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Church of St George, Church Lane, Modbury, Devon

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

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Research Report Series no. 70-2017

Cover: Church of St George, Modbury. The south pitch of the vestry roof during repairs. Photograph Robert Howard.

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CHURCH OF ST GEORGE
CHURCH LANE
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NGR: SX 65604 51548

ISSN 2398-3841 (Print)
ISSN 2059-4453 (Online)

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SUMMARY
Dendrochronological analysis was undertaken on 68 of the 90 core samples obtained from timbers in the nave, north aisle, chancel, Lady Chapel, and vestry roofs of the Church of St George, Modbury. The remaining 22 samples were found to have too few rings for reliable dating. This analysis produced two site chronologies. The first site chronology comprises 48 samples with an overall length of 198 rings and includes timbers from all five roofs sampled. These rings were dated as spanning the years AD 1343–1540. Interpretation of the sapwood on these dated samples suggests that all are broadly coeval with the majority likely to have been felled in the mid-sixteenth century. This indicates a major episode of reroofing of the church undertaken in the mid-sixteenth century. A second site chronology of two samples, 101 rings long, could not be dated. Eighteen of the measured samples remain ungrouped and undated.

CONTRIBUTORS
Alison Arnold, Robert Howard, and Cathy Tyers

ACKNOWLEDGEMENTS
Mr Alex Hammerstein (Churchwarden) is thanked for his unstinting help in advancing this project and for his help in arranging access for sampling. Jeremy Chadburn (Chadburn Conservation Architect) is also thanked for his help, particularly for the provision of plans and drawings used in this report. Beki Burns, and subsequently Shahina Farid (Historic England Scientific Dating Team) commissioned and facilitated this programme of tree-ring analysis.

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INTRODUCTION

The Grade 1 listed parish Church of St George, Modbury, Devon (Figs 1a–c) was formerly a dependency of Modbury Priory (List Entry Number: 1108059). It is a large church, and prominent landmark, comprising a tower and spire to the west, nave with north and south aisles to which a two-storey porch is attached to the latter, north and south transepts, and a chancel flanked by the vestry and Lady Chapel (Fig 2a). The main body of the church is fourteenth century and is constructed of coursed rubble with granite dressings beneath slate roofs. The tower has angle buttresses but has no battlements or transitional stage to the broach spire above which is one tier of small dormers (Cherry and Pevsner 1989). This is reputed to have been struck by lightning in AD 1621 and subsequently rebuilt in its original fourteenth century form. It is believed that refenestration occurred in the fifteenth century. The nave has a wagon roof, continuous through the crossing bay, as do the north and south aisles, north and south transepts, the Lady Chapel, the Vestry, and the chancel.

The Church of St George was placed on the Heritage at Risk Register in 2013 with the roofs being described as being in poor condition with internal cracking and damp areas and the tower, as damp with water ingress to the ringing chamber. A Heritage Lottery Fund grant, under the Grants for Places of Worship scheme, was awarded in 2015 for an extensive programme of roof repairs and restoration.

SAMPLING

Dendrochronological analysis was initially requested by Francis Kelly (Historic England Inspector of Historic Buildings and Areas) prior to his retirement, and subsequently followed through by Annie Evans (Historic England Heritage at Risk Architect), in order to enhance understanding of the historical development of the church and hence inform advice and significance.

The programme of repairs to the roofs involved the sequential stripping of tiles from different roof areas of the church, the underlying timber structure of the wagon roofs, thus, being revealed (Figs 2a–d).

From the timbers exposed during the progressive stages of the roof repair programme a total of 90 samples was obtained by coring. These samples were obtained during a series of site visits as the timbers of the various roofs were exposed by the works, the general location of group of samples being shown in Figure 3. It was hoped to obtain samples from all roof areas but given the speed of stripping and reroofing, and the limited amount of repair work required in certain areas, sampling was, in some cases, restricted, or simply not possible; the south aisle roof being the most notable unsampled area. Each sample was given the code MOD-A (for Modbury, site 'A') and numbered 01–90 (Table 1). The timbers have been located by reference to their frame number within each roof, always counting from the east end westwards, and being then, further identified on a north–south basis as appropriate. A typical truss, identifying the timber members, is illustrated in Figure 4.

ANALYSIS AND RESULTS

Each of the 90 samples obtained from the Church of St George was prepared by sanding and polishing. It was seen at this time that a total of 22 samples had less than the 40 rings here deemed necessary for reliable dating and they were rejected from this programme of analysis. The annual growth ring widths of the remaining 68 samples were, however, measured, these data being given at the end of this report. The 68 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process resulting in the production of two groups of cross-matching samples.

The first group comprises 48 samples, these cross-matching with each other as shown in Figure 5. These 48 cross-matching series were combined at their indicated offset positions to form site chronology MODASQ01, this having an overall length of 198 rings. Site chronology MODASQ01 was then compared to an extensive corpus of reference chronologies for oak, this indicating a consistent and repeated match when the date of its first ring is AD 1343 and the date of its last measured ring is AD 1540 (Table 2).

The second group comprises two samples, these cross-matching with each other as shown in Figure 6. These two samples were also combined at their indicated offset positions to form site chronology MODASQ02, this having an overall length of 101 rings. Site chronology MODASQ02 was also compared to an extensive corpus of reference chronologies for oak but there was no satisfactory repeated cross-matching at any position and these two samples must, therefore, remain undated.

The two site chronologies, thus, created, MODASQ01 and MODASQ02, were compared with the 18 remaining measured but ungrouped samples. There was, however, no further satisfactory cross-matching. These 18 ungrouped samples were then compared individually with the corpus of reference chronologies for oak but again, there was no reliable cross-matching and, thus, all 18 samples remain undated.

INTERPRETATION

Timbers from all five areas of roof sampled have been dated (Fig 7). However, none of the 48 dated series in site chronology MODASQ01 retain sapwood complete to the bark, the timbers having been heavily defrassed at some time in the past, and it is, thus, not possible to determine precisely when any individual tree was cut. A number of the samples do, however, retain the heartwood/sapwood boundary (Figs 5 and 7; Table 1), this indicating that it is only the sapwood rings that have been lost. Using a sapwood estimate of 15–40 rings (the 95% confidence interval) it is, thus, possible to calculate estimated felling date ranges within which it is most likely that the trees from which these timbers were derived were felled. It is clear that all of the dated timbers are likely to be broadly coeval (Fig 5) but the nature of the roofs and their constituent elements means that a large number of relatively small scantling timbers are required and, hence, the timbers derived from larger trees will be missing potentially significant amounts of heartwood, as well as the sapwood, lost during conversion of the tree into a series of timber elements. The overall variation in the heartwood/sapwood boundary dates ranges from AD 1511 (MOD-A89) to AD 1540 (MOD-A55) indicating an earliest estimated felling date range of AD 1526–51 and an estimated latest felling date range of AD 1555–80. This wide variation in the heartwood/sapwood boundary dates suggests that the trees utilised across the roofs under investigation were either felled over an extended period or represent a series of short episodes of intensive felling during the mid-sixteenth century. In this instance it is suggested that the latter may be the case as, whilst the felling date ranges obtained for individual timbers within the roofs clearly overlap, there does appear to be a possible minor progression of felling date ranges when looking at the interpretations for each of the five separate roofs given below.

None of the six dated samples from the Lady Chapel roof had retained any trace of sapwood (Fig 7; Table 1). The timbers have, thus, lost, during conversion, all of their sapwood rings and an unknown number of heartwood rings as well. They do, however, appear likely to be coeval. Thus, with a latest heartwood ring date of AD 1505 (MOD-A20), and allowing for a minimum of 15 sapwood rings, it is likely that these dated timbers were derived from trees felled after AD 1520.

One of the three dated samples from the vestry roof retained the heartwood/sapwood boundary (Fig 7; Table 1). The heartwood/sapwood boundary date is AD 1511 which gives this timber an estimated felling date range of AD 1526–51. Again, it appears likely that the other two timbers are coeval and, hence, have a similar felling date range.

Two of the eight dated samples from the chantry roof retained the heartwood/sapwood boundary (Fig 7; Table 1). The average heartwood/sapwood boundary on these two samples is AD 1519, which gives these timbers an estimated felling date range of AD 1534–59. The remaining six samples appear likely to have been more heavily trimmed during conversion with felled-after-dates ranging from AD 1471 (MOD-A37) to AD 1496 (MOD-A39). This, therefore, does not preclude these timbers from also being felled in AD 1534–59.

Three of the 11 dated samples from north aisle roof retain the heartwood/sapwood boundary. The average heartwood/sapwood boundary date is AD 1523, which gives these timbers an estimated felling date range of AD 1538–63. The remaining eight timbers have felled after dates ranging from AD 1467 (MOD-A75) to AD

1522 (MOD-A70), which allows for these timbers, some again appearing likely to have been more heavily trimmed, also being felled in AD 1538–63.

Nine of the twenty dated samples from the nave roof retain the heartwood/sapwood boundary. The average heartwood/sapwood boundary date is AD 1527, which gives these timbers an estimated felling date range of AD 1542–67. The remaining timbers have felled-after dates ranging from AD 1463 (MOD-A56) to AD 1528 (MOD-A08). This again, allows for these timbers to have also been felled in AD 1542–67, with some timbers again appearing to have been quite heavily trimmed.

DISCUSSION AND CONCLUSION

Dated timbers

Tree-ring analysis of timbers to the various roofs of the Church of St George has successfully dated 48 of the 68 samples that were measured. This analysis suggests that the felling of all of the timbers represented is likely to have taken place in the mid-sixteenth century, potentially in a series of short episodes, with construction of the various roofs following on shortly after felling.

The interpretation of the results for the individual roofs suggests that work may have commenced on the vestry, and then progressed sequentially to the chancel, then to the north aisle, and finally to the nave. If this schema of work had been followed, it might be reasonable to assume that work on the Lady Chapel took place between that to the chancel and the north aisle. Without precise felling dates, potentially due to defrassing having been undertaken at some point, it is unclear how long a gap there might have been between work on individual roofs and it remains a possibility that the entire mid-sixteenth century reroofing was undertaken in a single uninterrupted programme with felling of trees having occurred over an extended period. However, as indicated above, the results obtained do perhaps intimate, by way of the levels of cross-matching noted within and between the samples from the different roofs, that there were short gaps during the reroofing programme. The overall intra-roof cross-matching of samples tends to be higher, this perhaps suggesting that the timbers for each roof may have been sourced from single woodlands or closely related group of trees, and indeed there are a number of potential same-tree derivations for timbers within the nave roof, the north aisle roof and chancel roof (see below). The inter-roof cross-matching of samples, on the other hand, tends to be slightly lower, suggesting that different woodlands or areas of woodland were used for different roofs, and that periods of felling were episodic. If the reroofing had taken place as a single continuous uninterrupted programme of work, this distinction in the sourcing of timber might be less pronounced, although it should be noted that there are some potential same-tree derivations for timbers found in the nave and north aisle roofs (see below), suggesting that these two roofs might have been replaced with little or no break in the programme of works.

Thus, while this mid-sixteenth century programme of reroofing is perhaps best seen as a single large-planned project, the actual felling of timber may well have been undertaken as a series of discrete episodes during a period of perhaps two or three decades, with the hiatus between work on some roofs, the north aisle and nave for example, perhaps being shorter than others.

Woodland sources

In some programmes of tree-ring analysis it may be possible to make a comment in respect of the location of the woodland source for the timbers used in a particular building or phase of construction. In this instance, as may be noted from Table 2, although the site chronology MODASQ01 has been cross-matched with reference material from all parts of England, there is a distinct trend for it to cross-match best with chronologies from other sites in south-west England. This is also reflected in the sub-site chronologies representing each roof, which also demonstrate no clear differences in woodland source between the different groups of timbers. Although the exact source of the timber used in this church cannot be reliably determined, this cross-matching would strongly suggest that it was all from relatively local woodland sources, and potentially discrete areas within a single source of woodland for the different roofs.

Wherever the source woodland(s) was, it is likely, as intimated above, that some trees were growing close to each other in the same copse or area of woodland. In the chancel, for example, samples MOD-A39 and MOD-A41 cross-match with a value of t=8.5, while in the nave samples MOD-A03 and MOD-A61 cross-match with a value of t=8.6, and in the north aisle samples MOD-A69 and MOD-A73 cross-match with a value of t=8.3, these values suggesting the respective pairs of timbers were sourced from trees growing relatively nearby to each other. There are also, as indicated above, higher t-values suggesting that some timbers may have been derived from a single tree, although lower t-values do not preclude this possibility. Examples of these, amongst others, are in the nave MOD-A12 and MOD-A61 matching with a value of t=15.6, in the north aisle MOD-A69 and MOD-A72 matching with a value of t=17.2, in the chancel MOD-A36 and MOD-A49 matching with a value of t=11.5, and MOD-A12 from the nave and MOD-A70 from the north aisle matching with a value of t=13.5.

Undated timbers

The two samples of site chronology MODASQ02 remain undated but the high level of cross-matching between them (t = 8.1) does indicate that the two timbers represented are likely to be coeval. The fact that these two samples remain undated, along with the 18 ungrouped individual samples, does not necessarily mean that they are not of mid-sixteenth century date. As may be seen from Table 1, although some of these undated samples have higher numbers of rings (the longest ungrouped/undated sample, MOD-A76, having 73 rings), the majority tend towards lower numbers of rings making successful dating less likely. In addition, some of the samples, MOD-A82 for example, also show some distortion to their growth rings, which will hamper successful cross-matching and dating. It should also be noted that it is common to find that a percentage of apparently suitable measured series cannot be successfully grouped and dated from a phase or structure even though all other evidence points to them being coeval and, in this respect, the Church of St George, with over 70% of its measured samples dated, may be regarded as a successful analysis.

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TABLES

Table 1: Details of tree-ring samples from St George's Church, Modbury, Devon

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Nave roof - south side					
MOD-A01	South rafter, frame 4	103	no h/s	1380	------	1482
MOD-A02	South lower archbrace, frame 6	157	h/s	1365	1521	1521
MOD-A03	South lower archbrace, frame 7	139	no h/s	1369	------	1507
MOD-A04	South rafter, frame 8	nm	---	------	------	------
MOD-A05	South rafter, frame 9	85	h/s	1439	1523	1523
MOD-A06	South lower archbrace, frame 9	56	no h/s	1400	------	1455
MOD-A07	South rafter, frame 10	79	h/s	1447	1525	1525
MOD-A08	South rafter, frame 15	99	no h/s	1415	------	1513
MOD-A09	South rafter, frame 17	145	no h/s	1367	------	1511
MOD-A10	South rafter, frame 19	46	no h/s	------	------	------
MOD-A11	South rafter, frame 21	119	no h/s	1393	------	1511
MOD-A12	South rafter, frame 23	138	no h/s	1376	------	1513
MOD-A13	South rafter, frame 24	nm	---	------	------	------
MOD-A14	South lower archbrace, frame 32	73	h/s	1445	1517	1517
MOD-A15	South rafter, frame 33	60	no h/s	------	------	------
	Lady Chapel roof					
MOD-A16	South rafter, frame 1	nm	---	------	------	------
MOD-A17	Collar, frame 1	56	no h/s	1448	------	1503
MOD-A18	North rafter, frame 2	nm	---	------	------	------
MOD-A19	Collar, frame 3	54	no h/s	------	------	------
MOD-A20	Collar, frame 4	83	no h/s	1423	------	1505
MOD-A21	North rafter, frame 6	50	no h/s	1433	------	1482
MOD-A22	Collar, frame 6	78	no h/s	1413	------	1490
MOD-A23	Collar, frame 7	nm	---	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Lady Chapel roof (continued)					
MOD-A24	Collar, frame 8	nm	---	------	------	------
MOD-A25	North rafter, frame 10	70	no h/s	1433	------	1502
MOD-A26	South rafter, frame 11	nm	---	------	------	------
MOD-A27	Collar, frame, 11	nm	---	------	------	------
MOD-A28	South lower archbrace, frame 12	44	no h/s	------	------	------
MOD-A29	North rafter, frame 13	70	no h/s	1433	------	1502
MOD-A30	South lower archbrace, frame 15	55	17	------	------	------
MOD-A31	North rafter, frame 16	70	10	------	------	------
MOD-A32	South lower archbrace, frame 16	62	h/s	------	------	------
	Chancel roof					
MOD-A33	South rafter, frame 3	68	h/s	1450	1517	1517
MOD-A34	South rafter, frame 7	nm	---	------	------	------
MOD-A35	South rafter, frame 9	nm	---	------	------	------
MOD-A36	South rafter, frame 13	67	no h/s	1412	------	1478
MOD-A37	South rafter, frame 19	77	no h/s	1380	------	1456
MOD-A38	South rafter, frame 21	50	no h/s	------	------	------
MOD-A39	South rafter, frame 22	100	no h/s	1382	------	1481
MOD-A40	South rafter, frame 24	43	h/s	------	------	------
MOD-A41	South rafter, frame 25	92	no h/s	1389	------	1480
MOD-A42	South rafter, frame 26	nm	---	------	------	------
MOD-A43	South rafter, frame 30	nm	---	------	------	------
MOD-A44	North rafter, frame 7	60	no h/s	1427	------	1486
MOD-A45	North rafter, frame 8	55	h/s	1467	1521	1521
MOD-A46	North rafter, frame 9	46	no h/s	------	------	------
MOD-A47	North rafter, frame 14	nm	---	------	------	------
MOD-A48	North rafter, frame 19	nm	---	------	------	------
MOD-A49	North rafter, frame 20	73	no h/s	1396	------	1468

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Chancel roof (continued)					
MOD-A50	North rafter, frame 24	60	no h/s	------	------	------
MOD-A51	North rafter, frame 26	nm	---	------	------	------
MOD-A52	North rafter, frame 28	nm	---	------	------	------
	Nave roof - north side					
MOD-A53	North rafter, frame 23	65	h/s	1463	1527	1527
MOD-A54	North rafter, frame 26	65	h/s	1463	1527	1527
MOD-A55	North rafter, frame 29	58	h/s	1483	1540	1540
MOD-A56	North rafter, frame 30	106	no h/s	1343	------	1448
MOD-A57	North rafter, frame 32	100	no h/s	------	------	------
MOD-A58	North rafter, frame 33	75	h/s	1458	1532	1532
MOD-A59	North rafter, frame 36	69	h/s	1460	1528	1528
MOD-A60	North rafter, frame 44	98	no h/s	------	------	------
MOD-A61	North rafter, frame 45	111	no h/s	1375	------	1485
MOD-A62	North rafter, frame 46	127	no h/s	1378	------	1504
MOD-A63	North rafter, frame 47	81	no h/s	1428	------	1508
MOD-A64	Collar, frame 47	nm	---	------	------	------
	North aisle roof					
MOD-A65	Collar, frame 1	128	h/s	1392	1519	1519
MOD-A66	Collar, frame 5	102	no h/s	1363	------	1464
MOD-A67	Collar, frame, 9	52	h/s	------	------	------
MOD-A68	North lower archbrace, frame 9	88	h/s	1431	1518	1518
MOD-A69	Collar, frame 13	130	no h/s	1366	------	1495
MOD-A70	Collar, frame 14	114	no h/s	1394	------	1507
MOD-A71	Collar, frame 17	63	no h/s	1444	------	1506
MOD-A72	Collar, frame 19	82	no h/s	1421	------	1502
MOD-A73	Collar, frame 20	75	no h/s	1432	------	1506
MOD-A74	North lower archbrace, frame 31	119	h/s	1415	1533	1533

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	North aisle roof (continued)					
MOD-A75	North lower archbrace, frame 35	98	no h/s	1355	------	1452
MOD-A76	North lower archbrace, frame 38	73	no h/s	------	------	------
MOD-A77	North lower archbrace, frame 40	85	no h/s	1379	------	1463
MOD-A78	North wallplate (east end)	nm	---	------	------	------
	Vestry roof					
MOD-A79	Collar, frame 1	84	no h/s	1395	------	1478
MOD-A80	North lower archbrace, frame 3	46	h/s	------	------	------
MOD-A81	North lower archbrace, frame 4	48	13	------	------	------
MOD-A82	North rafter, frame 5	49+	+40nm to h/s	------	------	------
MOD-A83	Collar, frame 6	nm	---	------	------	------
MOD-A84	Collar, frame 7	nm	---	------	------	------
MOD-A85	North soulace, frame 7	46	h/s	------	------	------
MOD-A86	North soulace, frame 8	nm	---	------	------	------
MOD-A87	North rafter, frame 9	nm	---	------	------	------
MOD-A88	North rafter, frame 10	54	no h/s	1439	------	1492
MOD-A89	North rafter, frame 11	53	h/s	1459	1511	1511
MOD-A90	South rafter, frame 18	50	h/s	------	------	------

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

Table 2: Results of the cross-matching of site sequence MODASQ01 and relevant reference chronologies when the first-ring date is AD 1343 and the last-ring date is AD 1540

Reference chronology	Span of chronology	*t*-value	Reference
Leigh Barton, Churchstow, Devon	AD 1345–1484	9.1	Groves 2006
Holy Cross Church, Crediton, Devon	AD 1317–1536	8.1	Tyers 2004a
Pendennis Castle, near Falmouth, Cornwall	AD 1358–1541	8.1	Tyers 2004b
Church of St Ildierna, Lansallos, Cornwall	AD 1355–1514	7.8	Arnold and Howard 2006
Church House Inn, Churchstow, Devon	AD 1397–1505	7.8	Tyers *et al* forthcoming
Warleigh House, Tamerton Foliot, Devon	AD 1367–1539	7.4	Arnold *et al* 2006
Church of St Ciricus and St Julitta, St Veep, Cornwall	AD 1352–1512	7.4	Arnold *et al* 2005b
Poltimore House, Poltimore, Devon	AD 1380–1559	7.1	Arnold *et al* 2005a

FIGURES

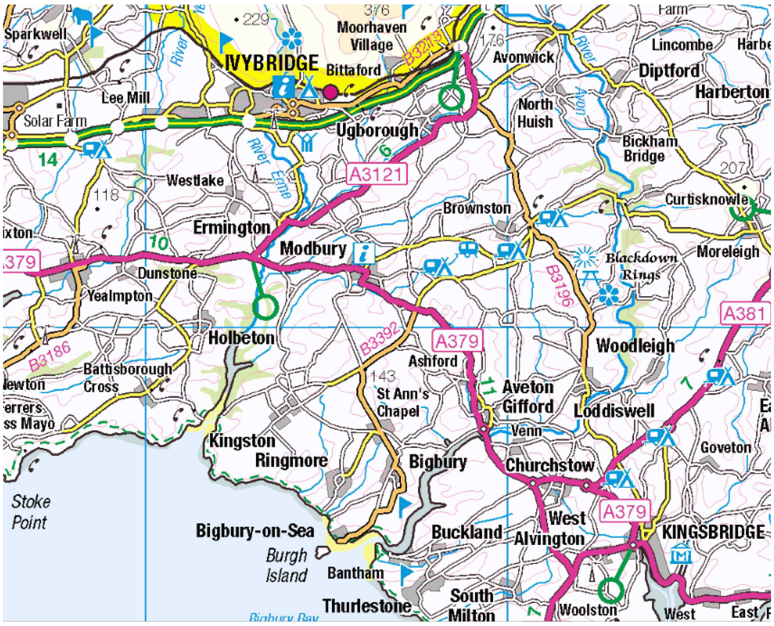


Figure 1a: Map to show the general location of Modbury, Devon. © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

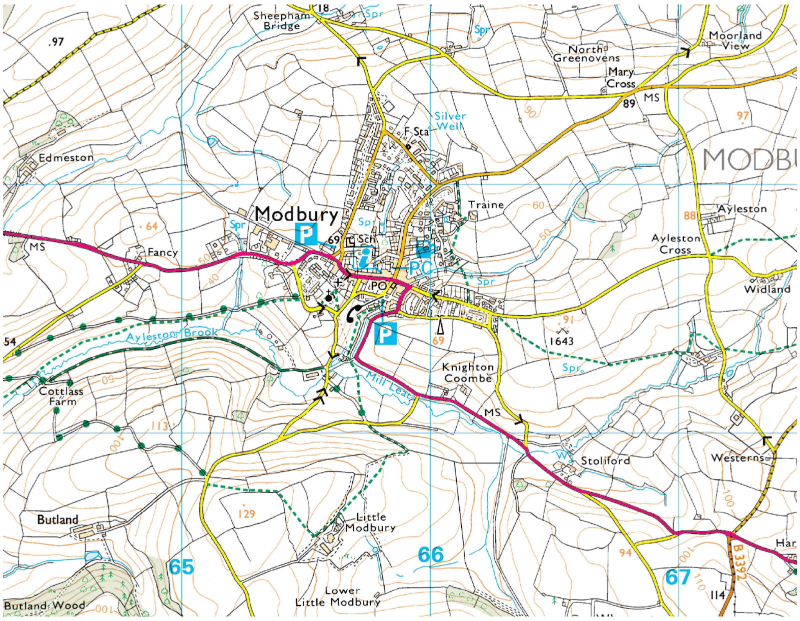


Figure 1b: Map to show the location of the Church of George, Modbury, Devon. © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

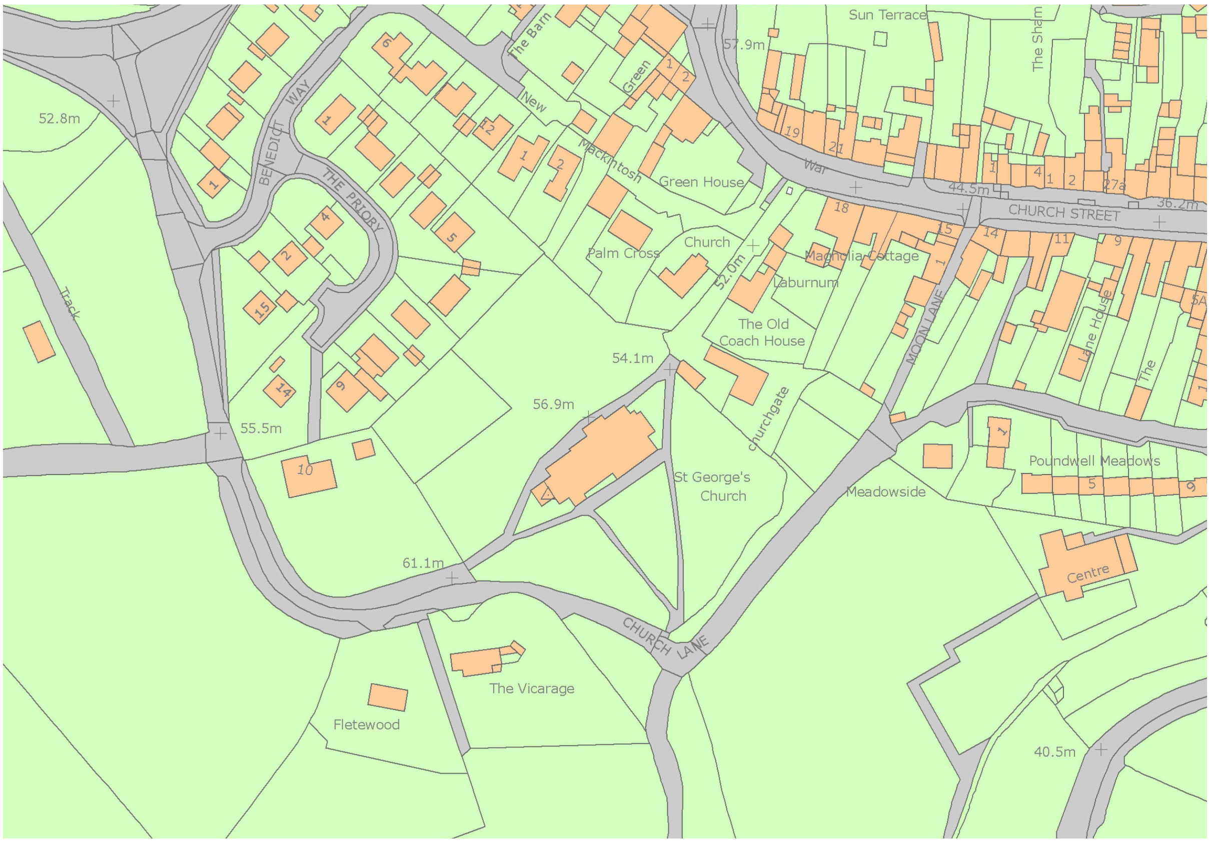


Figure 1c: Map to show the detailed location of the Church of St George, Modbury, Devon. © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2a: General view of the roofs looking east (photograph Robert Howard)

Figure 2b: The valley between the nave and the south aisle roofs during repairs (photograph Robert Howard)

Figure 2c: The north pitch to the chancel roof during repairs (photograph Robert Howard)

Figure 2d: The south pitch of the vestry roof during repairs (photograph Robert Howard)

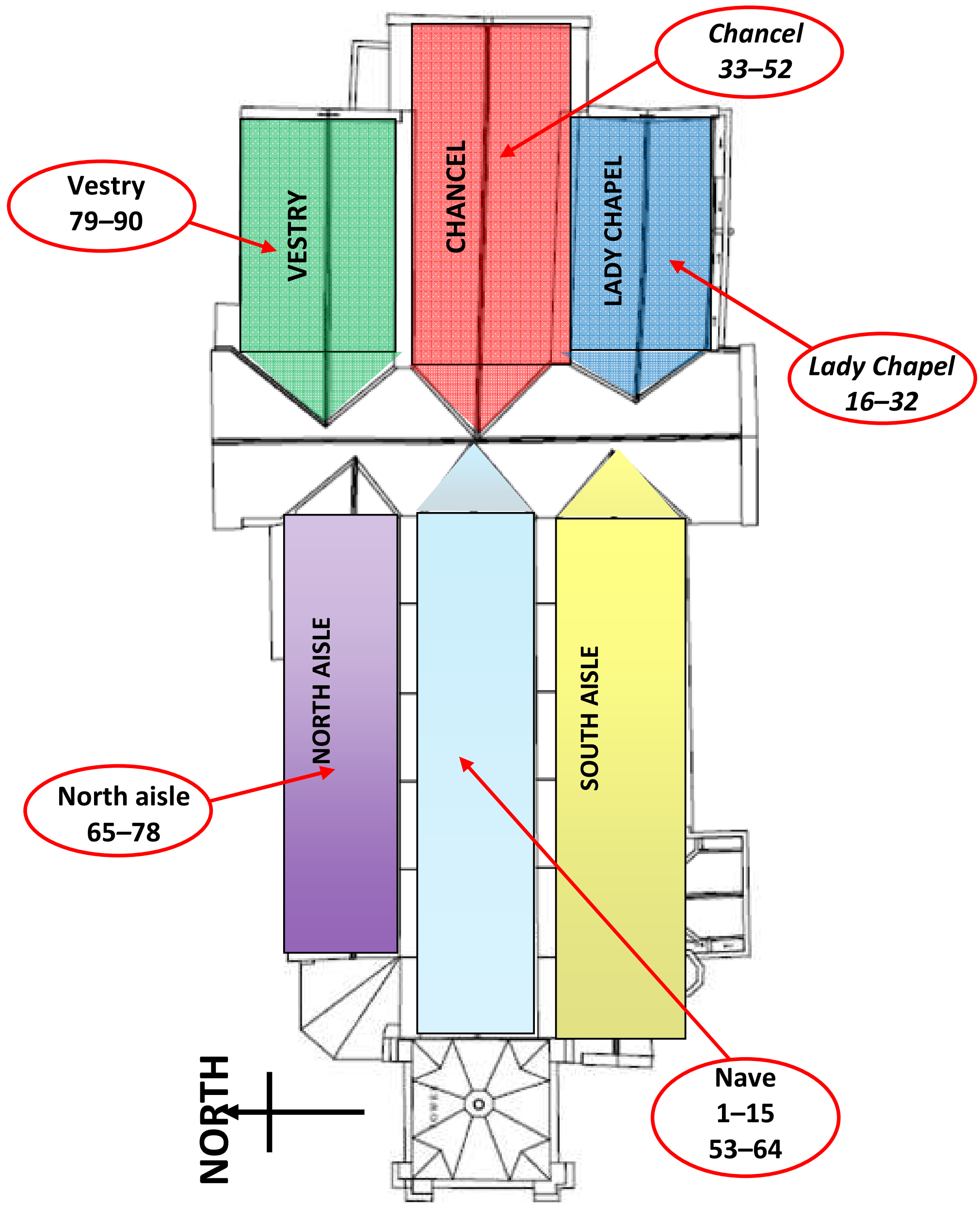


Figure 3: Plan of the roofs to help locate sampled areas (after Chadburn Conservation Architect)

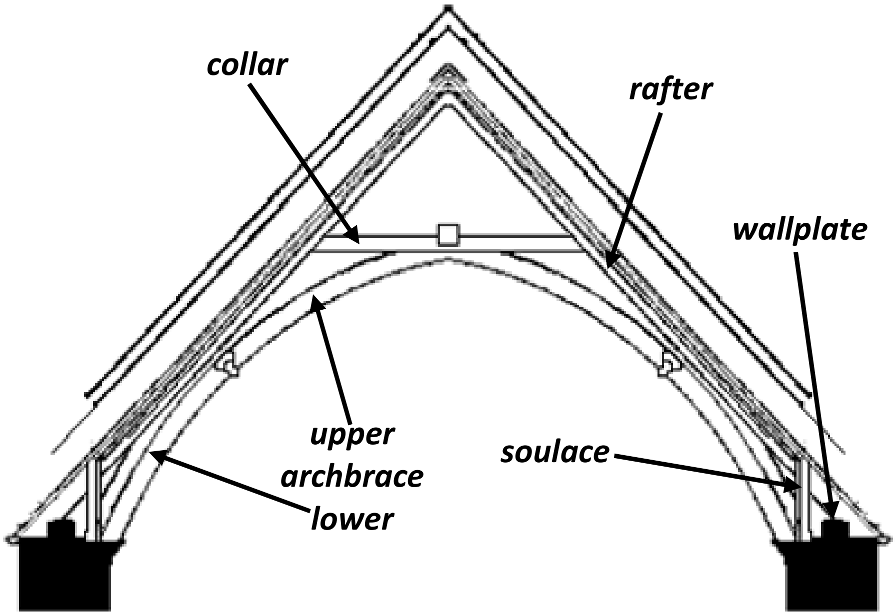
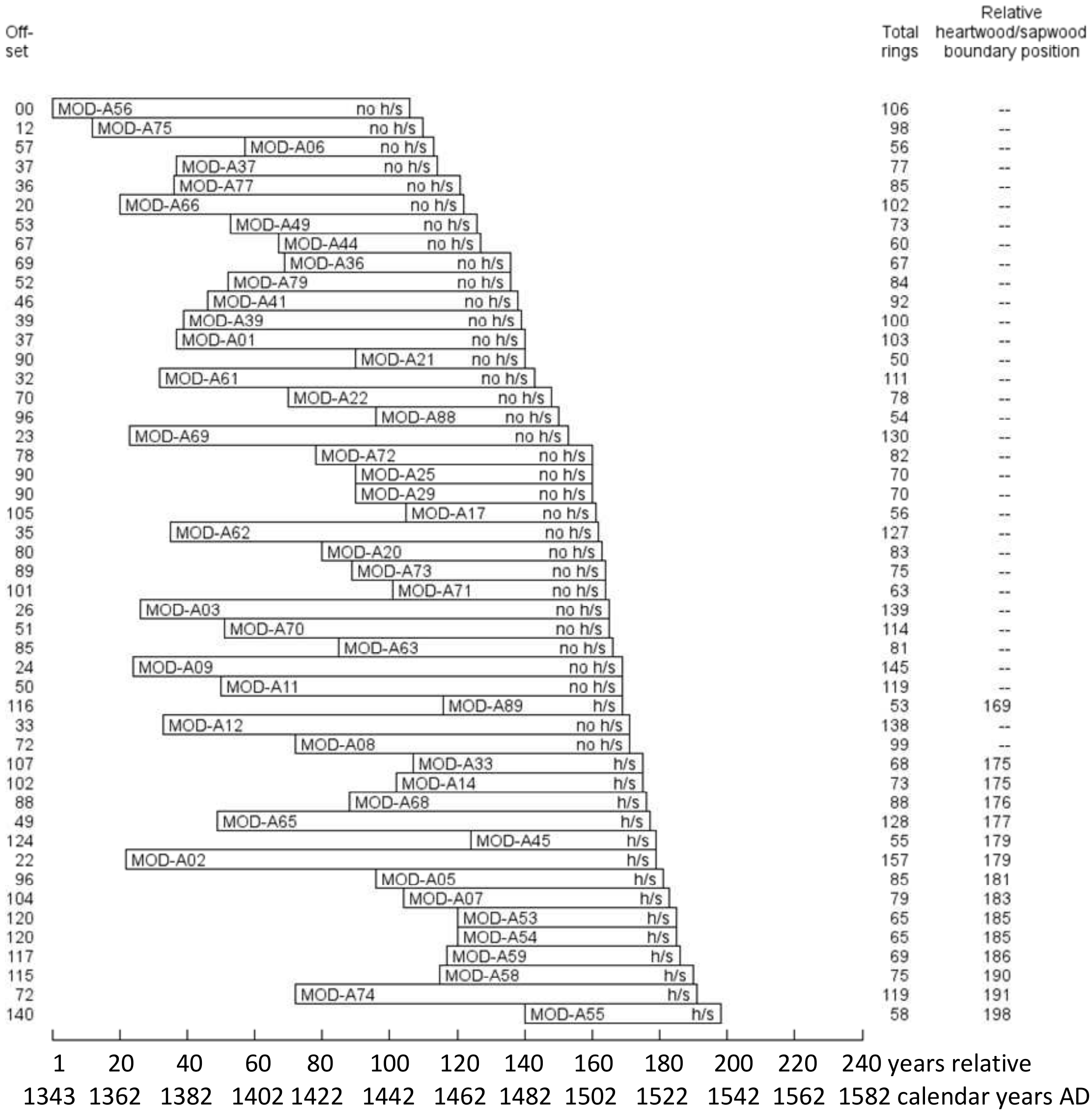
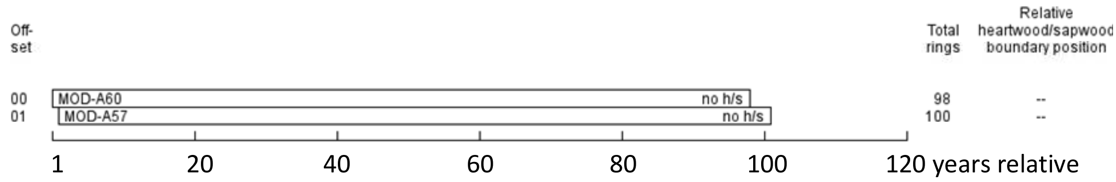


Figure 4: Schematic cross-section of a typical truss to help identify sampled timbers (after Chadburn Conservation Architect)



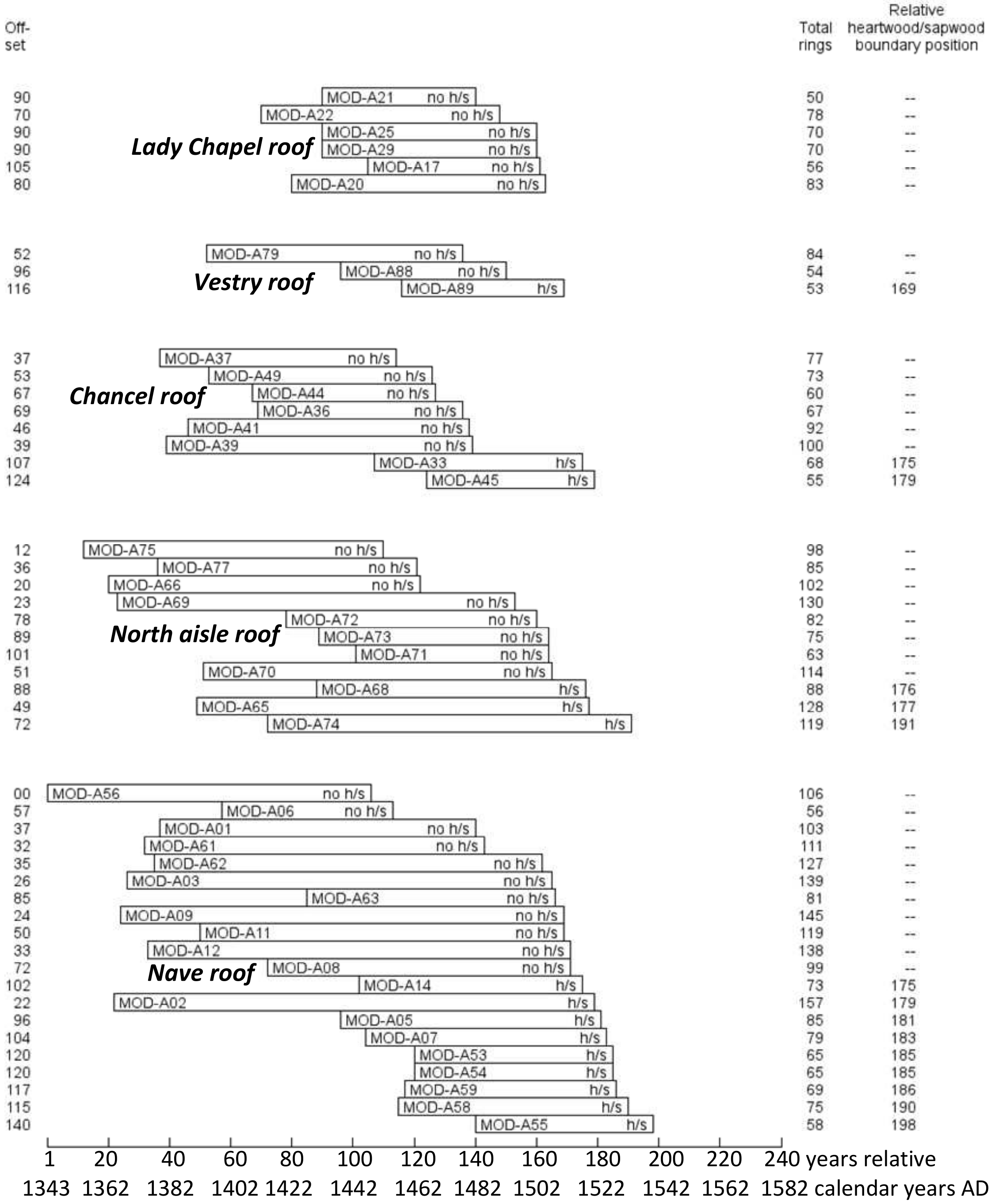
White bars = heartwood rings; h/s = heartwood/sapwood boundary

Figure 5: Bar diagram of the samples in site chronology MODASQ01



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

Figure 6: Bar diagram of the samples in site chronology MODASQ02



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

Figure 7: Bar diagram of the samples in site chronology MODASQ01 sorted by roof

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

MOD-A01A 103
93 102 85 173 129 144 171 197 184 93 57 44 58 53 55 70 101 66 78 70
54 88 88 57 87 123 78 51 85 48 67 89 100 107 116 100 71 46 45 47
53 91 67 85 101 99 83 67 73 78 85 76 105 139 91 151 92 110 78 42
79 78 89 85 60 89 109 105 64 98 75 71 80 73 106 95 62 79 89 71
71 77 103 96 113 93 115 153 155 94 153 162 196 175 135 205 156 93 119 72
107 175 179
MOD-A01B 103
85 98 92 185 121 157 168 201 183 89 61 43 52 62 54 68 101 66 78 69
71 83 75 70 76 121 71 55 81 45 64 83 107 134 101 110 73 44 42 38
53 86 67 89 89 97 95 64 71 75 92 78 108 157 76 166 84 106 78 43
83 78 88 86 53 90 118 97 66 96 79 70 76 73 107 114 71 70 95 71
60 89 102 96 107 96 95 147 146 110 156 187 195 176 134 203 170 95 114 78
98 179 182
MOD-A02A 157
161 134 130 67 93 94 66 72 106 117 100 74 67 65 63 59 69 87 95 82
51 73 64 53 51 33 34 63 73 89 75 106 64 67 82 67 73 71 105 122
139 129 116 101 81 75 56 92 122 108 90 65 47 59 53 67 106 78 101 92
92 41 61 89 81 89 74 119 92 60 110 49 96 56 51 78 53 63 62 62
101 79 105 106 92 64 82 79 79 93 87 85 84 68 53 81 90 84 75 63
66 92 90 67 73 76 56 60 51 48 73 84 52 59 50 73 63 62 43 60
87 95 76 81 42 71 62 36 53 50 57 69 53 32 43 48 43 59 50 62
62 56 45 48 52 44 43 43 53 79 37 40 34 46 70 56 90
MOD-A02B 157
145 132 134 64 90 88 69 71 103 116 98 70 76 63 63 54 72 83 93 90
48 69 64 55 53 35 37 60 73 91 73 103 66 67 78 78 66 74 101 128
139 128 119 88 71 75 58 89 126 105 91 64 50 60 52 64 107 77 99 96
79 46 66 85 83 84 88 116 92 57 105 50 97 63 54 77 60 64 64 62
96 82 107 107 90 62 82 75 82 100 77 91 84 68 55 76 90 95 75 65
73 92 88 67 75 85 65 59 48 53 72 85 43 56 54 70 64 62 42 66
80 101 79 78 41 72 65 37 45 53 53 70 54 30 39 57 40 56 51 60
60 62 40 53 50 43 42 43 54 83 39 49 32 40 77 55 93
MOD-A03A 139
95 66 57 43 50 61 97 82 112 105 97 87 68 58 121 105 94 94 85 108
76 65 87 57 77 104 122 150 115 100 103 119 121 153 169 171 156 146 133 105
92 71 110 115 174 147 187 81 75 75 71 110 116 91 142 148 125 116 102 122
100 150 144 149 143 110 134 71 134 105 78 88 93 134 112 64 98 86 70 62
84 69 51 62 46 81 64 54 78 63 42 44 57 86 84 60 67 64 64 68
43 50 42 56 51 49 42 55 37 40 35 35 53 46 34 54 55 68 68 70
33 56 56 55 122 74 86 74 79 76 69 62 54 89 93 59 75 48 82
MOD-A03B 139
101 58 59 43 52 57 103 75 116 101 107 87 71 58 113 108 99 92 90 110
74 71 85 55 80 103 123 147 116 112 110 119 116 150 166 175 153 141 121 125
91 71 104 121 173 143 200 99 71 64 71 103 122 85 141 161 118 120 100 117
107 151 142 146 139 110 129 68 137 103 85 95 110 146 125 64 107 84 78 62
76 70 57 60 54 70 66 53 78 62 50 37 50 93 82 54 71 64 57 76
38 50 45 53 54 46 40 60 29 43 38 36 52 47 31 52 58 66 64 71
40 50 63 57 121 71 87 71 76 73 72 65 50 75 104 57 68 53 89

MOD-A05A 85
331 215 355 206 285 286 346 319 400 350 225 206 221 161 149 398 361 335 207 243
166 205 165 173 189 118 129 167 133 172 147 141 119 125 116 169 205 172 132 153
113 97 129 123 114 164 98 92 103 107 85 92 93 95 92 189 146 191 130 146
190 157 120 148 189 190 92 96 40 68 59 78 95 78 65 95 53 48 40 49
68 84 93 111 92
MOD-A05B 85
346 215 346 219 276 288 347 311 398 348 237 207 214 170 121 397 342 360 209 242
174 184 165 178 192 117 123 168 126 175 146 138 128 130 120 176 239 179 148 146
105 102 137 125 112 164 98 96 101 103 81 109 92 84 87 192 139 192 138 139
181 159 128 131 193 187 90 92 42 68 67 79 105 65 69 73 50 56 37 51
73 70 115 111 91
MOD-A06A 56
214 248 210 213 209 285 276 223 228 191 215 190 190 210 191 184 151 145 125 114
170 210 150 192 185 184 105 100 142 147 173 122 135 154 141 248 261 260 171 114
165 151 200 224 207 231 203 154 84 78 71 111 126 181 253 153
MOD-A06B 56
204 257 214 193 213 294 261 219 230 192 214 185 172 209 192 182 152 151 121 114
179 205 156 196 185 179 126 84 153 160 142 129 140 162 157 242 268 260 170 106
175 148 195 228 190 226 193 154 71 89 78 118 111 193 225 157
MOD-A07A 79
629 459 542 154 52 135 119 314 207 128 167 191 177 180 192 178 230 289 117 127
150 202 175 185 136 188 188 178 288 232 164 107 79 96 118 131 223 184 150 159
146 153 109 182 193 253 116 166 208 273 123 94 123 79 92 102 172 127 80 114
85 87 98 64 131 151 165 226 90 93 107 125 175 183 253 165 114 131 150
MOD-A07B 79
598 473 509 154 64 121 126 316 200 135 171 210 185 179 181 182 228 300 121 142
150 181 182 195 129 189 192 182 296 232 170 98 65 101 126 131 218 175 155 175
141 154 109 162 195 254 104 175 203 274 127 99 112 86 93 98 171 126 87 115
84 87 95 68 125 145 171 215 93 101 105 127 181 182 262 164 114 133 135
MOD-A08A 99
129 121 123 106 102 159 150 117 170 167 175 123 107 112 96 119 117 209 151 146
137 140 159 133 87 125 158 118 132 118 126 133 135 162 129 93 110 100 100 105
93 135 130 110 114 104 107 146 139 112 112 125 139 185 128 150 142 120 120 123
159 176 111 94 96 106 126 153 114 150 129 139 126 114 148 137 137 125 113 131
136 199 137 123 156 146 132 106 154 207 126 157 131 126 142 126 147 163 166
MOD-A08B 99
131 123 121 108 106 154 153 111 176 175 171 125 112 108 91 123 125 203 149 139
135 148 144 132 82 135 143 117 119 135 128 137 130 166 138 86 107 100 100 105
89 145 129 103 96 111 116 147 126 119 109 123 140 185 128 159 123 120 123 129
162 176 99 101 95 104 131 156 109 150 131 142 126 106 146 142 135 112 118 136
118 201 135 128 148 154 135 109 145 214 139 153 134 126 146 130 135 165 165
MOD-A09A 145
139 134 127 134 133 136 178 164 171 151 141 160 196 103 93 110 185 186 159 212
153 150 157 103 132 107 113 82 104 110 85 78 82 81 96 96 94 101 108 119
117 118 58 96 123 178 195 150 132 118 95 95 73 92 126 105 111 135 125 140
79 87 72 78 68 125 100 89 100 75 95 89 54 79 98 100 60 50 82 103
84 57 57 67 53 38 57 73 68 46 50 43 46 48 46 63 51 56 46 64
73 71 52 82 73 74 65 65 75 104 65 78 53 76 84 65 73 93 73 95
96 78 54 77 97 71 83 105 75 87 51 55 53 51 43 51 66 76 68 126
101 88 83 101 140

MOD-A09B 145
147 128 129 144 134 128 148 174 167 156 143 158 191 105 92 121 168 195 157 204
151 149 157 99 131 99 103 82 102 112 78 72 92 85 109 92 88 100 99 109
114 111 64 96 119 182 187 164 135 113 109 91 76 89 125 98 120 137 118 150
68 89 70 84 70 126 100 90 92 81 106 84 61 75 99 98 60 43 95 107
72 63 58 59 54 43 56 79 59 50 50 45 43 46 50 66 48 57 46 75
75 65 57 78 79 70 70 56 79 109 59 83 50 79 76 73 66 96 70 93
100 79 56 83 80 89 82 106 76 81 56 47 50 41 45 50 74 71 77 116
102 87 92 95 144
MOD-A10A 46
366 242 545 300 425 288 237 314 430 367 415 310 402 399 354 310 339 408 146 404
231 298 332 187 232 210 214 315 296 214 223 270 190 177 233 187 212 164 192 246
269 201 190 179 250 293
MOD-A10B 46
366 230 521 323 455 282 231 325 442 367 414 325 344 407 360 318 335 407 174 381
210 275 311 203 207 215 228 303 306 206 270 253 181 181 228 184 214 173 165 254
276 212 171 193 248 267
MOD-A11A 119
308 159 233 259 217 175 209 207 228 192 290 276 230 200 180 189 82 105 140 177
246 160 202 226 196 157 130 178 226 232 190 240 231 246 174 152 132 170 210 258
239 276 285 223 285 203 129 128 116 125 109 82 126 120 134 131 112 115 101 101
112 117 103 127 139 98 84 71 78 121 100 99 89 95 101 90 73 89 84 96
83 85 94 106 79 65 68 81 93 99 100 142 121 171 122 103 118 125 131 107
109 140 78 109 74 63 68 62 77 60 73 82 96 100 95 103 87 85 106
MOD-A11B 119
348 165 224 248 216 175 207 210 242 184 290 269 259 221 180 184 87 103 142 158
228 178 200 220 197 154 128 178 222 232 217 248 229 225 192 152 126 156 224 285
233 276 281 220 285 225 127 126 123 108 109 85 126 120 131 134 115 109 104 104
89 110 100 137 123 121 81 73 87 116 96 101 95 94 92 87 80 84 87 91
98 79 95 112 68 70 68 81 100 90 97 134 120 162 134 100 110 133 131 115
93 126 87 105 85 51 71 66 71 56 85 68 80 110 86 107 89 93 146
MOD-A12A 138
124 125 98 82 82 53 65 120 114 135 96 128 135 84 71 50 78 128 135 137
146 78 100 101 82 108 130 91 110 126 85 67 83 53 77 79 93 163 130 146
76 50 55 65 81 112 85 114 97 133 100 75 71 95 97 95 126 163 113 198
98 150 78 37 81 53 106 93 62 98 107 107 45 91 60 56 92 73 114 101
87 123 92 73 60 89 98 93 90 92 96 78 66 63 100 81 104 74 82 98
130 50 68 65 114 104 143 132 159 77 103 54 64 34 65 82 59 98 96 118
152 78 60 78 96 81 87 145 96 98 112 95 173 189 162 219 167 166
MOD-A12B 138
114 112 94 81 87 62 62 112 127 118 108 121 146 100 65 56 82 125 138 144
157 76 97 96 89 116 103 85 114 132 88 60 85 50 78 75 100 168 132 148
68 52 51 65 78 100 96 113 99 132 94 78 82 86 92 103 113 175 107 196
103 159 85 45 68 59 103 89 53 103 119 100 60 87 65 44 91 76 106 106
85 120 103 90 56 84 103 94 96 85 85 82 65 57 90 70 104 77 78 114
125 56 62 72 101 110 135 127 161 77 100 53 68 42 68 62 67 92 103 115
149 85 51 78 102 75 93 148 106 101 155 106 156 217 138 212 137 201
MOD-A14A 73
252 294 384 288 215 163 272 280 276 341 241 225 215 232 129 173 232 201 274 253
225 171 169 162 139 234 175 164 172 123 189 219 118 106 135 166 156 163 209 321
218 263 241 213 217 193 214 224 295 313 182 228 219 129 142 140 107 110 168 159
157 157 117 188 235 168 197 206 156 196 139 143 150

MOD-A14B 73
229 312 364 290 235 166 264 291 289 306 241 224 217 232 132 181 218 178 285 253
228 171 175 160 151 233 171 174 177 121 204 215 118 101 134 159 167 157 218 316
235 273 239 229 210 194 212 231 282 310 182 234 212 118 173 126 100 108 164 157
153 165 136 184 217 157 208 196 160 206 141 128 157
MOD-A15A 60
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193 282 267 182 275 173 243 143 137 229 165 337 342 277 230 319 139 52 267 130
218 273 281 392 221 309 227 347 342 276 246 285 289 293 259 387 370 548 163 204
MOD-A15B 60
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189 280 293 202 270 160 245 146 137 239 198 315 360 285 229 295 123 51 234 131
207 265 282 384 230 294 257 381 320 239 243 256 285 318 253 390 371 559 159 263
MOD-A17A 56
254 188 173 197 156 299 208 237 222 193 137 100 105 191 187 164 178 148 185 196
196 128 135 163 160 157 117 200 189 185 178 214 197 185 253 258 264 248 225 210
204 168 223 148 148 146 179 160 203 118 96 181 156 130 169 216
MOD-A17B 56
246 177 171 160 178 300 201 243 214 200 114 87 119 184 184 175 182 131 176 199
210 122 132 145 140 174 108 192 173 193 178 204 216 183 257 235 268 236 228 226
184 183 200 186 140 137 160 173 190 115 98 179 151 117 169 215
MOD-A19A 54
232 150 227 272 315 251 311 339 310 194 280 154 184 312 161 318 299 246 235 250
294 274 323 147 253 336 271 194 90 178 156 137 151 112 129 113 99 128 187 190
209 176 135 253 205 227 227 192 145 170 154 96 140 150
MOD-A19B 54
238 152 231 265 309 260 305 337 326 190 255 173 175 317 181 309 281 247 232 256
294 281 309 145 278 313 274 159 131 175 168 133 142 114 137 114 110 122 184 193
199 187 130 247 208 222 199 191 152 184 172 106 134 149
MOD-A20A 83
135 152 123 159 142 119 123 185 194 201 192 188 198 135 114 94 89 140 154 290
262 192 259 177 248 321 320 158 150 173 201 398 334 313 223 196 118 78 160 262
365 303 215 396 418 207 93 67 102 267 224 137 428 439 279 176 92 145 114 190
185 237 337 350 230 207 89 181 147 246 206 178 219 275 136 193 193 182 156 190
276 262 262
MOD-A20B 83
130 151 123 159 129 121 126 183 187 195 189 201 178 126 114 96 86 153 146 296
254 191 253 173 269 317 313 171 147 164 208 385 328 338 208 193 126 75 149 272
374 314 211 410 425 204 96 73 91 269 212 146 417 462 275 173 103 142 121 179
173 267 346 325 225 210 89 177 157 253 204 172 215 271 143 192 176 204 167 192
267 265 269
MOD-A21A 50
305 303 330 223 284 159 148 194 200 192 200 198 180 162 219 248 237 196 150 204
176 232 177 207 183 166 139 130 134 163 173 230 189 209 213 265 156 178 164 164
173 146 229 185 184 167 159 209 209 232
MOD-A21B 50
311 290 337 229 277 151 160 185 208 182 193 201 173 174 214 235 244 194 148 211
179 228 184 202 191 171 132 128 130 164 170 226 180 215 206 256 151 183 160 175
176 131 224 212 176 165 154 195 217 226

MOD-A22A 78
246 192 169 139 99 82 72 138 129 123 222 230 219 117 134 144 78 116 175 282
253 175 189 217 189 162 128 212 208 141 215 151 171 212 261 274 228 198 115 140
198 256 164 176 209 215 189 145 104 142 101 84 107 118 89 131 64 68 56 60
50 70 99 79 48 62 51 65 61 71 66 70 67 90 107 92 75 85
MOD-A22B 78
259 212 170 126 103 95 57 141 126 143 169 212 181 122 146 168 94 125 180 295
237 167 196 196 181 132 117 222 227 160 210 136 186 251 233 225 208 200 114 137
184 254 165 171 220 220 184 137 132 106 90 75 115 118 85 131 78 63 67 54
51 67 90 72 54 48 64 68 53 68 65 73 69 94 96 98 76 98
MOD-A25A 70
283 270 355 232 224 144 85 159 164 180 117 125 117 194 169 107 128 80 96 89
126 107 114 108 123 122 55 67 67 75 96 59 72 70 67 75 71 91 66 81
55 50 79 82 70 64 67 97 160 185 53 112 129 167 198 189 132 139 162 207
199 158 204 156 76 62 56 95 71 103
MOD-A25B 70
276 267 351 223 220 153 85 153 166 177 129 119 139 202 178 107 137 76 83 94
89 125 108 117 106 103 72 83 85 88 79 69 69 57 67 63 85 85 78 76
52 50 63 96 62 71 66 92 160 171 67 95 128 169 177 178 115 137 137 162
194 171 206 150 69 73 50 109 70 101
MOD-A28A 44
459 406 488 423 455 372 330 232 186 200 314 314 391 285 381 342 293 198 214 294
248 282 312 245 240 182 229 210 259 162 160 218 231 181 240 176 170 105 173 175
229 173 242 249
MOD-A28B 44
397 378 517 398 448 325 345 268 203 184 325 332 409 255 392 360 311 190 222 286
251 278 267 244 224 175 229 221 234 181 175 215 229 176 247 183 166 104 173 184
241 168 232 248
MOD-A29A 70
193 247 370 241 223 152 83 155 149 157 133 128 127 192 189 133 141 84 91 86
101 103 111 88 115 123 72 80 68 81 71 66 64 77 61 67 85 82 79 65
60 40 70 94 62 71 67 102 151 98 73 112 108 184 225 159 88 154 137 196
197 180 210 148 129 65 46 54 65 99
MOD-A29B 70
200 262 371 236 218 159 80 155 153 171 136 120 135 186 183 132 136 84 91 86
96 107 104 107 114 105 60 89 75 57 73 82 57 78 61 68 87 82 75 79
66 57 67 87 55 65 71 110 161 100 78 114 107 179 215 182 101 148 140 201
180 201 208 175 115 67 44 58 64 95
MOD-A30A 55
266 322 372 490 342 548 318 264 221 137 231 215 192 125 223 158 268 216 173 214
133 247 252 225 162 171 225 179 201 240 175 114 121 133 82 121 150 181 196 123
93 192 267 199 167 134 148 148 234 235 139 179 151 240 214
MOD-A30B 55
266 334 414 460 350 539 328 262 216 143 232 203 193 128 218 171 268 221 167 207
144 247 235 228 180 164 231 190 203 224 171 100 134 121 84 118 171 173 182 134
95 185 267 209 157 131 150 158 225 279 134 182 151 259 196
MOD-A31A 70
51 38 50 107 89 102 95 99 124 225 301 250 322 352 224 376 300 325 247 189
225 158 236 215 259 184 205 200 196 192 221 165 144 116 141 106 70 59 117 99
124 171 114 101 89 107 96 150 146 155 138 152 116 103 129 126 95 81 81 101
76 101 100 96 94 76 62 61 60 81

MOD-A31B 70
42 30 53 101 94 95 104 94 124 220 290 268 310 359 246 373 296 326 260 171
228 167 257 217 253 189 192 209 186 199 211 150 150 117 137 101 70 59 108 100
123 162 98 84 73 87 89 126 138 133 128 138 109 104 124 117 98 84 100 105
89 103 118 85 96 78 70 53 77 75
MOD-A32A 62
60 81 138 288 234 352 184 172 245 202 167 75 45 93 98 85 83 57 39 46
73 82 92 150 117 142 134 285 404 343 248 157 107 185 171 104 98 97 99 127
151 200 210 160 177 94 85 84 76 71 66 108 85 140 148 106 81 76 76 81
53 69
MOD-A32B 62
56 86 143 277 242 346 181 174 253 207 154 83 44 89 94 94 82 46 43 43
80 89 79 152 110 135 146 291 405 350 239 160 112 188 182 100 85 94 92 114
150 214 217 195 171 107 100 85 73 84 75 92 98 155 137 106 84 73 79 84
56 70
MOD-A33A 68
225 284 256 231 362 225 243 265 268 217 260 171 194 165 178 142 202 196 173 125
109 107 116 135 105 193 109 110 176 164 164 116 113 96 121 145 128 107 112 79
109 118 106 106 135 110 115 101 109 96 92 76 78 98 112 71 79 62 85 84
51 85 73 78 93 64 85 110
MOD-A33B 68
231 268 268 226 364 197 224 243 296 219 259 173 201 159 184 142 189 212 206 118
112 97 114 125 96 181 113 105 184 155 181 107 102 96 103 146 120 103 125 87
95 117 112 94 123 115 117 87 121 105 89 82 68 96 114 68 79 68 84 79
55 92 62 84 98 65 60 114
MOD-A36A 67
204 267 129 177 156 175 107 92 157 114 123 231 167 150 137 113 111 109 105 103
187 151 156 164 134 192 198 176 175 223 189 168 112 172 146 153 151 123 104 126
98 94 117 92 132 114 92 104 83 103 126 109 79 148 112 164 165 160 209 189
231 117 243 171 239 121 175
MOD-A36B 67
199 277 131 167 150 167 116 100 150 125 108 231 163 148 128 123 99 100 103 100
185 146 151 171 125 196 192 178 175 219 196 159 116 174 143 149 151 124 113 125
79 106 115 103 125 128 96 94 82 98 134 109 78 132 110 167 172 149 201 181
202 136 230 157 257 106 151
MOD-A37A 77
227 181 199 239 317 220 254 230 210 230 128 182 107 167 221 282 171 191 164 211
239 250 294 337 219 215 178 162 223 189 299 248 306 349 206 279 198 235 211 148
243 157 154 307 246 212 201 168 173 134 160 175 217 172 188 208 177 296 228 181
196 212 185 158 119 162 137 176 159 156 140 191 128 123 150 111 175
MOD-A37B 77
204 169 184 239 325 223 255 228 200 226 150 195 108 176 214 289 173 199 159 214
228 264 310 328 196 228 167 135 230 176 307 251 288 327 212 268 201 231 210 150
234 160 153 312 235 212 209 178 164 140 159 168 218 164 171 220 170 288 214 198
201 215 210 160 125 161 129 170 165 171 126 189 119 142 139 130 172
MOD-A38A 50
222 270 310 250 285 454 315 333 207 210 208 228 200 159 191 157 356 171 136 256
206 203 150 225 166 172 249 285 246 249 275 318 259 300 185 204 226 200 143 207
275 281 272 263 517 416 355 254 303 328
MOD-A38B 50
243 277 311 257 278 520 304 318 216 219 202 248 188 165 219 161 335 193 117 220
210 217 146 226 160 184 247 282 237 265 273 321 264 296 190 209 231 198 148 206
265 274 296 279 520 390 360 248 292 325

MOD-A39A 100
290 259 270 171 189 162 141 112 86 155 71 119 143 169 103 112 89 115 137 167
182 196 125 154 114 123 164 103 132 123 221 254 107 156 118 130 89 78 114 100
104 217 171 184 148 130 97 99 107 114 136 98 118 154 125 181 107 108 85 130
146 167 137 196 103 118 79 92 85 75 67 74 59 64 90 82 69 69 40 73
90 65 37 64 63 112 140 87 125 89 114 92 140 54 171 107 97 88 164 121
MOD-A39B 100
282 246 288 172 208 128 138 121 91 153 80 108 126 160 119 117 83 130 146 148
173 200 129 157 132 142 178 108 152 144 199 264 133 158 130 145 95 75 112 97
107 243 178 173 137 130 96 100 106 123 135 104 117 146 115 182 110 96 76 132
150 173 131 223 114 121 71 101 78 73 73 56 71 65 92 80 77 71 37 75
79 67 34 65 58 95 160 100 132 101 123 86 104 84 195 101 114 85 181 131
MOD-A40A 43
521 300 250 300 476 255 219 221 198 296 275 190 291 247 178 240 259 204 167 157
236 227 149 103 124 96 93 111 191 100 76 57 56 82 142 144 132 123 157 105
139 137 156
MOD-A40B 43
458 263 236 311 461 219 200 205 199 316 264 192 328 253 189 244 259 219 175 162
250 228 166 124 135 100 82 117 186 107 75 58 57 71 148 150 121 102 165 104
111 131 145
MOD-A41A 92
220 140 261 143 210 229 277 138 160 154 170 164 167 207 323 228 176 154 155 203
196 168 214 293 317 189 221 192 182 137 106 179 156 123 228 184 182 184 175 155
139 139 117 137 135 151 182 182 188 140 131 122 199 128 131 87 121 107 101 119
85 73 103 93 93 95 99 109 118 92 95 68 89 96 76 48 87 71 100 83
73 104 79 118 65 120 57 100 35 79 39 113
MOD-A41B 92
213 147 264 135 211 234 270 151 157 162 162 167 179 203 325 228 184 151 155 204
181 186 225 286 331 189 204 184 196 154 94 197 142 129 223 184 179 165 175 157
140 137 125 134 143 157 184 181 181 149 132 125 203 127 118 92 121 104 104 112
86 79 95 89 96 101 90 106 120 92 96 73 95 95 68 48 89 65 92 92
79 98 96 92 73 112 53 100 34 74 41 118
MOD-A44A 60
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320 285 335 234 217 204 158 363 201 209 205 266 234 274 168 236 244 231 162 231
205 284 210 254 187 173 195 139 231 145 117 167 159 201 152 149 132 208 172 168
MOD-A44B 60
242 186 159 178 140 113 98 136 218 431 718 421 321 498 609 355 418 360 356 294
343 299 336 232 198 193 156 326 230 212 217 282 265 264 170 245 242 231 179 201
210 296 196 255 180 170 198 146 233 132 119 165 161 209 141 151 125 207 166 189
MOD-A45A 55
296 333 224 272 209 334 201 202 320 166 176 237 203 381 210 250 157 186 223 205
253 234 194 230 223 199 181 202 239 253 235 166 188 181 123 162 229 226 190 239
153 148 137 77 128 112 142 160 117 142 144 130 115 211 216
MOD-A45B 55
274 335 215 282 201 346 194 203 298 178 176 232 217 392 196 253 157 178 226 224
217 250 183 235 217 194 166 221 243 260 225 178 193 185 98 159 210 245 187 243
150 146 146 73 126 110 133 175 110 142 156 134 96 201 228
MOD-A46A 46
301 282 320 387 346 265 266 434 262 239 205 224 157 160 179 259 269 241 219 324
316 396 296 381 259 390 246 247 383 176 198 166 231 341 214 218 178 337 281 273
203 195 171 203 134 195

MOD-A46B 46
290 306 317 384 323 244 273 387 297 249 211 198 164 154 183 250 252 258 226 316
323 403 303 393 265 340 257 251 428 190 206 141 262 373 195 225 172 328 274 258
201 200 145 220 159 187
MOD-A49A 73
110 137 104 113 127 130 203 236 190 219 171 191 202 147 188 159 184 293 150 217
195 186 148 114 178 127 104 181 142 139 143 113 92 101 93 132 200 155 157 153
153 235 315 147 179 204 181 142 109 190 137 157 131 131 98 139 82 96 106 83
149 117 93 101 76 92 128 110 90 139 123 148 227
MOD-A49B 73
120 124 114 107 130 129 200 252 175 227 172 186 219 144 196 162 173 294 152 207
202 178 156 115 168 134 107 173 141 130 128 96 89 101 99 120 211 164 157 149
157 235 301 145 168 204 167 152 108 201 142 151 140 125 98 131 101 90 95 99
147 120 89 99 86 93 141 98 112 140 109 157 221
MOD-A50A 60
197 226 250 166 159 119 231 250 274 250 366 357 231 131 175 163 155 117 189 182
220 366 342 409 318 360 287 198 278 273 237 165 228 254 286 155 176 190 200 233
140 185 218 157 198 148 151 182 132 146 100 109 92 82 104 118 103 93 78 78
MOD-A50B 60
204 226 256 153 167 116 195 265 280 265 385 314 230 142 185 156 143 118 196 175
182 363 339 400 340 394 272 196 251 298 232 175 221 263 283 149 185 196 212 218
145 192 204 171 218 134 151 181 134 118 95 120 87 84 101 114 109 96 67 79
MOD-A53A 65
413 361 295 370 440 318 198 241 228 415 290 328 301 253 282 290 231 235 296 213
214 222 267 229 241 218 165 160 193 158 158 216 154 250 172 133 201 121 70 84
118 128 103 115 98 87 139 73 142 120 140 143 92 101 146 121 151 133 221 221
170 184 272 163 154
MOD-A53B 65
411 376 303 387 459 326 200 219 228 381 300 345 290 277 286 293 226 229 279 210
199 221 245 215 225 237 146 168 193 160 148 214 167 231 181 135 184 107 78 81
132 132 95 109 95 92 126 87 128 110 129 129 84 103 140 109 147 139 228 242
171 183 280 156 155
MOD-A54A 65
245 174 184 196 228 250 198 199 116 201 126 180 282 144 206 136 137 222 225 196
128 199 197 181 213 178 181 189 210 210 171 197 167 320 170 118 231 295 232 233
269 190 282 232 195 115 129 102 167 143 175 200 160 103 90 91 129 89 101 153
126 107 95 103 129
MOD-A54B 65
247 177 183 194 232 230 191 194 112 209 126 191 275 135 212 142 135 210 222 202
118 207 201 175 212 183 190 185 221 225 172 203 148 319 182 114 242 315 253 221
272 192 275 242 190 107 129 106 164 142 182 192 171 111 91 89 131 90 103 140
129 107 98 95 130
MOD-A55A 58
192 229 192 196 170 120 117 148 142 125 126 90 114 337 250 210 330 316 174 215
278 314 209 205 142 200 135 178 214 204 159 179 130 110 74 84 132 121 175 235
165 154 137 159 129 165 175 189 201 162 156 210 237 134 287 254 282 223
MOD-A55B 58
194 221 208 204 169 124 115 152 156 102 134 96 125 337 248 210 360 353 178 204
289 317 213 228 141 205 128 178 213 200 160 184 132 107 70 85 132 117 175 229
176 143 135 157 128 163 192 175 204 160 156 206 251 137 292 235 292 223

MOD-A56A 106
111 128 119 108 100 96 62 39 50 59 84 108 133 116 73 69 73 41 49 112
222 207 90 107 99 75 122 112 92 114 92 94 119 115 128 117 121 92 89 95
82 124 100 116 135 123 109 105 98 142 178 154 106 117 96 117 114 103 86 103
126 117 109 143 125 118 112 101 117 135 154 146 123 128 143 121 128 163 168 179
201 187 226 181 151 150 111 160 137 226 148 162 148 179 185 185 134 176 148 165
159 164 176 194 212 241
MOD-A56B 106
111 121 127 104 108 93 58 39 53 68 105 91 146 124 72 74 69 55 51 98
222 225 78 108 80 89 126 124 84 115 84 85 126 134 133 129 114 82 96 94
78 114 104 142 110 117 107 98 92 119 178 140 101 148 96 115 110 99 100 99
135 113 112 134 129 126 106 98 126 140 151 143 137 137 140 128 125 177 167 165
176 206 221 184 172 137 135 160 127 231 137 170 151 168 187 179 128 185 154 144
168 156 182 196 203 246
MOD-A57A 100
227 319 214 217 247 275 250 196 192 141 139 129 112 96 107 110 103 94 94 52
97 101 145 157 93 88 86 82 109 85 90 107 117 88 104 102 114 106 92 100
114 85 107 75 65 67 133 158 132 133 127 85 88 82 78 66 84 89 101 78
85 87 82 64 60 75 76 103 81 93 88 110 87 59 76 70 87 89 126 109
74 93 92 91 110 72 96 101 96 104 135 137 81 128 181 307 406 440 389 359
MOD-A57B 100
239 311 193 236 250 257 256 191 194 139 131 135 114 92 107 107 96 89 78 62
89 92 153 152 100 82 89 99 104 86 91 111 114 100 102 96 113 111 105 100
122 92 110 83 71 65 130 149 139 138 139 92 79 84 75 67 78 93 95 85
89 87 78 64 63 75 84 104 67 101 94 107 89 66 72 71 87 84 114 115
73 95 97 96 103 74 97 100 99 100 121 135 82 120 178 307 427 446 392 355
MOD-A58A 75
430 272 274 256 371 285 382 182 179 218 489 212 350 157 293 289 153 291 255 140
150 125 234 175 172 238 243 198 243 164 204 54 162 131 174 104 159 180 284 284
215 235 168 182 379 234 175 89 141 110 278 279 104 129 70 110 198 126 151 131
184 131 121 215 159 163 200 186 125 114 171 67 112 224 228
MOD-A58B 75
430 274 250 286 364 317 361 189 185 201 487 213 382 153 287 293 171 283 249 126
153 123 232 164 178 253 243 194 249 160 193 64 156 135 167 107 153 183 279 281
211 225 172 193 365 228 170 91 135 103 285 259 118 131 62 110 206 109 157 126
182 145 127 193 156 168 200 181 128 114 168 64 106 250 221
MOD-A59A 69
430 350 434 419 284 344 271 346 309 246 209 285 412 253 254 268 226 217 210 146
146 141 174 192 204 217 229 214 190 118 171 175 202 130 168 223 332 205 173 220
193 143 146 177 161 132 171 164 173 153 118 170 179 135 208 150 134 132 170 225
204 228 196 147 181 155 121 126 186
MOD-A59B 69
420 340 443 411 288 334 257 347 307 251 216 269 414 260 251 262 218 219 200 141
146 140 182 196 192 226 212 201 186 121 174 181 198 126 186 214 337 195 178 217
200 153 142 171 162 137 165 164 168 157 109 181 173 142 216 130 140 129 168 213
224 221 203 139 191 140 132 137 179
MOD-A60A 98
357 358 393 389 332 390 407 407 310 323 231 232 249 225 190 163 135 125 130 137
75 139 97 129 142 121 99 100 86 81 85 81 92 93 87 92 73 105 74 42
48 53 32 40 35 21 21 35 45 50 65 48 54 37 46 41 37 54 43 62
41 54 48 46 34 35 39 43 64 62 62 70 81 81 51 60 46 54 53 64
65 53 41 53 51 41 58 67 63 68 42 69 53 35 40 53 98 135

MOD-A60B 98
356 354 391 375 331 385 378 380 296 345 219 221 246 217 189 146 150 121 127 142
68 145 96 128 142 121 103 93 85 84 87 78 96 86 91 81 70 100 68 51
41 53 32 40 32 26 21 31 53 42 70 50 52 39 44 38 43 50 50 59
35 56 48 48 37 34 39 39 62 64 54 79 83 83 55 66 35 50 50 75
66 53 43 51 51 46 57 62 62 60 50 58 52 45 40 57 96 137
MOD-A61A 111
147 223 217 178 171 159 126 106 210 203 183 169 198 209 153 98 97 100 142 154
139 180 123 163 120 129 128 144 104 153 170 119 84 92 66 76 84 94 146 132
160 101 64 85 101 115 158 160 154 135 162 110 108 109 126 131 121 159 181 134
195 109 140 102 69 146 117 139 130 81 135 149 126 73 106 79 66 83 74 126
70 57 78 78 67 60 70 104 109 93 81 85 89 104 82 94 86 99 87 84
114 107 64 71 58 78 107 112 102 168 153
MOD-A61B 111
143 215 221 179 176 150 136 108 206 199 198 171 194 198 166 103 98 96 150 151
148 171 131 150 116 125 124 146 107 146 175 115 81 93 60 92 80 85 133 116
157 100 71 81 98 107 158 173 160 150 157 132 110 104 121 143 125 160 190 123
185 96 152 101 62 128 107 150 128 75 135 154 103 76 104 76 64 79 70 144
81 64 76 81 63 69 65 103 105 96 92 87 95 103 85 94 81 100 87 90
92 109 65 60 64 81 107 112 107 165 151
MOD-A62A 127
150 181 110 119 135 188 217 182 192 190 169 184 119 142 109 140 121 146 135 100
78 121 96 111 94 121 118 114 107 122 109 57 113 151 178 182 137 143 100 113
89 83 110 169 109 119 144 107 121 90 115 80 80 78 125 96 110 103 95 117
59 56 79 87 81 54 58 50 66 76 70 71 72 34 48 54 89 84 59 48
59 56 59 65 100 76 68 79 87 100 81 72 84 84 98 93 73 90 131 75
93 73 92 128 98 107 151 98 123 85 77 58 110 128 92 109 137 85 96 85
72 81 109 65 84 99 125
MOD-A62B 127
149 184 110 123 133 194 221 170 176 166 166 210 121 142 108 135 117 153 138 87
90 128 90 110 106 128 129 110 114 101 101 53 108 147 175 180 141 140 110 101
100 78 103 167 107 131 135 117 111 96 108 82 81 71 126 96 112 112 85 125
60 57 75 92 70 65 40 70 66 69 64 74 48 48 51 65 85 78 60 62
59 54 60 67 92 82 73 60 96 94 87 71 89 85 90 95 74 98 120 90
96 68 96 122 101 98 149 95 109 92 85 57 123 121 98 102 135 87 95 79
64 79 106 70 90 93 126
MOD-A63A 81
131 110 238 208 192 243 226 318 159 211 105 155 160 353 246 217 211 232 216 390
199 256 144 250 249 196 289 203 242 214 373 206 210 123 159 203 177 146 171 153
300 195 345 245 282 303 245 275 228 126 296 279 276 201 181 276 260 209 207 180
281 61 171 122 152 114 184 186 343 244 158 196 307 128 156 100 129 70 146 97
165
MOD-A63B 81
127 120 231 212 190 257 202 321 160 203 125 142 148 364 256 244 225 223 222 382
206 249 143 260 252 196 282 203 252 223 379 192 204 129 165 195 182 137 158 152
297 219 333 262 287 287 259 285 228 123 293 289 298 193 165 280 251 199 225 171
262 84 170 120 134 115 183 181 331 263 125 214 339 121 150 101 122 65 157 105
168

MOD-A65A 128
152 217 169 232 236 217 201 173 139 134 135 169 185 175 198 167 145 103 99 116
153 129 106 103 100 110 86 82 113 122 71 135 130 120 96 96 93 71 95 76
136 133 99 126 92 117 71 76 89 65 67 84 82 100 83 79 48 76 57 82
65 64 70 65 59 76 59 56 54 45 71 90 75 104 98 101 110 84 90 86
112 101 84 132 128 76 83 64 84 95 80 78 107 114 147 87 90 64 117 98
99 84 140 118 159 103 81 90 68 76 56 67 87 80 55 45 35 64 39 67
79 53 85 70 67 66 59 72
MOD-A65B 128
167 203 193 238 238 209 208 177 141 135 148 172 192 173 191 165 144 98 103 100
157 139 100 110 96 101 78 77 99 132 59 105 126 117 100 92 89 76 90 82
128 141 95 135 89 126 63 82 92 59 74 78 84 106 76 82 50 85 64 88
55 64 73 68 78 70 67 56 61 54 62 90 78 106 100 87 109 81 96 89
107 103 82 125 132 70 79 63 75 97 80 84 107 109 148 85 82 70 103 103
101 85 137 121 154 104 78 92 65 76 55 68 87 78 52 50 34 67 42 72
70 53 84 68 68 63 79 74
MOD-A66A 102
350 349 159 197 157 190 159 192 146 246 150 180 194 216 167 200 214 125 139 132
106 149 114 157 150 135 117 111 109 122 142 127 126 138 117 153 142 110 133 111
135 92 96 107 89 110 75 84 104 100 89 85 68 65 84 87 89 90 82 95
93 85 98 85 65 70 67 68 63 106 78 92 101 94 113 85 70 80 106 89
124 103 121 107 128 143 89 75 101 76 89 96 78 129 98 89 87 89 86 140
107 96
MOD-A66B 102
348 351 153 193 162 185 151 184 155 226 141 182 201 191 134 209 221 120 133 124
113 145 108 168 165 145 117 107 103 118 171 132 141 146 121 149 140 123 130 117
126 95 93 106 89 112 75 87 103 103 93 84 59 67 89 87 96 82 89 87
89 84 100 90 62 71 60 76 56 109 78 90 100 90 117 85 71 84 103 100
134 95 119 118 128 126 120 70 114 71 82 107 80 132 107 90 71 90 100 140
123 115
MOD-A67A 52
177 179 225 268 217 168 125 119 117 161 244 268 157 194 171 164 169 175 164 175
196 200 142 223 168 289 191 186 180 182 96 72 42 30 38 45 36 61 39 78
72 67 81 41 81 104 95 101 85 148 165 170
MOD-A67B 52
189 166 239 266 209 170 120 125 110 164 237 266 150 182 173 166 185 175 165 181
209 208 129 231 178 271 207 196 182 171 115 67 47 35 27 59 32 66 33 57
70 60 78 45 69 100 99 104 95 140 153 156
MOD-A68A 88
144 112 139 146 127 154 220 156 84 124 112 115 153 121 134 168 186 142 157 89
146 102 145 157 143 191 192 171 128 130 119 148 136 121 149 139 153 167 124 149
130 121 92 126 175 126 132 128 98 110 106 145 101 97 103 89 104 87 101 115
104 73 67 70 75 105 95 87 85 85 93 79 104 102 78 62 42 57 70 57
85 75 48 71 37 35 39 70
MOD-A68B 88
140 119 132 142 133 147 229 161 85 117 110 126 154 128 132 169 182 150 142 92
125 101 144 167 140 190 194 178 143 134 118 150 139 130 149 137 160 171 121 141
139 125 99 118 160 146 146 139 93 109 110 137 100 103 104 95 104 73 89 104
104 66 67 71 79 97 92 84 96 89 97 78 106 96 84 54 48 55 75 53
81 78 51 64 43 44 35 62

MOD-A69A 130
229 229 180 262 224 253 280 196 250 236 203 216 174 184 140 139 125 177 214 200
175 174 178 137 103 105 110 145 147 190 186 119 133 125 137 147 123 110 165 218
151 112 137 89 110 100 104 176 110 162 140 89 90 87 93 144 106 132 103 150
113 106 121 139 114 126 123 157 125 268 125 115 87 58 100 104 143 154 67 106
128 121 85 86 76 53 54 65 58 52 45 67 62 46 49 50 65 62 71 50
46 65 66 65 81 75 74 56 52 75 75 38 27 56 57 64 57 42 83 71
81 56 62 39 62 71 55 57 100 115
MOD-A69B 130
261 206 184 254 222 241 285 205 223 246 203 217 162 232 178 146 121 178 228 192
160 187 175 153 98 106 106 153 132 196 182 121 128 119 131 155 129 109 160 194
160 114 142 87 114 100 107 159 128 156 139 92 82 88 94 146 109 129 107 142
112 114 120 132 128 111 120 159 126 260 118 123 92 56 109 114 134 150 65 109
139 127 95 90 68 50 61 66 52 60 51 58 66 43 46 46 68 65 65 51
45 62 71 63 84 76 75 58 42 43 37 40 26 51 54 65 55 50 82 67
88 59 69 34 62 65 62 62 93 109
MOD-A70A 114
276 258 232 159 184 192 167 149 152 101 147 169 112 94 114 74 73 96 145 227
153 179 106 71 66 64 100 125 107 164 128 163 86 75 85 108 75 100 122 160
104 293 132 165 92 44 100 82 100 98 62 89 89 90 52 56 44 40 45 48
40 35 40 46 40 34 46 41 75 58 67 76 55 80 90 67 86 60 89 87
75 114 122 53 48 57 87 110 108 93 156 108 122 70 87 38 79 67 85 67
103 115 175 84 71 97 154 120 167 210 145 129 265 198
MOD-A70B 114
245 270 219 156 195 197 160 153 155 103 121 181 109 83 112 76 75 107 139 226
144 171 107 72 67 67 92 126 108 155 134 165 93 65 97 98 77 107 124 157
101 288 133 170 81 58 89 77 102 106 56 98 100 91 52 64 51 35 39 51
42 37 31 46 39 45 32 37 60 76 68 67 64 71 86 65 78 81 92 87
75 121 135 62 53 64 84 103 110 93 154 113 114 68 79 46 89 67 90 70
109 123 164 81 78 103 156 120 165 205 146 134 239 204
MOD-A71A 63
110 75 65 97 48 90 61 55 49 67 37 39 49 42 41 31 36 34 42 33
67 65 97 162 243 167 248 169 195 148 110 106 121 78 70 94 119 153 100 96
168 86 95 57 71 26 86 74 50 40 77 53 173 70 48 75 78 67 65 92
68 49 66
MOD-A71B 63
109 75 68 99 46 92 60 59 49 68 39 41 49 43 40 34 37 34 45 31
69 66 89 163 248 161 251 172 194 143 111 109 119 80 74 98 99 158 101 96
163 80 100 58 74 28 90 72 48 38 79 52 174 75 51 67 80 66 65 92
79 39 73
MOD-A72A 82
114 112 113 100 137 85 91 104 105 107 89 111 150 117 214 100 108 85 54 101
105 125 139 78 109 155 137 82 79 68 53 57 71 59 44 42 64 60 42 39
44 61 57 60 61 59 71 62 60 91 64 69 55 47 69 77 41 28 35 55
50 52 42 89 63 76 63 65 35 64 67 67 64 114 117 189 75 63 92 109
69 125
MOD-A72B 82
102 104 121 106 130 106 94 92 100 110 88 108 129 110 234 112 107 87 50 101
103 134 135 73 106 144 132 82 80 74 53 63 52 64 50 41 55 59 46 39
42 71 71 62 63 46 71 60 64 100 56 68 61 45 58 73 28 29 38 53
53 46 50 80 67 82 53 67 35 55 62 64 60 96 105 192 82 62 82 105
71 137

MOD-A73A 75
94 180 131 182 92 130 71 37 75 55 97 86 43 91 96 103 64 75 61 50
42 74 45 47 35 46 60 42 42 39 36 34 53 60 41 52 57 58 68 59
89 80 85 110 107 66 51 69 90 109 160 109 179 123 126 76 81 46 84 100
137 135 131 156 206 103 78 107 140 95 153 199 165 173 343
MOD-A73B 75
146 172 136 191 92 135 67 30 84 66 86 87 50 87 86 100 67 71 63 56
48 51 49 46 37 50 57 43 39 28 41 30 51 53 35 44 61 50 62 51
87 77 74 114 105 59 50 60 85 107 164 101 184 126 121 75 84 50 78 109
126 135 132 163 207 102 76 106 135 104 159 185 169 175 315
MOD-A74A 119
124 90 105 64 56 76 93 79 79 86 89 62 35 65 50 49 58 70 84 71
96 73 90 48 27 32 30 30 42 48 44 63 57 51 52 49 44 42 32 46
41 50 51 55 51 57 46 67 60 66 64 57 93 134 101 138 98 102 83 107
112 139 101 54 95 89 129 134 125 187 184 157 195 139 146 107 170 117 201 152
148 212 143 131 95 115 93 117 117 107 139 126 95 84 85 81 103 135 135 225
140 131 198 159 169 136 277 261 188 162 114 120 125 146 118 87 150 120 151
MOD-A74B 119
99 88 98 72 54 75 95 71 80 94 87 68 30 67 51 43 56 79 76 80
86 75 87 48 29 32 30 31 43 50 46 57 56 55 55 41 44 39 46 33
44 48 48 57 54 55 51 66 62 58 75 58 87 129 101 141 93 100 84 97
124 137 106 64 78 99 131 143 132 178 178 160 196 147 132 103 169 127 185 153
150 203 156 93 120 111 104 107 128 100 142 128 100 98 87 75 98 132 168 239
140 123 200 160 170 143 277 251 184 156 129 126 126 150 118 90 142 118 178
MOD-A75A 98
124 103 142 153 138 155 142 90 91 92 58 71 58 50 68 48 55 50 52 63
84 57 101 85 108 105 80 55 103 82 85 99 135 102 73 78 65 66 65 113
114 186 112 116 127 120 129 145 205 185 157 225 164 134 78 71 150 146 216 174
329 164 92 85 85 192 113 153 218 206 121 128 70 137 121 153 164 164 188 196
290 134 321 163 112 135 160 159 175 92 153 103 175 110 190 98 133 155
MOD-A75B 98
115 84 145 163 136 160 134 101 91 89 67 64 64 46 71 48 55 53 53 50
71 51 115 91 109 100 67 55 96 85 103 94 141 126 69 80 64 62 66 123
97 176 113 115 114 103 125 145 203 207 139 212 186 129 92 85 132 142 203 183
279 143 95 87 85 195 120 167 212 195 125 123 65 115 125 147 165 195 184 204
285 110 306 173 106 143 167 157 188 89 157 120 162 109 191 103 125 165
MOD-A76A 73
250 262 242 222 170 79 71 98 133 206 248 371 407 441 189 138 85 95 76 68
66 52 67 82 101 144 126 110 119 102 160 303 408 380 382 377 333 255 192 230
309 324 348 278 251 232 107 101 125 182 187 121 212 209 159 178 215 146 185 239
235 190 160 126 116 97 90 115 143 193 146 210 220
MOD-A76B 73
256 259 243 225 142 90 78 97 131 200 248 371 431 430 192 134 86 92 83 63
67 54 67 78 105 137 130 107 118 102 160 308 421 344 373 356 314 243 203 232
307 309 335 272 265 229 112 102 131 198 176 129 231 207 150 197 191 121 200 239
207 209 153 132 122 88 93 107 150 179 170 198 268
MOD-A77A 85
181 85 64 142 175 189 169 125 121 108 92 90 50 77 83 125 167 175 132 126
112 94 89 100 129 137 117 95 89 62 57 60 67 71 60 71 59 61 53 61
72 84 84 60 87 77 82 67 68 84 68 67 63 96 78 87 98 85 111 79
44 60 60 61 94 77 84 103 77 78 88 47 84 65 89 81 79 79 79 98
81 87 59 93 128

MOD-A77B 85
159 84 62 137 163 188 161 134 120 108 83 96 58 80 82 116 153 176 139 133
123 92 89 100 127 134 110 102 87 70 61 56 68 77 57 67 64 62 46 58
73 80 85 58 85 89 84 71 61 78 67 67 64 94 74 85 96 94 112 76
50 54 61 67 81 78 89 96 93 86 77 55 77 65 90 92 70 84 87 92
76 79 75 90 117
MOD-A79A 84
229 116 137 125 121 161 174 176 228 210 214 208 187 280 155 176 119 125 169 120
157 110 154 140 97 128 130 105 148 146 110 89 152 116 110 133 130 122 87 100
124 103 166 150 136 139 125 118 101 73 114 103 110 89 105 82 125 73 123 106
86 99 112 132 103 71 112 131 84 75 112 98 104 132 87 93 82 111 92 109
109 112 65 120
MOD-A79B 84
230 126 120 132 109 157 167 175 228 225 234 214 185 255 161 180 132 163 183 119
157 117 132 126 117 116 158 94 150 136 99 89 128 120 121 120 124 114 95 98
132 87 146 140 140 135 118 123 101 71 117 106 106 96 108 80 122 73 126 109
90 100 123 131 103 89 100 129 93 68 107 93 102 139 95 89 82 121 89 113
86 121 71 122
MOD-A80A 46
310 366 276 266 142 125 190 191 230 167 235 221 200 208 193 189 160 205 225 277
210 223 233 217 120 74 46 63 48 71 75 103 99 98 69 128 120 147 87 126
54 82 89 104 198 196
MOD-A80B 46
322 366 279 263 132 167 201 185 220 153 246 232 200 214 200 169 167 210 228 273
221 226 230 211 113 78 50 57 47 74 68 106 100 99 63 118 125 146 89 125
53 84 92 98 201 199
MOD-A81A 48
124 107 112 222 265 145 205 217 172 171 253 143 75 175 298 290 117 82 112 160
82 49 31 43 102 125 102 92 156 123 155 161 58 94 120 102 156 83 141 116
62 74 98 75 89 52 67 82
MOD-A81B 48
120 105 112 224 280 151 212 208 150 176 228 150 80 176 275 283 116 80 112 155
82 46 35 43 92 125 113 82 160 120 152 146 60 84 117 71 178 80 131 108
55 61 89 73 88 58 67 79
MOD-A82A 49
301 248 221 138 90 132 139 142 132 191 132 169 148 184 142 147 136 95 88 80
69 36 32 59 109 67 83 66 78 46 59 46 34 46 50 28 37 37 35 21
30 29 33 41 26 18 26 30 31
MOD-A82B 49
300 244 210 144 92 131 141 137 143 221 142 159 142 167 149 132 141 98 91 88
60 30 28 53 109 72 84 68 71 52 59 50 33 50 46 30 35 37 45 21
29 23 35 42 25 19 26 29 29
MOD-A85A 46
254 272 341 334 671 381 227 185 187 185 169 218 242 367 371 368 284 344 203 225
225 173 124 322 326 346 237 237 293 271 192 231 279 203 132 246 198 117 182 114
175 182 81 137 110 125
MOD-A85B 46
249 278 347 330 649 401 225 155 185 178 180 223 246 358 373 350 271 328 207 227
236 175 114 333 306 362 237 259 295 267 182 242 271 226 134 205 183 126 181 103
173 177 80 135 110 123

MOD-A88A 54
174 234 158 225 150 88 117 211 222 166 298 341 376 369 395 572 400 269 267 245
217 242 312 232 235 201 249 382 225 322 245 216 159 270 232 241 236 237 68 54
40 65 85 112 148 182 205 172 169 181 176 217 328 301
MOD-A88B 54
178 230 159 215 153 89 126 214 221 177 301 339 394 400 385 568 396 259 238 252
217 225 285 244 235 204 259 362 231 329 245 215 157 264 235 248 241 249 54 51
57 56 92 110 143 187 204 174 158 185 180 203 327 293
MOD-A89A 53
180 429 398 523 395 328 308 293 357 269 219 277 335 313 379 289 337 316 262 214
237 193 285 245 269 230 298 231 244 203 207 328 212 140 130 141 86 125 38 58
129 260 148 275 164 179 203 120 160 210 218 300 219
MOD-A89B 53
175 419 388 521 385 319 321 294 373 255 232 275 334 308 364 291 329 304 255 225
260 185 293 245 268 216 305 242 246 189 201 319 208 121 159 142 87 134 35 58
126 235 140 276 162 167 198 123 151 209 212 267 222
MOD-A90A 50
318 235 313 200 219 199 227 360 241 226 198 185 235 187 278 318 355 272 257 207
253 155 70 84 65 65 96 160 218 134 139 126 75 81 100 142 248 198 176 135
152 143 100 168 273 201 317 196 220 256
MOD-A90B 50
317 228 327 196 225 199 229 360 258 205 209 174 232 190 265 305 358 285 270 197
251 159 69 88 70 67 95 165 217 147 125 117 81 73 100 151 245 184 168 162
131 159 93 155 254 193 327 196 217 259

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular 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

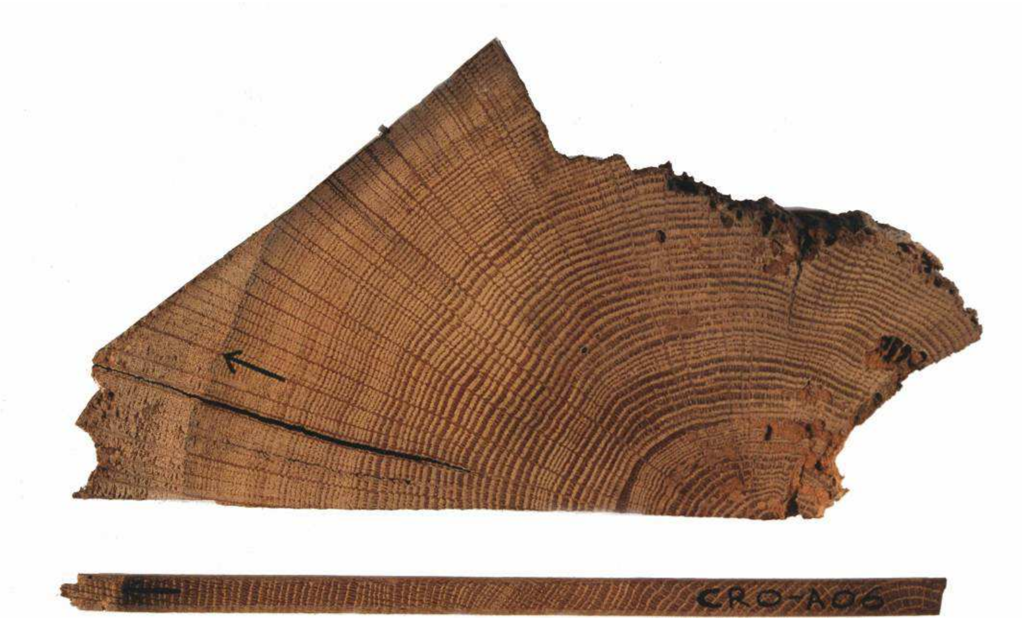


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

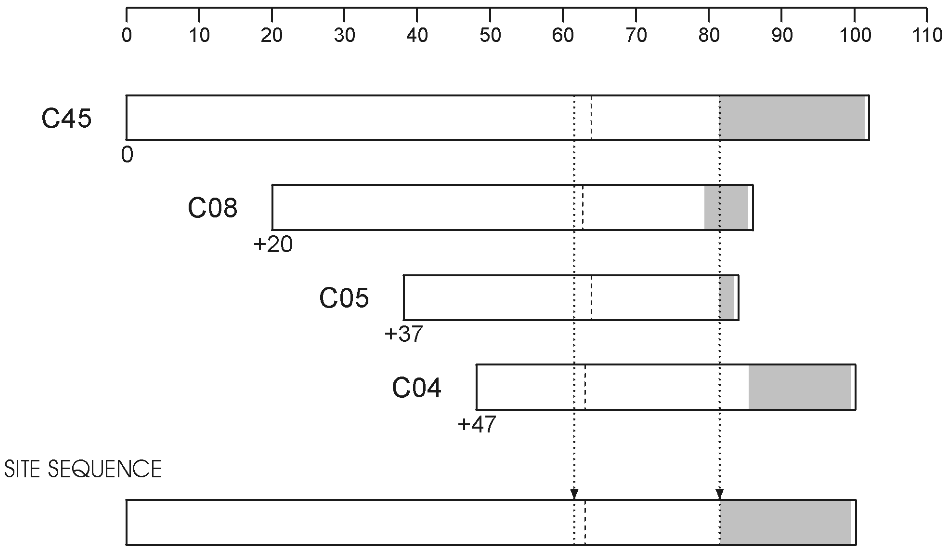


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

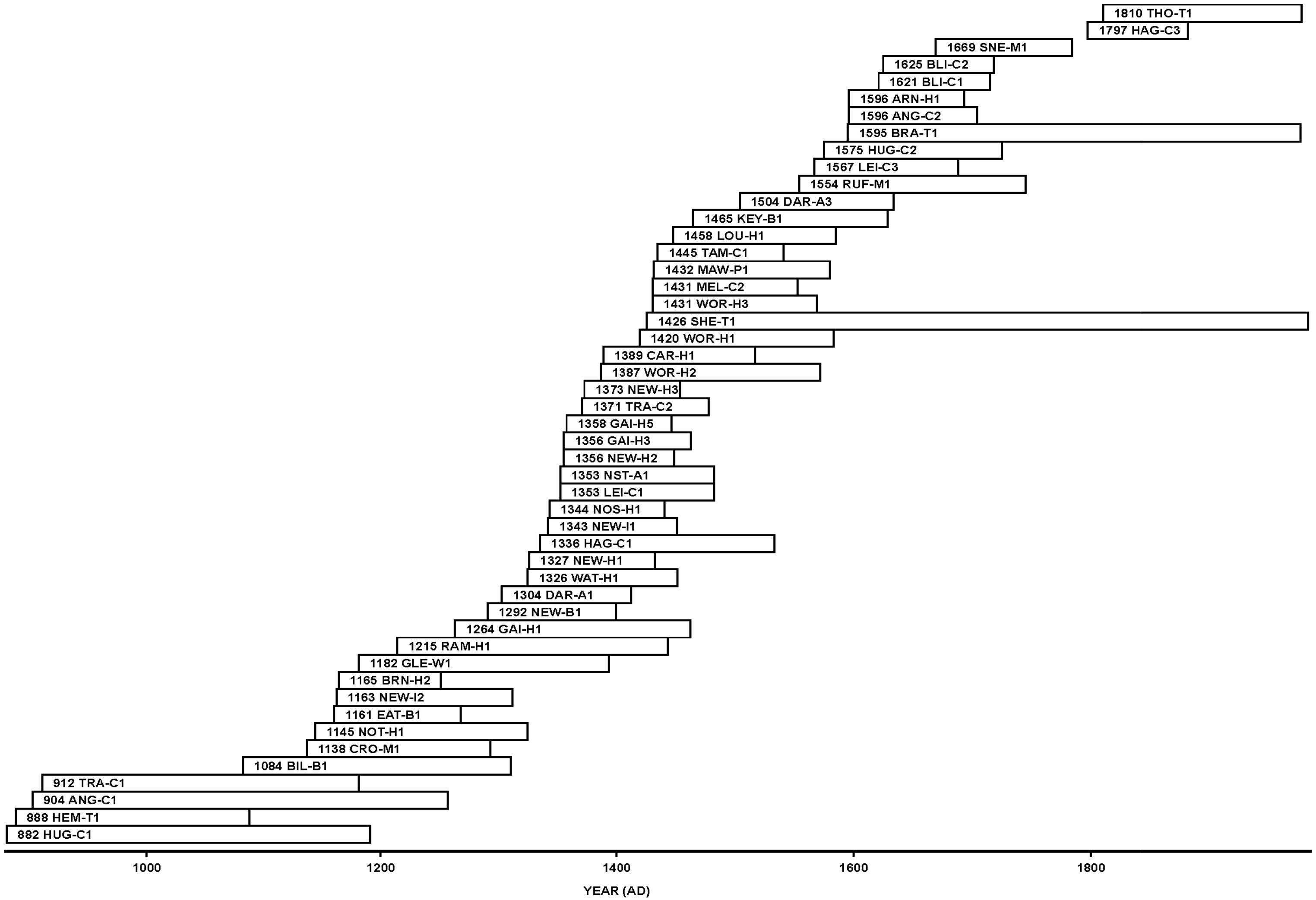
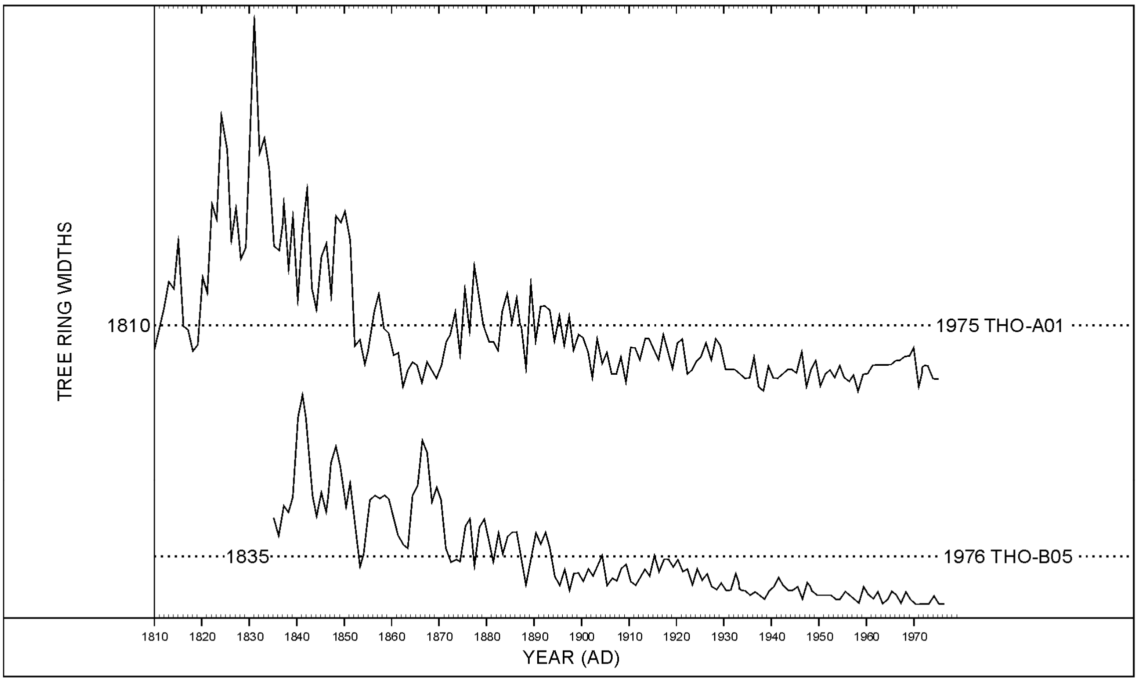


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

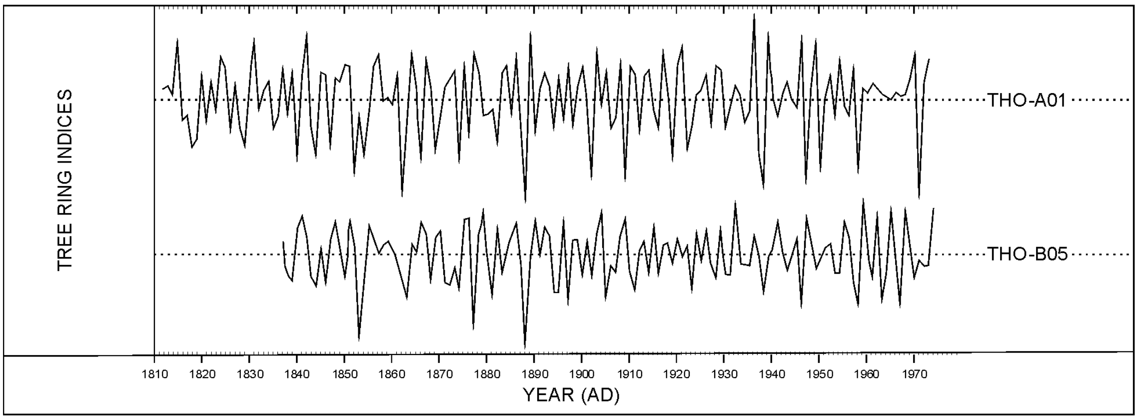


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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ISSN 2398-3841 (Print)
ISSN 2059-4453 (Online)