TREE-RING ANALYSIS OF TIMBERS FROM WARLEIGH HOUSE, TAMERTON FOLIOT, BICKLEIGH, SOUTH HAMS, NEAR PLYMOUTH, DEVON

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Summary

Analysis of samples from 67 oak timbers from Warleigh House (62 of which were measured) produced two dated site chronologies. The first site chronology, TMFASQ01 comprising 41 samples and 173 rings long, spans AD 1367 – 1539. The second site chronology, TMFASQ02, comprises five samples, its 104 rings spanning AD 1671 – 1774.

Interpretation of the sapwood would indicate that the majority of dated timbers were felled in the mid- to third quarter of the sixteenth century and represent those used in the primary construction phase of the present building. Other oak timbers were felled in AD 1774. These later timbers could be part of a late-eighteenth century remodeling of the house, but they may simply represent roof repairs.

Samples from 21 pine timbers were also analysed. From these samples two dated site chronologies were created. The first, TMFASQ05, comprising eight samples and 137 rings long, spans AD 1670 – 1806. The second pine site chronology, TMFASQ06, of 217 rings, spans AD 1543 – 1759. Between them they appear to represent early-nineteenth century refashioning.

Introduction

Warleigh House, a Grade II* listed building, stands in its own grounds on the east bank of the River Tavy, close to its confluence with the Tamar, near the village of Tamerton Foliot which is approximately four miles north-west of Plymouth (SX 456 617, Figs 1 and 2). This two-and-a-half story, double-pile building, once of stone with ashlars but now with roughcast render, is generally of irregular E-shaped plan, the short, full-height, single-bay arms beneath gabled roofs projecting eastwards to the front (see Fig 3). There are further short extension wings to the north and north-west. A simplified plan of the building is given in Figure 4.

It is believed, from documentary sources, that the manor of Tamerton had come to the Foliot family by the mid-twelfth century, when Sampson Foliot erected the earliest structure on this site sometime between AD 1135 and AD 1154. The family continued to own the estate until AD 1253, when it passed to the Gorges, who were, in any case, descended from Sampson Foliot, and then to other descendants, the Bonvilles, in AD 1435.

The manor then passed by marriage in AD 1472 to the Copplestone Family, who originally lived near Crediton, Devon. At some time in the sixteenth-century, the exact date is not known, the Copplestones moved to Warleigh and built the present structure. Warleigh then became the seat of the Radcliffe family in AD 1741. The house appears on a map by Donn of AD 1765, and it is known to have been refashioned by John Foulston in AD 1825 – 32.

The central arm of the 'E' contains the porch which leads to a two-storied hall in the eastern range of the house. This hall, remodelled in the eighteenth century with a moulded plaster frieze and cornice and given a balustrade to the gallery, contains a splendid granite fireplace. From this hall two moulded granite four-centred arch doorways lead to the screens passage, and a wide dogleg staircase, stylistically also probably of eighteenth-century date, leads to the upper floors. On the ground floor at the south end to the west or rear range, beyond the hall, is a large dining room, possibly original but with decorative features dating to the eighteenth century.

Sampling

Warleigh House contains what appear to be 11 distinct areas of timber (see Fig 4), the analysis of which, it was believed, might help establish the date of the original building and demonstrate its developmental stages. It is not necessarily the case, however, that each area, or group of timbers, represents a distinct and different phase of construction. It is likely that some phases of construction are represented by more than one group of timbers.

These distinct areas or groups of timbers comprise, firstly, at the north end of the west range, what might originally have been an open hall, the roof here being formed of five slender and highly moulded archbrace trusses (Fig 5). This hall appears to have been floored at first-floor level at some time, the joists of this floor frame forming the second distinct group of timbers.

Also at the north end of the building, but in the east range, and also forming the roof of the northern gable or projecting arm of the 'E', is to be found timber group three, a series of roof frames. The frames of this area have various forms of construction, with principal rafter trusses, and common rafter frames being used. Some timbers appear to have been cut through to allow for the insertion of later beams, and not all timbers are jointed or pegged to each other (Fig 6).

The attic floor-frame of this northern end of the east range forms timber group four. Again, there are a variety of beam types, with bridging beams and bressummers of different sizes being used in conjunction with common joists, also of varying scantling. It is thus quite possible that the roof and floor frame here contain timber of different dates. The framing of this area is further complicated by the fact that almost all the timbers have been removed and stored *ex situ*.

To the south of this, but still entirely in the east range, runs a second hall, the south hall, also roofed by a series of archbrace trusses, see Figure 7. These appear to consist of primary timber with no evidence of reuse, thus forming timber group five, and a series of other timbers with redundant mortices and tennons giving the impression that they are reused in this roof, which are taken to comprise timber group six. Timber groups seven and eight are formed by the roofs of the central and southern projecting arms of the 'E', respectively. All timbers described thus far are of oak.

In addition to the roof timbers of the south hall, there are also the beams of the first floor ceiling/attic floor frame of this portion forming timber group nine. These are of pine, and comprise a series of main bridging beams and common joists. Further pine timbers, group ten, are found in the ceiling of the basement to the rear or west range of Warleigh House.

Finally, additional oak timbers, group 11, are found in the ceiling of the ground floor of the north end of the west range. These form a series of longitudinal joists of approximately similar size.

The timbers in all other areas, the remaining roofs of the west range, the ground floor ceiling frames of both the east and west range are either modern, probably twentieth-century replacements, or have been removed at some time in the past.

Sampling and analysis by tree-ring dating of timbers within these component elements of Warleigh House were commissioned by English Heritage. The purpose of this was to aid in the production of a conservation plan for this grade II* complex, which is also on the Buildings at Risk register, priority category 'A'. It was hoped that tree-ring analysis would more reliably determine the date of the various elements and establish the sequential development of the site. It was hoped too that analysis would determine how much of the timber-work was original and how much of it was re-used or replaced, there being structural evidence for considerable alteration to parts of the building.

From the oak timbers available a total of 67 core samples was obtained. Each sample was given the code TMF-A, for Tamerton Foliot, site 'A', and numbered 01 – 67. From the pine timbers available, mainly beams of the floor of the south hall of the east range, and those of the basement ceiling of the west range, a total of 21 core samples was obtained. These have been numbered TMF-A68 – 88.

In a number of the component elements of the building the majority of sampled timbers appeared to be primary and integral with each other, being jointed and pegged. In some instances, however, this appeared not to be the case. This was particularly so with the roof at the north end of the east range, and with some of the timbers in the roof of the southern portion of the east range. Given the amount of restoration and alteration that has taken place over the centuries, it is possible that other timbers have been re-used in such a way as to not show any evidence for this.

Some areas of the building, however, were not sampled, most conspicuously the roof of the hall at the north end of the west range (to the rear). It was seen clearly from empty mortices and various cut surfaces that the timbers used for all the beams here, principal rafters, archbraces, collars, etc, were derived from very fast grown trees. Given the slender nature of the timbers and the way they were cut from the wood it was quite clear that they had too few rings (ie less than 54) for reliable analysis.

The timbers forming the roof of the northern end of the east range also remain unsampled. Despite the varied form of construction and the differences in the sizes of the beams, all the timbers appeared to be derived from very fast grown trees, and as such have too few rings for reliable analysis.

The positions of all these samples, from both oak and pine timbers, are marked on either architects plans made and provided by Shane Maddison Conservation and Design, of Totnes, Devon, annotated photographs, or on sketch plans made at the time of sampling. These are reproduced here as Figure 8a – d. Details of the samples are given in Table 1. In this Table, all timbers are identified and numbered on a north – south, or east – west basis, as appropriate.

The Nottingham Tree-Ring Dating and Sheffield Dendrochronology Laboratories would like to take this opportunity to thank all those who helped with this programme of analysis, particularly Shane Maddison of Conservation Design for arranging access and for providing plans.

Analysis - oak samples

Each of the 67 oak samples was prepared by sanding and polishing. It was seen at this time that five samples, TMF-A23, A40, A60, A61, and A63, had substantially less than the minimum of 54 rings required for reliable tree-ring dating, and these were rejected. The annual growth-ring widths of the remaining 62 oak samples were measured. The data of these measurements are given at the end of the report.

The growth-ring widths of all 62 measured oak samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of t=4.5, four different groups of cross-matching oak samples could be formed, the samples of each cross-matching group being combined at the indicated off-set positions to form site chronologies TMFASQ01 – SQ04. The relative positions of the samples in each group are shown in the bar diagrams, Figures 9 – 13. It will be seen from these figures that there is one large group of 41 samples, and three other groups of six, two, and two samples, giving a total of 51 grouped samples. Of the 62 measured oak samples 11 remain ungrouped.

Each of the four site chronologies was then compared with a full range of reference chronologies for oak. This indicated cross-matches and dates for two chronologies, TMFASQ01 and TMFASQ02. The 173 rings of site chronology TMFASQ01 can be satisfactorily dated as spanning the years AD 1367 – 1539, while the 104 rings of site chronology TMFASQ02 are dated as spanning the years AD 1671 – 1774. Evidence for these dates is given in the t-values of Tables 2 and 3 respectively. Site chronologies TMFASQ03 and SQ04, with 65 and 95 rings respectively, are undated.

Each of the four oak site chronologies was then compared with the other three, and with the 11 remaining individual ungrouped oak samples. There was, however, no further reliable cross-matching. Each of the 11 measured but ungrouped oak samples was than compared individually with the full range of oak reference chronologies. There was, however, no reliable cross-matching and all these 11 individual samples must remain undated.

Analysis - pine samples

Each of the 21 pine samples was also prepared by sanding and polishing, each one having satisfactory numbers of rings, and being measured. The data of these measurements are also given at the end of the report.

The growth-ring widths of all the pine samples were then compared with each other by the Litton/Zainodin grouping procedure. By this method four different groups of cross-matching pine samples could be formed, the samples of each cross-matching group being combined at the indicated off-set positions to form site chronologies TMFASQ05 – SQ08. The relative positions of the samples in each group are shown in the bar diagrams, Figures 14 – 17. It will be seen from these figures that there is one group of eight samples, one group of four samples, and two groups of two samples. Five pine samples remain ungrouped.

Each of the four pine site chronologies was then compared with a full range of reference chronologies for pine. This indicated cross-matches and dates for two of the four site chronologies, TMFASQ05 and TMFASQ06. The 137 rings of site chronology TMFASQ05 can be satisfactorily dated as spanning the years AD 1670 – 1806. Site chronology TMFASQ06 has 217 rings. These rings can be dated as spanning the years AD 1543 – 1759. Evidence for these dates is given in the *t*-values of Tables 4 and 5. Pine site chronologies TMFASQ07 and SQ08 are undated. This analysis is summarised over below.

Site chronology	Number of samples	Number of rings	Date span (where dated)
TMFASQ01 (oak)	41	173	AD 1367 – 1539
TMFASQ02 (oak)	6	104	AD 1671 – 1774
TMFASQ03 (oak)	2	68	undated
TMFASQ04 (oak)	2	95	undated
TMFASQ05 (pine)	8	137	AD 1670 – 1806
TMFASQ06 (pine)	4	217	AD 1543 – 1759
TMFASQ07 (pine)	2	132	undated
TMFASQ08 (pine)	2	122	undated
Ungrouped oak	11	---	undated
Ungrouped pine	5	---	undated
Unmeasured oak	5	---	---

<u>Interpretation – oak samples</u>

Site chronology TMFASQ01

Analysis by dendrochronology of 62 measured oak samples has produced four oak site chronologies. Two of these oak site chronologies can be dated. The first dated oak site chronology, TMFASQ01, comprises 41 samples, its 173 rings spanning the years AD 1367 – 1539.

None of the dated samples in oak site chronology TMFASQ01 retain complete sapwood and it is thus not possible to provide the exact felling date of any of the timbers represented. Several of them, however, do retain the heartwood/sapwood boundary (designated by ‘h/s’ in Table 1 and the bar diagrams). The presence of the heartwood/sapwood boundary allows an estimated likely felling date range to be calculated.

It will perhaps be seen from the bar diagram of site chronology TMFASQ01 (Fig 9) that, apart from sample TMF-A54, there is not a great difference between the earliest heartwood/sapwood transition on any individual sample and the latest. For the majority of samples, this transition varies by a maximum of 18 rings from relative position 151, AD 1517, on sample TMF-A47, to relative position 169, AD 1535, on sample TMF-A58.

Using a 95% confidence limit of 15 to 40 rings for the amount of sapwood the trees represented by site chronology TMFASQ01 might have had would indicate that the earliest felling (represented by sample TMF-A54) could have taken place sometime between AD 1514 – 39, whilst the latest felling (represented by sample TMF-A58) is estimated to have taken place between AD 1550 – 75. The two timbers represented by these upper and lower limits of the heartwood/sapwood boundary thus share a possible felling in the overlapping dates between AD 1550 – 57. The degree of overlap between other timbers with the heartwood/sapwood boundary increases between these two limits, thus increasing the possibility that they were all cut at the same time in a single felling.

The only outlier from this group of timbers is represented by sample TMF-A54 which has a heartwood/sapwood transition at year relative position 133, AD 1499. Using the same sapwood estimate as above, 15 – 40 rings, would give this timber an estimated felling date in the range AD 1514 – 1539, slightly earlier than the other timbers. Given that the timber is from an inserted floor a different felling date for it is not impossible, though, given that some timbers are likely to have higher numbers of sapwood rings, it is possible that it was felled at roughly the same time as the other in this group.

However, while it is *possible* that all the timbers were cut in a single operation, the variation in the range of the heartwood/sapwood boundary date, AD 1517 – 35, is perhaps more indicative of the timbers having been cut over a period of time, possibly in closely related fellings. As perhaps can be seen from the bar diagram Figure 9, there do appear to be three or four sub-groups of samples which have more closely spaced heartwood/sapwood boundary positions. Indeed, as again might be seen from the bar diagram, there are groups of timbers with identical relative heartwood/sapwood transitions, ie, samples TMF-A02, and A19, or samples TMF-A10, A31, and A67. It is possible that such timbers were cut in groups as work progressed.

In bar diagram Figure 10, where the dated samples of site chronology TMFASQ01 are sorted according to location, it may be seen that almost all areas have provided samples with the heartwood/sapwood transition. The limited range of the heartwood/sapwood variation may again be noticed in that there is little difference between the samples from each area.

Site chronology TMFASQ02

The second dated oak site chronology, TMFASQ02, comprises six samples, all from the south gable roof of the south hall of the east range. This site chronology has 104 rings spanning the years AD 1671 – 1774. One sample in this site chronology, TMF-A34 retains complete sapwood, that is, it has the last ring the tree represented produced before it was cut. This last complete sapwood ring is dated to AD 1774, and it is thus the felling date of the tree. The sapwood complement and the relative positions of the heartwood/sapwood boundaries on the other dated samples in site chronology TMFASQ02 are similar, varying by only 12 years. Such a limited range is indicative of a single phase of felling and it is likely that all the other timbers represented by TMFASQ02 were felled in AD 1774 as well.

Interpretation – pine samples

Site chronology TMFASQ05

Analysis of 21 pine samples produced five pine site chronologies, three of which can be dated. The first dated pine site chronology, TMFASQ05, comprises eight samples, all from the floor frame of the south hall of the east range. This chronology has 137 rings dated as spanning the years AD 1670 – 1806. A number of the pine samples in this site chronology appear to retain some sapwood, though none of the samples has complete sapwood. Given that the latest ring of any sample is dated to AD 1806 (TMF-A74) and the wide variation in numbers of expected sapwood rings, it is likely that these timbers were felled in the early to mid nineteenth century

Site chronology TMFASQ06

The second dated pine site chronology, TMFASQ06, comprise four samples, these being from timbers forming the ceiling of the basement area at the southern end of the west range. This chronology has 217 rings dated as spanning the years AD 1543 – 1759. Only one sample in site chronology TMFASQ07 retains any sapwood, TMF-A82, with only one other sample, TMF-A87 having a heartwood/sapwood boundary. Taking into account that these timbers appear to be derived from longer-lived trees it is possible that they may have been felled at approximately the same time as those represented in site chronology TMFASQ05, with the possibility that they could be slightly earlier.

Conclusion

Samples were obtained from 67 different oak timbers at Warleigh House, of which 62 were analysed. This analysis produced two oak site chronologies. The first site chronology, comprising 41 samples, has a combined overall length of 173 rings. These rings were dated as spanning the years AD 1367 – 1539. The second oak site chronology comprises five samples, its 104 rings spanning AD 1671 – 1774.

Analysis by tree-ring dating of this material from Warleigh House has shown that a substantial quantity of it, that represented by site chronology TMFASQ01, dates from between about the mid- to third-quarter of the sixteenth century. This includes the main roof of the south hall of the east range, the gable roofs to the central porch and the south arm of the east range, and a few beams to the ceiling of the ground floor. It is highly likely that this phase of felling is connected with the move of the Copplestone family from Crediton to Warleigh and the construction of their new house here. Thus whilst, due to the lack of bark edge or complete sapwood, it has not been possible to be precise as to the felling date of individual timbers, tree-ring dating has provided a firm date bracket for construction.

The felling date range of the timbers from the floor-frame to the north end of the west range appears to be greater, but it too is almost certainly in the mid- to third quarter of the sixteenth century. Structural evidence would suggest that this floor is made up of some reused timber.

Analysis has also shown that the roof of at least one element of the building, that of the south gable arm, contains material which is later, some timbers for this phase having been felled in AD 1774. This period of felling, represented by samples in site chronology TMFASQ02, is possibly connected with the eighteenth century remodeling of the south hall when the moulded plaster freeze, cornice, wide staircase, and the balustrade to the gallery, were introduced. The exact date of this work is not otherwise known. However, given that the samples are from a relatively small area of roof not directly above the rooms re-worked in the eighteenth century, it is perhaps just as likely that the felling is connected with simple repair or renewal work to this roof.

It is possible that a small number of other dated pine timbers, from the ceiling of the basement to the southern end of the west range, and represented by pine site chronology TMFASQ06, were also felled in the early-nineteenth century. These timbers are below rooms dated to this time on stylistic evidence.

Other dated pine timbers, represented by site chronology TMFASQ05, probably correspond with the further refashioning of the building known from documentary sources to have been undertaken AD 1825 – 32 by John Foulston. It is possible that these late-eighteenth and early-nineteenth century developments account for the reuse within the building of original, sixteenth-century timbers such as those seen in the roof of the south hall to the east range, and the floor-frame of the northern hall to the west range.

Judging by the *t*-values of the cross-matching between a few samples, it is quite possible that they represent timbers derived from the same tree. The maximum value, *t*=14.7, for example, is found between samples TMF-A66 and A67. A value of *t*=12.8 is found between samples TMF-A53 and A58. Both pairs of samples are from timbers within the same sampling group, ie lintels to the ground floor and the inserted floor frame at the north end of the west range. Several other samples probably represent trees growing very close to each other, with a number of values in excess of *t*=8.0 being observed. At the very least it would appear that many of the timbers represented are from trees growing in the same general area of woodland, there being many values in excess of *t*=6.0. This similarity of timber sourcing might again be taken to indicate that all the timber represented by site chronology TMFASQ01, was felled at roughly the same time.

There is no clear evidence as to where the dated timber used at Warleigh House was originally grown. However, there is no reason to suspect that it was anything other than relatively local. As may be seen from Tables 2 and 3, most of the reference chronologies providing the best cross-matches with site chronologies TMFASQ01 and SQ02 are from western or southern England, particularly the West Midlands and Gloucestershire, with one chronology from Cornwall also being listed.

Of the 62 measured oak samples, 11, or just under 18%, remain ungrouped and undated. All such ungrouped samples have sufficient rings for reliable analysis, though some do have lower numbers of rings, samples TMF-A15 and TMF-A59, for example, have 55 rings each. The longest ungrouped sample is TMF-A39 with 90 rings.

Given the potential for repair and reuse of timber in this building it is quite possible that many ungrouped individuals represent single timbers, each with a different felling date, and from a different source to all, or many, of the other timbers. Single timbers are often more difficult to date. Some timbers do have problematic rings with bands of what appear to be irregular or disturbed growth. It is possible features such as these make some samples difficult to date. Many other samples, however, show no problems that might cause difficulty in cross-matching and dating.

The oak material from Warleigh House has produced a long, well-replicated, site chronology covering the period AD 1367 – 1539. A second oak site chronology spans AD 1671 – 1774. Such reference material will be of particular use in the southwest which does not yet have an especially great complement of reference material, particularly into the more recent period. With site chronology TMFASQ02 providing data up to 1774, at which point data from modern trees becomes available, it may be of particular use in creating a regional southwest England chronology directly anchored into the present day.

The pine samples are also of importance in helping to establish reference data for conifers in relation to a current English Heritage funded research programme on the importation of such material in to the British Isles. This data will in due course help build an extensive and well replicated corpus of conifer data. Judging by the cross-matches with the reference material seen in Tables 4 and 5, it is likely that some of the pine timbers, those represented by site chronology TMFASQ5, have been imported from northern or central Poland, or possibly Estonia. Other pine timbers, those represented by site chronology TMFASQ06, may have come from further east still.

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Table 1: Details of samples from Warleigh House, Tamerton Foliot near Plymouth, Devon

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	South Hall, archbrace roof					
TMF-A01	East principal rafter, truss 1	86	no h/s	AD 1430	------	AD 1515
TMF-A02	East wall plate, at truss 1	152	h/s	AD 1367	AD 1518	AD 1518
TMF-A03	West archbrace, truss 1	80	h/s	AD 1445	AD 1524	AD 1524
TMF-A04	East principal rafter, truss 2	71	no h/s	------	------	------
TMF-A05	West principal rafter, truss 2	95	h/s	------	------	------
TMF-A06	West archbrace, truss 2	106	h/s	AD 1417	AD 1522	AD 1522
TMF-A07	East principal rafter, truss 3	125	13	AD 1415	AD 1526	AD 1539
TMF-A08	West principal rafter, truss 3	94	no h/s	AD 1402	------	AD 1495
TMF-A09	Collar, truss 3	100	no h/s	AD 1409	------	AD 1508
TMF-A10	Collar, truss 4	111	h/s	AD 1418	AD 1528	AD 1528
TMF-A11	East principal rafter, truss 6	105	h/s	AD 1418	AD 1522	AD 1522
TMF-A12	West archbrace, truss 6	61	h/s	AD 1467	AD 1527	AD 1527
	South Hall, reused purlins					
TMF-A13	Lower east purlin, truss 2 – 3	87	no h/s	AD 1419	------	AD 1505
TMF-A14	Middle east purlin, truss 2 – 3	72	no h/s	AD 1414	------	AD 1485
TMF-A15	Middle west purlin, truss 2 – 3	55	no h/s	------	------	------
TMF-A16	Lower west purlin, truss 2 – 3	68	no h/s	AD 1424	------	AD 1491
TMF-A17	East lower purlin, truss 3 – 4	148	h/s	AD 1376	AD 1523	AD 1523
TMF-A18	West lower purlin, truss 6 – south gable	60	6	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	South Hall – centre gable roof					
TMF-A19	North common rafter, frame 3	107	no h/s	AD 1412	------	AD 1518
TMF-A20	Collar, frame 3	65	no h/s	AD 1439	------	AD 1503
TMF-A21	North common rafter, frame 5	64	h/s	------	------	------
TMF-A22	North common rafter, frame 6	77	h/s	AD 1458	AD 1534	AD 1534
TMF-A23	Collar, frame 7	nm	---	------	------	------
TMF-A24	South common rafter, frame 9	59	h/s	------	------	------
TMF-A25	Collar, frame 10	60	no h/s	AD 1422	------	AD 1481
TMF-A26	North common rafter, frame 12	105	h/s	AD 1421	AD 1525	AD 1525
TMF-A27	South common rafter, frame 13	104	no h/s	AD 1396	------	AD 1499
TMF-A28	Collar, frame 13	80	h/s	AD 1449	AD 1528	AD 1528
	South Hall – south gable roof					
TMF-A29	North common rafter, frame 10	91	no h/s	AD 1398	------	AD 1488
TMF-A30	North common rafter, frame 11	77	h/s	AD 1451	AD 1527	AD 1527
TMF-A31	South common rafter, frame 11	90	h/s	AD 1439	AD 1528	AD 1528
TMF-A32	Collar, frame 11	89	no h/s	AD 1416	------	AD 1504
TMF-A33	South common rafter, frame 12	60	no h/s	AD 1439	------	AD 1498
TMF-A34	South-east hip rafter	92	18C	AD 1683	AD 1756	AD 1774
TMF-A35	South-west hip rafter	76	h/s	AD 1679	AD 1754	AD 1754
TMF-A36	East purlin	82	h/s	AD 1680	AD 1761	AD 1761
TMF-A37	South-east lower purlin	89	12	AD 1671	AD 1747	AD 1759
TMF-A38	South-west lower purlin	85	17	AD 1680	AD 1747	AD 1764

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	North end, east attic floor frame					
TMF-A39	Main central north – south beam	90	h/s	------	------	------
TMF-A40	Common joist, location unknown	nm	---	------	------	------
TMF-A41	Common joist, location unknown	57	10	------	------	------
TMF-A42	Common joist, location unknown	66	h/s	------	------	------
TMF-A43	Common joist, location unknown	61	15	------	------	------
TMF-A44	Common joist, location unknown	114	h/s	AD 1406	AD 1519	AD 1519
TMF-A45	Common joist, location unknown	67	h/s	------	------	------
TMF-A46	Common joist, location unknown					
	North end, west side – inserted floor					
TMF-A47	Main northern floor beam	110	h/s	AD 1408	AD 1517	AD 1517
TMF-A48	Middle bridging beam	112	no h/s	AD 1379	------	AD 1490
TMF-A49	South bridging beam	82	no h/s	------	------	-------
TMF-A50	Joist 2 from east, north window bay	54	no h/s	AD 1421	------	AD 1474
TMF-A51	Joist 3 from east, north window bay	62	no h/s	------	------	-------
TMF-A52	Joist 4 from east, north window bay	69	no h/s	AD 1443	------	AD 1511
TMF-A53	Joist 5 from east, north window bay	132	h/s	AD 1393	AD 1524	AD 1524
TMF-A54	Joist 3 from east wall, south end	90	h/s	AD 1410	AD 1499	AD 1499
TMF-A55	Joist 4 from east wall, south end	98	no h/s	AD 1399	------	AD 1496
TMF-A56	Joist 5 from east wall, south end	64	no h/s	AD 1397	------	AD 1460
TMF-A57	Joist 7 from east wall, south end	73	h/s	AD 1447	AD 1519	AD 1519
TMF-A58	Joist 9 from east wall, south end	130	h/s	AD 1406	AD 1535	AD 1535

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	North end, west side, attic corridor floor frame					
TMF-A59	Common joist 2	55	10	------	------	------
TMF-A60	Common joist 3	nm	---	------	------	------
TMF-A61	Common joist 4	nm	---	------	------	------
TMF-A62	Common joist 7	61	10	------	------	------
TMF-A63	Common joist 10	nm	---	------	------	------
	Lintels and beams to ground floor					
TMF-A64	Lintel / main ceiling beam	92	4	AD 1437	AD 1524	AD 1528
TMF-A65	Common joist 3	102	18	AD 1437	AD 1520	AD 1538
TMF-A66	Common joist 4	79	h/s	AD 1454	AD 1532	AD 1532
TMF-A67	Main ceiling beam	125	h/s	AD 1404	AD 1528	AD 1528

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	South hall – main attic floor area (pine timbers)					
TMF-A68	North-most main bridging joist	101	20	AD 1676	AD 1756	AD 1776
TMF-A69	North-middle main bridging joist	67	20	------	------	------
TMF-A70	South Middle maim bridging joist	69	19	AD 1705	AD 1755	AD 1774
TMF-A71	South-most main bridging beam	94	10	------	------	------
TMF-A72	Common joist 3, bay 5	89	no h/s	------	------	------
TMF-A73	Common joist 4, bay 5	57	no h/s	AD 1683	------	AD 1739
TMF-A74	Common joist 5, bay 4	104	13	AD 1703	AD 1793	AD 1806
TMF-A75	Common joist 4, bay 4	89	4	AD 1670	AD 1754	AD 1758
TMF-A76	Common joist 3, bay 4	85	h/s	AD 1682	AD 1766	AD 1766
TMF-A77	Common joist 9, bay 3	81	h/s	------	------	------
TMF-A78	Common joist 4, bay 2	77	no h/s	AD 1690	------	AD 1766
TMF-A79	Common joist 3, bay 2	56	no h/s	AD 1703	------	AD 1758
	Basement area ceiling (pine timbers)					
TMF-A80	North-east common joist	61	h/s	------	------	------
TMF-A81	Common joist 6	85	h/s	------	------	------
TMF-A82i	Common joist 7 (part 1)	108	no h/s	AD 1548	------	AD 1655
TMF-A82ii	Common joist 7 (part 2)	84	10	AD 1661	AD 1734	AD 1744
TMF-A83	Common joist 5	69	no h/s	AD 1627	------	AD 1695
TMF-A84	North middle main joist	170	h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Basement area ceiling (pine timbers)					
TMF-A85	South Middle main joist	67	no h/s	------	------	------
TMF-A86	Common joist 4	161	no h/s	AD 1543	------	AD 1703
TMF-A87	Common joist 10	117	h/s	AD 1643	AD 1759	AD 1759
TMF-A88	North-east main joist	132	h/s	------	------	------

* h/s = the heartwood/sapwood boundary is the last ring on the sample, the sapwood element is missing
C = complete sapwood retained on the sample, the last measured ring date is the felling date of the timber
nm = sample not measured

Table 2: Results of the cross-matching of oak site chronology TMFASQ01 and relevant reference chronologies when first ring date is AD 1367 and last ring date is AD 1539

Reference chronology	Span of chronology	*t*-value	
Mercer's Hall, Gloucester	AD 1289 – 1541	10.5	(Howard *et al* 1996a)
Wales and West Midlands	AD 1341 – 1636	9.3	(Siebenlist-Kerner 1978)
MC10---H	AD 1386 – 1585	8.8	(Fletcher 1978)
England, London	AD 413 – 1728	8.5	(Tyers and Groves 1999 unpubl)
England	AD 401 – 1981	8.4	(Baillie and Pilcher 1982 unpubl)
St Veep, Cornwall	AD 1352 – 1512	7.7	(Arnold *et al* 2005)
Naas House, Lydney, Glos	AD 1360 – 1591	7.4	(Howard *et al* 1997)
East Midlands	AD 882 – 1981	6.6	(Laxton and Litton 1988)

Table 3: Results of the cross-matching of oak site chronology TMFASQ02 and relevant reference chronologies when first ring date is AD 1671 and last ring date is AD 1774

Reference chronology	Span of chronology	*t*-value	
Quenby Hall, Quenby, Leics	AD 1648 – 1765	7.0	(Howard *et al* 1993 unpubl)
Stoneleigh Abbey, Stoneleigh, Warwicks	AD 1646 – 1813	6.3	(Howard *et al* 2000)
England	AD 401 – 1981	6.1	(Baillie and Pilcher 1982 unpubl)
East Midlands	AD 882 – 1981	6.0	(Laxton and Litton 1988)
Trentham's Barn, Purley, Berks	AD 1640 – 1751	5.6	(Howard *et al* 1996b)
Catholme, Staffs	AD 1649 – 1750	5.4	(Howard *et al* 1992 unpubl)
Coates' Barn, Main Street, Cosby, Leics	AD 1642 – 1734	5.3	(Alcock *et al* 1991 unpubl)

Table 4: Results of the cross-matching of pine site chronology TMFASQ05 and relevant reference chronologies when first ring date is AD 1670 and last ring date is AD 1806

Reference chronology	Span of chronology	*t*-value	
Poland north central	AD 1168 – 1994	7.9	(Zielski pers comm)
Gayle Mill, North Yorkshire	AD 1581 – 1783	6.3	(Arnold *et al* forthcoming(a))
House Mill, Bromley by Bow, London	AD 1608 – 1801	6.3	(Arnold *et al* forthcoming(b))
Wallace Collection London	AD 1651 – 1751	5.4	(Groves pers comm)
Gotland, Sweden	AD 1124 – 1987	5.0	(Bartholin pers comm)

Table 5: Results of the cross-matching of pine site chronology TMFASQ06 and relevant reference chronologies when first ring date is AD 1543 and last ring date is AD 1759

Reference chronology	Span of chronology	*t*-value	
UK Import: Danson House, Bexley, Kent	AD 1489 – 1758	6.3	(Groves 2002)
Dannensterna House, Riga, Latvia	AD 1445 – 1694	5.9	(Zunde 1998)
Norfolk, Oxburgh Hall	AD 1554 – 1748	5.2	(Tyers 2004)
Gotland, Sweden	AD 1124 – 1987	5.1	(Bartholin pers comm)
Gravsten, Sweden	AD 1469 – 1840	4.8	(Bartholin pers comm)
Poland north central	AD 1168 – 1994	4.6	(Zielski pers comm)
Stockholm/Uppland, Sweden	AD 1127 – 1671	4.1	(Bartholin pers comm)
Norway south-east	AD 871 – 1986	4.0	(Thun pers comm)

Figure 1: Map to show general location of Warleigh House to Tamerton Foliot and Plymouth

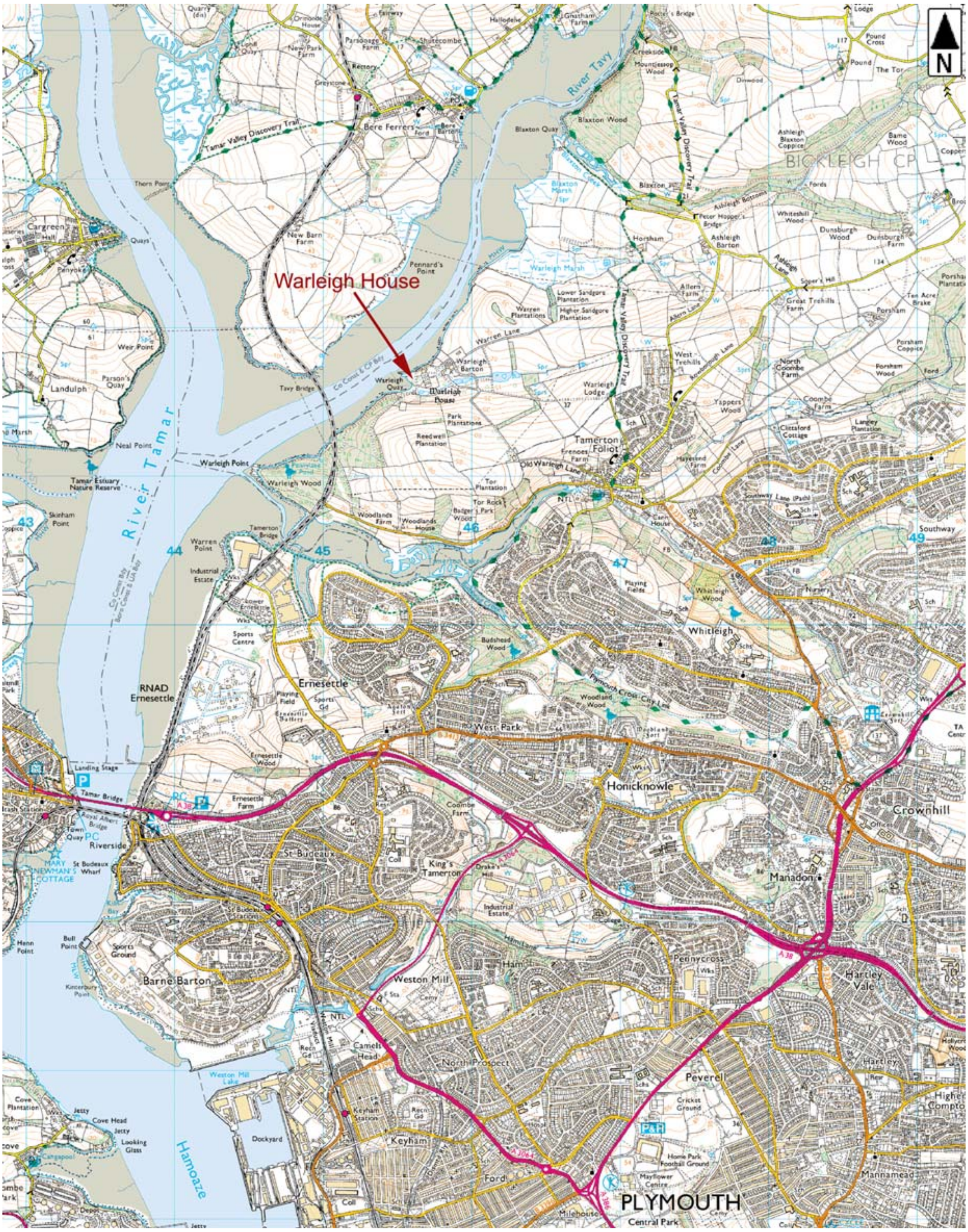


Figure 2: Map to show location of Warleigh House

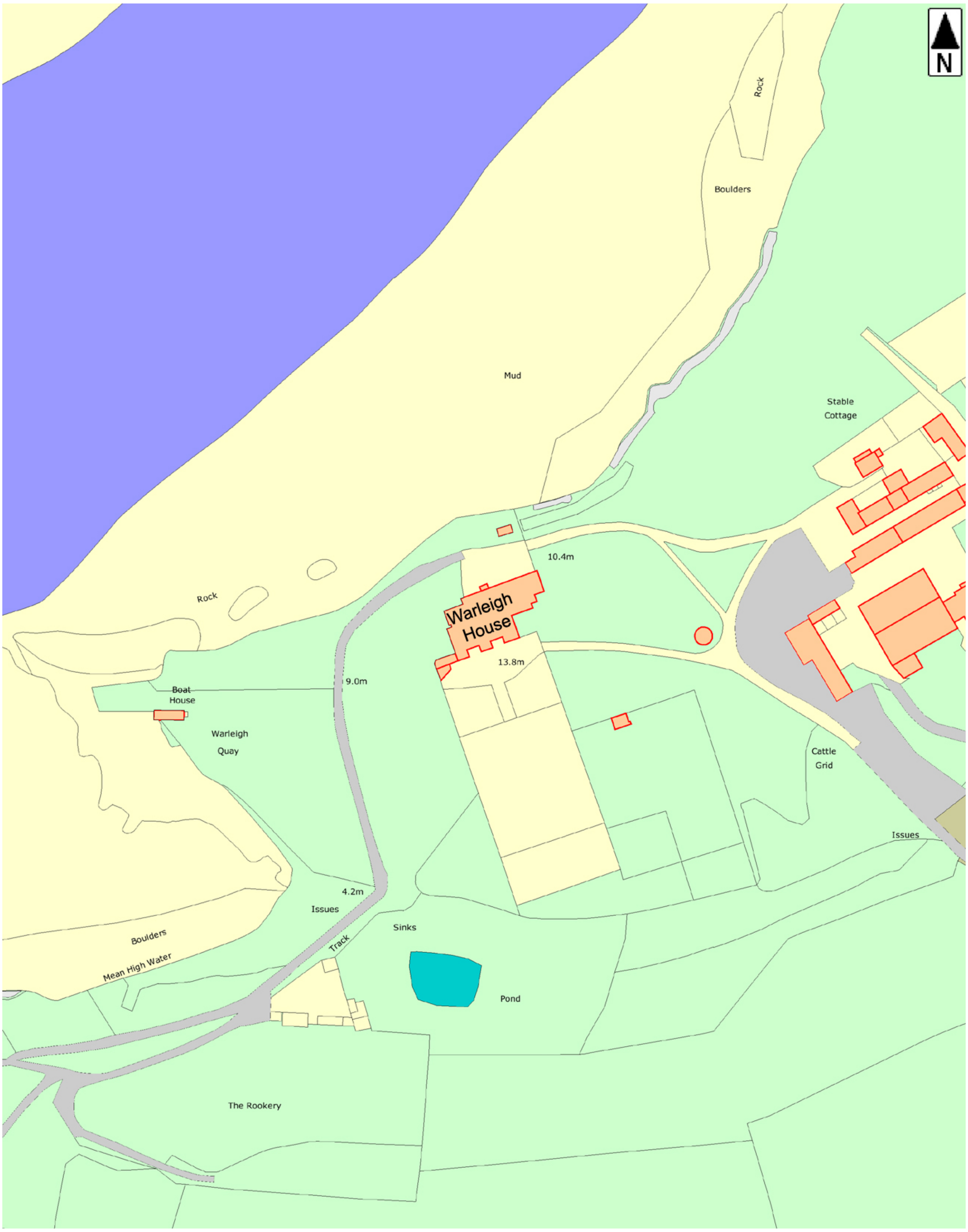


Figure 3: View of Warleigh House from the front or east

Figure 4: Simplified plan of Warleigh House to show timber groups / phases
(after Shane Maddison Conservation and Design)

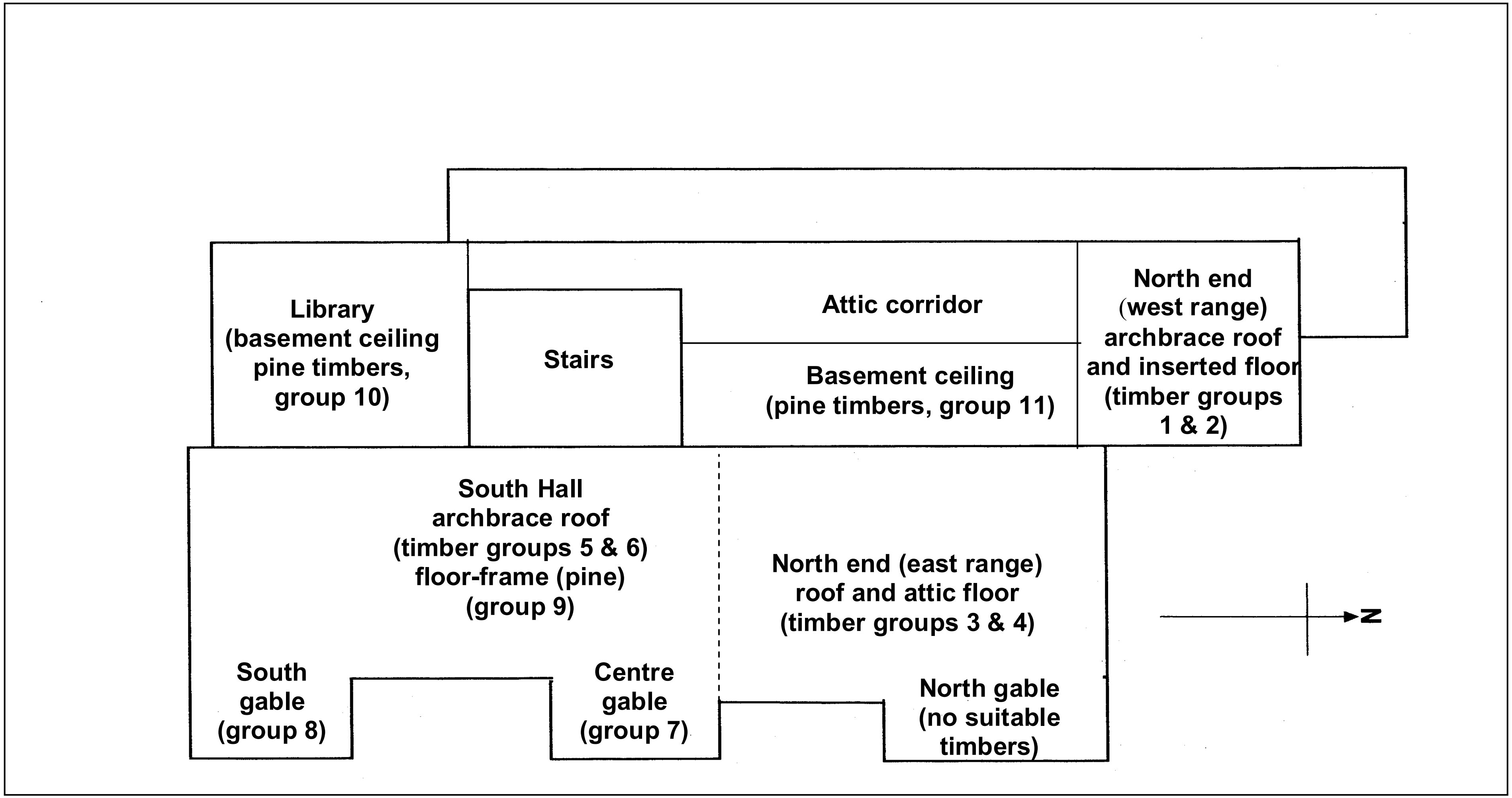


Figure 5 (to left): Archbraced trusses of the hall at the north end of the west range
Figure 6 (to right): Miscellaneous timbers at the north end of the east range

Figures 7a/b: Views of the south hall of the west range viewed from the west looking east (left) and the east looking west (right)

Figure 8a: Simplified plan to show location of samples from the south hall of the west range

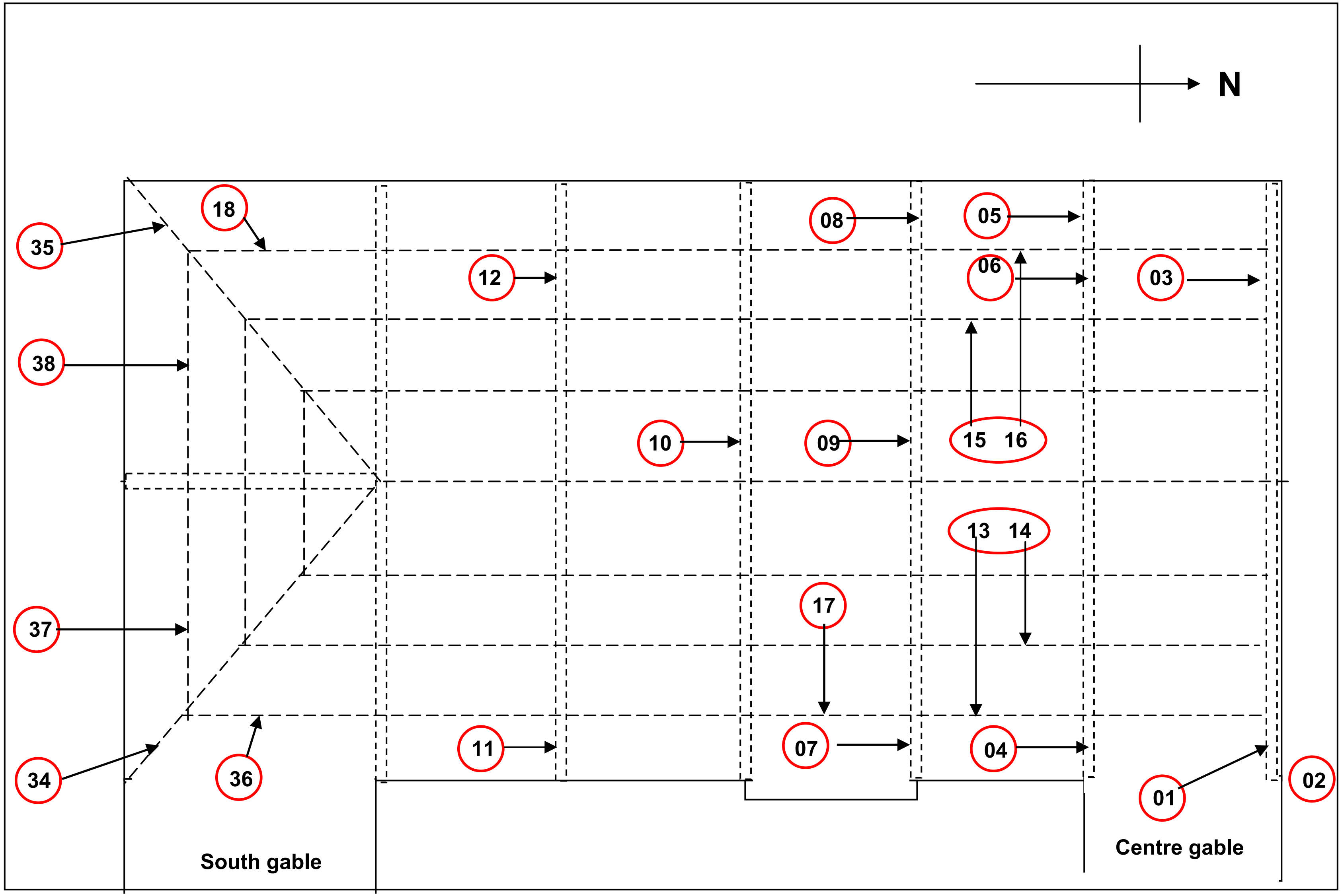


Figure 8b: Simplified plan to show location of samples from the gable roofs

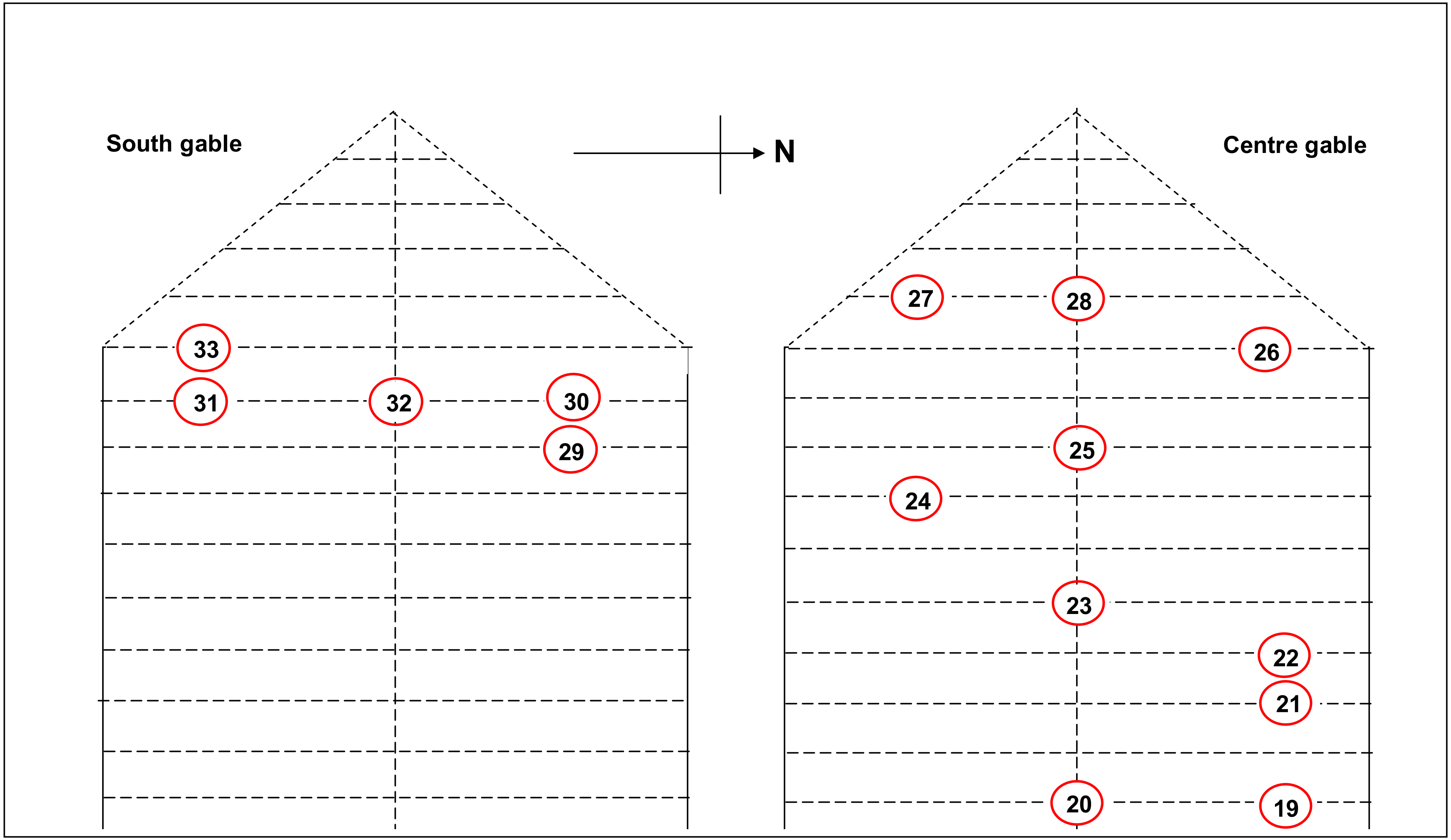


Figure 8c: Plan to show approximate location of samples from the first-floor ceiling/ attic floor frame (after Shane Maddison Conservation and Design)

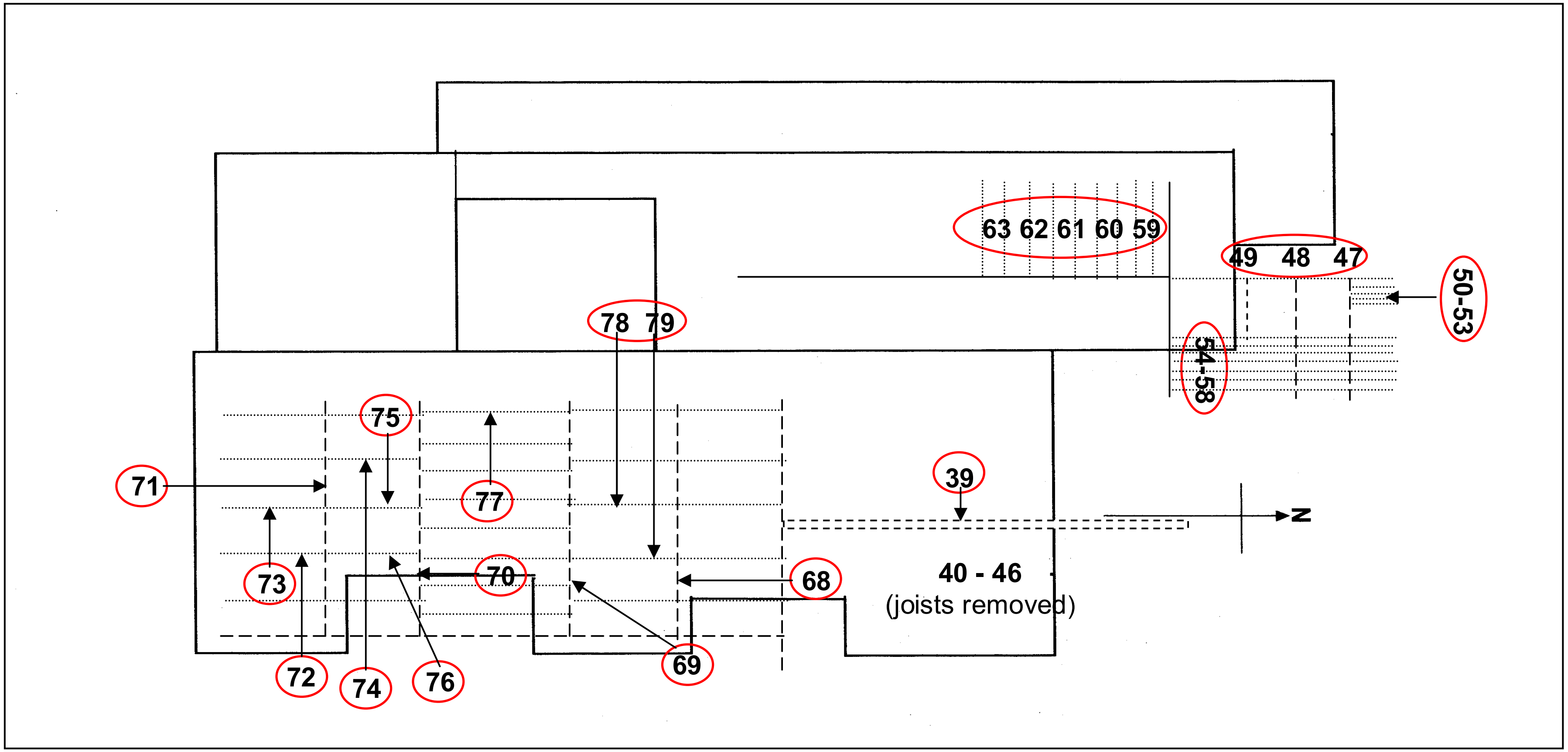


Figure 8d: Plan to show location of samples from the basement ceiling timbers
(after Shane Maddison Conservation and Design)

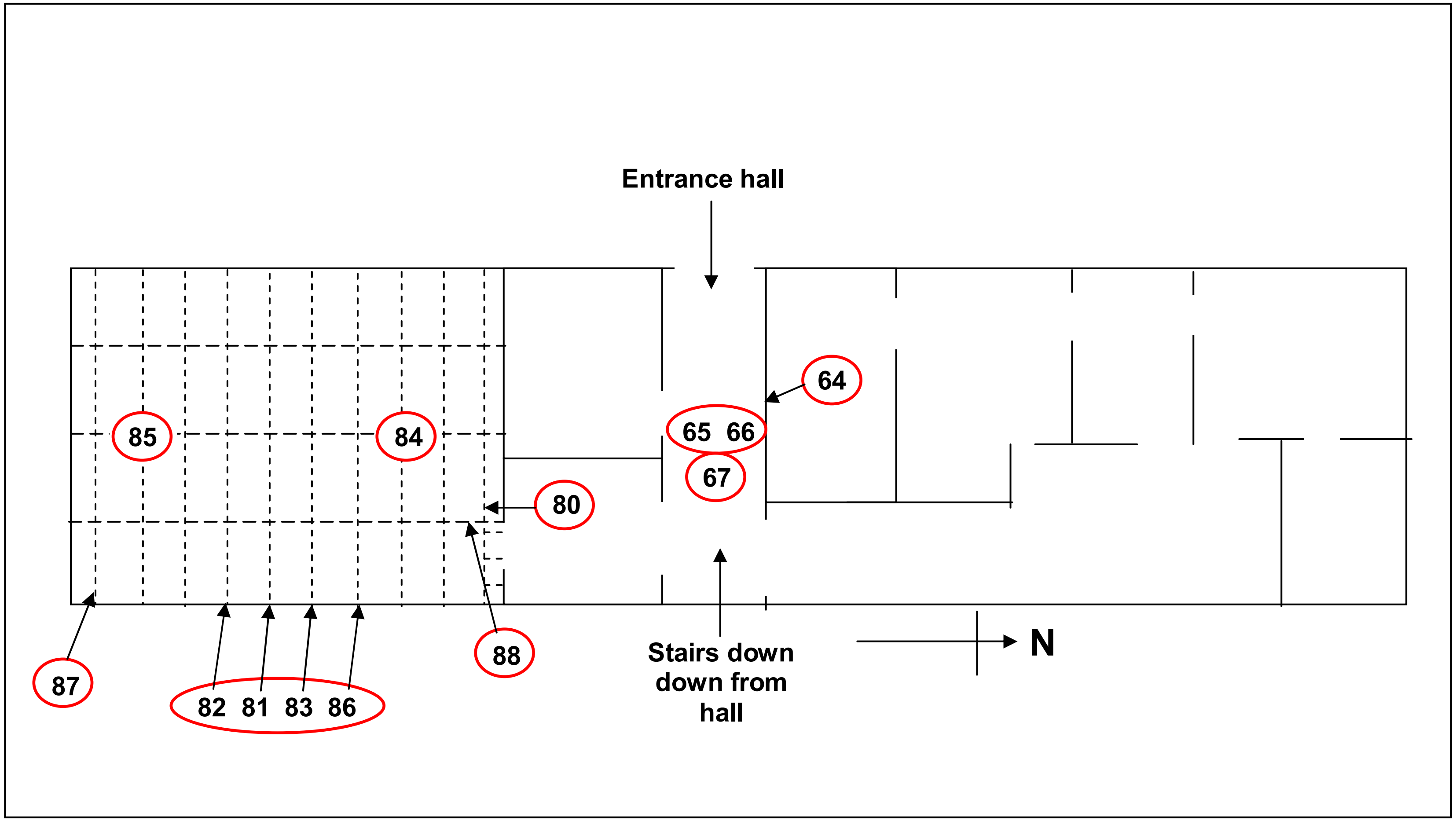
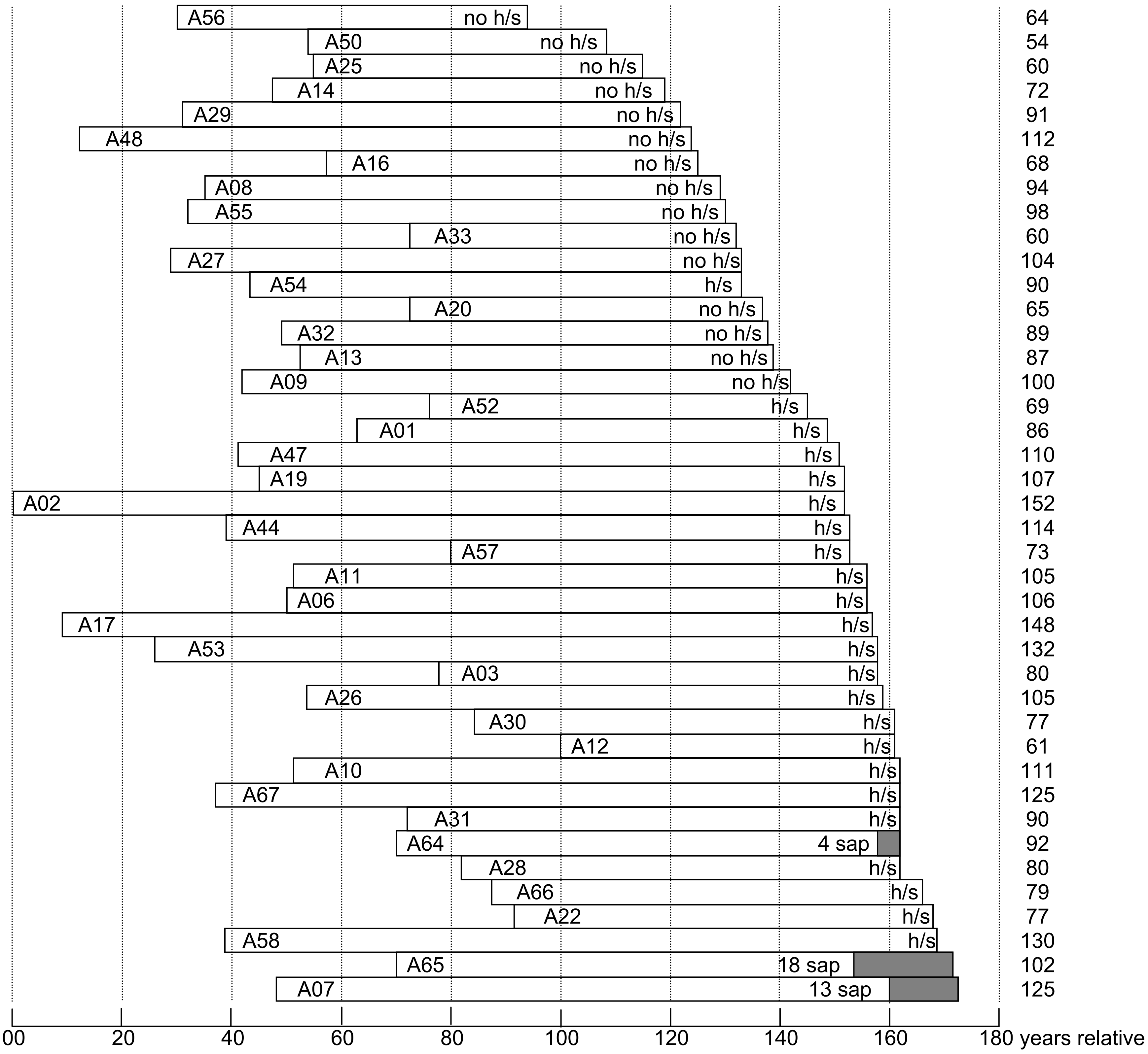


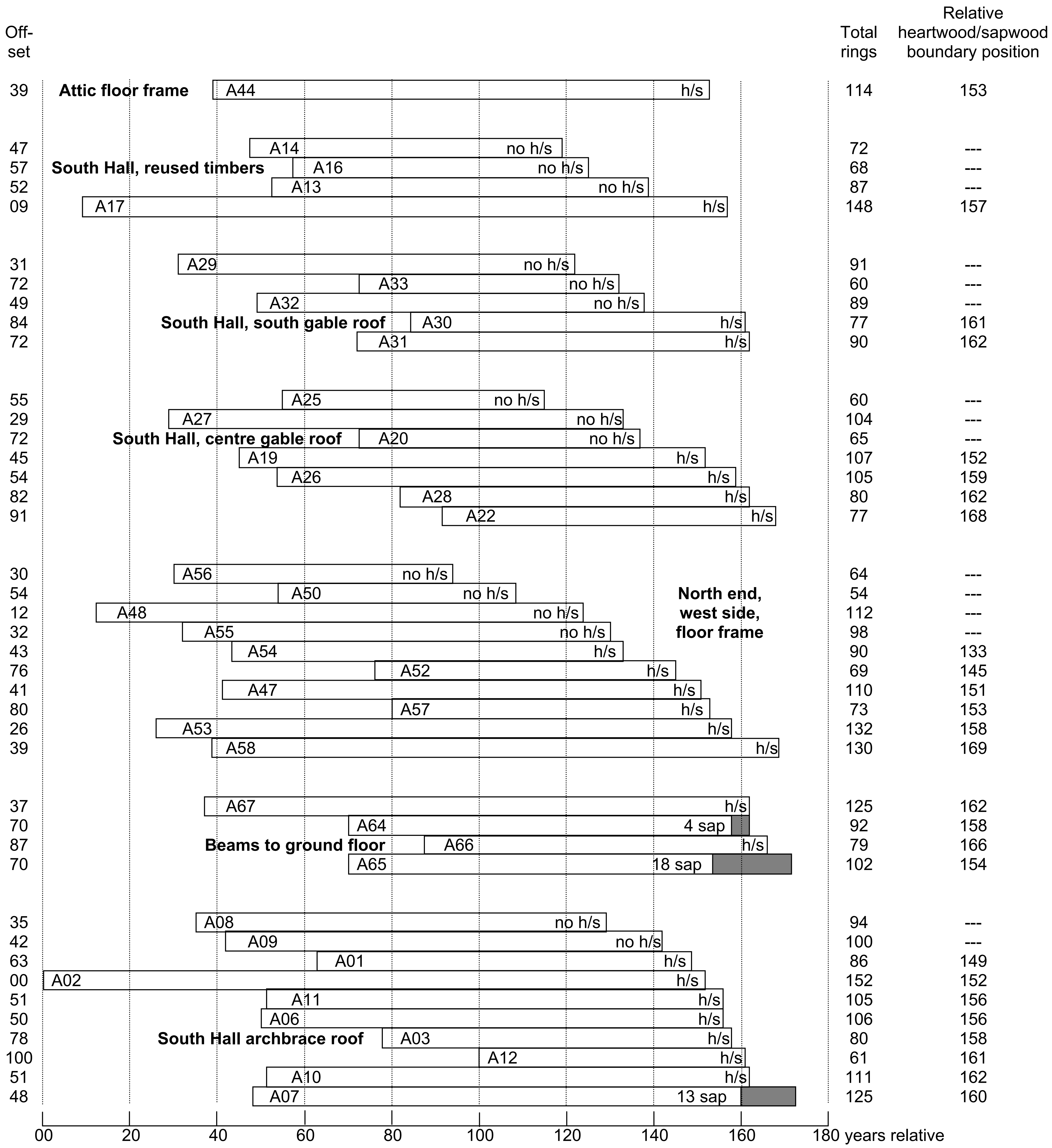
Figure 9: Bar diagram of the samples in site chronology TMFASQ01, sorted by last measured ring position



Off-set	Sample	Last ring	Total rings	Relative heartwood/sapwood boundary position
30	A56	no h/s	64	---
54	A50	no h/s	54	---
55	A25	no h/s	60	---
47	A14	no h/s	72	---
31	A29	no h/s	91	---
12	A48	no h/s	112	---
57	A16	no h/s	68	---
35	A08	no h/s	94	---
32	A55	no h/s	98	---
72	A33	no h/s	60	---
29	A27	no h/s	104	---
43	A54	h/s	90	133
72	A20	no h/s	65	---
49	A32	no h/s	89	---
52	A13	no h/s	87	---
42	A09	no h/s	100	---
76	A52	h/s	69	145
63	A01	h/s	86	149
41	A47	h/s	110	151
45	A19	h/s	107	152
00	A02	h/s	152	152
39	A44	h/s	114	153
80	A57	h/s	73	153
51	A11	h/s	105	156
50	A06	h/s	106	156
09	A17	h/s	148	157
26	A53	h/s	132	158
78	A03	h/s	80	158
54	A26	h/s	105	159
84	A30	h/s	77	161
100	A12	h/s	61	161
51	A10	h/s	111	162
37	A67	h/s	125	162
72	A31	h/s	90	162
70	A64	4 sap	92	158
82	A28	h/s	80	162
87	A66	h/s	79	166
91	A22	h/s	77	168
39	A58	h/s	130	169
70	A65	18 sap	102	154
48	A07	13 sap	125	160

white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 10: Bar diagram of the samples in site chronology TMFASQ01, sorted by sample location



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 11: Bar diagram of the samples in oak site chronology TMFASQ02

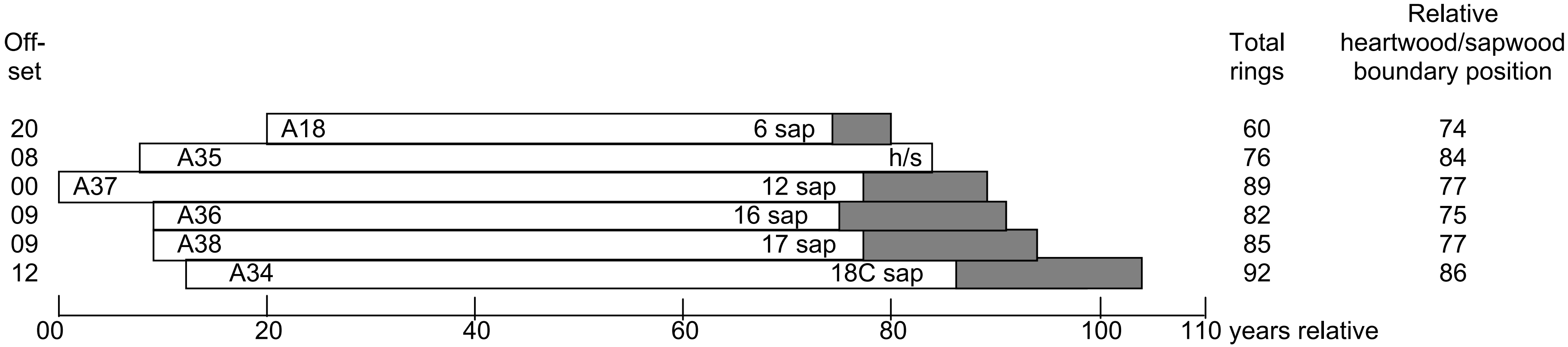
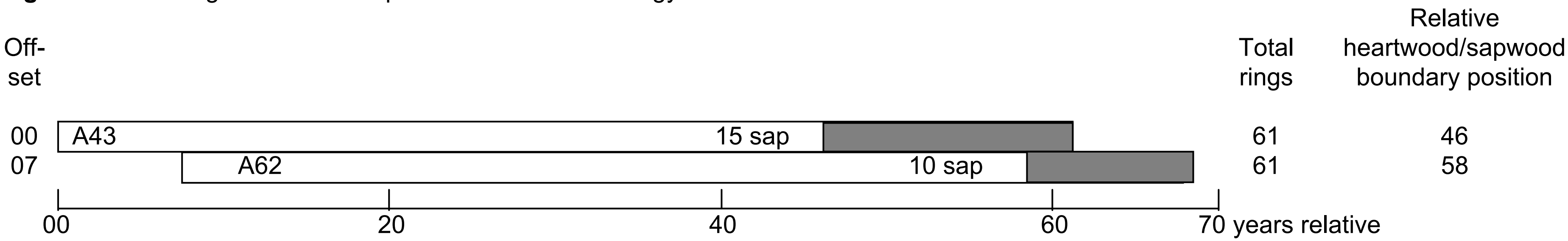
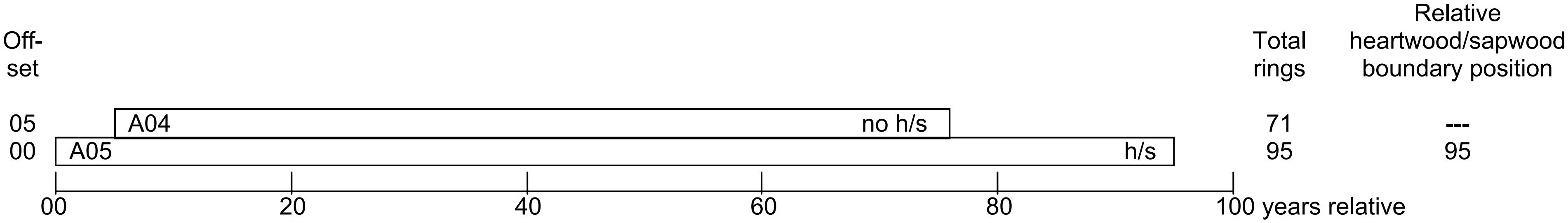


Figure 12: Bar diagram of the samples in oak site chronology TMFASQ03



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

Figure 13: Bar diagram of the samples in oak site chronology TMFASQ04



White bars = heartwood rings
h/s = the heartwood/sapwood boundary is the last ring on the sample

Figure 14: Bar diagram of the samples in pine site chronology TMFASQ05

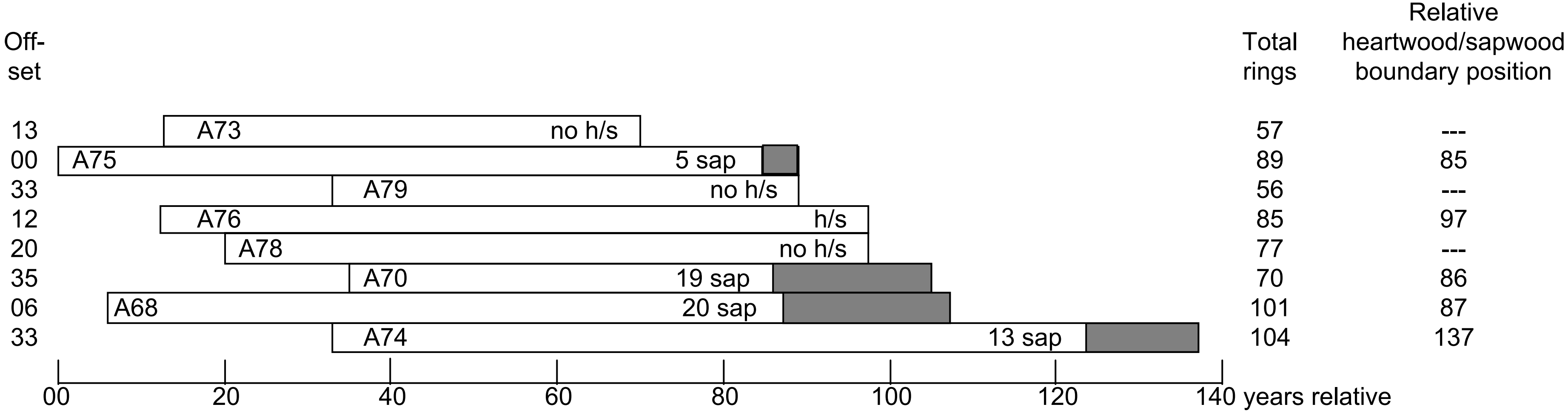
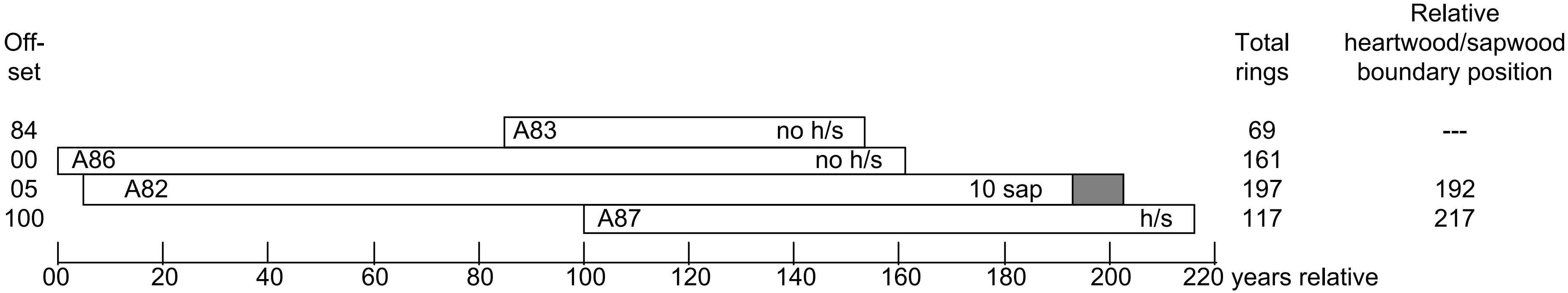


Figure 15: Bar diagram of the samples in pine site chronology TMFASQ06



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Figure 16: Bar diagram of the samples in site chronology TMFASQ07

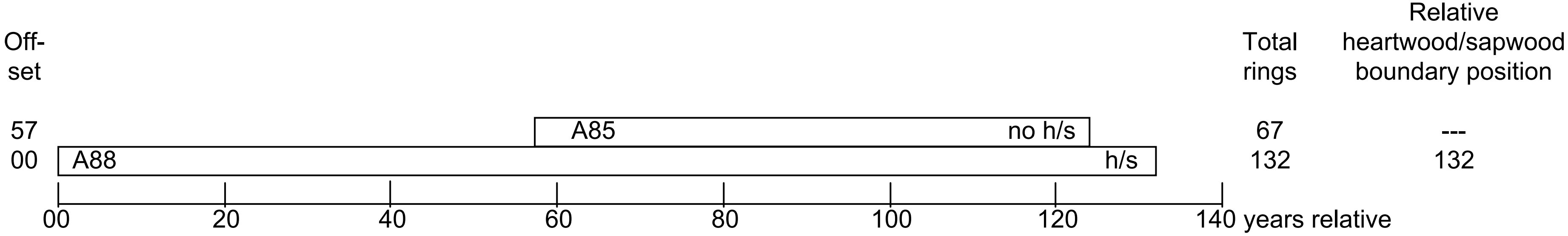
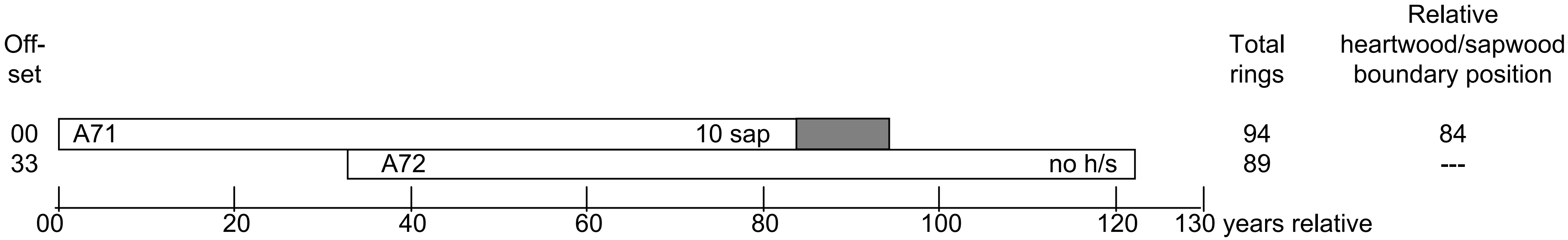


Figure 17: Bar diagram of the samples in pine site chronology TMFASQ08



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Data of measured oak samples – measurements in 0.01 mm units

TMF-A01A 86
115 126 170 110 169 206 200 200 136 83 96 175 96 84 198 145 240 269 281 255
125 253 191 228 206 191 282 214 340 369 403 196 230 259 151 197 227 265 318 288
315 158 109 116 84 195 217 156 151 239 293 309 305 200 295 379 289 311 248 234
236 189 216 187 391 190 462 257 164 238 230 205 170 205 189 146 158 192 120 63
45 44 53 60 70 94
TMF-A01B 86
99 128 164 111 170 205 211 198 136 82 94 196 90 71 209 139 267 245 278 252
127 241 181 217 236 179 267 225 334 367 396 223 238 244 142 210 247 259 315 280
297 161 105 120 75 175 218 159 145 244 270 300 298 235 278 388 304 295 257 248
242 208 187 180 369 197 455 259 177 238 220 199 194 191 214 143 152 186 99 70
37 54 50 64 67 106
TMF-A02A 152
230 136 206 227 182 220 294 182 184 214 157 176 289 260 227 211 186 247 157 147
176 181 208 142 100 71 76 105 132 188 181 149 146 172 119 121 188 148 135 120
125 208 213 76 77 82 146 170 166 214 139 129 69 92 81 50 64 90 125 192
143 193 219 178 177 123 88 95 113 93 157 88 63 90 91 87 124 133 134 144
111 94 99 68 103 95 104 159 95 116 112 141 107 66 72 83 107 83 65 115
129 126 102 141 87 66 64 56 81 87 37 49 56 64 69 66 60 54 66 72
89 61 60 50 45 49 66 67 71 85 81 50 39 49 66 75 85 79 134 86
131 120 85 87 118 172 158 113 81 88 107 109
TMF-A02B 152
227 135 190 235 187 221 243 186 187 194 157 195 259 280 220 209 194 239 150 167
172 180 218 112 111 83 71 125 126 207 174 150 157 166 121 106 180 141 138 124
119 172 199 81 72 86 151 163 159 203 139 117 81 80 72 62 62 93 98 178
137 188 194 164 170 124 78 90 103 108 144 94 59 86 103 76 142 114 140 158
102 101 85 86 94 101 103 149 93 131 116 146 88 60 78 69 102 77 73 120
139 132 110 123 91 76 56 49 79 85 41 52 59 63 63 69 66 53 67 62
84 65 81 36 43 59 58 69 74 85 83 52 43 58 60 69 90 71 133 88
134 114 95 91 108 170 155 110 78 96 93 130
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175 179 129 229 167 161 218 161 216 209 160 164 182 303 240 230 195 213 209 159
260 204 225 271 208 171 142 197 159 185 229 227 188 147 168 216 267 199 172 221
284 215 324 181 202 152 170 192 184 210 162 308 161 133 201 273 183 209 214 238
239 114 173 152 148 85 91 78 89 134 179 174 177 166 285 154 229 185 162 204
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258 208 225 257 214 195 134 150 186 187 248 234 191 150 174 226 226 183 164 238
256 232 322 183 196 170 181 168 179 215 154 314 170 131 218 274 173 225 213 255
215 128 180 143 148 84 102 78 74 150 155 153 195 155 294 141 241 181 171 182
TMF-A04A 71
166 221 189 148 173 165 137 268 185 138 141 125 100 191 123 153 150 132 119 191
188 112 149 123 170 128 203 190 178 137 109 126 125 136 151 171 191 176 80 127
163 129 97 161 169 128 160 161 155 153 101 147 85 83 125 178 99 125 123 96
97 46 55 103 182 190 111 127 151 170 176
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184 218 179 148 187 150 152 224 205 130 149 131 91 172 154 156 143 126 119 211
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91 56 52 112 167 193 109 141 157 172 169
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345 404 307 367 337 151 302 243 170 204 177 187 221 156 112 131 97 114 159 114
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81 134 148 69 110 103 85 104 121 146 146 150 192 172 182 109 187 106 134 132
189 128 210 155 117 108 80 92 101 140 173 120 91 116 132 109 88 146 129 153
162 135 171 159 97 90 153 252 249 154 146 154 105 163 195

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95 80 79 68 103 110 61 93 85 83 110 142 130 119 111 91 108 102 90 86
87 119 158 72 106 110 98 106 118 145 142 141 201 171 163 119 183 108 139 130
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168 135 187 137 96 90 163 247 233 152 149 149 99 146 178
TMF-A06A 106
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225 121 167 137 182 119 132 172 126 130 123 173 96 163 185 89 106 107 71 101
64 87 64 35 37 42 61 50 101 129 90 101 125 143 60 77 70 66 85 95
79 52 74 86 72 82 75 67 61 54 71 72 69 41 49 35 31 42 47 53
38 29 46 33 37 45 40 50 74 55 69 72 86 70 80 73 57 98 87 83
77 63 132 70 105 108
TMF-A06B 106
110 160 115 136 91 100 130 98 102 129 102 156 162 126 149 173 139 168 198 221
213 123 163 129 198 109 133 168 133 133 116 167 112 162 158 109 126 97 77 95
69 102 79 43 44 49 48 48 100 129 98 104 118 147 64 71 64 71 88 92
84 47 75 81 84 70 81 69 53 63 71 64 64 51 48 33 40 36 40 58
33 36 36 35 40 36 45 53 77 49 72 73 83 66 79 77 60 92 87 79
73 58 132 76 107 127
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291 257 233 157 58 254 133 67 122 99 97 80 93 155 159 151 176 135 113 123
309 182 213 206 152 186 139 130 213 236 220 207 286 192 211 155 311 200 259 230
219 244 229 277 189 244 149 169 162 159 242 198 208 209 193 207 146 146 156 186
206 213 134 152 152 144 239 193 205 221 204 211 224 231 133 151 160 140 139 115
100 250 167 98 128 164 115 141 125 151 116 116 109 94 94 100 121 121 89 129
100 91 85 113 138 97 152 141 127 111 115 121 145 178 167 113 167 148 176 193
173 155 109 134 179
TMF-A07B 122
357 265 221 162 67 243 143 58 130 98 92 87 96 148 165 153 180 113 115 131
306 179 202 207 149 176 157 131 214 226 218 222 272 161 202 171 288 196 278 225
223 240 228 273 191 242 156 166 169 199 181 202 206 236 184 196 156 147 154 178
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92 253 155 108 120 165 126 142 141 151 114 115 99 106 91 102 109 130 102 118
95 88 88 108 144 92 155 145 122 109 124 116 126 184 183 108 138 152 183 200
171 156
TMF-A08A 94
165 170 221 375 305 222 236 166 174 169 219 288 353 243 237 231 225 108 156 137
65 138 125 107 121 109 130 115 84 106 90 74 72 116 89 123 97 111 107 112
69 83 101 93 86 96 93 117 110 137 115 102 122 107 85 88 104 89 104 64
83 90 68 95 90 85 91 95 117 84 93 117 145 166 115 94 83 82 101 130
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TMF-A08B 94
188 160 213 373 288 238 248 162 171 175 218 284 331 245 241 255 253 99 161 160
65 142 140 97 117 123 135 106 94 88 96 75 85 96 96 121 95 123 92 122
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88 81 146 121 105 95 92 60 69 72 46 79 67 90
TMF-A09A 100
188 188 161 249 186 200 133 129 135 92 85 87 136 94 144 127 153 100 99 137
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96 76 124 94 116 89 85 80 87 110 100 82 77 78 94 72 157 91 84 71
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TMF-A53A 132
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194 279 137 178 160 151 113 127 177 116 149 115 69 95 85 116 84 74 66 74
75 99 138 148 154 75 70 73 67 54 62 81 50 70 81 52 96 70 94 91
106 90 104 71 73 76 61 55 46 85 79 51 83 94 94 80 70 84 64 53
48 63 73 119 56 39 69 64 85 73 75 63 84 82 67 65 67 58 86 48
48 69 75 112 35 52 61 69 46 64 81 101 64 62 81 56 77 68 66 68
80 96 80 82 75 60 150 59 117 121 105 139
TMF-A53B 132
211 172 217 176 175 122 155 137 177 112 161 131 113 230 169 221 124 115 99 134
191 280 144 171 157 146 98 140 190 117 174 96 85 77 89 97 93 77 63 71
83 90 132 139 154 83 54 83 51 53 78 62 60 79 73 76 78 82 81 105
95 103 79 72 68 77 68 45 51 90 55 60 85 97 89 90 60 94 70 56
72 48 89 100 62 51 59 63 89 63 75 62 95 84 65 70 56 58 80 53
49 77 69 102 51 54 56 65 49 72 69 97 71 68 68 60 90 53 74 67
95 87 99 67 79 63 153 65 121 103 115 130
TMF-A54A 90
182 177 212 255 359 268 263 248 241 141 204 206 112 173 186 174 189 144 169 135
120 140 165 109 107 163 139 204 185 207 149 132 83 104 122 115 115 115 105 100
77 107 101 88 133 90 112 118 116 132 124 103 109 106 88 129 112 110 93 83
123 79 78 77 87 107 100 88 66 73 80 68 65 63 66 100 69 75 69 69
40 54 38 46 61 47 61 68 37 48
TMF-A54B 90
218 166 203 276 359 256 260 231 258 135 201 216 108 172 181 175 196 149 175 130
124 145 177 111 97 160 140 201 173 165 160 129 82 112 105 126 114 109 97 113
70 104 106 84 131 98 104 110 139 110 120 121 108 116 84 130 118 106 87 93
119 83 70 81 90 110 100 88 60 86 74 74 71 63 73 95 83 65 53 83
47 47 49 44 50 57 56 64 43 55
TMF-A55A 98
177 243 246 138 261 159 174 279 164 269 160 157 129 157 160 233 160 148 125 177
86 95 200 99 158 131 91 170 172 267 118 137 137 183 124 131 247 211 214 162
145 138 108 80 100 136 174 135 131 110 169 148 225 129 162 149 103 158 119 131
100 97 84 101 137 80 207 178 143 178 166 182 144 89 166 126 147 186 132 97
141 147 149 112 149 131 192 187 186 150 133 113 150 92 105 92 83 173
TMF-A55B 98
199 242 234 128 249 160 173 282 159 270 135 158 139 151 152 240 160 148 110 193
83 101 191 97 163 135 87 177 172 256 134 152 136 165 124 133 259 208 206 160
144 122 115 89 100 132 172 145 120 126 162 137 233 137 168 162 104 141 125 134
94 90 77 107 125 76 201 191 144 160 190 185 139 92 155 123 140 195 129 95
158 136 143 99 152 136 198 187 175 161 118 133 146 96 98 101 72 176
TMF-A56A 64
128 196 246 253 225 132 159 196 235 309 166 247 210 221 162 186 209 240 237 210
224 235 105 149 179 106 152 185 189 224 192 161 134 107 114 144 85 60 79 88
135 106 117 142 104 88 86 122 116 100 107 88 102 70 103 118 90 132 96 106
93 145 114 155
TMF-A56B 64
141 197 244 243 236 129 135 196 244 324 175 224 222 217 152 186 220 234 218 229
237 237 116 149 176 99 145 197 187 229 218 161 137 104 118 134 75 68 85 86
132 102 117 127 119 66 99 111 109 120 99 89 92 80 113 109 96 125 104 107
96 143 116 157
TMF-A57A 73
129 200 162 143 159 142 125 138 154 160 172 111 108 89 102 116 121 106 162 160
163 103 155 188 135 138 204 151 240 234 106 114 145 123 155 144 198 247 357 290
224 136 119 117 139 98 165 184 166 316 203 131 161 153 139 155 163 172 141 137
155 161 154 172 218 192 148 181 124 93 123 108 176

TMF-A57B 73
128 195 161 153 158 145 126 130 147 172 140 124 109 107 97 114 121 124 160 161
155 104 149 183 174 147 190 158 222 246 121 112 155 112 151 151 194 278 303 321
219 141 94 127 137 84 158 179 165 303 202 126 148 129 136 162 146 163 132 134
156 154 155 169 187 167 147 172 125 99 123 132 192
TMF-A58A 130
228 223 315 135 183 151 185 200 247 144 128 181 192 129 122 175 128 230 129 98
110 136 200 141 113 95 120 129 141 209 181 199 94 104 114 101 85 90 123 98
115 115 93 122 133 199 128 120 109 123 95 96 105 84 100 91 134 100 56 115
132 156 104 83 112 94 103 94 91 151 167 98 74 89 86 117 108 94 116 113
165 125 123 81 116 147 57 97 115 89 173 72 56 94 87 55 61 80 104 134
81 85 88 74 53 62 54 82 109 118 73 116 63 174 79 154 98 134 122 143
124 131 123 101 73 127 74 69 75 90
TMF-A58B 130
217 225 304 146 180 149 184 192 260 138 130 185 193 109 139 178 119 233 129 99
110 129 210 129 121 85 107 142 142 219 193 197 106 93 118 108 87 102 117 102
113 124 95 136 122 183 129 116 108 115 89 103 114 88 106 92 128 100 56 110
138 153 111 73 116 94 104 95 87 148 169 99 70 79 90 122 108 101 104 126
169 138 119 80 121 148 70 88 107 90 174 72 60 101 76 56 60 75 103 141
85 90 81 73 53 64 58 80 104 97 84 111 70 179 74 171 88 135 127 143
119 125 129 102 66 130 60 91 79 95
TMF-A59A 55
279 216 311 341 185 334 338 178 342 583 659 347 371 310 367 407 466 496 344 484
251 224 207 335 321 275 279 281 343 333 228 221 182 155 153 101 87 87 129 129
113 73 153 102 169 114 84 125 106 110 40 74 55 132 32
TMF-A59B 55
270 175 306 355 196 314 345 250 337 580 649 326 370 301 296 430 459 516 325 474
250 208 208 352 351 269 274 295 364 279 228 243 169 131 135 119 107 70 138 140
111 68 150 104 166 116 81 128 112 125 40 69 51 128 32
TMF-A62A 61
101 124 155 119 80 44 113 95 139 146 174 172 159 141 210 204 309 179 155 235
165 77 61 68 201 82 158 135 70 42 97 101 111 177 83 213 380 211 127 205
429 341 411 398 232 230 355 287 253 234 213 289 242 237 253 297 299 333 240 290
360
TMF-A62B 61
109 138 145 112 71 56 98 103 155 147 173 163 143 126 192 188 299 185 153 243
154 75 59 83 229 87 158 136 81 53 86 103 107 187 87 203 381 207 122 207
428 336 414 397 224 250 362 268 258 240 201 293 241 239 273 276 309 343 256 288
297
TMF-A64A 92
284 293 221 265 389 196 393 253 141 179 200 191 119 144 216 134 205 242 172 158
156 240 194 400 141 156 169 144 256 164 204 221 187 182 112 111 142 192 180 154
91 68 79 136 191 128 121 141 146 103 138 137 147 91 155 79 67 97 88 170
118 70 93 145 124 153 155 157 136 121 174 82 97 70 80 138 173 133 199 92
163 125 251 110 143 146 104 89 85 111 139 122
TMF-A64B 92
319 310 220 263 373 194 442 250 141 178 198 186 122 131 237 125 209 256 156 141
140 277 201 413 153 172 163 142 259 167 193 228 185 182 112 122 96 185 186 145
96 75 70 140 196 119 123 137 149 106 141 135 144 101 140 81 65 103 89 172
117 62 96 147 109 172 162 149 138 128 165 78 96 66 90 128 150 146 214 104
145 107 228 104 150 152 122 77 109 117 124 119
TMF-A65A 102
113 239 231 233 246 124 168 178 190 198 189 153 178 167 218 153 181 192 209 178
139 195 109 117 89 158 142 96 143 159 195 213 137 180 135 136 128 139 206 214
101 92 75 125 217 149 168 242 303 248 233 206 167 178 281 134 185 168 156 303
171 111 203 225 159 183 180 373 391 336 313 294 345 157 195 176 174 263 288 174
179 194 297 130 525 236 153 113 107 91 104 123 154 128 169 100 117 103 144 107
212 231

TMF-A65B 102
116 244 233 230 254 123 168 180 195 202 183 153 178 178 212 153 183 189 211 172
137 191 104 122 95 158 139 92 146 165 186 205 144 168 139 136 128 149 180 226
119 81 74 121 218 149 182 241 296 253 235 215 164 183 273 137 174 170 153 305
159 112 201 235 156 187 186 364 376 343 309 287 342 143 204 182 180 255 254 181
177 190 258 155 559 216 144 112 103 107 93 111 147 121 202 88 99 94 156 121
194 237
TMF-A66A 79
140 171 185 128 119 79 67 81 82 102 57 105 135 141 154 163 224 115 100 123
80 110 124 76 59 70 89 105 77 86 122 222 220 253 211 163 134 222 85 129
102 97 275 135 65 122 120 102 145 156 192 155 155 265 245 379 240 230 349 356
326 360 148 303 215 439 146 270 210 269 169 190 168 161 288 224 222 302 255
TMF-A66B 79
139 166 197 121 127 71 81 65 98 92 53 110 131 145 153 160 216 115 97 127
89 125 125 71 63 74 84 108 65 102 128 201 195 240 229 157 141 236 85 128
96 100 285 127 80 108 116 114 143 144 180 153 158 267 240 391 235 223 338 367
332 359 140 307 212 435 154 257 225 262 172 185 174 172 262 240 210 339 251
TMF-A67A 125
233 244 389 223 365 213 210 149 204 230 249 157 156 118 136 88 106 111 52 117
101 88 86 97 117 106 78 77 144 83 101 129 138 196 125 87 88 93 68 91
116 96 75 74 71 87 91 154 108 109 92 97 122 101 123 68 65 62 82 83
55 87 113 135 149 111 121 75 85 107 79 96 110 62 45 61 83 101 93 106
122 189 150 206 164 112 116 163 54 99 80 80 198 102 89 132 80 95 87 138
111 153 115 197 147 193 104 95 130 143 148 158 71 124 120 250 124 237 166 239
193 279 179 191 346
TMF-A67B 125
240 245 395 222 356 222 207 134 206 229 254 151 161 118 134 88 110 110 53 102
115 89 83 88 119 106 82 78 133 78 111 138 130 205 129 88 85 96 67 99
109 85 85 72 88 72 96 155 100 109 89 106 116 97 127 71 70 56 81 86
54 89 109 132 152 117 117 89 71 104 75 98 116 56 48 65 82 93 91 105
118 188 148 221 181 132 103 163 55 113 82 74 200 106 87 129 83 87 100 130
113 146 118 203 140 194 106 103 120 139 145 166 73 127 114 268 106 239 159 244
187 266 192 182 336

Data of measured pine samples – measurements in 0.01 mm units

TMF-A68A 101
442 423 376 392 402 246 376 406 335 250 275 253 226 243 144 192 205 157 98 85
122 147 203 170 120 122 141 114 110 121 120 80 125 110 155 139 135 168 166 155
149 148 97 106 116 95 134 204 223 228 127 161 177 190 187 134 143 128 173 146
154 159 137 117 110 97 101 111 98 90 155 149 96 97 164 155 192 178 156 157
185 171 118 139 71 74 25 140 148 132 129 122 112 134 87 68 57 105 99 77
131
TMF-A68B 101
470 409 420 418 390 250 389 382 353 261 285 252 230 247 139 187 210 160 87 92
123 148 200 173 119 117 143 99 115 129 106 82 120 108 158 135 141 166 161 156
145 151 102 100 125 94 134 196 231 223 131 164 176 196 181 129 144 123 178 142
154 172 142 116 111 103 95 115 87 99 160 142 97 102 162 145 197 182 160 155
173 179 124 144 58 76 31 142 136 130 131 124 118 124 89 71 58 95 96 128
118
TMF-A69A 67
575 540 578 643 469 467 590 601 570 456 428 454 543 628 454 463 555 647 489 527
414 363 495 627 368 441 396 296 285 232 275 188 144 243 274 328 254 279 234 171
235 196 179 222 186 225 286 326 272 246 180 154 202 238 212 198 317 167 148 134
132 110 194 183 158 139 181
TMF-A69B 67
571 536 579 644 464 467 578 591 569 444 413 464 530 620 445 458 553 647 486 523
426 355 488 619 360 448 396 310 285 224 288 179 140 234 264 332 243 273 247 162
233 183 188 214 195 231 273 303 267 235 181 154 202 238 222 186 327 178 144 147
128 109 196 173 170 144 179
TMF-A70A 70
183 133 119 186 178 211 219 144 187 195 147 161 198 163 121 74 67 136 199 244
283 152 176 182 211 159 130 152 180 186 195 199 204 199 259 160 133 109 126 121
129 167 181 96 87 163 164 182 193 161 166 170 135 99 139 79 137 123 133 136
140 130 155 167 161 159 108 61 111 110
TMF-A70B 70
196 140 124 186 178 215 204 157 181 192 157 164 188 166 121 78 72 132 211 237
270 151 168 181 218 169 117 148 189 186 192 217 212 208 253 155 130 109 123 131
128 158 174 104 102 178 192 172 217 154 163 172 134 96 140 84 126 116 148 138
136 154 161 163 151 96 71 110 102 110
TMF-A71A 94
410 470 343 363 296 268 186 197 189 154 224 229 188 158 140 292 371 280 323 242
237 263 186 233 176 211 216 287 255 222 268 163 108 131 133 81 94 138 169 141
90 53 63 66 65 101 80 125 150 106 114 131 146 110 81 79 109 136 108 140
82 115 126 96 48 51 56 101 99 114 118 163 57 146 108 145 140 191 188 156
147 151 150 166 89 120 119 124 163 154 215 184 183 111
TMF-A71B 94
407 467 328 365 245 273 212 185 179 156 231 227 191 160 124 267 412 268 324 236
238 254 190 228 185 226 215 267 269 222 277 159 112 129 118 85 96 135 173 148
86 50 59 70 64 99 80 126 160 111 109 129 152 106 85 80 115 139 100 140
93 115 121 98 52 52 55 103 95 116 109 161 63 137 121 155 135 177 185 161
164 144 151 172 90 114 124 123 160 159 224 182 175 122
TMF-A72A 89
345 338 227 228 228 308 240 275 195 237 327 341 506 322 281 236 155 160 228 265
217 216 228 226 181 159 165 145 202 177 188 121 137 150 216 203 174 149 134 87
110 117 143 170 221 228 168 143 112 128 126 87 76 92 116 125 116 111 115 84
79 99 43 103 114 129 117 100 214 136 118 91 65 81 96 102 83 89 80 90
77 80 70 90 115 106 83 107 108

TMF-A72B 89
352 339 230 229 228 316 249 268 198 250 329 335 505 338 271 237 158 156 230 259
203 228 233 218 179 159 163 156 212 182 183 103 133 157 214 203 172 142 136 93
111 116 154 150 219 234 150 141 115 133 115 85 81 100 116 127 116 110 119 95
68 85 85 51 109 118 129 115 203 142 111 97 60 74 95 105 75 101 83 85
75 70 81 91 110 103 90 105 103
TMF-A73A 57
272 227 358 458 342 340 383 356 370 360 355 451 366 485 414 313 282 223 252 363
289 235 269 210 142 191 207 258 294 272 336 185 221 193 187 193 166 176 143 153
195 201 169 133 151 174 166 132 135 172 218 204 167 192 184 196 189
TMF-A73B 57
267 233 363 449 339 341 394 359 373 358 353 453 359 488 410 297 294 229 239 389
272 247 268 207 154 188 209 240 302 261 346 187 231 198 191 188 166 173 142 158
188 205 163 137 144 169 165 132 136 169 221 198 174 196 178 192 181
TMF-A74A 104
326 265 281 249 202 284 248 331 316 261 270 207 191 182 180 234 209 133 144 137
165 177 162 120 135 147 100 99 83 137 157 157 148 153 165 170 125 86 98 122
138 119 187 179 125 85 104 121 111 123 150 116 195 147 156 142 138 87 119 87
64 85 139 146 135 122 132 107 84 121 156 163 134 123 83 100 119 101 99 107
109 88 118 111 115 121 133 101 86 74 85 144 79 94 71 77 85 80 101 121
96 91 108 123
TMF-A74B 104
332 266 299 240 183 302 244 354 322 306 279 218 203 186 186 243 215 138 154 138
188 160 166 144 133 137 104 96 88 127 166 152 154 145 159 172 128 92 108 107
132 115 181 177 131 76 101 127 107 123 146 128 184 158 139 136 138 88 122 82
65 93 118 133 123 131 132 104 89 115 146 152 128 123 81 101 114 91 104 114
92 89 109 120 116 113 134 101 103 69 88 145 76 97 75 76 82 79 95 125
77 110 98 102
TMF-A75A 89
266 510 427 533 422 421 360 426 296 411 406 270 333 345 377 374 328 312 249 233
243 215 221 162 129 70 94 133 162 144 157 156 187 187 126 122 113 92 119 153
156 147 170 173 147 168 138 154 96 87 90 69 117 159 171 167 149 151 182 208
193 144 153 139 156 143 136 119 109 111 100 97 92 89 98 94 128 97 72 101
171 145 180 177 168 156 158 156 162
TMF-A75B 89
292 521 436 532 422 427 365 423 297 410 410 260 339 346 369 364 327 318 244 245
236 221 219 165 121 79 100 124 165 148 152 159 187 184 130 116 117 84 125 156
158 149 165 177 148 165 132 148 105 77 97 63 129 160 159 159 160 146 185 219
187 139 150 142 151 148 144 116 107 106 101 109 78 102 97 93 125 97 85 94
175 143 169 185 167 159 171 140 146
TMF-A76A 85
390 316 388 303 345 346 272 258 227 272 212 158 119 97 137 160 178 156 141 205
193 128 129 130 131 116 111 112 186 132 153 185 179 209 240 217 158 147 108 78
131 214 224 204 161 150 222 237 173 123 129 145 178 114 145 118 150 176 116 100
101 101 90 104 143 106 107 115 163 185 171 201 153 172 202 168 139 138 96 126
141 162 165 150 163
TMF-A76B 85
376 312 406 352 346 329 294 268 230 244 215 134 118 79 141 157 172 155 135 199
186 132 140 118 133 116 112 119 177 132 148 190 144 229 251 217 158 139 119 72
141 211 247 195 141 177 214 241 188 116 112 144 181 117 142 124 148 179 108 114
90 99 95 99 149 114 102 116 162 180 185 203 156 171 189 171 142 143 98 117
157 166 163 144 154
TMF-A77A 81
621 577 688 533 499 668 483 611 515 436 405 441 361 260 186 166 220 224 212 147
205 172 179 189 125 177 140 167 126 187 198 201 157 207 179 183 177 189 158 175
157 199 195 203 184 175 183 241 280 283 276 284 330 466 383 399 313 324 308 279
295 323 295 273 232 158 245 251 184 212 262 353 332 181 234 386 311 261 299 306
303

TMF-A77B 81
564 576 684 540 474 682 494 647 512 428 397 456 343 269 184 161 216 238 188 154
202 159 190 191 129 171 135 166 127 176 226 188 172 197 190 172 175 195 168 164
171 195 194 202 175 181 197 234 277 287 285 272 326 447 401 410 304 310 320 271
290 330 304 270 237 139 277 230 182 222 245 367 331 198 223 398 292 273 307 294
305
TMF-A78A 77
337 439 407 357 467 469 543 397 332 340 340 394 446 337 277 312 268 224 337 254
280 329 271 322 227 224 141 165 323 260 199 196 187 167 163 153 101 118 110 117
82 76 114 186 158 135 149 149 185 140 114 106 115 154 133 204 171 182 89 118
161 140 133 134 144 170 147 162 149 141 83 118 86 86 114 146 188
TMF-A78B 77
342 427 411 365 496 453 527 407 322 339 343 405 430 342 282 323 260 226 347 252
295 313 274 323 221 218 137 178 315 265 206 188 176 171 166 141 107 123 102 118
77 74 122 187 154 134 154 150 187 132 118 103 128 152 134 200 172 182 87 125
167 133 130 142 139 172 155 172 154 133 76 103 72 83 100 149 185
TMF-A79A 56
348 265 328 191 129 190 156 251 270 225 250 166 178 138 156 211 183 141 173 152
190 168 151 121 122 127 108 104 111 149 174 154 141 142 135 155 125 86 94 126
136 139 147 153 161 90 96 126 127 131 164 95 130 131 124 133
TMF-A79B 56
347 263 325 186 132 187 157 260 288 244 265 181 173 129 166 223 174 142 172 174
190 152 142 124 128 120 110 117 118 145 175 147 143 154 141 138 123 90 100 113
144 138 149 150 153 90 100 122 125 132 159 102 128 128 143 147
TMF-A80A 61
240 394 361 280 371 360 384 478 390 451 301 91 270 379 395 398 449 406 487 388
141 247 196 241 204 324 294 315 307 240 238 333 315 277 329 324 313 239 197 207
159 219 210 331 229 298 338 302 224 298 224 175 222 141 163 171 167 163 168 154
191
TMF-A80B 61
242 386 350 262 366 357 367 464 391 405 294 95 280 375 357 407 447 389 469 394
140 237 201 240 207 327 299 313 297 251 238 327 333 330 321 322 332 219 200 210
178 218 207 315 224 303 330 314 224 291 233 168 223 137 159 178 167 154 168 165
187
TMF-A81A 85
251 342 415 368 356 308 412 317 302 364 294 173 225 201 216 241 198 184 188 204
147 134 192 153 150 91 67 97 158 141 104 103 69 87 123 89 87 71 109 172
128 73 77 108 90 111 86 56 27 47 56 59 75 99 63 63 76 111 108 130
93 73 67 57 30 57 104 72 44 63 49 61 102 132 106 156 225 122 81 132
93 53 56 66 86
TMF-A81B 85
240 338 422 367 343 300 406 294 292 383 288 174 251 221 217 230 202 181 190 199
142 124 191 156 143 97 67 95 138 140 115 97 77 78 124 85 86 71 100 159
123 72 73 104 100 116 84 56 26 53 52 62 79 98 68 62 68 114 113 121
96 74 70 57 28 71 99 73 39 52 40 68 95 135 111 152 229 118 79 136
89 56 53 67 92
TMF-A82iA 108
241 190 202 139 197 207 150 168 199 125 106 142 191 204 170 118 115 121 174 242
156 123 125 80 85 84 114 78 63 92 57 81 79 62 58 58 57 90 64 75
74 65 51 57 40 45 52 46 78 56 78 56 49 42 60 55 49 39 66 82
59 78 71 81 73 59 47 114 117 151 151 113 109 111 80 116 68 53 81 86
87 61 88 93 84 84 81 82 126 80 63 38 54 81 55 54 69 81 60 47
61 79 75 54 73 84 101 89

TMF-A82iB 108
253 195 172 142 212 209 135 165 193 121 108 151 167 204 164 108 90 132 182 212
155 123 130 90 83 90 116 71 62 92 57 90 79 61 55 55 68 88 61 70
70 62 59 61 39 55 48 46 78 55 78 56 49 48 70 55 47 50 56 73
68 69 72 84 68 72 41 130 110 145 151 115 110 106 93 105 71 58 74 95
85 67 76 105 81 91 73 73 130 74 61 39 57 82 64 46 63 89 54 52
66 79 80 56 70 89 96 94
TMF-A82iia 84
109 116 132 108 110 126 89 117 107 92 108 56 43 49 70 95 85 67 57 83
89 122 135 112 72 113 112 67 58 53 74 64 43 65 71 62 58 56 53 68
59 86 77 53 65 46 75 62 70 74 63 76 102 87 73 80 78 77 64 80
77 61 66 79 59 56 74 75 82 75 68 47 74 89 56 45 53 60 89 48
40 49 51 82
TMF-A82iib 84
106 125 123 108 115 120 95 121 92 103 103 60 46 44 65 102 87 66 57 84
86 126 139 106 77 108 111 66 60 52 78 62 40 65 75 60 60 52 53 71
59 91 81 47 52 60 66 62 68 73 66 70 111 79 80 75 90 71 72 77
70 65 70 74 66 50 71 79 75 88 65 57 68 87 68 46 41 78 77 45
42 43 50 70
TMF-A83A 69
89 65 76 112 92 129 124 103 102 107 127 73 54 72 48 56 66 102 131 105
128 96 121 116 75 106 152 132 173 212 136 151 121 161 167 134 145 141 103 115
99 83 85 99 74 52 59 51 80 105 111 76 56 85 88 133 142 108 89 144
142 75 71 55 87 62 52 85 97
TMF-A83B 69
87 67 77 109 96 139 127 100 110 112 136 80 58 69 62 57 61 99 138 106
136 108 113 113 108 106 149 137 186 216 143 149 115 163 163 146 148 140 94 120
101 80 87 95 83 61 50 60 89 115 107 74 59 82 90 136 138 100 93 141
122 83 64 59 88 60 56 80 87
TMF-A84A 170
124 86 105 90 95 127 181 107 103 95 76 100 89 95 90 91 104 82 85 130
41 55 74 68 74 71 75 64 62 83 63 84 71 85 86 24 15 34 37 38
41 42 56 52 54 58 44 34 62 65 51 75 71 55 51 50 66 87 70 59
76 79 81 67 91 71 65 60 54 54 75 56 59 66 61 73 66 56 75 58
50 58 60 53 73 44 49 56 58 57 61 73 75 67 66 61 76 77 65 66
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52 56 55 45 39 39 52 64 34 39 30 41 32 54 27 43 46 64 48 43
40 47 60 48 39 44 40 29 55 64
TMF-A84B 170
124 83 103 89 93 133 175 112 106 95 80 100 91 94 87 96 103 82 86 124
44 53 77 66 75 71 76 67 63 81 64 83 71 83 89 22 16 35 37 37
40 43 57 54 47 57 46 40 59 66 54 74 70 54 52 55 61 90 71 58
78 76 79 73 88 70 64 62 53 54 72 55 51 72 63 76 65 53 75 58
51 62 57 57 74 44 47 62 60 52 61 61 74 66 61 72 78 69 71 64
55 65 23 29 74 66 65 69 57 76 77 62 60 72 55 80 56 37 26 43
51 55 74 58 69 69 53 53 57 60 81 57 63 68 63 47 53 57 56 55
53 53 59 47 39 35 56 61 35 37 33 42 32 51 27 47 44 62 51 42
39 47 67 43 40 46 40 30 51 62
TMF-A85A 67
124 93 124 71 95 80 87 95 179 129 107 126 128 105 89 106 126 116 64 92
117 86 96 94 129 154 115 90 103 131 146 134 109 50 107 30 39 53 106 85
94 104 90 89 107 48 109 105 130 134 96 81 64 106 102 137 118 112 88 119
64 76 91 107 66 76 88
TMF-A85B 67
131 97 130 78 92 67 97 95 157 122 102 128 130 103 89 103 111 119 63 102
126 87 96 88 131 154 116 98 108 120 129 135 111 56 104 34 44 47 115 72
110 100 105 82 106 43 93 105 127 138 96 83 71 110 106 120 140 109 86 112
58 89 76 122 56 97 109

TMF-A86A 161
241 165 139 116 133 225 176 203 182 205 203 132 169 162 81 145 207 235 278 212
141 117 113 149 237 266 256 169 116 106 123 180 192 144 156 166 165 144 129 86
78 69 86 74 88 72 78 91 109 118 117 110 83 120 110 120 137 151 119 162
155 165 90 108 104 64 60 73 176 156 140 115 166 159 221 174 145 124 94 77
118 88 100 96 122 74 95 136 90 103 98 74 84 80 80 63 38 51 41 54
37 55 101 82 77 78 69 63 78 67 79 65 92 117 83 111 101 129 140 147
150 96 83 76 82 93 86 69 65 47 41 39 58 65 61 53 53 50 72 101
104 100 77 99 95 71 61 51 62 58 44 56 77 61 61 50 40 42 55 83
64
TMF-A86B 161
246 167 121 124 155 220 175 197 168 198 209 110 167 162 83 143 209 240 295 201
146 108 108 156 219 251 259 165 116 102 125 175 191 161 163 151 166 156 139 89
71 78 75 77 87 74 71 90 116 115 115 111 86 118 100 128 125 154 118 166
164 157 89 110 102 70 55 70 173 160 142 109 167 162 224 174 147 125 89 78
118 89 97 96 116 81 86 123 96 92 93 73 79 83 82 67 39 44 45 57
34 63 99 84 76 76 66 71 78 63 76 66 85 127 78 111 105 132 140 147
143 107 92 77 80 95 85 67 67 52 39 39 56 65 73 53 44 56 69 105
100 99 71 109 93 67 57 51 62 58 45 62 74 57 62 44 42 43 56 79
59
TMF-A87A 117
59 89 124 109 81 101 75 96 67 54 94 70 106 75 88 58 51 94 97 97
106 87 77 79 64 81 79 104 75 68 62 54 77 69 88 63 52 55 65 93
71 73 48 66 78 51 60 64 61 39 42 53 62 37 48 39 39 48 66 80
74 49 91 85 91 73 64 79 51 53 76 79 60 77 100 122 97 87 82 69
107 99 107 68 101 91 93 85 65 63 98 102 67 45 47 101 85 82 66 69
86 53 89 91 81 83 87 112 104 83 94 114 103 119 99 89 94
TMF-A87B 117
48 108 115 105 78 85 75 94 66 68 71 88 104 101 66 82 72 87 100 107
93 99 64 88 62 82 83 95 82 55 80 46 67 83 82 68 47 54 70 84
86 62 51 67 69 52 59 60 65 48 42 48 65 37 42 40 40 51 59 95
66 52 93 82 92 75 79 78 54 58 51 71 57 75 115 118 90 98 82 92
108 104 108 65 92 99 91 86 61 69 101 107 49 52 43 100 87 88 64 75
80 63 85 93 78 91 83 118 104 82 111 108 101 118 101 84 93
TMF-A88A 132
73 94 91 64 114 115 138 69 93 85 81 72 110 36 61 92 109 75 80 91
64 66 80 87 72 63 86 90 14 18 39 49 52 66 64 67 84 85 78 113
95 93 109 87 65 82 48 76 107 130 54 95 93 123 123 135 81 104 73 88
61 84 78 70 98 110 101 78 83 110 86 68 93 94 122 65 95 71 84 80
90 132 143 109 124 123 111 156 104 94 48 82 32 46 63 77 82 95 93 113
84 74 68 94 119 105 120 81 81 58 99 105 114 119 98 78 126 71 84 80
118 54 71 83 69 66 66 75 66 73 66 63
TMF-A88B 132
87 93 95 56 110 113 142 66 93 81 88 74 106 37 61 93 103 79 79 92
62 64 76 86 72 63 85 90 18 15 35 44 45 68 61 71 87 73 72 111
99 88 116 82 70 68 52 69 108 127 58 89 108 125 107 130 84 97 72 96
54 90 72 88 98 111 100 78 73 106 90 75 97 95 122 74 91 68 85 86
94 120 145 111 117 124 110 166 88 92 51 78 37 40 59 86 73 96 91 124
82 76 68 88 104 99 120 76 82 70 113 100 117 118 95 77 128 70 85 80
115 58 72 76 75 57 64 80 63 72 64 61

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building'* (Laxton and Litton 1988) and*, Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 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 1, 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 2 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 to 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 2; it is about 15cm long and 1cm 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 1: 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 determined by counting back from the outside ring, which grew in 1976.

Figure 2: Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Figure 3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure 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 4: 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 2. 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 3).

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 4). 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 5 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 5. 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 5 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 straight forward 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. Actually it could be the year after if it had been felled in the first three months 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 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 Fig 6 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 Fig 6. 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 Fig 7. 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 phenomena 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	

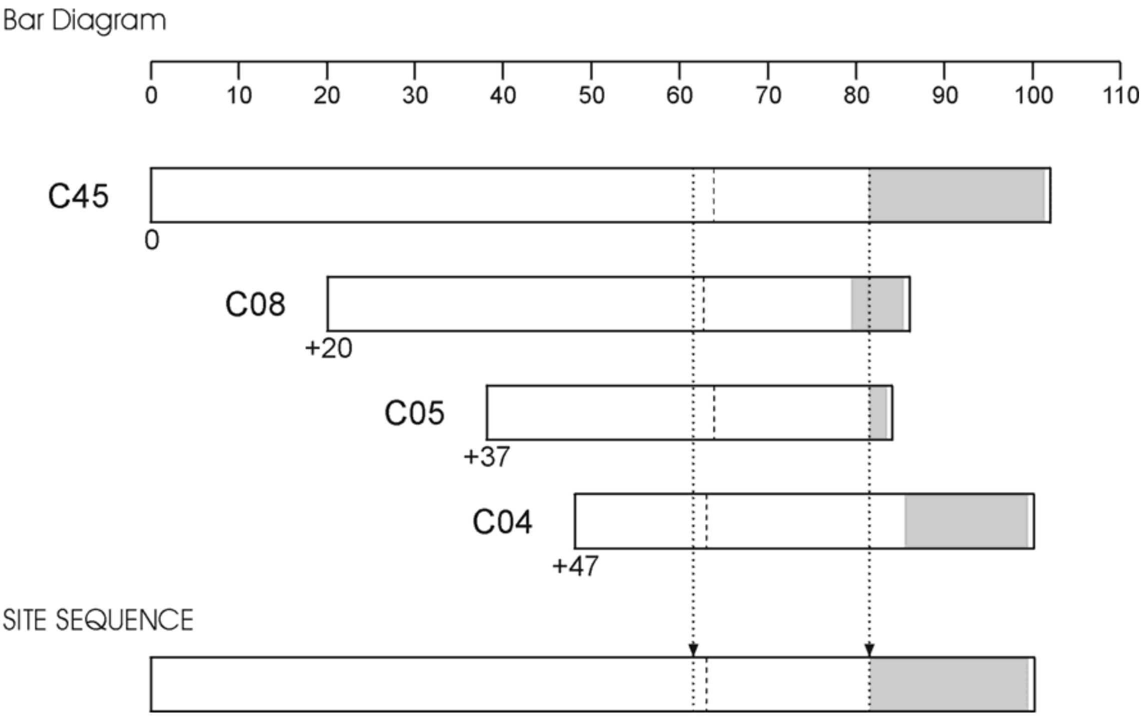


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

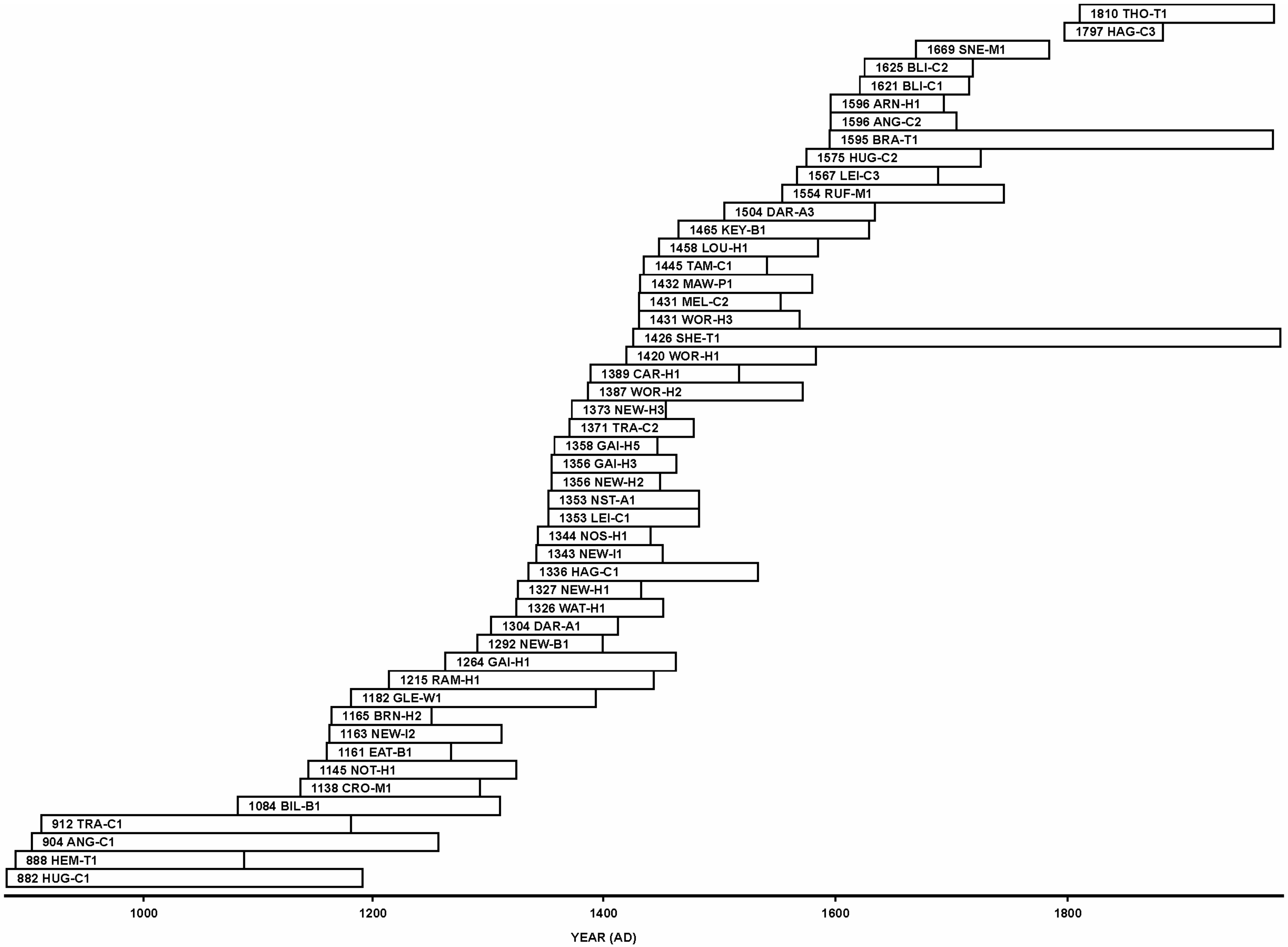
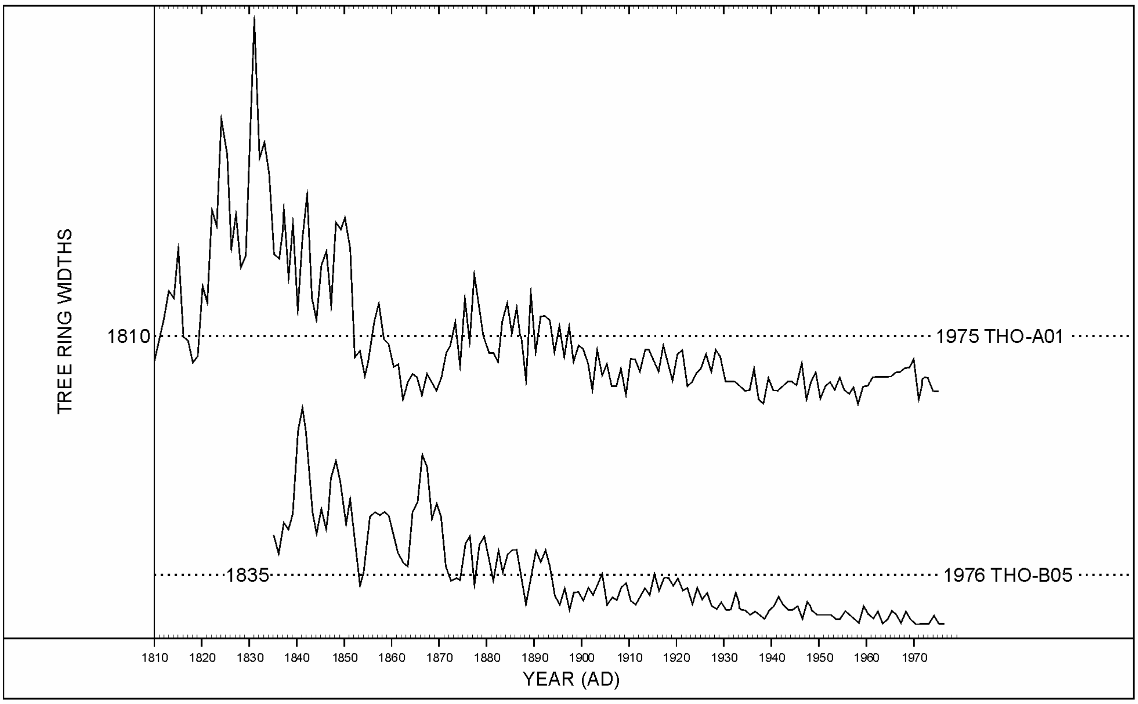


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

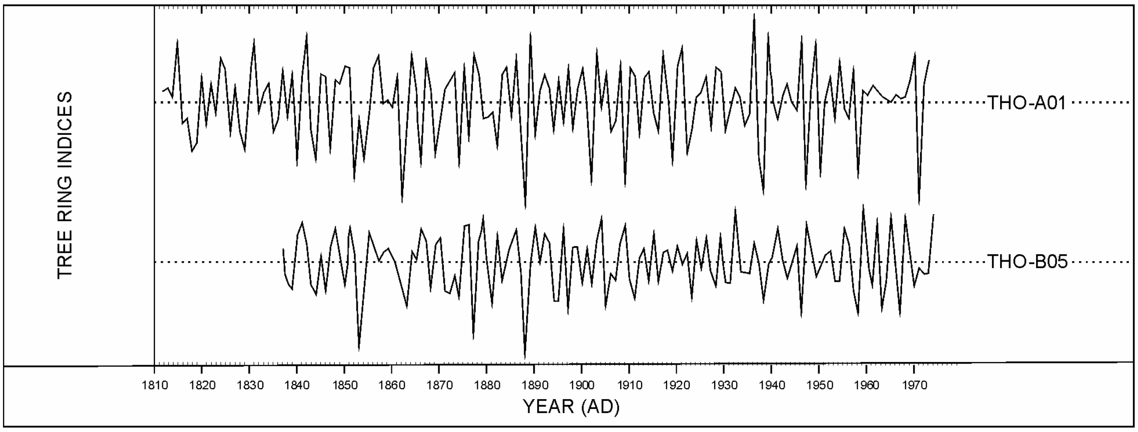


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Figure 7 (b): The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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