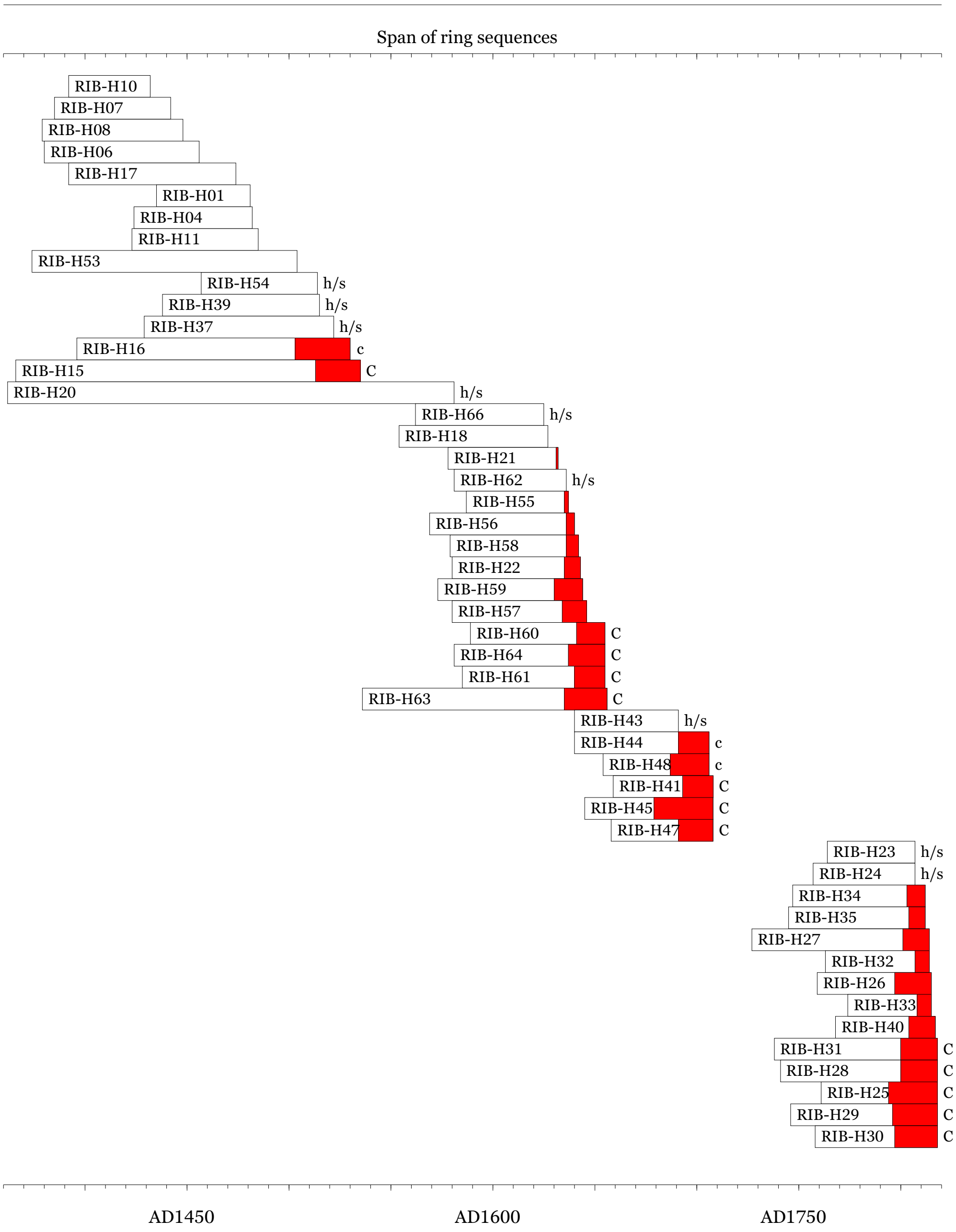

White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber represented; c = complete sapwood is found on the timber, but a portion has een lost from the sample in coring

*Figure 8: Bar diagram of the samples in site chronology RIBHSQ04*



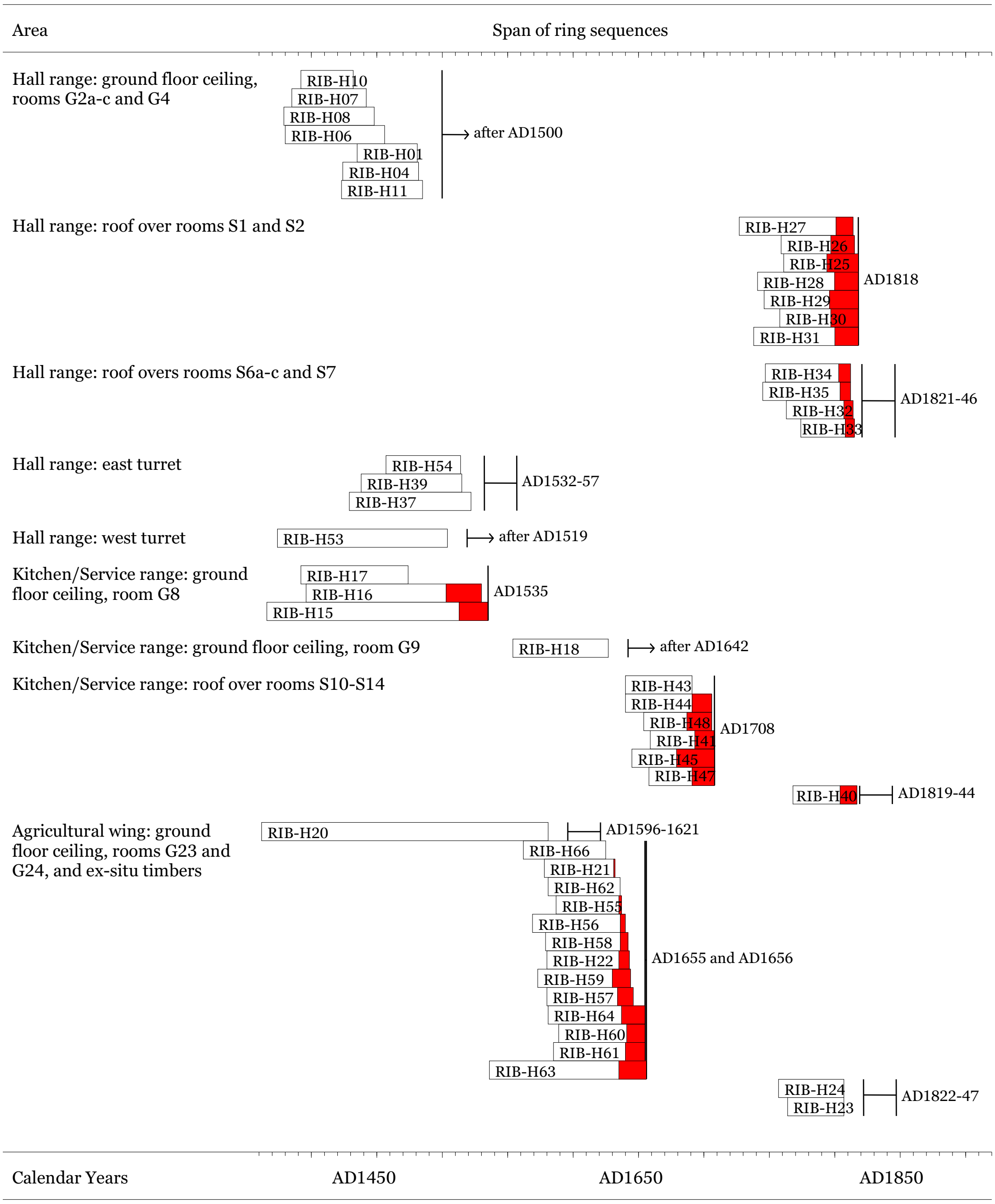

White bars = heartwood rings; h/s = heartwood/sapwood boundary

*Figure 9: Bar diagram of the samples in site chronology RIBHSQ05*




White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber represented; c = complete sapwood is found on the timber, but a portion has been lost from the sample in coring

*Figure 10: Bar diagram of all dated samples, sorted by end ring*




White bars = heartwood rings; red bars = sapwood rings

*Figure 11: Bar diagram of all dated samples, sorted by area and end ring, with felling dates / date ranges*

## DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

RIB-H01A 47
275 228 191 213 217 192 237 180 253 294 284 216 235 259 275 253 284 260 185 252
225 253 234 239 210 249 207 233 229 157 164 246 253 252 232 232 187 193 179 176
250 221 232 217 228 223 284

RIB-H01B 47
272 220 195 212 218 191 218 171 273 289 262 228 214 274 268 239 270 235 211 259
207 250 221 230 231 247 218 234 220 151 173 237 241 260 236 243 166 179 181 192
257 221 223 212 223 226 341

RIB-H04A 59
142 134 163 131 213 193 130 170 142 177 142 203 189 171 233 162 191 194 144 214
215 158 179 210 214 193 185 253 178 157 202 215 200 202 206 143 245 207 150 179
146 107 118 152 156 204 190 154 154 150 192 246 156 151 147 140 104 145 153

RIB-H04B 59
153 139 157 121 213 194 134 163 164 159 157 206 176 175 226 160 183 200 165 204
204 157 184 226 210 209 193 228 208 155 190 221 214 190 200 131 255 186 159 190
145 117 120 148 154 201 201 146 142 165 181 246 156 168 139 143 110 121 165

RIB-H06A 77
153 128 160 138 194 179 221 199 149 174 192 351 189 256 167 157 335 190 264 236
202 190 210 314 233 234 256 314 285 320 304 221 295 251 259 267 354 284 399 175
460 269 207 389 493 487 328 385 368 313 374 222 310 275 181 179 165 162 268 187
212 209 127 178 250 196 178 170 128 194 203 227 203 180 170 196 298

RIB-H06B 77
124 132 162 143 188 190 223 200 153 175 182 359 196 253 159 160 341 200 250 228
210 142 220 325 243 228 253 302 292 287 296 209 268 248 253 249 342 288 407 176
468 236 203 373 500 486 343 381 346 297 368 221 307 230 181 169 170 159 270 201
204 208 122 184 259 206 161 166 155 182 209 237 188 173 181 218 250

RIB-H07A 58
174 221 238 309 329 305 329 282 275 169 264 284 264 295 339 252 333 273 346 218
146 167 187 211 272 295 187 189 190 165 218 173 193 181 134 192 179 157 198 221
267 195 240 295 365 271 253 318 243 265 334 267 198 221 171 158 178 314

RIB-H07B 57
177 218 242 301 305 318 301 240 239 150 246 278 268 293 346 250 326 284 342 235
153 173 185 200 282 300 187 185 179 200 212 183 171 167 151 165 204 153 199 220
247 213 255 299 361 303 275 306 218 246 317 275 208 223 162 156 187

RIB-H08A 70
115 125 129 167 222 253 207 368 391 319 271 293 428 399 272 262 241 428 373 480
612 510 534 454 425 252 275 329 348 293 403 384 314 306 225 190 309 253 278 362
270 581 343 228 332 335 271 242 257 562 628 646 459 609 634 661 674 572 397 507
247 485 525 250 238 360 299 300 246 272

RIB-H08B 70
132 111 125 167 227 249 211 380 389 309 278 287 391 417 285 268 237 398 369 443
601 537 484 440 460 250 259 329 328 293 401 393 306 299 225 189 357 246 275 334
287 618 301 246 356 371 287 251 257 548 659 639 471 609 625 657 665 599 414 461
237 510 515 264 225 375 283 295 244 307

RIB-H10A 41
316 429 416 402 527 301 400 532 511 450 368 352 275 232 282 191 305 384 370 244
245 215 272 218 203 157 162 118 192 171 207 231 153 220 209 137 185 176 159 128
164

RIB-H10B 41
308 438 406 396 520 279 414 527 506 431 360 357 285 243 260 182 272 418 353 245
237 237 254 244 165 182 176 85 175 228 189 257 184 214 228 141 179 175 151 143
171

RIB-H11A 63
198 273 204 162 188 307 334 253 154 247 184 188 255 230 192 192 85 111 122 149
157 189 160 167 155 160 122 188 140 171 152 225 226 156 204 196 125 175 128 110
154 154 159 245 281 271 338 219 192 176 156 182 275 221 170 185 126 167 225 259
270 395 255

RIB-H11B 63
219 259 192 175 187 292 347 250 153 242 183 177 244 230 191 173 86 111 130 139
167 182 165 156 161 150 132 187 153 175 150 213 230 150 210 192 117 179 120 110
156 162 155 245 293 248 329 235 190 179 146 171 269 224 167 192 134 168 225 228
262 403 300

RIB-H15A 170
249 318 299 434 388 266 319 262 266 212 254 209 241 332 361 237 301 264 201 228
285 332 264 318 250 264 170 116 86 82 169 225 232 310 175 235 186 217 149 145
229 210 198 207 187 120 139 160 117 154 107 103 113 111 132 123 178 196 163 190
87 96 138 125 143 140 185 135 159 144 81 80 90 68 84 109 100 115 106 81
93 90 132 105 96 131 134 114 134 127 141 103 133 78 79 76 58 53 57 49
50 77 69 71 92 77 86 76 61 93 84 62 68 85 74 83 109 78 65 45
40 90 77 100 125 97 115 90 93 120 110 92 62 62 68 37 53 62 83 106
67 40 43 59 87 75 83 81 77 65 57 32 61 68 70 66 89 97 96 65
65 89 134 120 122 143 133 100 106 145

RIB-H15B 170
217 333 293 459 349 262 321 275 246 230 237 213 208 306 318 237 314 248 196 251
304 331 259 304 256 278 173 117 84 85 182 203 234 301 171 234 190 214 132 153
243 200 193 214 173 120 142 173 127 160 103 99 126 112 140 120 189 190 156 185
103 93 134 121 145 121 187 146 156 146 75 73 96 74 81 118 96 118 109 74
96 94 127 93 109 124 118 98 132 138 125 102 120 75 80 75 68 53 54 68
35 78 67 78 74 77 84 81 56 85 80 61 78 75 78 88 105 82 57 41
49 88 73 100 122 100 113 83 96 112 98 89 55 72 63 42 53 65 82 109
66 36 50 57 79 78 81 75 80 79 43 47 61 75 65 71 81 98 96 69
70 95 131 115 128 135 136 109 97 155

RIB-H16A 135
104 142 142 133 88 147 127 136 54 66 115 102 99 66 58 46 58 74 43 58
60 60 50 33 39 39 46 53 51 41 21 32 38 45 62 55 114 67 58 88
55 46 54 57 58 78 60 46 73 55 57 52 64 42 41 50 52 63 50 54
60 46 57 31 53 28 35 25 39 40 35 46 66 80 91 82 42 39 31 78
67 40 45 50 32 59 43 46 40 26 38 26 32 37 31 32 28 39 39 45
46 39 43 46 39 42 53 59 75 109 61 63 64 62 67 76 93 79 60 51
51 42 40 61 69 57 64 51 57 62 60 60 56 86 103

RIB-H16B 135
111 147 145 132 87 161 125 132 56 67 117 106 99 68 56 48 61 71 44 56
57 59 56 33 28 42 46 60 48 38 21 32 37 48 62 52 113 69 55 84
54 38 61 53 56 78 61 45 80 47 62 47 66 40 39 56 60 58 50 55
55 45 56 32 44 33 33 32 36 40 38 46 64 85 89 85 50 35 35 67
66 43 41 55 29 60 43 44 50 21 35 31 28 33 24 36 26 42 35 42
53 41 42 52 35 46 48 62 75 111 54 62 68 56 68 67 96 71 59 59
67 30 48 68 50 57 67 59 59 58 74 59 62 85 104

RIB-H17A 83
108 92 152 131 183 152 163 194 207 209 173 235 170 219 171 136 154 245 181 221
199 207 228 213 152 153 204 114 182 161 121 190 133 154 104 138 216 230 175 210
231 175 160 243 195 203 198 138 211 183 139 182 203 176 217 162 153 151 103 176
60 60 123 146 239 237 234 200 225 213 233 233 132 115 165 179 139 365 302 178
214 162 203

RIB-H17B 83
112 102 143 141 179 165 163 192 224 204 175 228 178 221 164 134 148 255 179 221
207 201 239 176 142 134 176 93 206 162 125 178 131 142 103 139 219 230 185 228
229 184 159 248 190 200 201 144 220 196 145 179 201 180 210 150 153 154 101 170
81 54 115 134 242 206 227 173 218 239 231 232 122 126 157 184 145 329 331 164
212 176 199

RIB-H18A 74
200 313 213 228 105 113 156 269 334 230 235 175 135 130 164 204 219 231 254 282
250 194 128 94 92 94 105 125 113 122 152 151 30 28 42 50 54 71 66 94
110 85 90 67 87 93 90 132 131 161 154 104 126 150 126 150 132 196 129 156
149 150 156 151 151 165 246 217 254 239 227 232 210 261

RIB-H18B 74
199 309 343 229 101 92 150 273 351 226 245 179 123 132 174 200 214 224 252 300
252 190 132 88 90 94 107 132 109 125 151 141 34 25 42 53 57 67 60 89
121 81 84 75 85 92 95 129 134 145 150 101 129 151 128 143 134 200 136 148
148 146 160 137 162 165 251 223 259 234 225 226 201 254

RIB-H19A 64
159 155 109 119 147 204 236 318 428 507 296 239 123 125 115 104 178 164 162 179
200 218 94 78 94 167 121 164 152 128 150 160 135 114 121 135 100 176 151 195
165 189 184 198 188 209 212 228 182 201 181 189 218 189 189 59 46 48 39 82
67 95 90 142

RIB-H19B 64
136 151 116 117 133 253 232 300 427 510 301 235 110 128 102 107 162 171 176 171
199 214 109 75 81 145 132 167 170 128 153 157 142 115 123 140 93 167 173 200
170 194 182 194 186 215 217 221 185 200 182 198 208 189 188 48 48 32 56 75
81 110 86 125

RIB-H20A 220
90 167 146 112 179 194 128 200 155 119 86 100 135 91 117 98 110 132 98 72
50 40 55 46 58 48 48 53 46 41 44 42 50 44 43 53 53 64 66 60
52 50 58 60 67 50 57 67 53 62 53 48 69 42 43 55 40 38 50 50
53 60 61 58 47 59 53 50 60 60 57 63 62 42 34 41 50 35 40 31
41 34 58 42 36 36 41 42 41 42 32 42 33 37 46 36 34 40 48 42
37 47 40 48 58 66 57 67 50 53 60 56 68 73 54 65 56 57 42 64
59 60 57 72 56 67 60 65 60 64 75 64 56 67 78 73 59 90 80 74
71 78 90 140 118 106 100 135 114 118 134 113 94 106 95 112 110 118 112 104
124 100 123 100 100 101 135 134 105 135 96 106 95 110 107 69 80 103 106 131
121 90 87 97 90 95 107 124 106 125 101 113 89 111 85 87 91 95 129 118
136 79 98 94 81 84 112 150 116 145 121 146 156 121 100 111 94 106 106 114

RIB-H20B 220
103 165 145 114 180 199 132 217 149 118 85 96 119 85 111 97 105 130 101 66
46 48 53 42 57 53 49 46 41 50 46 41 46 48 46 47 60 64 60 64
49 47 57 60 62 46 61 67 55 61 56 59 53 39 47 48 48 44 48 58
49 61 58 60 44 58 55 56 60 51 63 57 53 38 40 36 51 36 37 35
36 35 57 43 35 39 39 39 46 41 35 40 34 32 46 39 25 40 45 46
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55 64 56 68 57 64 60 69 55 70 70 59 58 70 73 71 60 89 83 75
76 70 90 139 123 103 96 142 117 120 140 123 89 101 96 109 109 121 107 106
125 104 131 96 100 106 139 134 112 153 87 96 112 115 103 72 79 108 102 130
119 88 81 96 91 95 112 121 112 134 103 111 91 118 81 81 102 101 133 130
137 91 108 94 86 84 100 165 129 148 106 153 162 107 100 104 97 130 87 134

RIB-H21A 55
188 225 283 257 254 247 239 249 179 174 130 129 62 130 107 178 151 169 96 121
185 146 137 164 160 125 119 101 185 195 227 253 218 210 163 356 168 187 264 298
370 218 384 318 250 207 159 226 327 254 235 187 212 256 195

RIB-H21B 55
193 235 293 270 255 234 250 231 193 181 108 123 66 125 100 143 158 165 95 114
157 158 122 159 168 121 125 99 174 204 223 250 217 205 169 352 216 186 257 290
373 212 381 318 242 209 168 226 321 257 246 197 199 226 260

RIB-H22A 64
289 365 282 335 447 417 242 262 346 340 210 253 192 213 265 217 220 191 238 221
143 187 178 166 176 233 209 178 187 170 139 126 116 236 132 140 134 173 198 185
242 234 287 279 218 290 183 300 194 264 198 176 265 225 127 153 141 121 165 98
112 102 100 151

RIB-H22B 64
276 346 284 318 477 396 239 273 332 343 212 250 207 200 270 242 217 201 234 232
140 190 171 173 175 245 209 190 171 181 148 116 114 233 137 140 126 174 193 189
237 240 292 279 217 293 179 301 193 267 195 163 280 200 150 160 125 117 165 106
111 93 103 140

RIB-H23A 44
221 144 302 232 307 293 302 309 335 366 341 213 235 205 163 211 264 237 319 328
376 240 271 117 157 229 307 250 221 179 256 368 346 296 235 200 127 86 60 77
113 202 197 186

RIB-H23B 44
223 146 301 233 306 298 308 310 330 350 344 223 247 205 193 188 249 222 317 330
383 221 269 114 163 231 301 254 214 190 267 354 348 279 249 201 129 78 73 70
121 218 176 202

RIB-H24A 51
237 230 249 333 251 200 351 259 225 362 317 489 360 407 346 278 432 453 360 377
326 267 226 253 273 257 350 290 182 118 59 82 144 232 259 364 216 278 312 226
226 170 228 107 66 55 55 94 112 151 199

RIB-H24B 51
254 227 247 329 271 191 326 282 239 368 335 493 369 408 339 278 422 457 366 361
319 279 221 251 270 262 346 286 190 109 75 85 148 235 267 348 214 259 304 214
251 164 221 90 64 54 53 97 106 137 176

RIB-H25A 58
269 211 393 310 221 399 262 355 278 262 224 260 310 412 321 255 241 225 211 318
293 361 320 282 161 137 78 70 106 114 125 160 123 128 235 131 129 106 148 101
47 71 68 96 135 160 160 156 107 129 114 114 195 198 210 162 217 220

RIB-H25B 58
270 212 403 311 220 369 268 351 275 271 246 253 311 421 323 251 239 225 202 319
292 353 343 293 167 132 84 60 104 120 109 151 125 135 220 127 124 114 142 103
40 80 68 95 133 160 164 160 105 112 109 126 170 179 200 169 199 220

RIB-H26A 57
4 425 318 169 306 231 200 322 273 379 346 371 339 349 325 326 320 268 232 237
205 298 346 384 389 340 215 168 121 84 148 145 150 239 160 182 271 192 210 231
229 117 97 68 101 135 201 203 237 171 122 146 132 159 187 219 243

RIB-H26B 57
434 418 308 177 296 225 207 305 280 380 331 378 333 350 314 332 325 267 228 239
198 307 332 384 393 344 210 182 112 79 157 140 157 233 160 184 279 176 209 235
234 115 95 76 104 138 192 195 240 164 127 153 126 159 190 212 215

RIB-H27A 88
229 245 204 115 147 185 137 200 187 236 183 269 196 133 117 130 73 75 96 90
115 150 155 222 240 267 253 353 270 303 207 326 253 304 345 189 229 211 154 194
153 181 237 228 190 197 211 264 204 187 220 213 142 167 195 234 264 217 143 131
104 95 128 192 168 213 184 183 252 200 243 171 190 153 90 70 75 75 144 162
160 180 159 162 162 141 166 199

RIB-H27B 88
215 260 205 113 158 181 143 192 194 231 167 239 208 143 121 135 76 64 92 85
117 147 155 221 246 283 249 348 255 303 210 341 235 320 342 169 233 207 142 208
149 192 235 225 188 193 220 264 203 196 214 206 156 178 165 196 210 178 153 126
84 78 128 160 132 170 134 137 226 147 165 129 157 136 89 59 60 68 125 143
151 140 155 186 161 143 150 187

RIB-H28A 77
145 159 87 51 53 46 66 99 107 132 133 225 188 324 239 266 198 298 244 275
338 183 295 228 178 237 189 258 233 268 225 233 289 293 228 193 204 187 141 182
181 215 244 230 175 168 100 123 165 220 179 287 190 198 228 210 210 186 221 176
104 71 70 85 142 173 228 179 184 171 190 159 209 191 174 190 247

RIB-H28B 78
139 159 87 41 58 46 66 96 117 130 135 217 184 335 243 265 187 296 255 279
334 186 303 229 169 244 192 257 232 283 214 245 271 290 232 187 195 189 148 164
193 193 245 229 171 185 103 111 167 213 195 248 190 185 226 192 207 176 226 153
100 78 64 87 140 162 244 179 179 169 191 158 214 206 168 200 204 220

RIB-H29A 73
180 242 146 131 123 125 119 150 146 179 186 140 239 401 526 400 271 418 410 274
272 188 229 234 245 180 125 121 206 237 243 232 232 189 245 243 240 320 268 196
69 51 123 196 179 159 253 135 194 323 153 210 204 129 68 42 42 42 37 90
121 136 109 74 111 81 159 234 241 218 287 206 213

RIB-H29B 73
194 219 149 111 133 132 121 146 154 188 196 146 227 410 519 411 258 414 404 284
301 183 194 234 229 167 117 127 213 214 223 231 259 192 239 248 251 296 265 199
78 51 120 193 178 164 241 133 185 333 155 212 212 132 67 54 37 28 51 87
120 125 110 70 120 82 165 222 246 214 296 209 208

RIB-H30A 61
241 451 448 306 206 312 300 219 369 255 217 240 176 132 136 214 268 272 260 279
250 192 283 220 236 196 181 157 67 68 85 114 100 100 138 103 154 225 164 217
154 109 73 50 47 51 75 178 200 175 176 109 182 120 168 184 160 140 179 140
135

RIB-H30B 61
223 448 486 304 209 321 307 201 359 261 221 242 203 156 108 213 286 271 268 275
248 205 281 257 247 212 178 151 62 71 90 122 96 100 143 90 141 245 131 184
146 115 76 43 43 48 83 178 204 178 175 113 170 126 157 232 132 148 182 131
142

RIB-H31A 81
252 310 113 153 208 122 66 70 50 88 140 159 164 221 308 189 367 290 368 271
318 306 337 415 214 407 369 219 383 289 372 354 357 276 267 251 346 295 301 265
245 160 195 204 225 248 220 173 134 87 104 128 168 156 189 160 184 302 221 226
173 182 134 77 59 67 64 142 163 170 151 121 196 209 125 190 190 171 207 230
200

RIB-H31B 81
274 309 111 144 210 100 66 67 60 74 155 148 173 210 230 196 365 284 367 271
326 315 334 418 223 401 345 223 384 289 370 345 366 265 264 250 331 277 292 271
235 136 203 190 231 268 238 170 135 95 95 129 162 150 207 160 196 284 215 228
180 186 149 68 60 60 84 123 163 181 144 118 181 168 150 199 196 175 200 249
205

RIB-H32A 52
293 291 295 367 297 399 278 191 116 208 307 332 430 379 307 250 152 208 362 318
317 365 292 167 90 179 235 189 205 177 184 235 421 345 270 300 325 262 282 236
257 228 195 195 243 219 210 212 244 214 242 290

RIB-H32B 52
330 292 327 376 266 382 287 184 112 194 305 345 435 357 300 239 153 214 354 325
310 363 291 172 97 175 236 187 200 189 195 243 422 346 284 298 320 260 278 232
255 219 200 198 234 196 212 207 215 246 229 309

RIB-H33A 42
488 429 379 302 261 162 298 297 325 401 409 335 235 103 92 242 235 237 310 305
410 531 478 441 476 448 398 292 275 327 300 278 276 268 245 262 275 298 303 328
289 406

RIB-H33B 42
514 452 360 321 260 164 305 294 339 343 403 344 241 104 92 253 228 234 318 318
414 525 476 448 473 446 400 298 264 318 316 281 270 277 234 261 287 298 278 331
306 392

RIB-H34A 66
292 192 128 154 258 144 146 150 117 84 66 60 82 319 488 227 310 303 185 321
291 330 289 259 171 188 232 271 482 446 209 257 242 285 252 245 256 265 167 137
125 78 145 200 282 390 231 266 303 242 185 237 281 246 138 126 168 260 312 277
385 292 162 143 150 258

RIB-H34B 66
236 181 167 163 257 153 144 142 110 100 61 59 80 308 488 222 316 262 200 311
278 334 293 267 182 186 232 253 445 411 201 259 240 286 246 248 220 276 168 126
112 85 150 210 276 365 229 268 268 237 185 234 279 226 170 128 171 273 291 284
412 265 162 137 162 241

RIB-H35A 68
186 212 231 217 223 204 156 121 94 112 110 123 71 63 58 210 194 167 249 197
185 285 251 375 277 260 194 173 202 251 537 373 256 243 217 284 227 238 234 260
182 145 124 101 164 243 290 340 206 225 340 195 201 203 248 171 121 121 151 193
260 205 181 106 96 103 81 124

RIB-H35B 68
174 242 234 196 236 151 133 108 102 121 110 123 66 64 64 201 189 176 241 201
180 278 260 362 287 258 203 183 193 239 538 384 239 229 220 265 246 229 240 261
184 149 119 101 173 238 293 337 199 225 325 200 202 206 240 170 135 120 142 195
256 218 183 106 91 102 87 103

RIB-H37A 94
264 274 246 381 318 304 282 283 253 262 268 275 273 215 238 221 252 224 246 201
219 160 195 238 172 190 138 187 159 159 129 139 128 129 186 85 123 126 179 201
200 195 179 178 232 206 232 196 186 173 175 156 123 132 157 168 175 176 262 178
145 200 129 159 140 147 146 205 156 159 131 113 123 126 115 130 163 114 129 134
171 143 236 156 159 142 127 166 135 171 190 137 184 227

RIB-H37B 94
180 278 234 372 294 275 284 269 239 260 255 279 271 216 235 241 252 215 246 216
212 175 192 203 167 189 147 194 137 156 142 121 141 131 171 118 120 135 171 195
193 192 190 161 216 200 245 189 182 182 154 154 134 126 173 164 157 182 259 162
134 195 136 155 135 151 150 194 161 145 154 113 109 133 115 135 168 128 124 132
175 149 236 148 173 128 128 162 123 171 181 140 180 190

RIB-H39A 78
168 240 251 196 135 236 268 215 142 123 149 159 101 144 166 294 273 221 198 139
157 125 189 250 251 232 158 292 308 283 293 349 364 295 339 267 296 332 315 334
243 392 357 375 294 281 259 365 328 334 275 309 265 262 241 215 212 180 209 156
140 231 190 165 287 347 411 404 242 310 255 306 224 338 289 334 256 293

RIB-H39B 78
166 229 254 190 140 242 257 221 150 128 148 157 110 157 148 253 291 232 203 142
156 126 187 247 260 230 147 278 328 318 275 337 354 284 370 267 282 334 317 335
270 373 369 364 299 276 267 333 339 337 273 304 274 275 237 228 230 175 215 159
156 224 189 167 282 356 408 337 222 318 281 333 228 344 335 346 266 324

RIB-H40A 50
178 162 180 165 177 288 452 359 217 169 203 199 262 230 233 274 318 215 164 101
112 393 189 208 216 139 164 285 196 223 184 218 185 95 65 87 147 179 179 254
234 198 142 107 121 209 167 218 249 254

RIB-H40B 50
180 155 194 159 181 284 450 359 230 151 209 201 264 232 232 275 328 224 153 100
112 391 190 203 202 146 181 271 214 235 195 200 181 93 71 65 151 175 184 237
235 172 134 102 126 192 162 221 243 253

RIB-H41A 50
612 429 468 577 491 575 564 597 557 628 456 425 432 321 479 389 235 262 359 373
207 360 342 357 270 234 293 359 296 334 313 231 302 286 282 262 255 296 325 343
278 261 243 154 190 296 131 166 186 308

RIB-H41B 50
592 465 477 530 482 582 576 603 542 643 478 445 426 309 484 389 242 267 348 351
218 362 356 328 268 228 290 373 296 336 317 222 303 280 304 237 252 308 307 309
300 240 240 162 221 271 128 162 178 306

RIB-H43A 52
334 364 318 298 295 339 398 309 506 296 369 317 278 285 285 356 295 478 402 312
289 325 346 370 484 348 265 380 334 345 362 410 237 490 415 273 256 446 355 308
375 261 290 315 275 312 415 318 296 340 315 323

RIB-H43B 52
331 352 310 302 297 342 421 310 493 309 370 314 286 292 289 335 325 481 384 311
306 335 348 385 462 350 264 387 364 310 360 396 232 490 414 276 250 448 356 303
380 262 298 312 284 314 404 304 315 334 321 321

RIB-H44A 67
289 294 402 325 283 206 114 70 77 65 71 71 85 98 191 228 142 136 120 101
116 107 125 189 189 228 145 156 209 165 193 265 106 110 117 89 61 95 104 95
163 100 198 229 130 174 186 135 178 164 140 114 140 195 190 145 165 142 201 148
131 154 164 294 268 123 250

RIB-H44B 67
279 308 395 303 286 207 116 60 73 64 67 64 85 108 194 232 139 141 108 100
119 92 143 181 178 228 154 150 203 159 211 260 117 109 109 90 60 82 112 89
151 108 198 225 142 187 176 143 173 154 129 110 136 235 206 129 175 145 208 135
151 142 170 302 258 125 247

RIB-H45A 64
214 194 170 196 134 122 137 143 117 136 212 150 157 155 150 162 155 173 276 220
235 169 203 267 231 178 216 215 180 213 228 203 268 185 146 197 160 175 241 157
146 167 139 143 149 143 121 131 131 142 109 118 121 99 87 93 85 118 165 178
130 126 131 166

RIB-H45B 64
213 236 151 200 136 123 126 118 121 134 224 153 155 150 153 164 153 162 288 237
211 178 200 267 224 181 203 221 178 200 253 217 267 187 146 198 157 178 237 171
151 175 140 138 153 151 103 148 124 145 109 114 115 104 94 87 87 118 176 173
120 132 137 170

RIB-H46A 40
268 236 388 258 163 103 144 140 128 121 110 100 152 294 291 192 207 163 207 207
226 250 242 295 298 339 300 235 206 222 250 322 342 357 293 284 490 289 265 203

RIB-H46B 40
261 244 406 257 170 102 151 137 129 125 92 105 149 287 268 207 194 170 211 202
223 257 232 291 303 349 297 253 208 221 237 340 335 362 295 285 364 300 266 199

RIB-H47A 51
330 282 394 376 377 498 527 385 332 484 458 376 378 388 267 398 479 329 301 481
389 367 457 348 440 353 310 337 442 303 348 387 326 432 312 342 263 309 306 328
228 210 237 284 234 348 297 171 250 174 244

RIB-H47B 51
326 308 387 384 357 466 541 380 347 484 501 390 385 382 251 360 454 334 301 475
379 365 457 356 434 362 321 317 403 293 350 379 326 445 340 344 261 307 307 331
251 209 228 288 220 347 309 161 244 171 241

RIB-H48A 53
274 305 461 509 430 264 307 276 268 262 328 255 201 303 330 293 299 264 158 291
253 190 157 287 233 232 289 182 315 262 206 225 275 245 236 210 218 332 196 214
209 209 229 221 189 160 207 217 168 266 175 158 243

RIB-H48B 53
287 304 460 520 431 266 307 275 268 258 321 253 205 298 328 284 301 268 155 278
271 189 150 285 235 234 312 204 315 261 208 217 237 251 226 203 217 301 210 217
207 204 232 254 187 173 214 218 179 262 190 146 232

RIB-H49A 64
254 263 199 93 181 111 147 184 165 213 230 285 217 274 71 76 191 201 249 208
232 178 158 129 200 303 207 232 186 167 196 154 141 210 135 152 103 90 114 123
93 127 115 131 104 157 92 115 102 81 130 113 155 148 101 78 90 73 81 81
81 76 82 118

RIB-H49B 64
248 256 202 93 176 111 153 175 157 229 234 282 215 278 71 82 187 197 253 207
221 182 144 122 179 293 208 237 184 153 196 122 108 206 160 139 103 112 106 121
103 135 114 139 109 162 92 100 106 79 109 118 150 154 97 74 96 76 80 82
76 85 84 118

RIB-H50A 49
346 326 327 251 262 234 217 235 251 307 283 226 189 228 172 156 142 156 185 207
212 184 200 188 158 88 221 218 216 230 182 226 132 146 112 103 120 110 110 118
120 157 145 171 179 145 189 148 212

RIB-H50B 49
355 316 327 254 264 242 225 223 237 285 282 234 189 217 182 171 135 156 169 212
217 182 202 188 162 90 216 217 221 233 196 221 117 158 106 110 106 115 105 107
135 146 156 168 206 137 185 153 216

RIB-H53A 131
270 184 245 192 171 176 161 128 153 208 204 169 201 212 189 248 221 271 205 231
148 104 153 239 313 396 326 443 267 390 200 170 248 229 240 280 251 173 160 182
160 162 164 164 151 121 190 182 173 232 187 172 163 170 232 214 191 173 179 160
187 198 192 170 158 166 178 183 122 153 192 169 122 155 137 150 162 162 159 167
174 150 182 153 157 83 119 116 96 107 74 106 103 131 117 142 124 90 109 100
97 157 141 174 175 163 168 162 141 140 188 131 156 140 111 108 131 110 100 116
106 100 134 137 133 158 149 134 155 129 180

RIB-H53B 131
259 188 239 171 182 186 157 134 142 213 220 166 192 216 203 239 212 275 223 228
150 108 153 242 311 381 339 442 274 416 197 167 254 235 239 273 243 170 161 176
170 167 157 167 171 123 189 171 182 230 177 175 155 178 215 229 184 167 182 154
182 209 185 172 157 159 187 181 118 145 193 146 127 147 146 150 149 169 162 168
166 162 171 159 152 84 115 120 100 108 71 93 99 143 120 134 128 96 90 100
100 155 140 175 171 165 156 171 143 146 200 128 150 131 115 105 128 117 87 128
103 105 151 146 131 152 154 152 151 130 178

RIB-H54A 58
328 303 263 270 206 215 225 174 280 372 408 412 497 471 338 403 300 364 391 291
410 357 450 385 380 337 323 361 439 365 362 217 242 198 196 249 242 242 207 240
177 178 267 236 181 247 259 387 484 336 351 276 293 168 295 228 228 285

RIB-H54B 58
320 303 263 282 207 230 235 176 279 366 402 439 461 476 357 402 276 368 388 285
385 364 462 389 410 317 323 381 453 350 357 216 251 193 206 256 235 266 202 209
196 192 259 246 178 254 237 401 496 324 362 286 285 187 281 227 225 289

RIB-H55A 51
229 383 190 125 182 184 169 221 222 145 227 313 316 174 201 196 196 209 135 232
257 253 196 197 167 115 243 146 150 207 185 171 121 182 171 157 156 117 118 122
180 156 159 203 143 173 157 124 109 98 96

RIB-H55B 51
264 365 197 136 184 173 172 220 212 153 230 301 318 174 198 207 185 217 146 232
242 243 195 191 175 120 246 142 149 192 190 171 122 170 162 164 153 104 123 142
178 148 171 218 143 171 115 110 115 96 110

RIB-H56A 72
475 313 462 196 244 173 108 143 137 166 162 369 242 260 223 325 414 328 357 446
365 160 211 180 190 287 237 198 206 235 191 104 164 193 142 171 131 200 238 241
206 225 201 153 314 182 234 230 256 209 170 286 341 481 325 240 296 238 303 271
414 434 334 317 303 157 131 134 119 91 101 137

RIB-H56B 72
412 313 484 192 211 162 91 180 166 163 150 343 227 278 271 275 350 272 310 352
354 170 242 177 185 285 231 207 215 251 182 107 150 207 135 164 134 191 244 225
223 218 190 150 319 180 243 229 251 215 181 292 337 489 309 253 300 221 297 253
436 460 340 339 343 146 141 136 114 96 105 131

RIB-H57A 67
154 297 273 314 368 392 230 289 366 338 190 221 213 203 260 190 189 183 203 200
136 174 189 149 164 160 277 176 189 181 142 132 112 229 128 131 135 162 193 215
235 204 300 250 206 238 190 295 221 292 165 168 290 200 153 155 130 107 134 99
106 87 102 82 101 110 104

RIB-H57B 67
176 289 259 319 357 384 230 262 362 330 198 218 207 199 239 196 200 175 232 210
124 192 167 172 168 157 253 236 258 225 160 157 131 281 144 137 145 159 198 171
218 200 268 256 185 230 176 320 243 278 156 179 274 225 154 157 139 108 125 100
104 91 98 76 103 100 109

RIB-H58A 64
333 313 197 235 234 215 291 171 177 248 249 143 144 145 164 202 178 102 148 217
189 150 181 182 171 192 150 220 236 267 225 199 178 94 243 117 147 148 181 173
103 193 214 207 217 148 195 181 207 187 212 208 144 239 199 114 143 112 107 112
71 118 92 112

RIB-H58B 64
336 314 198 240 230 213 300 192 175 235 240 143 142 143 162 196 178 95 159 219
196 179 214 188 175 196 142 231 247 296 221 189 189 81 231 137 120 153 182 163
117 200 214 206 203 152 201 179 212 196 223 210 134 271 198 101 143 126 104 98
92 121 87 125

RIB-H59A 72
254 354 412 278 264 307 191 308 273 216 250 249 282 185 240 197 160 114 124 106
125 119 96 81 75 86 105 67 129 132 107 97 82 132 153 144 179 151 140 129
245 119 177 207 221 181 122 201 190 161 143 126 193 210 190 151 115 156 139 190
162 96 93 75 82 62 50 67 39 75 37 82

RIB-H59B 72
231 332 397 253 256 327 187 248 273 212 207 223 250 185 227 208 198 128 146 122
117 127 93 81 79 100 110 85 132 143 104 98 82 125 153 145 164 150 140 131
248 133 164 204 216 164 126 178 186 202 146 134 186 204 175 143 120 161 138 181
171 97 94 74 82 62 52 67 36 76 34 87

RIB-H60A 67
187 171 145 160 204 258 243 157 199 218 215 173 232 234 214 316 257 321 413 318
309 328 135 90 260 217 177 241 315 298 204 276 287 283 289 198 259 275 321 192
204 218 161 207 195 135 168 140 148 220 179 203 189 214 194 199 153 146 172 224
131 187 144 104 100 87 143

RIB-H60B 67
200 163 150 165 213 250 237 142 223 217 212 183 236 248 212 323 229 310 396 328
297 309 149 104 270 212 191 246 331 288 222 258 266 290 275 215 267 257 325 223
215 182 148 220 184 140 159 137 160 218 181 212 185 218 185 193 162 153 181 221
153 139 159 98 96 96 126

RIB-H61A 71
132 142 279 229 239 177 123 194 214 274 209 144 156 185 186 170 178 188 176 207
157 242 252 225 196 202 107 76 228 177 199 202 212 206 156 231 240 229 237 175
196 233 257 213 242 250 278 274 203 156 178 117 143 231 195 210 146 201 182 203
156 159 123 223 125 189 106 92 72 75 152

RIB-H61B 71
130 143 270 230 229 175 130 187 216 264 201 141 149 189 184 180 167 188 171 204
153 229 259 221 192 197 106 82 221 176 200 204 214 212 142 236 246 212 232 185
162 264 253 239 285 229 281 300 208 138 173 134 150 232 182 200 159 175 187 193
154 165 129 225 125 176 108 87 68 65 144

RIB-H62A 56
84 100 172 140 292 286 166 250 272 181 196 152 174 189 151 118 117 175 184 157
178 157 129 175 120 179 192 278 259 264 233 171 301 287 235 238 295 306 243 265
285 314 375 279 381 260 384 301 331 306 250 345 301 223 168 162

RIB-H62B 56
80 99 173 135 301 297 167 254 266 176 193 151 167 185 146 114 114 164 192 153
164 171 153 186 138 207 180 270 253 268 221 183 277 276 254 266 296 307 242 260
287 307 372 267 354 314 406 317 289 265 267 350 305 213 190 145

RIB-H63A 121
36 57 48 53 91 110 142 171 154 132 84 77 85 105 102 184 106 149 121 156
94 92 42 55 66 67 95 68 98 94 72 96 103 167 119 141 92 134 167 182
166 141 147 156 163 128 111 117 278 388 232 210 182 165 114 154 132 119 127 110
118 96 123 148 107 132 107 110 117 85 79 90 91 113 97 100 81 93 82 118
104 103 104 115 122 129 142 106 138 147 118 115 154 168 150 103 137 115 86 113
72 88 135 95 110 137 153 146 133 139 142 100 115 109 101 93 93 94 87 108
123

RIB-H63B 121
39 55 48 57 99 109 146 159 150 137 88 76 84 108 92 190 104 138 128 145
96 91 38 57 64 67 95 73 105 87 72 96 89 157 125 143 102 160 157 204
167 147 145 138 175 133 109 121 266 396 220 212 174 169 121 158 129 125 118 106
129 90 135 165 103 139 107 109 107 86 94 84 87 98 89 104 67 92 81 115
95 105 97 104 139 115 131 118 121 140 127 120 146 153 153 115 128 120 87 110
85 96 134 90 112 133 152 140 132 134 150 106 115 110 103 92 93 90 90 99
121

RIB-H64A 75
164 111 124 359 359 250 235 282 305 211 178 166 126 176 159 124 122 187 173 162
207 175 159 185 129 150 159 158 153 187 186 120 150 131 137 138 132 137 102 144
126 173 148 110 115 89 70 96 210 181 218 208 173 123 146 93 137 164 130 178
193 206 183 202 187 209 126 139 117 146 137 140 109 100 160

RIB-H64B 75
135 112 123 352 369 245 239 286 294 210 175 148 140 157 172 116 120 183 178 161
205 182 171 189 108 149 166 162 160 181 196 139 143 117 132 151 137 131 106 141
110 160 134 103 115 92 73 81 217 193 217 213 171 125 160 87 134 173 131 174
194 195 193 193 200 191 128 141 106 143 145 135 131 98 153

RIB-H65A 48
318 278 367 430 287 240 478 343 314 454 576 491 386 507 525 511 473 360 442 428
398 322 273 362 364 446 412 321 414 343 398 93 83 132 169 173 278 350 293 302
225 440 303 312 111 139 153 246

RIB-H65B 48
348 273 373 427 292 244 482 334 312 451 558 493 376 496 551 504 481 375 450 432
396 318 279 354 353 468 414 306 421 336 425 92 87 129 168 159 265 357 293 305
225 430 299 311 109 135 139 250

RIB-H66A 64
136 82 152 114 69 82 104 120 163 189 200 300 258 162 103 69 80 105 112 137
94 107 157 199 80 49 38 64 37 78 71 78 117 102 101 70 69 71 94 132
112 114 128 86 92 87 81 83 75 105 67 83 66 61 60 66 82 71 89 83
68 46 55 81

RIB-H66B 64
108 78 160 117 66 83 94 123 159 200 200 306 255 162 98 71 76 100 112 137
92 116 146 205 71 50 46 49 50 57 71 78 107 96 93 74 79 67 90 137
121 128 126 100 89 89 82 74 80 96 71 75 74 59 66 65 65 75 82 84
54 51 64 63

# APPENDIX: TREE-RING DATING

## The Principles of Tree-Ring Dating

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

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

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

### *1. Inspecting the Building and Sampling the Timbers.*

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

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

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

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

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

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


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

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


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

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

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for

C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

### *4. Estimating the Felling Date.*

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

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

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

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

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

### *5. Estimating the Date of Construction.*

There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after

(Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

### 6. *Master Chronological Sequences.*

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

### 7. *Ring-Width Indices.*

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

*t*-value/offset Matrix

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

Bar Diagram

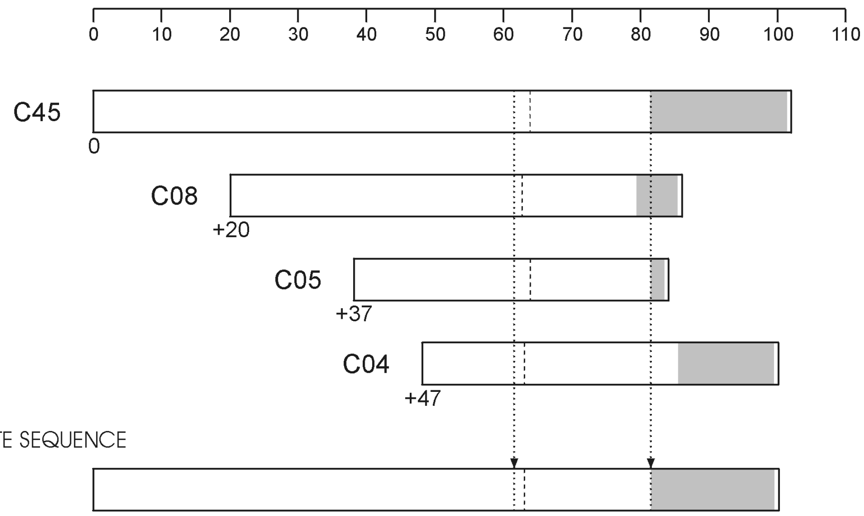



*Figure A5:  Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them*

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.

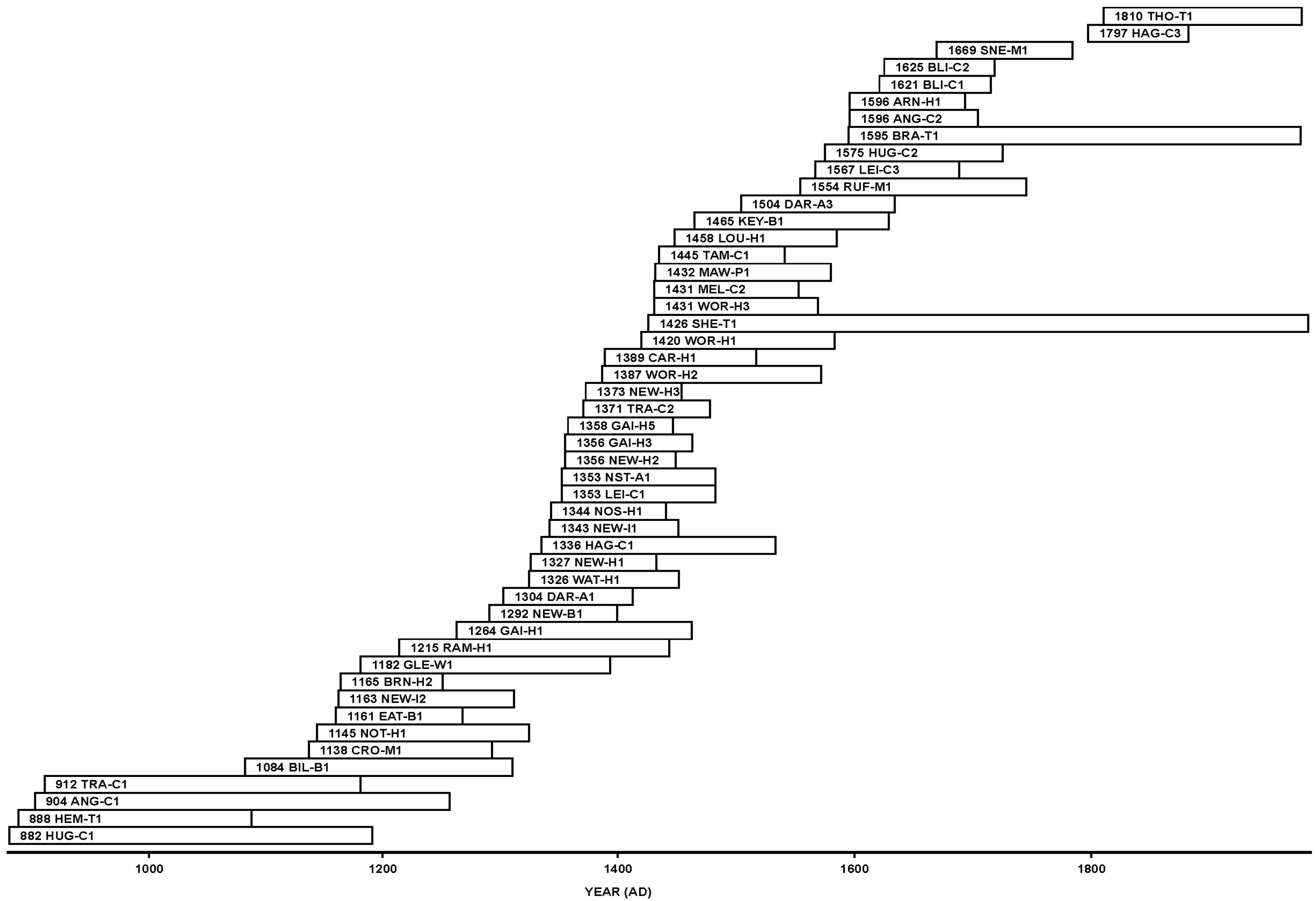
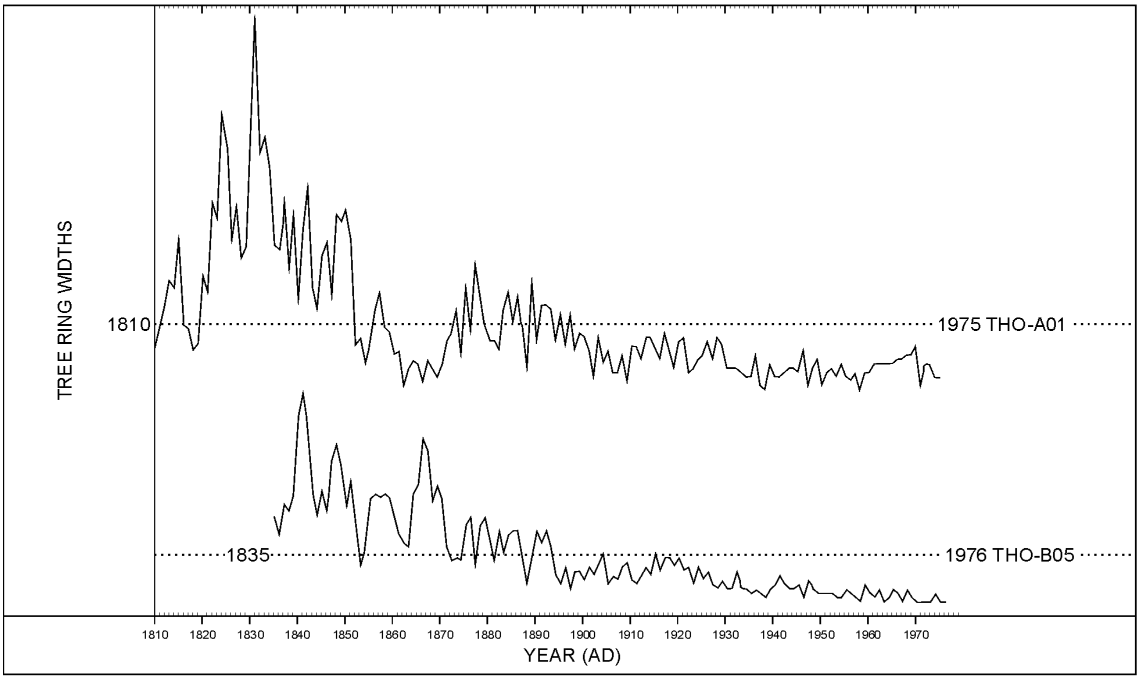



*Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87*

(a)




(b)

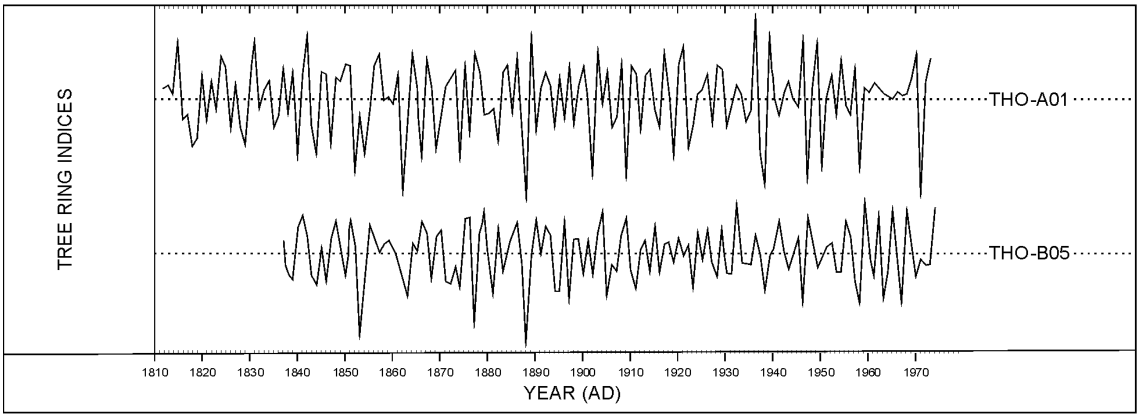



*Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

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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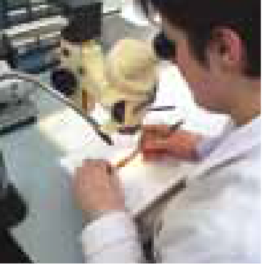 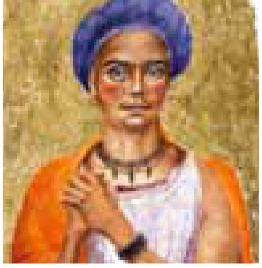   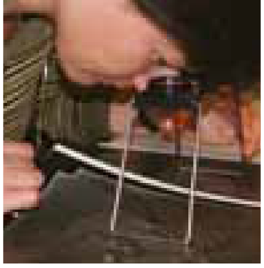 

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