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SOCKBURN HALL, SOCKBURN, DARLINGTON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

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SUMMARY

Analysis undertaken on pine and oak samples from the main house, coach house, mash house, and stables resulted in the construction of 14 site sequences, none of which could be dated.

At present the dating of Sockburn Hall must therefore rely on documentary and stylistic grounds only.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Simon Taylor for his assistance in facilitating access and for sharing his invaluable knowledge of the building, Mr and Mrs Geary and Ms Gatheral for their hospitality and kindness in showing us around during the initial assessment phase and the subsequent sampling phase. Thanks are also given to Cathy Tyers and Shahina Farid of the English Heritage Scientific Dating Team for commissioning the analysis and also for their advice and assistance throughout the production of this report.

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INTRODUCTION

Sockburn Hall is a Grade II* listed house located just north of the Church of All Saints in the parish of Sockburn, Darlington (Figs 1–3). The main body of the house is square in plan and of two storeys plus attics (Fig 4). The front of the house faces south-west and is of three bays; the outer ones of which project and have shaped gables. This is repeated on two of the other sides of the square (Fig 5). To the left or north-west of the main house are two further ranges at a lower level (Fig 6). Behind these is a brick extension and a series of other, mostly derelict, brick-built structures forming a courtyard.

Of particular interest within the house are the panels lining the 'dining room' which are thought to be dismantled French dower chests (Fig 7). The framing holding them in place may date to the AD 1920s when the room was changed from a 'gun room' to 'dining room' but the panels are thought to be much older, although this date is unclear.

To the north of the house is the coach and mash house (Fig 8). The ground floor of the mash house is thought to be where the food for the horses was prepared, whilst the upstairs formed accommodation. To the west of the mash house are the remains of the stables (Fig 9).

The main house, coach, and mash house are thought to be of largely single-phase construction dating to *c* AD 1834: built by Sir Edward Blackett for his younger brother Henry Collingwood Blackett. Sockburn Hall is on the Heritage at Risk Register and English Heritage has commissioned project development work to help progress a new viable use for the Hall and its grounds.

Hall roofs

There are three ranges of roofs over the main body of the house, here known as south, north, and east ranges. Each is of simple common-rafter type with purlins and hip rafters at the junctions (Fig 10).

The lower range to the north (north-rear range) has a single, exposed crown-post truss with struts (Fig 11). The other half of this range (the back kitchen) has the remains of a ceiling which was unsafe to access. The lower range to the south (south-rear range) is bedroom space and has two exposed trusses, consisting of principal rafters and collars, between which are purlins (Fig 12).

Coach/mash house roofs

The roof over the coach house is again of simple common-rafter type with intermittent collars and purlins (Fig 13), and the roof of the mash house is of common-rafter type with hip rafters (Fig 14).

Stables

The stables no longer have a roof but the remains of a first-floor frame survives as do some post and rails associated with partitioning (Fig 15).

SAMPLING

A dendrochronological survey was requested by Simon Taylor, English Heritage Senior Investigator, Assessment Team North. It was hoped that this would provide dating evidence for, and identify the likely source of, the timber for the dower-chest panels. In addition, it was hoped to obtain independent dating evidence for the hall and coach/mash house to confirm or refute the hypothesis that all are largely of single-phase construction. The construction of these elements in the early nineteenth century is likely to have used imported conifers, the dendrochronological dating of which might also provide evidence for the origin of these timbers. The date of Sockburn Hall is such that the pine timbers used represent a period when imported Scandinavian and Baltic pine timbers were increasing in importance following an apparent influx of North American imports in the early nineteenth century, although this is a period for which there is very little dendrochronological evidence (Tyers pers comm). It was also hoped that dating of the red-brick construction would provide dating evidence for this undated part of the building. The only structural timbers found to be oak on site were some of the components of the partitioning within the stables.

Assessment showed there to be no suitable timbers within the red-brick extension which could be sampled and so no further work was undertaken in this area. Additionally, as it is possible that the panelling in the 'dining room' may be dismantled as works progress, it was decided to defer this analysis as dismantling would provide infinitely better access to the individual elements some time in the future.

A total of 73 timbers (67 pine; 6 oak) from various areas of the building was sampled by coring. Each sample was given the code SBR-N and numbered 1–73. The location of all samples was noted at the time of sampling and has been marked on Figures 16–20. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Twelve samples, six from the main body of the house, one from the south rear-range roof, one from the coach house, two from the mash house, and two from the stables had too few rings for secure dating and so were discarded prior to measurement. The remaining 61 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 39 samples matching to form 14 groups.

The relevant samples were combined at their offset positions to form 14 site sequences (Figs 21–34). Attempts to date these site sequences and the remaining ungrouped sequences were unsuccessful and all remain undated despite comparing them not only with reference chronologies available from sites right across Britain but also those available from elsewhere in Europe and America.

DISCUSSION

It was hoped that undertaking tree-ring dating at Sockburn House would provide independent dating evidence to support that indicated by the documentary sources; this had suggested largely contemporary construction in *c* AD 1834. It is unfortunate that in this instance dendrochronology has been unsuccessful in providing dates for any of the timbers sampled.

The tree-ring analysis resulted in the formation of 14 (12 pine and 2 oak) separate site sequences. In all but two cases each site sequence is represented by samples from a single area, raising the possibility of different woodland sources being exploited for different areas. Thus, we have site sequence SBRNSQ01 which contains six samples from timbers of the east range of the main roof which all match each other very well and are clearly a discrete group of timbers. The exceptions to this are sequences SBRNSQ02 and SBRNSQ06; SBRNSQ02 contains two, south, rear-range samples, a coach house sample, and one from the stables whilst SBRNSQ06 consists of one sample each from the north-range roof, south range, and north-rear range.

Generally the better replicated and longer a site sequence is the greater the possibility of successful dating and this is especially true when dealing with softwood. The longest and best replicated site sequence created from the samples taken at Sockburn Hall is SBRNSQ01 which contains six samples and spans 240 rings. Apart from SBRNSQ02 which contains four samples, the rest of the site sequences have only two or three samples in them and are not particularly long in terms of softwood sequences, making the lack of dating perhaps predictable.

Slightly more surprising is the fact that none of the oak samples have been dated either. The four analysed oak samples grouped to form two separate site sequences (SBRNSQ13 and SBRNSQ14) of 153 and 122 rings, respectively. Oak sequences of these lengths would normally be expected to have a reasonable chance of successful dating. However, when looked at more closely it can be seen that the two samples represented by SBRNSQ13 (SBR-N71 and SBR-N72) match each other at t=12.5 and those by SBRNSQ14 (SBR-N67 and SBR-N70) at t=10.1. These values are of a level which may suggest in both cases a single tree provided the two timber elements represented. If this is the case then the probability of successful dating of these two site sequences would be reduced to that of individual samples, something which is notoriously difficult. Additionally, with the likelihood of these timbers dating to the first half of the nineteenth century or later we are entering a period which is not well represented within the reference chronologies.

This lack of dating at Sockburn Hall is disappointing and is thought most likely due to the material being of a much more disparate nature than anticipated and potentially derived from multiple variable woodland sources. This would be compounded by the late date expected from these timbers and the paucity of reference material with which to compare them. Generally, it should be noted that, although successful dating of imported softwood timbers has been undertaken in England, research in this area is still in its infancy and has by chance focussed on late seventeenth- and eighteenth-century material. It would be hoped that as more work is undertaken the rate of success will increase and successful dating by dendrochronology of buildings such as Sockburn Hall may stand a greater chance in the future.

TABLES

Table 1: Details of tree-ring samples from Sockburn Hall, Sockburn, Darlington

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Main Roofs						
North range						
SBR-N01	East hip rafter	152	33	----	----	----
SBR-N02	West hip rafter	NM	--	----	----	----
SBR-N03	West common rafter 2, gable	NM	--	----	----	----
SBR-N04	West common rafter 6, gable	NM	--	----	----	----
SBR-N05	East common rafter 7, gable	NM	--	----	----	----
SBR-N06	North common rafter 4	60	--	----	----	----
SBR-N07	South common rafter 5	70	--	----	----	----
SBR-N08	North common rafter 8	79	05	----	----	----
SBR-N09	North common rafter 13	64	--	----	----	----
SBR-N10	North common rafter 17	54	--	----	----	----
East range						
SBR-N11	North-east hip rafter, bay 1	142	--	----	----	----
SBR-N12	North-west hip rafter, bay 1	56	--	----	----	----
SBR-N13	South-east hip rafter, bay 1	111	64	----	----	----
SBR-N14	South-west hip rafter, bay 1	112	14	----	----	----
SBR-N15	East common rafter 3, bay 1	NM	--	----	----	----
SBR-N16	East common rafter 4, bay 1	NM	--	----	----	----
SBR-N17	North-west hip rafter, bay 2	115	--	----	----	----
SBR-N18	South-east hip rafter, bay 2	123	54	----	----	----
SBR-N19	South-west hip rafter, bay 2	98	--	----	----	----
South range						
SBR-N20	West common rafter 2, south gable	73	--	----	----	----
SBR-N21	East common rafter 2, south gable	57	--	----	----	----
SBR-N22	West common rafter 4, south gable	77	--	----	----	----

SBR-N23	East common rafter 5, south gable	88	--	----	----	----
SBR-N24	South common rafter 3	80	14	----	----	----
SBR-N25	South common rafter 4	59	13	----	----	----
SBR-N26	North common rafter 4	94	--	----	----	----
SBR-N27	South common rafter 5	62	--	----	----	----
SBR-N28	South common rafter 15	105	53	----	----	----
SBR-N29	South common rafter 17	86	--	----	----	----
SBR-N30	South-west hip rafter	61	02	----	----	----
Lower roofs						
North rear range						
SBR-N31	North principal rafter	66	--	----	----	----
SBR-N32	South principal rafter	66	--	----	----	----
SBR-N33	Tiebeam	58	21	----	----	----
South rear range						
SBR-N34	North principal rafter, truss 1	NM	--	----	----	----
SBR-N35	South principal rafter, truss 1	74	--	----	----	----
SBR-N36	Tiebeam, truss 1	84	18	----	----	----
SBR-N37	North principal rafter, truss 2	50	02	----	----	----
SBR-N38	South principal rafter, truss 2	125	26	----	----	----
SBR-N39	Tiebeam, truss 2	96	40C	----	----	----
SBR-N40	North purlin	69	07	----	----	----
Coach house						
SBR-N41	North common rafter 2, bay 1	62	16	----	----	----
SBR-N42	North rafter, truss 1	69	02	----	----	----
SBR-N43	North common rafter 4, bay 3	105	--	----	----	----
SBR-N44	South common rafter 4, bay 3	62	11	----	----	----
SBR-N45	South rafter, truss 3	77	14	----	----	----
SBR-N46	North common rafter 4, bay 5	NM	--	----	----	----
SBR-N47	North common rafter 6, bay 5	58	07	----	----	----
SBR-N48	North common rafter 8, bay 5	91	54	----	----	----
SBR-N49	North-west diagonal rafter, bay 5	73	40	----	----	----
SBR-N50	West common rafter 18, bay 5	51	--	----	----	----

SBR-N51	Collar, truss 5	114	--	----	----	----
SBR-N52	West common rafter 1, bay 6	79	13	----	----	----
SBR-N53	East common rafter 2, bay 6	84	37	----	----	----
SBR-N54	West common rafter 2, bay 6	97	48	----	----	----
SBR-N55	West common rafter 2, bay 7	97	22	----	----	----
SBR-N56	East common rafter 2, bay 8	74	21	----	----	----
SBR-N57	East common rafter 3, bay 8	51	07	----	----	----
SBR-N58	West common rafter 3, bay 8	93	01	----	----	----
SBR-N59	West rafter, truss 8	99	13	----	----	----
SBR-N60	North purlin	85	12	----	----	----
SBR-N61	South purlin	87	--	----	----	----
Mash house						
SBR-N62	North-east hip rafter	90	--	----	----	----
SBR-N63	North-west hip rafter	NM	--	----	----	----
SBR-N64	South-east hip rafter	NM	--	----	----	----
SBR-N65	Joist 9	97	28	----	----	----
SBR-N66	Joist 10	95	22	----	----	----
Stables						
SBR-N67	Post A - oak	122	h/s	----	----	----
SBR-N68	Post B - oak	NM	--	----	----	----
SBR-N69	Post C - oak	NM	--	----	----	----
SBR-N70	Post D - oak	119	--	----	----	----
SBR-N71	Post E - oak	106	--	----	----	----
SBR-N72	Post F - oak	146	h/s	----	----	----
SBR-N73	Post G - pine	78	--	----	----	----

*NM = not measured
**h/s = heartwood/sapwood boundary is the last-measured ring
C = complete sapwood retained on sample, last measured ring is the felling date

FIGURES

Figure 1: Map to show the general location of Sockburn, circled.

Figure 2: Map to show the general location of Sockburn Hall, arrowed.

Figure 3: Map to show the location of Sockburn Hall. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

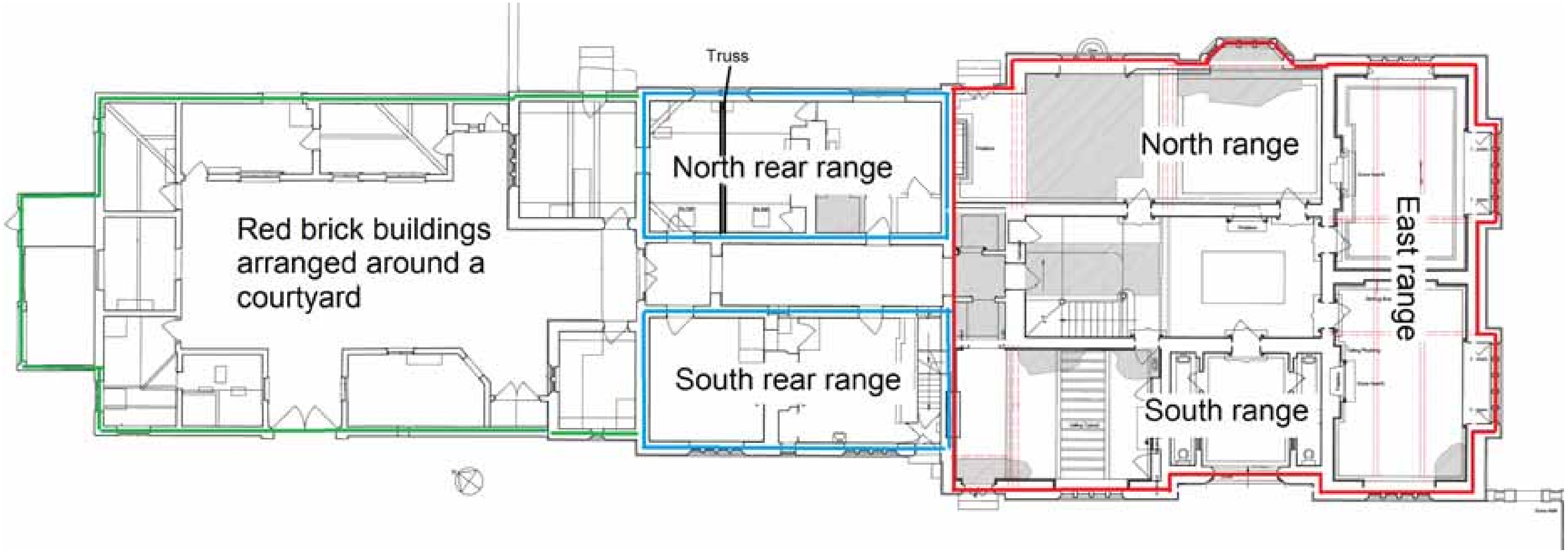

Figure 4: Plan of Sockburn Hall with areas investigated within the house outlined, and the location of the roof truss in the north-rear range marked (Blackett-Ord Conservation)

Figure 5: Sockburn Hall, main block, photograph taken from the east (Alison Arnold)

Figure 6: Rear ranges of the house, photograph taken from the north-west (Alison Arnold)

Figure 7: Panels lining the 'dining room', photograph taken from the south-east (Alison Arnold)

Figure 8: Coach house (to the right) and mash house (to the left), photograph taken from the south (Alison Arnold)

Figure 9: Ruined stables, photograph taken from the south-east (Alison Arnold)

Figure 10: Sockburn Hall, north range roof, photograph taken from the south-east (Alison Arnold)

Figure 11: Sockburn Hall, north rear-range roof, photograph taken from the north-west (Alison Arnold)

Figure 12: Sockburn Hall, south-rear range, truss 1, photograph taken from the north-west (Alison Arnold)

Figure 13: Coach house, roof, photograph taken from the north (Alison Arnold)

Figure 14: The mash house roof, photograph taken from the north (Alison Arnold)

Figure 15: The stables, surviving partitioning, photograph taken from the east (Alison Arnold)

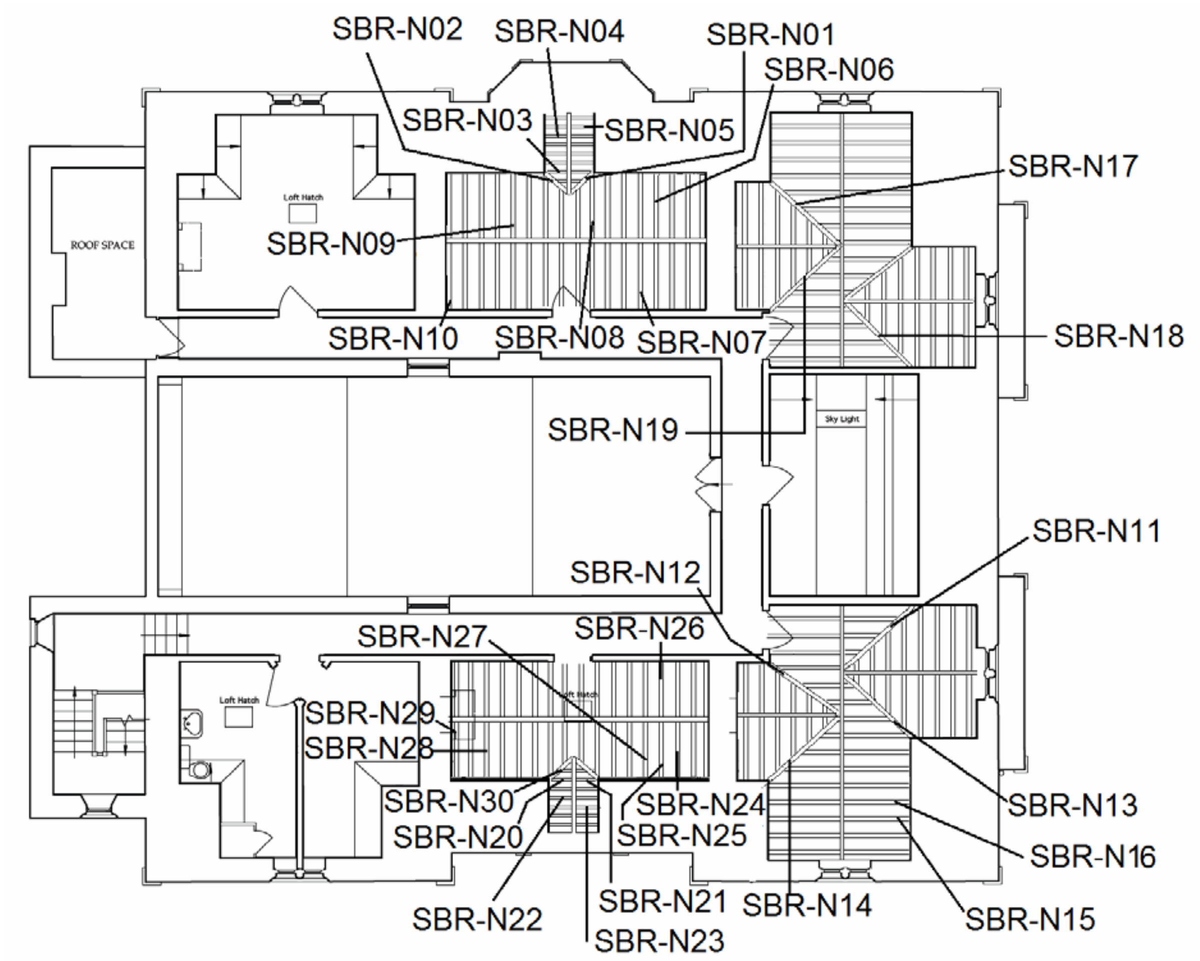

Figure 16: Second-floor plan, showing the location of samples SBR-N01–30 (Blackett-Ord Conservation))

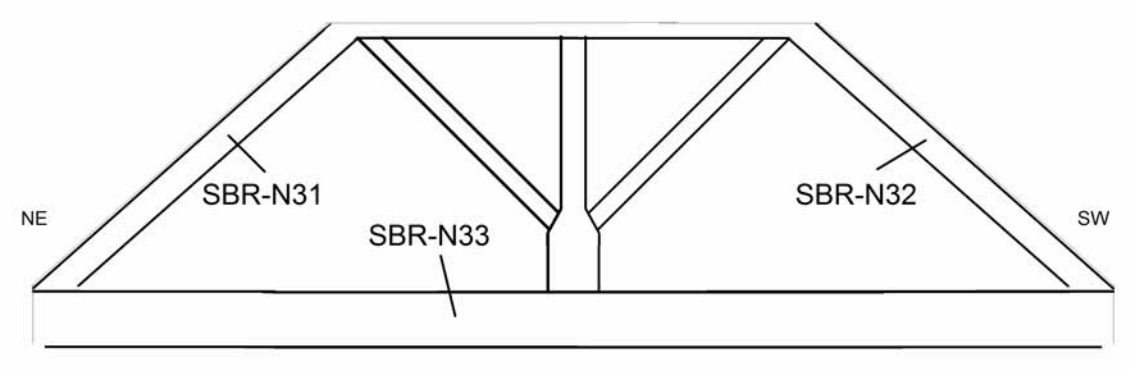

Figure 17: Sketch of the truss in the north-rear range, showing the location of samples SBR-N31–33

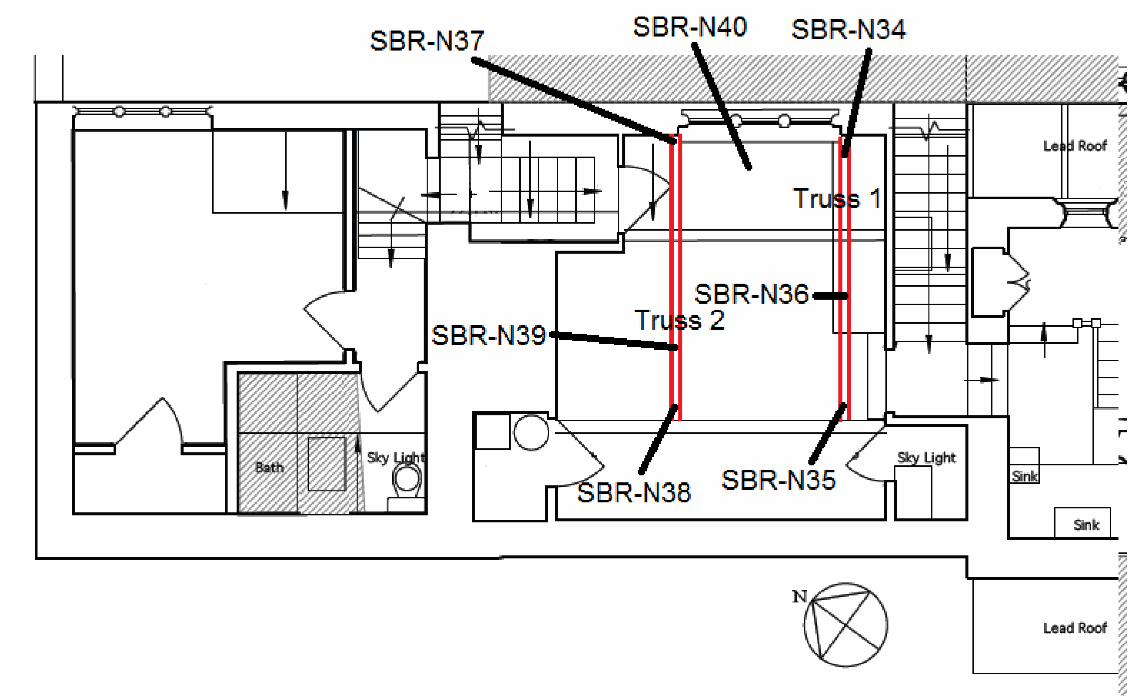

Figure 18: First-floor plan showing the position of trusses in the south-rear range and the location of samples SBR-N34–40 (Blackett-Ord Conservation)

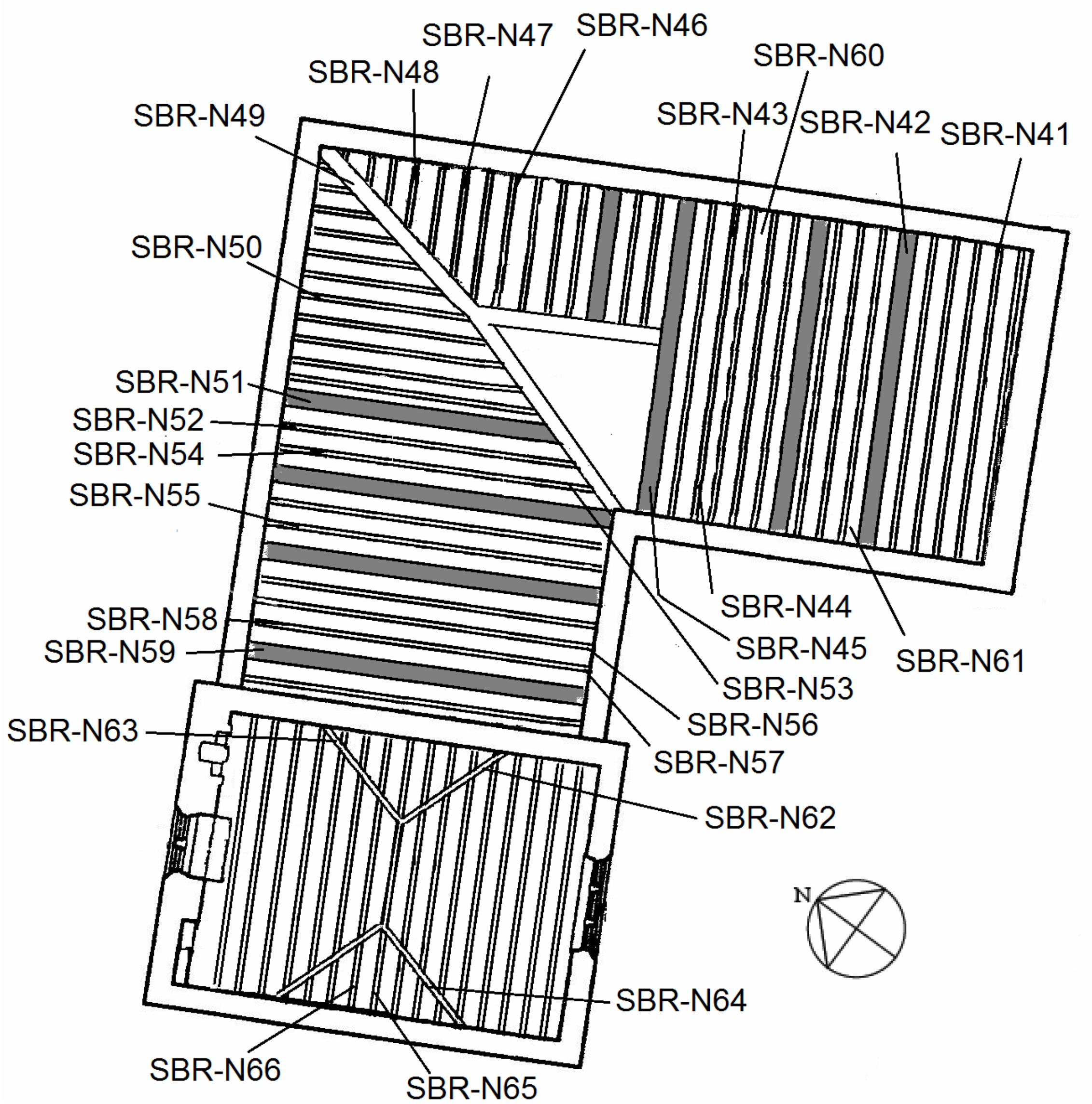

Figure 19: First-floor plan, showing the location of samples SBR-N41–66 (Blackett-Ord Conservation)

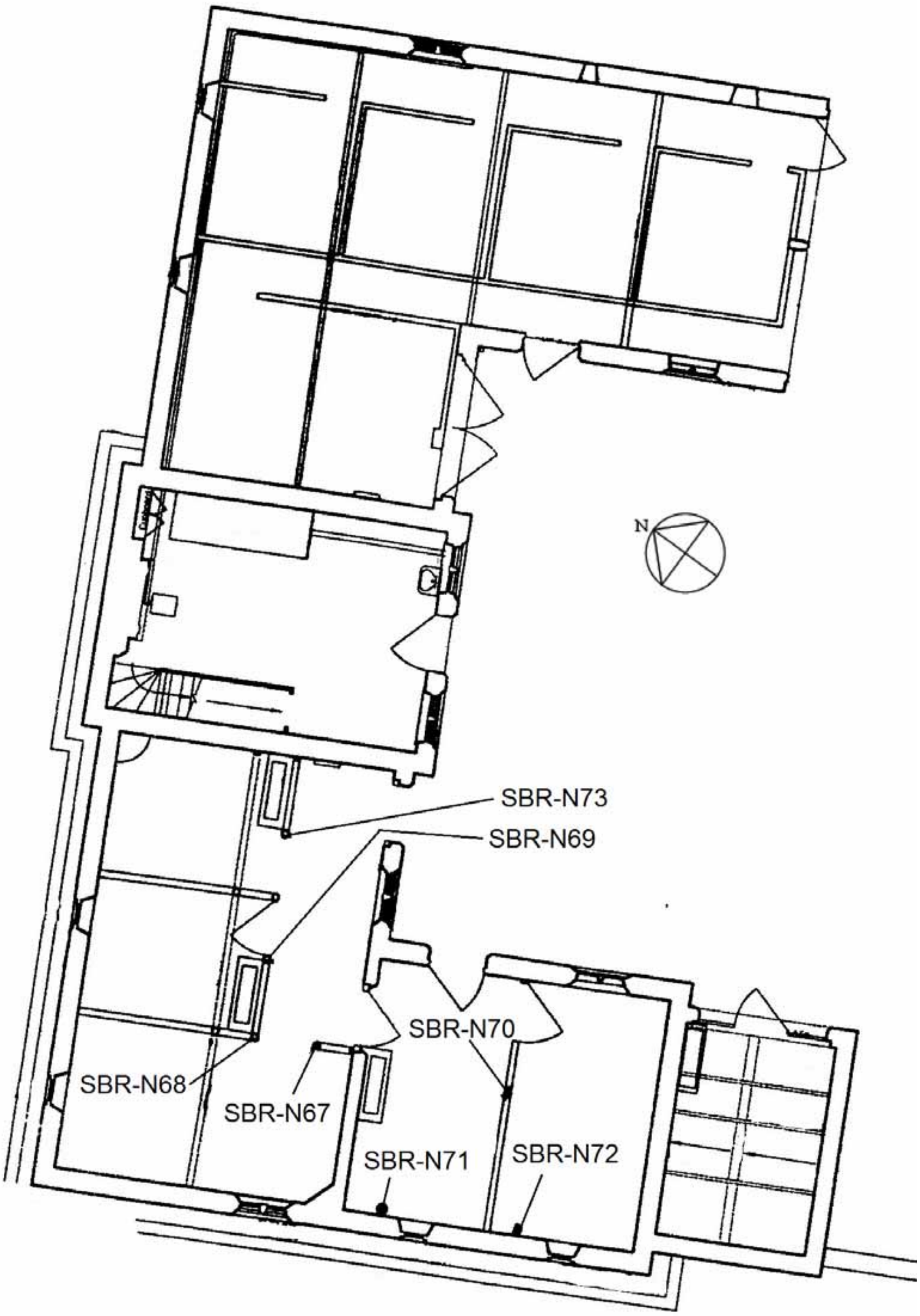

Figure 20: Ground-floor plan of the coach/mash houses and stables, showing the location of samples SBR-N67–73

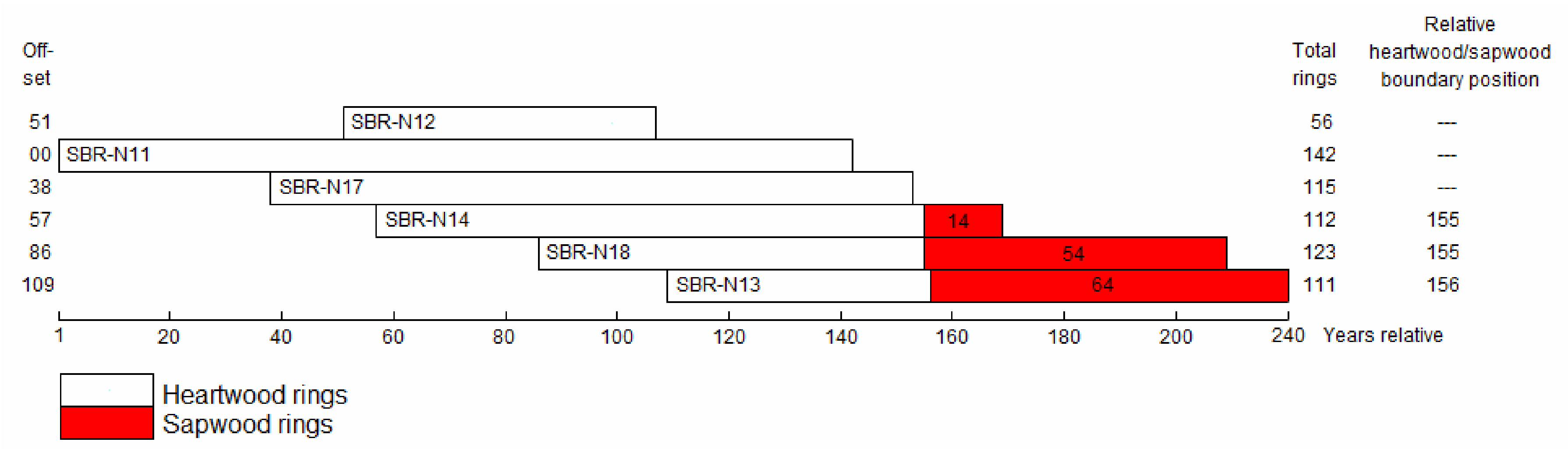

Figure 21: Bar diagram of samples in site sequence SBRNSQ01

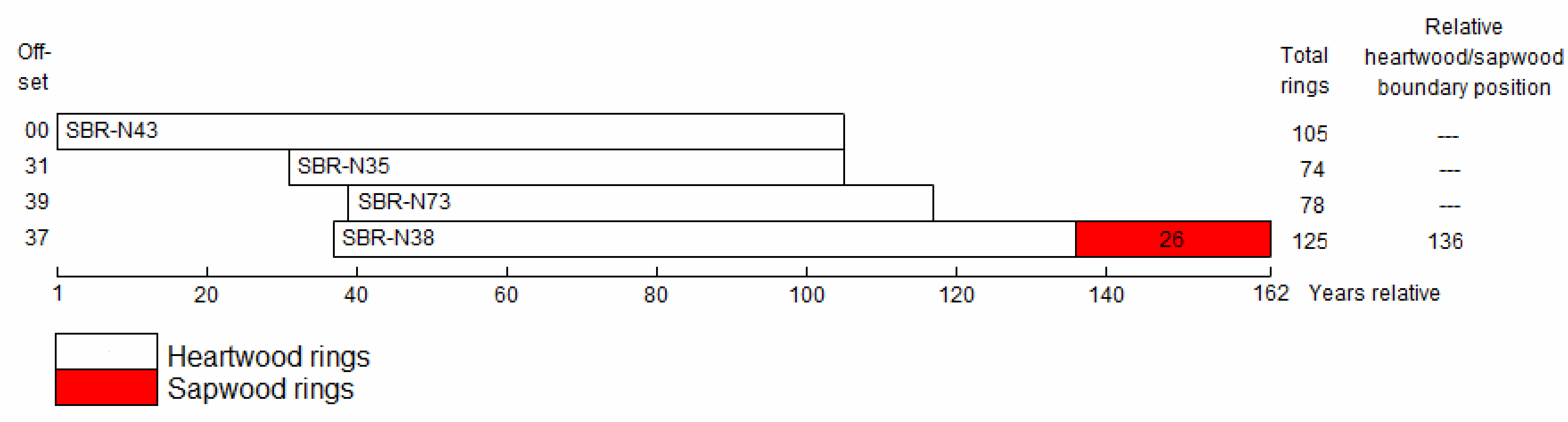

Figure 22: Bar diagram of samples in site sequence SBRNSQ02

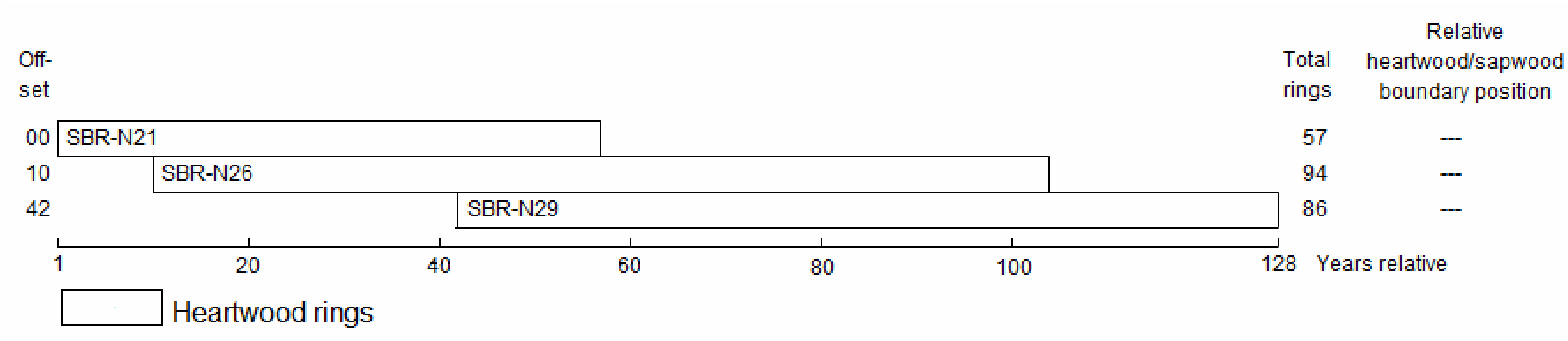

Figure 23: Bar diagram of samples in site sequence SBRNSQ03

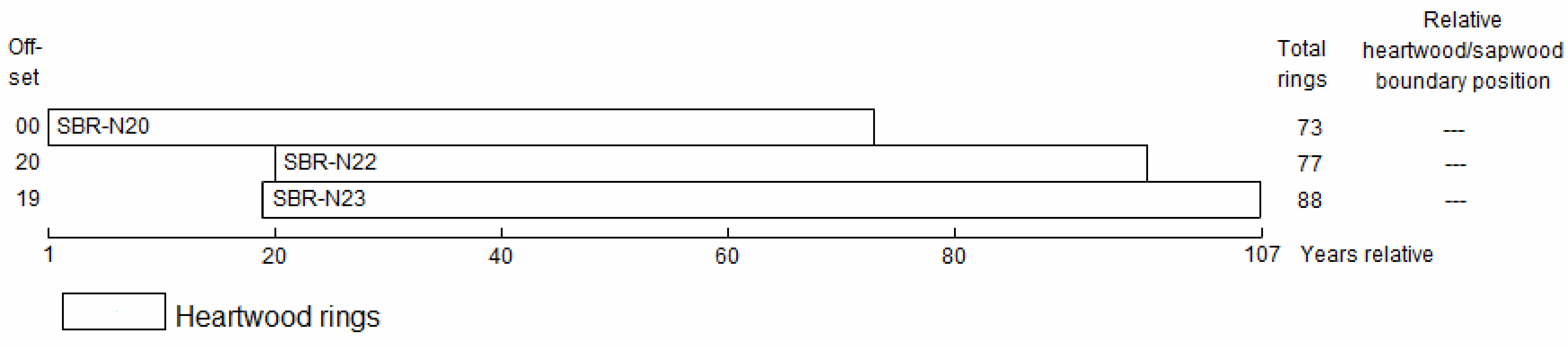

Figure 24: Bar diagram of samples in site sequence SBRNSQ04

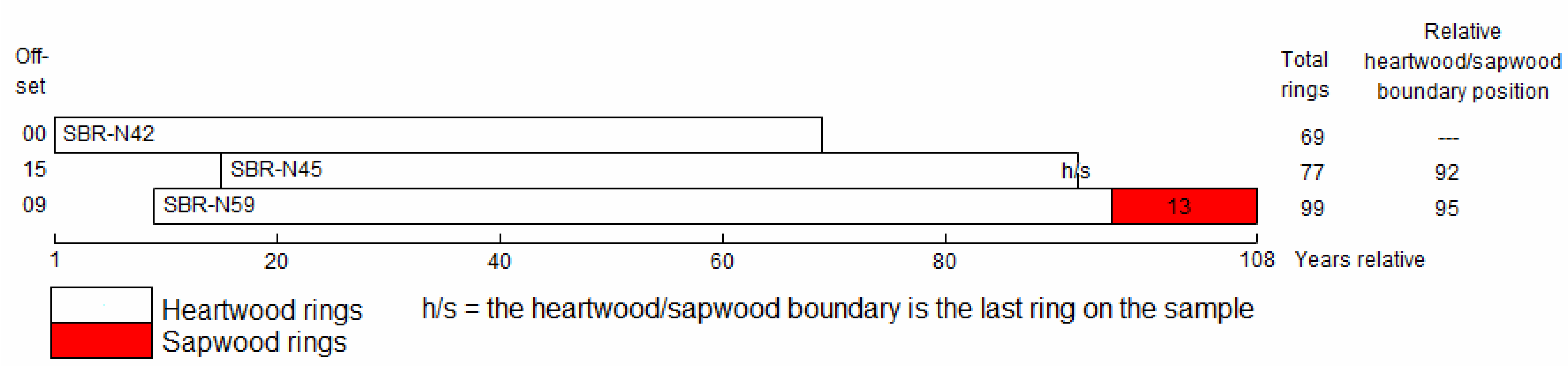

Figure 25: Bar diagram of samples in site sequence SBRNSQ05

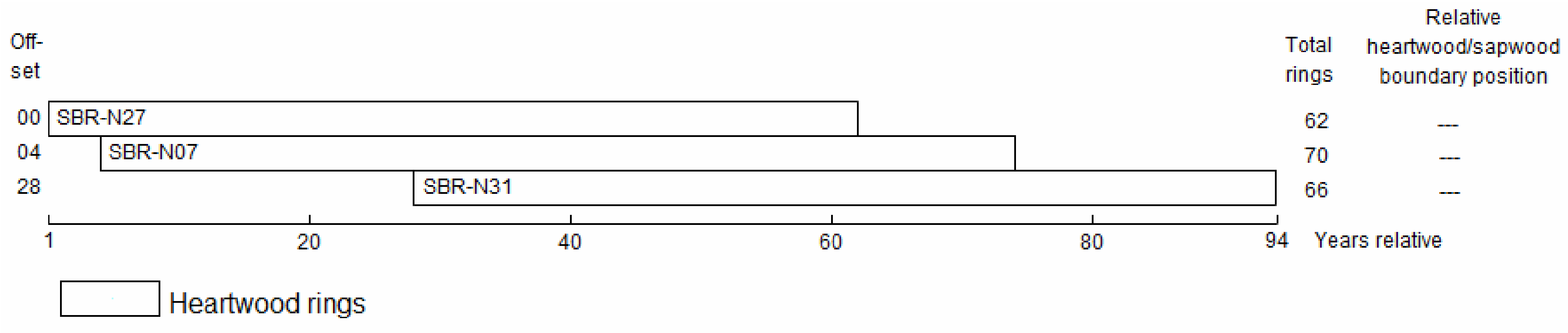

Figure 26: Bar diagram of samples in site sequence SBRNSQ06

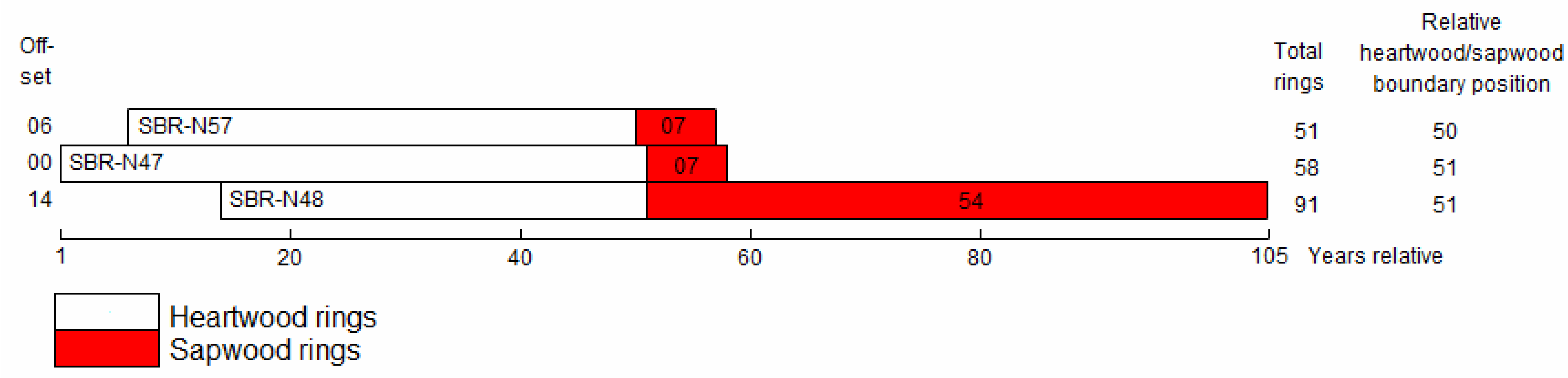

Figure 27: Bar diagram of samples in site sequence SBRNSQ07

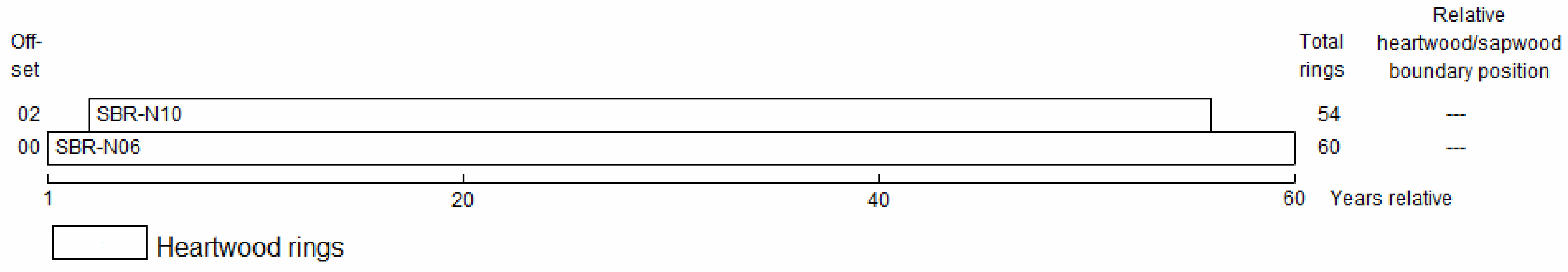

Figure 28: Bar diagram of samples in site sequence SBRNSQ08

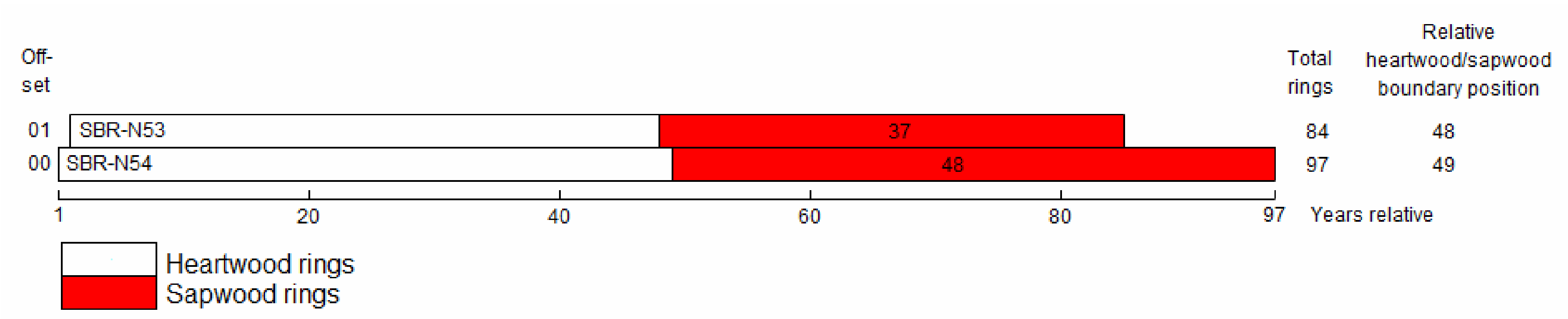

Figure 29: Bar diagram of samples in site sequence SBRNSQ09

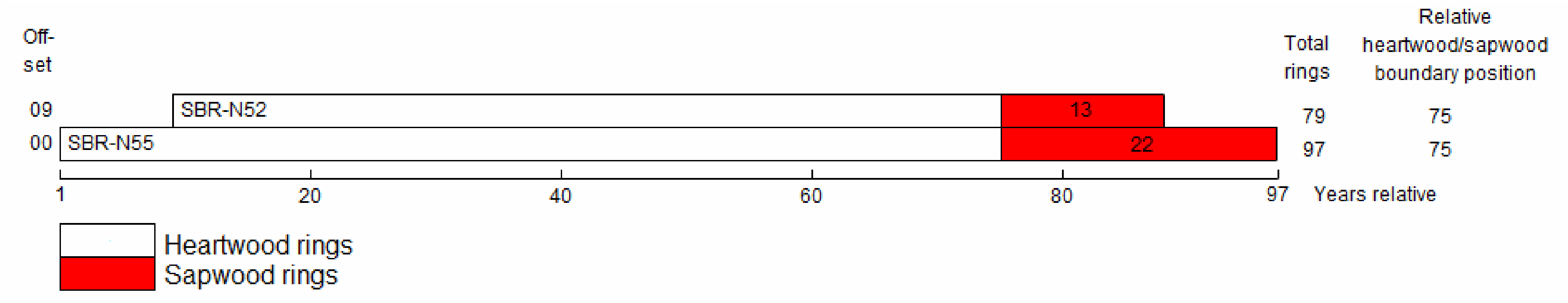

Figure 30: Bar diagram of samples in site sequence SBRNSQ10

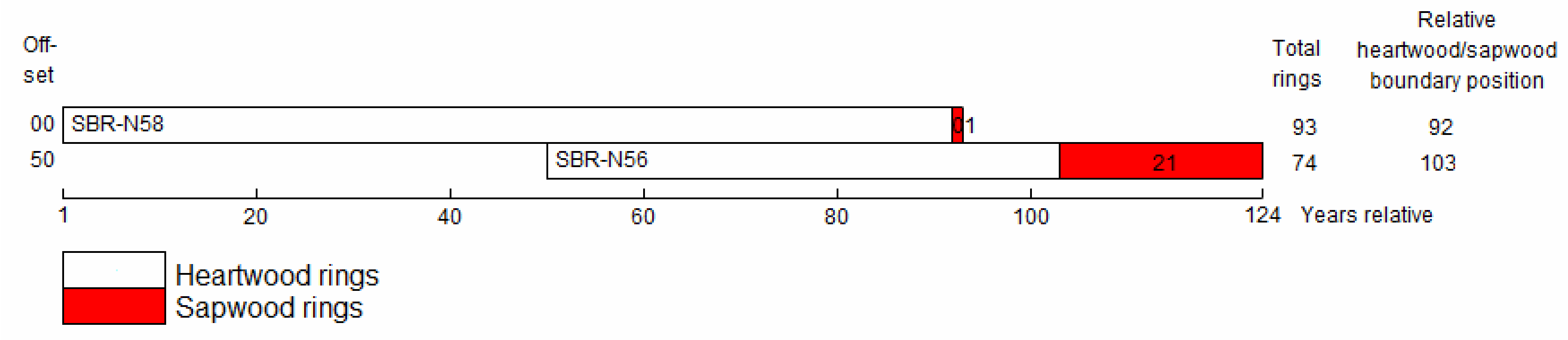

Figure 31: Bar diagram of samples in site sequence SBRNSQ11

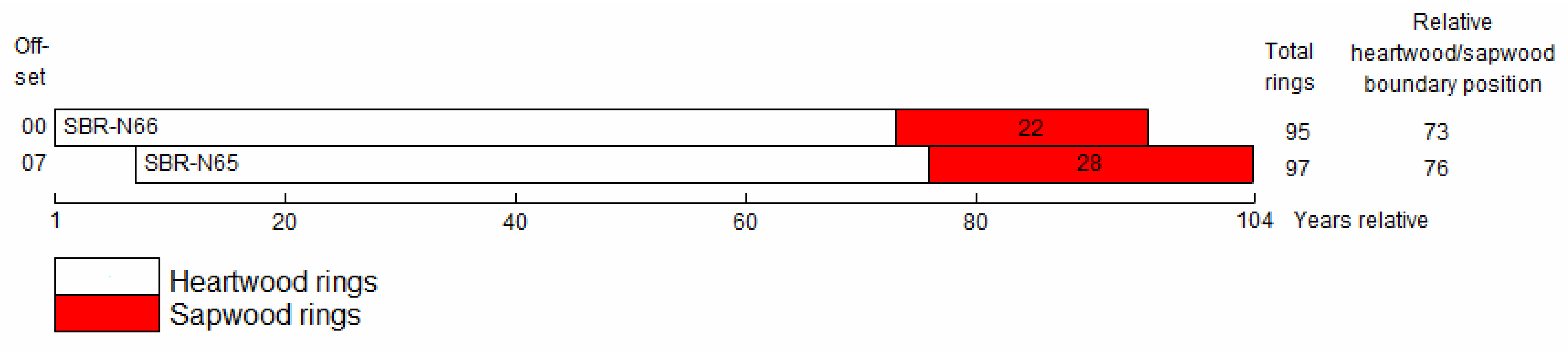

Figure 32: Bar diagram of samples in site sequence SBRNSQ12

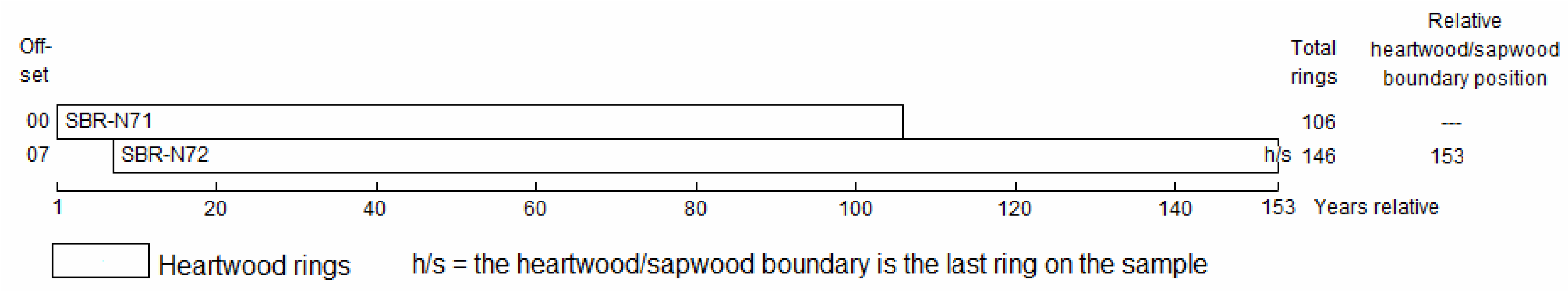

Figure 33: Bar diagram of samples in site sequence SBRNSQ13

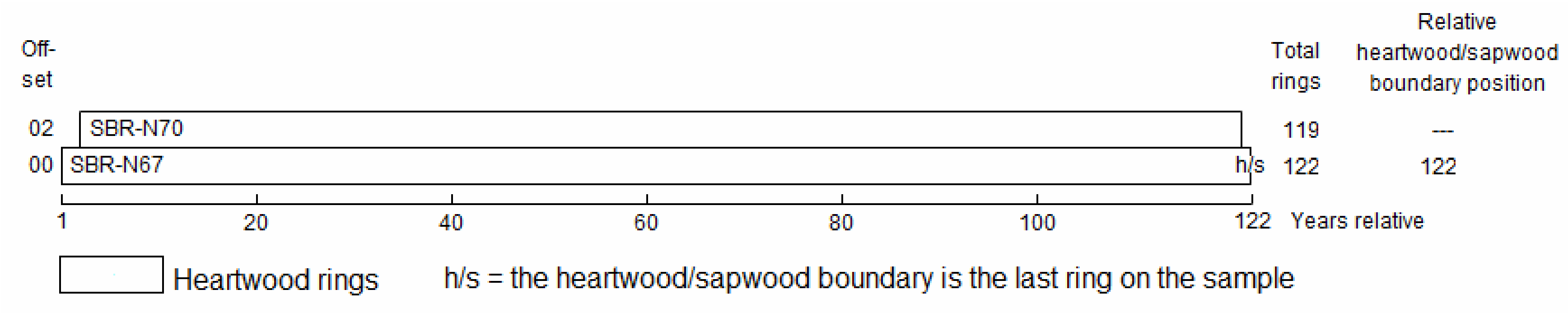

Figure 34: Bar diagram of samples in site sequence SBRNSQ14

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

SBR-N01A 152
142 152 179 172 182 154 159 148 138 134 102 121 86 94 80 89 72 77 94 105
109 104 98 110 97 112 117 93 86 102 118 83 79 84 74 38 41 41 48 34
49 44 34 28 16 23 34 31 42 42 51 24 41 28 42 35 36 31 32 42
50 60 47 49 59 32 61 73 61 69 75 64 71 72 36 57 53 47 47 54
73 61 63 45 35 32 37 26 34 27 47 49 56 58 49 47 57 56 56 45
58 49 42 39 48 51 42 49 67 54 47 41 68 89 81 54 58 53 57 63
78 64 65 49 37 24 19 45 37 46 52 55 66 99 88 85 113 80 62 38
37 28 35 63 52 49 62 48 34 32 42 51
SBR-N01B 152
142 152 185 182 181 155 157 151 149 139 110 122 76 104 82 81 63 84 87 108
111 105 106 112 96 107 112 107 86 101 112 89 82 81 70 41 46 35 47 40
54 36 31 32 16 35 36 25 38 41 42 22 40 44 40 35 34 31 31 46
49 56 46 43 56 37 59 72 61 75 70 63 76 68 36 55 57 54 52 44
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

1. Inspecting the Building and Sampling the Timbers. Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

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

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

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

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

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

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

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

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

t-value/offset Matrix

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

Bar Diagram

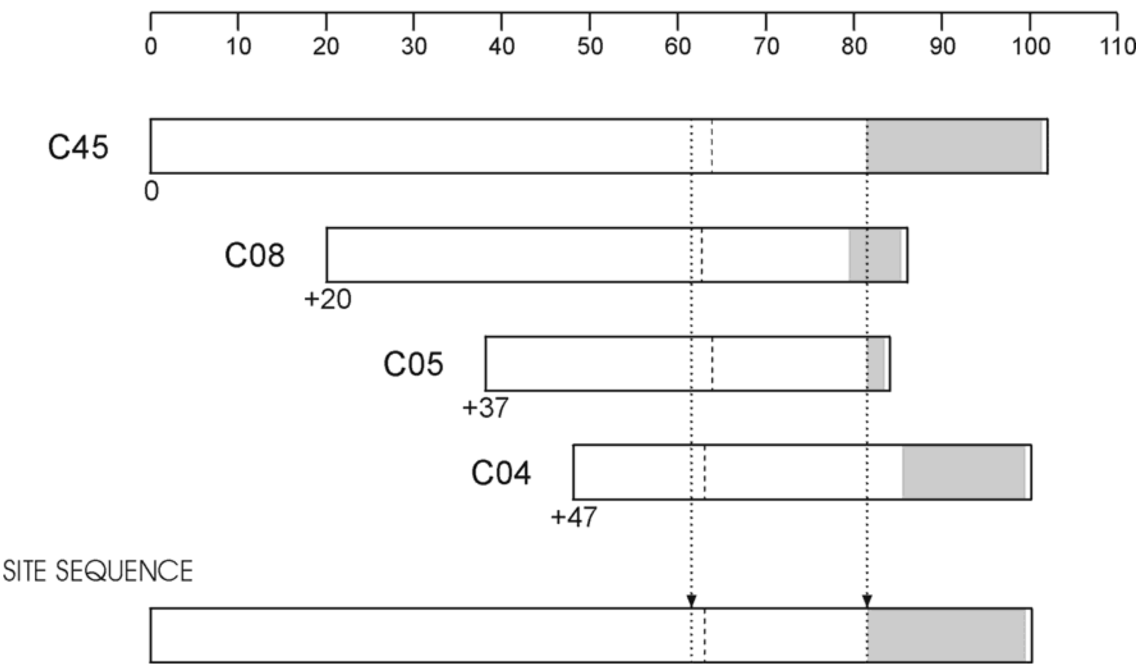


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

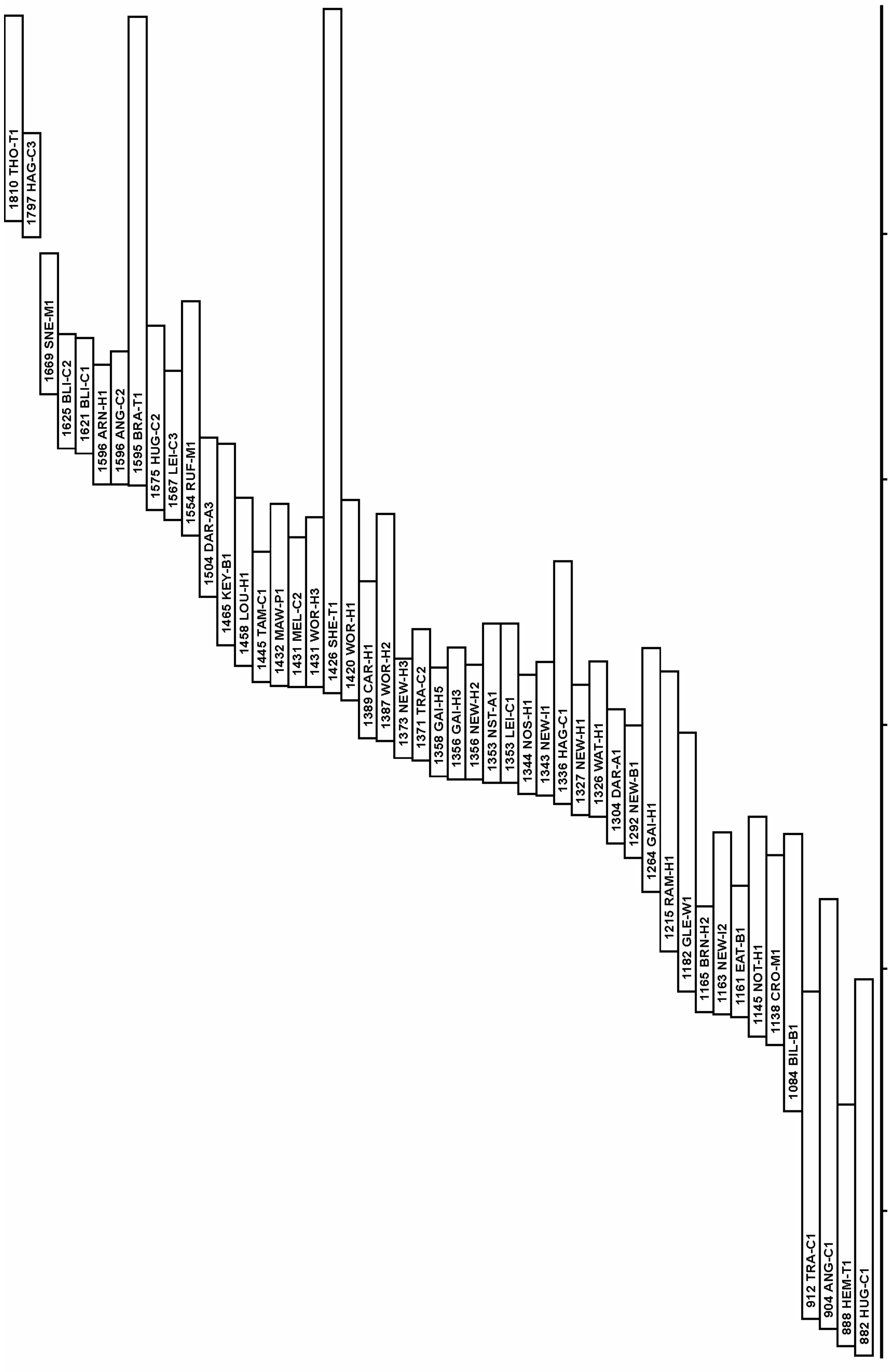
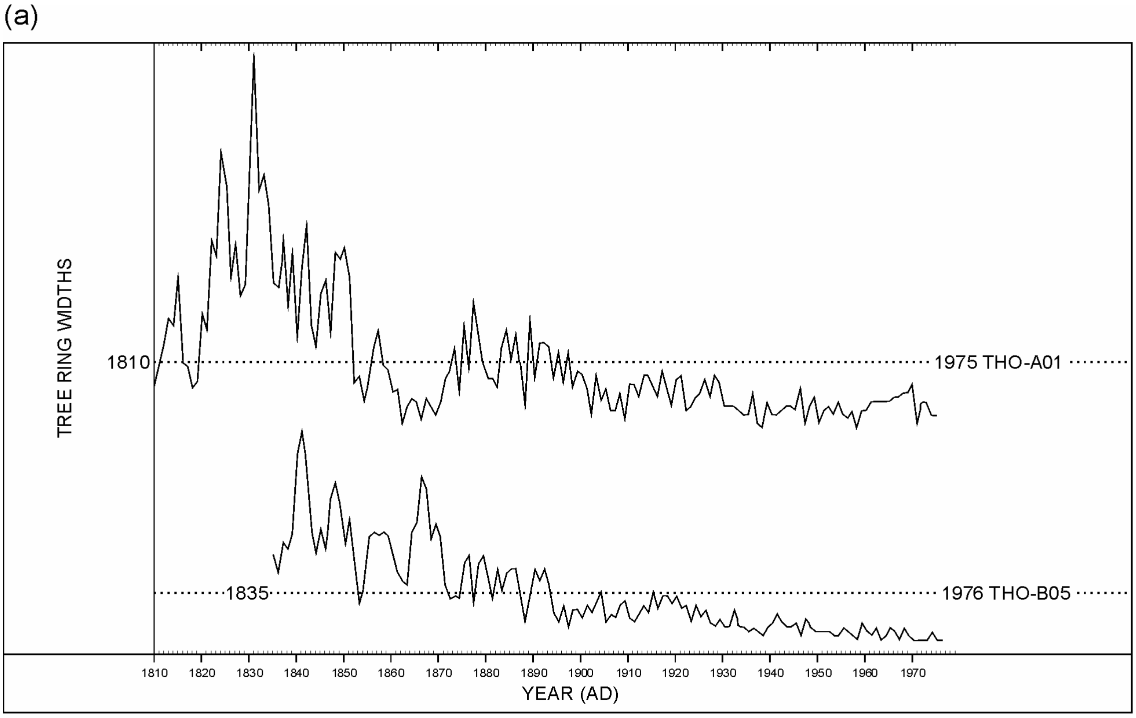


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



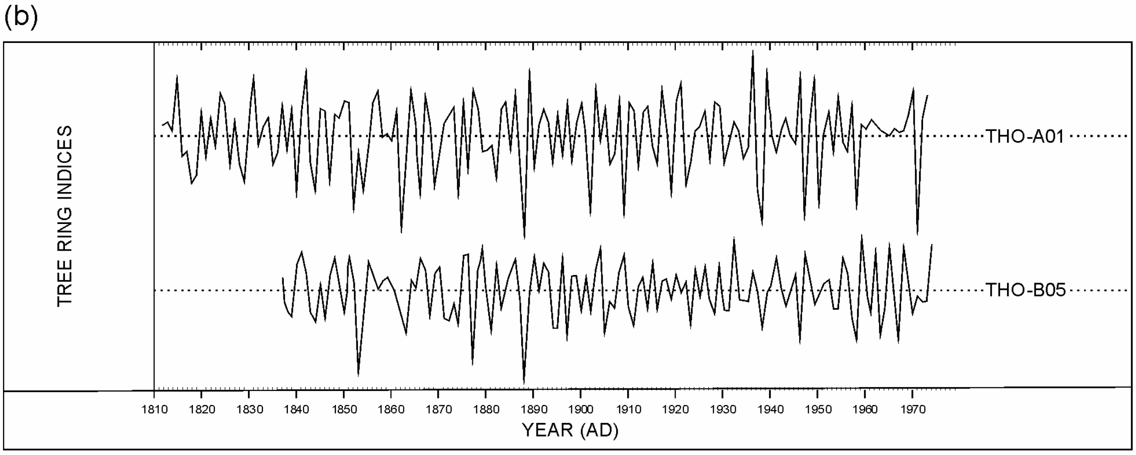


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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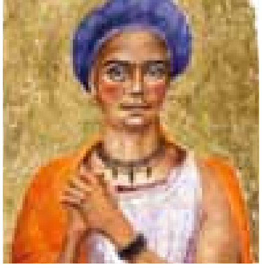


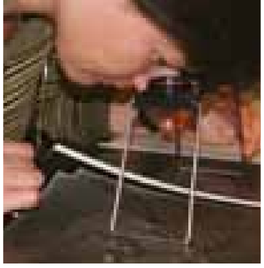


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