RESEARCH DEPARTMENT REPORT SERIES no. 29-2010 ISSN 1749-8775

MITCHELL'S BREWERY, BREWERY LANE, LANCASTER
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 29-2010

MITCHELL'S BREWERY
BREWERY LANE
LANCASTER

TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: SD 4479 617

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.
Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers must consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:
Res.reports@english-heritage.org.uk
or by writing to:
English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Please note that a charge will be made to cover printing and postage.

SUMMARY

Analysis of 38 conifer samples from the malthouse and 'tower' areas of the Mitchell's Brewery complex has resulted in the production of five different site sequences, comprising 22 of the 33 samples which were measured. Three of these five site sequences, LNCASQ01, LNCASQ02, and LNCASQ03, accounting for eight, five, and two samples, and being 128, 183, and 133 rings long, can be dated as spanning AD 1627–1754, AD 1551–1733, and AD 1605–1737, respectively. Interpretation of the sapwood on these dated samples indicates that they were probably all felled and, allowing for transportation, initially used in the mid-AD 1750s. There is no evidence for reuse and hence, assuming that these timbers are integral to the malthouse, it appears likely that it was constructed at this time. Two further site sequences remain undated, and a further 11 measured samples remain ungrouped and undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Mr Andrew Barker and Mr Jonathan Barker, joint managing directors of Mitchell's Hotels and Inns Ltd, for the help and cooperation they, and their colleagues, have shown throughout this programme of sampling for tree-ring analysis. The Laboratory would also like to thank members of the various English Heritage teams that have been involved in this case for their help and assistance, particularly Nick Bridgland, Adam Menuge, Ken Robinson, and Cathy Tuck. We would also like to thank Dr Peter Marshall of English Heritage's Scientific Dating team, for commissioning the tree-ring analysis at this site. In addition Cathy Tyers, Sheffield Dendrochronology Laboratory, provided valuable assistance with the analysis and dating of the material, including co-ordinating the input from various laboratories elsewhere in Europe, and comments relating to the ongoing English Heritage research into the dating and provenancing of imported conifers.

ARCHIVE LOCATION

Lancashire Historic Environment Record
LCC Environment Directorate
PO Box 9, Guild House, Cross Street
Preston PR1 8RD

DATE OF INVESTIGATION

2009

CONTACT DETAILS

Alison Arnold and Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
roberthoward@tree-ringdating.co.uk
alisonarnold@tree-ringdating.co.uk

CONTENTS

Introduction 1
The Brewery Complex 1
The malthouse 2
The north wing 2
The 'tower' 2
The 19th century building, the south wing, and the original courtyard 3
Sampling 3
Analysis and Results 5
Interpretation 6
Site chronology LNCASQ01 6
Site chronology LNCASQ02 7
Site chronology LNCASQ03 7
Discussion and Conclusion 7
Site chronology LNCASQ01 8
Site chronology LNCASQ02 8
Site chronology LNCASQ03 8
Site chronology LNCASQ04 9
Site chronology LNCASQ05 9
Ungrouped samples 9
Bibliography 10
Tables 12
Figures 17
Data of Measured Samples 32
Appendix: Tree-Ring Dating 40
The Principles of Tree-Ring Dating 40
The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory 40
1. Inspecting the Building and Sampling the Timbers. 40
2. Measuring Ring Widths. 45
3. Cross-Matching and Dating the Samples. 45
4. Estimating the Felling Date. 46
5. Estimating the Date of Construction. 47
6. Master Chronological Sequences. 48
7. Ring-Width Indices. 48
References 52

INTRODUCTION

The complex known as Mitchell's Brewery, on Brewery Lane, Lancaster (SD 479 617, Figs 1 and 2) comprises a range of buildings and ancillary structures, including a 'tower' in which the brewing process took place until closure of the works in 1999 and a former maltings believed to be of late eighteenth-century date.

It is not certain when brewing commenced on this site. A building, identified as a brewery, appears on a 'Plan of the Town of Lancaster' by Stephen Mackreth, dated 1778, but no such structure is shown on the Kenneth Docton map of the 1950s, copied from the Towneley map, believed to date to 1684 (but possibly predating 1669). From around 1800–11 the brewery was owned by John Proctor, after which it was bought by the Walker family of Preston. By 1833 the site was in the ownership of a Mr Towneley of Blackburn, but then appears to have ceased brewing operations, a capacious building in 'The Old Brewery' being described as the drill room of the 10th Lancaster Rifles. A Wesleyan Sunday School was also held here at about this time.

About 1872 the site was possessed by the firm Jackson and Yates, who operated as maltsers only. Towards the end of the 1870s the firm had changed its name to Yates and Jackson, and by the mid-1880s brewing had restarted, with some of the existing buildings being converted, while others were demolished and new ones added. In 1901 a major extension of the brewery was undertaken, with further extensions being added to the north in 1910.

In 1969 further alterations to the site included the demolition of the eighteenth century stables and the in-filling of the original courtyard. In 1984 Yates and Jackson was taken over by the brewing firm Thwaites, and the Lancaster site was sold to Mitchell's Hotels and Inns Ltd. Mitchell's ceased brewing here in 1999, but have continued to use the modern yard and warehouse at the far northern end of the site (to the north of the 'old' brewery proper) for distribution purposes.

Collectively Mitchell's Brewery attests to the long history of malting and brewing in this part of the city and, although altered slightly in the late-twentieth century, it is considered to be one of the few buildings of this industrial type surviving near a town centre in the north-west region. The malthouse, for example, is believed to be one of the few large urban examples to survive nationally, and its size and potential late eighteenth-century date make it a rare survival (Patrick 2004; 2007; Pearson 2009).

The Brewery Complex

The brewery complex comprises what appear to be a number of different elements (see basic schematic plan, Fig 3, and Fig 4).

The malthouse

One of the older parts of the site is believed to be represented by the malthouse, a long building of three floors plus attic, running north–south, towards the rear, or east side, of the complex. The first- and second-floor frames both comprise 12, large, main east–west beams (Fig 5), the beams of both floors coinciding with each other. The ends of these beams are set in the side-walls of the malthouse. The ends of some, but not all, of these main beams are further supported by stone corbels in the side walls. All such main beams are of conifer. The frame of the second floor, however, has been strengthened by the insertion of three rolled steel joists. Between the main beams of the floor frame run a series of smaller, secondary or common, joists. These common joists are also all of conifer.

The roof of the malthouse comprises eight king-post trusses with principal rafters and tiebeams (Fig 6). It would appear that originally there were also struts rising from near the bases of the king posts to the principal rafters. The majority of these struts are now missing. Within these king-post trusses we find a combination of timber species, with the tiebeams, resting directly on the side walls of the malthouse without wall plates, being of conifer, while the king posts, principal rafters, and few remaining struts, are all of oak. The double purlins to each pitch of the roof appear to be modern, probably twentieth-century, softwood insertions, perhaps connected with the conversion of the roof covering to corrugated iron. There are now no common rafters to this roof and are no further timbers, either oak or conifer, to the walls of the malthouse.

The north wing

The north wing comprises a large, double-height, space, open to the roof, immediately behind the arched double doors of the main Brewery Lane entrance. The roof here again comprises king-post trusses, four in number, the king posts having expanded heads, with shoulders near their bases from which struts rise to the principal rafters (Fig 7). The trusses carry double purlins to each slope of the roof. As far as can be discerned, beneath several layers of paint and other debris, all these timbers are of conifer. There are no common rafters visible to this roof, and no timbers in the walls.

The 'tower'

The 'tower' lies to the north end of the malthouse, representing the north-east corner of the original site, and is believed to be either contemporary with the malthouse, or possibly slightly older than it, there being no convincing evidence either way. The 'tower', apparently originally built largely of stone, rises higher than either the north wing or the malthouse. Given that at one time the south wall of the 'tower' contained a doorway, at third floor level, which is now bricked up and which is cut by the pitched roof of the malthouse, it would appear likely that the 'tower' was in place before the malthouse was built.

Within the 'tower' we find a relatively modern, probably late-twentieth century, conifer, coupled common rafter, roof, which retains two conifer purlins to its southern pitch (Fig 8) and a single conifer purlin to its north pitch (Fig 9). Two window openings, also at third-floor level, one to the west or front, and another (now bricked up) to the east or rear, each retain single conifer lintels. It is believed that at least one of these windows, the now-blocked east window, which is in a stone wall, may be part of the primary build of the 'tower', there being no evidence for it having been knocked through later. There is slightly less certainty about the still-open, west, window, which is in a brick wall. It is thought possible that this wall may represent a later modification of the 'tower', in which case the window would not be primary.

The 'tower' also retains the partial remains (probably half) of the frame to the third floor. This comprises two east–west joists (much smaller than the large beams of the malthouse floors), their ends set in the walls, between which run a series of short and stub common joists (Fig 10). All such timbers are again of conifer. Given that the timbers of this frame are distinctly different to those of the floor frames of the malthouse, being much smaller and more squarely sawn, they are thought to be later, possibly being an insertion of nineteenth- or even twentieth-century date.

There are no further timbers to the walls at either the third-floor level, or to the walls of the lower levels. There are also no further frames visible to the lower floors.

The nineteenth-century building, the south wing, and the original courtyard

The remaining areas of the brewery complex, that is the nineteenth-century building, the south wing, and the original courtyard (altered and enclosed in the late 1960s), contain very little visible timber, modern or otherwise. There are certainly no major roof trusses or areas of floor framing in either conifer or oak, and no timbering to any of the walls, these areas having been constructed or heavily altered in the late-nineteenth and early-twentieth centuries, apparently using iron, steel, and small amounts of modern softwood.

SAMPLING

Tree-ring analysis of the Mitchell's Brewery complex were requested by English Heritage to inform possible listing in relation to the redevelopment of the entire site that has been the focus of the recent Canal Corridor North Public Inquiry (Montague Evans 2008).

It was anticipated that tree-ring analysis would establish with greater reliability and precision the probable construction date of various parts of the complex and more clearly demonstrate the sequential development of this complicated site. It was also hoped that analysis would establish how much, if any, of the surviving timber was from the potentially eighteenth-century original building and how much represented later periods of change and alteration. With these aims in mind it was requested that samples be obtained from three key elements of the complex, namely the malthouse, the 'tower', and, if possible, the north wing.

Thus, from the conifer timbers available throughout the building, a total of 38 samples was obtained by coring, each sample being given the code LNC-A (for Lancaster, site 'A') and numbered 01–33. Twenty of these samples, LNC-A01–20, were obtained from the main beams forming the frames of the first and second floors of the malthouse (samples LNC-A01–10 and A11–20 respectively) and two of the tiebeams of the roof trusses to the malthouse (samples LNC-C19 and 20). As far as could be seen, the timbers of the malthouse appeared to represent the primary construction phase of the present building and showed no evidence, by way of redundant peg holes, mortices, or other joints, of reuse or later insertion, and were presumably acquired specifically for the present building.

With respect to the malthouse, sampling of the upper floors and roof timbers was somewhat restricted by safety considerations as a consequence of the building having been unoccupied and unused for several years. Only two samples, for example, were obtained at roof level, both of these being from the only two accessible tiebeams that contained sufficient numbers of rings for analysis. In addition to safety considerations, inspection of the principal rafters and the king posts ascertained that although these timbers were of oak, they were derived from fast-grown oak trees and contained too few rings, ie less than 54, for reliable dating purposes. It was also noted that the associated purlins appeared to be more modern insertions. No samples were obtained from the smaller common joists between the main beams of the floor frames of the malthouse. In this instance, although the timbers were of conifer, it was seen that they contained far too few rings for reliable analysis.

In addition to the samples from the malthouse, a further 13 samples, LNC-A21–33, were obtained from the frame of the third floor to the 'tower' area of the brewery. A final five samples, LNC-C34–38, were then obtained from the two third-floor window lintels and the three roof timbers of the 'tower' which appeared not to be modern replacements. None of the sampled timbers in the 'tower' show any evidence, by way of redundant peg holes, mortices, or other joints, of reuse. However, given that this part of the site may have undergone alteration, it is not certain that these timbers represent the primary phase of construction or a period of change and alteration.

It had been hoped that samples might also be obtained from the four roof trusses of the north wing. However, given the difficult and potentially unsafe conditions of the site in general, and those of access to these four high-level trusses in particular, combined with the overall urgency of the investigation, there was insufficient time for the necessary arrangements to be made. A visual inspection of the few timbers which could be safely reached indicated that they were indeed of conifer, but possibly had variable ring numbers. Some of the timbers possibly had sufficient rings for analysis, while others are likely to have fewer than the minimum required. Further discussions with English Heritage concluded that, in the circumstances, sampling of the north wing should be abandoned.

Where possible, the positions of these samples are marked on drawings, based on the plans of the original survey, made at the time of sampling, these being reproduced here as Figures 11a–d. Details of the samples are given in Table 1. In this table, an attempt has been made to identify and number beams and other timbers from north to south, or, where this is not practicable (as in the second floor frame of the 'tower'), in some form of consistent or consecutive order. It is hoped that these plans, in conjunction with Table 1, can identify the location of all samples.

ANALYSIS AND RESULTS

Each of the 38 samples obtained was prepared by sanding and polishing. It was seen at this time that five samples had less than 54 rings, the minimum here deemed necessary for reliable dating, and these samples were rejected from this programme of analysis. The annual growth-ring widths of the remaining 33 samples were measured, and the data of these measurements are given at the end of this report. The data of these 33 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a minimum value of t=4.5, five separate satisfactory groups could be formed, accounting for 22 of the 33 measured samples. Other potential intra-site cross-matching was noted for a number of samples, but without further statistical support these were considered too weak to be acceptable.

The samples of each cross-matching group were combined at their respective positions to form site chronologies LNCASQ01–SQ05. Each of the five site chronologies were then compared with an extensive series of reference chronologies for various conifer species held by the Nottingham Tree-ring Dating Laboratory and the Sheffield Dendrochronology Laboratory, as well as various laboratories elsewhere in northern Europe, this process resulting in the satisfactory dating of three of the five chronologies created, LNCASQ01, LNCASQ02, and LNCASQ03.

Site chronology LNCASQ01, comprising eight samples with an overall length of 128 rings, was found to match repeatedly and consistently with a series of reference chronologies when the date of its first ring is AD 1627 and the date of its last measured ring is AD 1754. Site chronology LNCASQ02, comprising five samples with an overall length of 183 rings, was found to match when the date of its first ring is AD 1551 and the date of its last measured ring is AD 1733. Site chronology LNCASQ03, comprising two samples with an overall length of 133 rings, was found to match when the date of its first ring is AD 1605 and the date of its last measured ring is AD 1737. The evidence for this dating is given in Tables 2, 3, and 4. The samples of these three site sequences are shown in bar diagram Figure 12a.

It should be noted that these reference chronologies are all of Scots pine (*Pinus sylvestris* L.). Whilst microscopic examination only allows identification down to a series of groups of species within the genus *Pinus*, by taking into account the additional evidence provided by the successful dating of these three sequences, it seems highly likely that all these dated timbers, at least, are *Pinus sylvestris*.

The two final site chronologies, LNCASQ04 and SQ05, shown in Figure 12b/c, remain undated. The 11 remaining measured but ungrouped single samples were also compared to a full series of reference chronologies for various conifer species, but again there was no satisfactory cross-matching and these timbers, therefore, must also remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD
(where dated)			
LNCASQ01	8	128	1627–1754
LNCASQ02	5	183	1551–1733
LNCASQ03	2	133	1605–1737
LNCASQ04	5	179	undated
LNCASQ05	2	211	undated
ungrouped	11	---	undated
unmeasured	5	---	---

INTERPRETATION

Site chronology LNCASQ01

Of the eight samples in the dated site chronology, LNCASQ01, two, samples LNC-A03 and 08, appear to retain complete sapwood. This means that they both have the last ring produced by the trees they represent before they were cut down. The last, complete, sapwood rings of these samples, and thus the felling of the two trees represented, are dated to AD 1753 and AD 1754, respectively.

Four other samples, LNC-A01, 04, 06, and 07, in site chronology LNCASQ01, also retain sapwood. The amount of sapwood on these timbers suggests that they all appear likely to have lost only minimal amounts of sapwood during conversion or indeed, in the case of A06, during coring. Thus it seems likely that they are coeval with the two timbers with precise felling dates, and hence were also probably felled in the mid-AD 1750s. Further support for this interpretation is provided by the relative position of the heartwood/sapwood boundary on these six samples; the average date of this boundary being AD 1704.

The felling date range of the two remaining dated samples, LNC-A02 and 05, in site chronology LNCASQ01, cannot be estimated with reliability, but there is little reason to suspect, given the wide variation in numbers of expected sapwood rings in pine timbers (eg Groves and Locatelli 2005), that the trees these three samples represent were not also felled in the mid-AD 1750s.

Site chronology LNCASQ02

None of the five samples in site chronology LNASQ02 retains complete sapwood, and it is thus not possible to give a precise felling date for any of the timbers represented. Three of the samples, however, LNC-A11, 12, and 14, do retain some sapwood, with last measured ring dates of AD 1733, AD 1720, and AD 1727, respectively. The relative position of the heartwood/sapwood boundary on these three is such as to suggest the likelihood that they are coeval, the average date of this boundary being AD 1691. Given the last measured ring dates on these three samples (and, in the case of sample LNC-A11, an additional 10 unmeasurable sapwood rings), and given the wide variation in the expected number of sapwood rings, it is highly likely that these timbers were also felled in the mid-eighteenth century.

The felling date range of the two remaining dated samples in site chronology LNCASQ02, LNC-A09 and 15, cannot be estimated with reliability. There is little reason, however, to suspect, that the trees these two samples represent were not also felled in the mid-eighteenth century.

Site chronology LNCASQ03

Likewise, neither of the two samples in site chronology LNASQ03 retains complete sapwood, and it is thus not possible to give a precise felling date for the timbers represented. One sample, LNC-A20, does, however, retain sapwood, with last measured ring date of AD 1737 and heartwood/sapwood boundary of AD 1691, it is thus again possible that the timber was also felled in the mid-AD 1750s. The degree of cross-matching between sample LNC-A20 and the other sample in this site chronology, LNC-A19, is such as to suggest that the timbers are likely to be coeval

DISCUSSION AND CONCLUSION

The tree-ring analysis of the Mitchell's Brewery complex has successfully provided dating evidence for one area, demonstrating extant remains of a mid-eighteenth-century structure. It has, however, unfortunately not been possible to elucidate the sequential development of this complicated site, due to the inability to successfully date the remaining timbers. In addition to the dating evidence obtained, the analysis has provided information relating to the potential source of at least some of the timber used within the malthouse and has provided valuable data for the on-going English Heritage research project into the "dating and provenancing of imported conifers in England". This analysis also emphasises the variable success rates associated with the analysis of conifers within individual sites (eg Groves 2004; Groves and Locatelli 2005; Arnold *et al* 2007).

Site chronology LNCASQ01

Tree-ring analysis has identified cross-matching between a group of eight samples, all from the first-floor frame of the malthouse. The resultant site sequence has been successfully dated to the period AD 1627–1754. The dated timbers form a coherent group and the presence of bark edge on at least two of these indicates that they were all probably felled and, allowing for transportation, initially used in the mid-AD 1750s. There is no evidence for reuse and hence, assuming that these timbers are integral to the malthouse, it appears likely that the frame to the first floor was constructed at this time.

The level of cross-matching between some of the samples from this floor, and given that each beam appears to represent a whole tree, suggests that it is likely that some of the trees represented here were growing close to each other in the same area of woodland. Samples LNC-A05 and 06, for example, cross-match with each other with a value of t=10.0, samples LNC-A01 and 04 cross-match with a value of t=11.3, and samples LNC-A07 and 08 cross-match with a value of t=16.6. These timbers are also clearly imported, with site sequence LNCASQ01 showing a very high level of similarity with reference chronologies from north/central Poland, north/east Germany and buildings in England containing timber also thought to have been imported from this region.

Site chronology LNCASQ02

In addition, the malthouse is represented by site sequence LNCASQ02, dated as spanning the years AD 1551–1733. While four of the five samples in this group are from the beams of the second floor, one sample, LNC-A09, is from a beam of the first floor. Interpretation of the sapwood on the three samples in this site chronology where it exists, and the degree of cross-matching between all five samples, would suggest that the timbers they represent are likely to be coeval. The similarity in the dates of the heartwood/sapwood boundaries with those from LNCASQ01 suggests that these five timbers are also all likely to have been felled and used in the mid-eighteenth century.

It is again likely that the trees represented in this site sequence are from a single source. Two samples, LNC-A14 and 15, cross-match with each other with a value of t=12.4, which, given that the beams appear to be whole trees, would suggest that these trees were also growing close to each other. The dating evidence obtained for these timbers suggests a source to the east of the likely source region identified for LNCASQ01.

Site chronology LNCASQ03

The malthouse is further represented by site chronology LNCASQ03, composed of two samples, LNC-A19 and 20, both from the roof. This site chronology has been dated as spanning the years AD 1605–1737. Interpretation of the sapwood, and the degree of cross-matching between the two samples would suggest that they are contemporary. Again the similarity in the date of the heartwood/sapwood boundary with those from both LNCASQ01 and LNCASQ02 suggests that these two samples were likely to have been felled in the mid-eighteenth century. A match between LNCASQ01 and LNCASQ03 was noted, but these sequences were kept separate due to the possibility that they are from slightly different woodland sources.

It is again possible that the timbers represented by these two samples, again both whole trees, represent a different woodland source to that used for the first and second floors, represented by site chronologies LNCASQ01 and SQ02 respectively. These timbers are also clearly imported but again the source region is relatively difficult to identify; a north/central Poland or east German source seems most likely.

Site chronology LNCASQ04

A mixing of sample locations, similar to that in site chronology LNCASQ02, is also to be seen in site chronology LNCASQ04, which contains sample LNC-A16 from the frame of the second floor of the malthouse, and samples LNC-A22, 23 and 24, from the floor frame, and sample LNC-A35, from the west window, of the 'tower'. In this instance, however, whilst the samples are clearly broadly coeval, the lack of any traces of sapwood on the four timbers from the 'tower' makes it difficult to link the two potential phases of construction in these two separate areas and hence determine whether or not they are contemporary.

Site chronology LNCASQ05

Site chronology LNCASQ05 is also composed of two samples, from the two remaining purlins to the south slope of the 'tower' roof. Whilst these two timbers are broadly coeval it is not possible, given that neither sample retains the heartwood/sapwood boundary, to ascertain whether these two timbers represent a single felling period or not.

Ungrouped samples

The 11 ungrouped samples (three from the malthouse and eight from the 'tower') show no obvious growth anomalies that would preclude successful cross-matching or dating. However, the highly variable nature of conifer assemblages and the resultant highly variable success rates with respect to dating has been previously noted (Tyers pers comm). The lack of cross-matching does not necessarily demonstrate that they represent different phases of felling, but could suggest the use of multiple diverse sources.

BIBLIOGRAPHY

Arnold, A, Howard, R, and Tyers, C, 2007 *Durham Cathedral, County Durham: tree-ring analysis of timbers from the Refectory and Librarian's Loft*, EH Res Dept Rep Ser, 39/2007

Arnold, A, Howard, R, and Tyers, C, forthcoming *Gayle Mill, near Hawes, North Yorkshire: tree-ring analysis of timbers*, EH Res Dept Rep Ser

Crone, B A, 2007 *Elderslie House, Glasgow: dendrochronological analysis*, unpubl report for AOC Archaeology

Docton, K, Map of the 1950s based on the original of AD 1684 by Towneley, Lancaster University Library Map Collection

Groves, C, 2000 Belarus to Bexley and beyond: dendrochronology and dendroprovenancing of conifer timbers, *Vernacular Architect*, 31, 59–66

Groves, C, 2002 *Dendrochronological analysis of conifer timbers from Danson House and Danson Stables, Bexley, Kent*, Centre for Archaeol Rep, 69/2002

Groves, C, 2004 *Dendrochronological analysis of conifer timbers from the Giltspur Street Compter, City of London (KEW98),* Centre for Archaeol Rep, 20/2004

Groves, C, and Locatelli, C, 2005 *Tree-ring analysis of conifer timbers from 107 Jermyn Street, City of Westminster, London,* Centre for Archaeol Rep, 67/2005

Howard, R E, Litton, C D, Arnold, A J, and Tyers, C, 2006 *Tree-ring analysis of timbers from Warleigh House, Tamerton Foliot, Bickleigh, South Hams, near Plymouth, Devon,* EH Res Dept Rep Ser, 38/2006

Mackreth, S, Plan of the town of Lancaster 1778, Lancaster University Library Map Collection

Montague Evans, *Canal Corridor North, Lancaster: PPG 15 Assessment*, June 2008

Patrick, A, 2004 *Maltings in England: Strategy for the Historic Industrial Environment Report No. 1*, unpubl rep, July 2004

Patrick, A, 2007 *The Malthouse and Brewery (Mitchell's Brewery site), Brewery Lane, Lancaster,* unpubl rep, August 2007

Pearson, L, 2009 *The Brewing Industry: Strategy for the Historic Industrial Environment*, Brewery History Society, unpubl rep, September 2009

Tyers, I, 2004 *The tree-ring analysis of timbers from Oxburgh Hall, Oxborough, Norfolk,* ARCUS Rep, 717L

Wazny, T, 2001 *Dendrochronologia obiektów zabytkowych w Polsce, Dendrochronology of historical objects in Poland*. Gdansk: Muzeum Archeologiczne w Gdansku

Zunde, M, 1998 Dendrochronological and historical dating of the Dannenstern House and an eighteenth century revetment along the River Daugava, *Sena Riga*, 315–32

TABLES

Table 1: Details of tree-ring samples from Mitchell's Brewery (malthouse and 'tower'), Lancaster

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD
	Malthouse					
LNC-A01	First-floor frame, beam 1	106	46 +2mm	1645	1704	1750
LNC-A02	First-floor frame, beam 2	93	No h/s	1627	------	1719
LNC-A03	First-floor frame, beam 3	101	50C	1653	1703	1753
LNC-A04	First-floor frame, beam 4	108	42	1637	1702	1744
LNC-A05	First-floor frame, beam 5	64	No h/s	1666	------	1729
LNC-A06	First-floor frame, beam 6	86	19 +2mm	1668	1734	1753
LNC-A07	First-floor frame, beam 7	117	58 +4mm	1631	1689	1747
LNC-A08	First-floor frame, beam 8	119	65C	1636	1689	1754
LNC-A09	First-floor frame, beam 10	76	No h/s	1624	------	1699
LNC-A10	First-floor frame, beam 11	97	64	------	------	------
LNC-A11	Second-floor frame, beam 3	101	34 +10mm	1633	1699	1733
LNC-A12	Second-floor frame, beam 4	104	24	1617	1696	1720
LNC-A13	Second-floor frame, beam 5	113	No h/s	------	------	------
LNC-A14	Second-floor frame, beam 7	140	50	1588	1677	1727
LNC-A15	Second-floor frame, beam 8	117	No h/s	1551	------	1667
LNC-A16	Second-floor frame, beam 9	175	65C	------	------	------
LNC-A17	Second-floor frame, beam 10	149	No h/s	------	------	------
LNC-A18	Second-floor frame, beam 11	nm	---	------	------	------
LNC-A19	Tiebeam, truss 6	77	No h/s	1605	------	1681
LNC-A20	Tiebeam, truss 7	131	46	1607	1691	1737

Table 1 - continued: Details of tree-ring samples from Mitchell's Brewery (malthouse and 'tower'), Lancaster

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD
	'Tower' floor frame and roof					
LNC-A21	Floor joist 1	nm	---	------	------	------
LNC-A22	Floor joist 2	102	No h/s	------	------	------
LNC-A23	Floor joist 3	101	No h/s	------	------	------
LNC-A24	Floor joist 4	100	No h/s	------	------	------
LNC-A25	Floor joist 5	57	31	------	------	------
LNC-A26	Floor joist 6	nm	---	------	------	------
LNC-A27	Floor joist 7	115	35+2mmC	------	------	------
LNC-A28	Floor joist 8	82	No h/s	------	------	------
LNC-A29	Floor joist 9	79	17	------	------	------
LNC-A30	Floor joist 10	119	51C	------	------	------
LNC-A31	Floor joist 11	57	No h/s	------	------	------
LNC-A32	Floor joist 12	nm	---	------	------	------
LNC-A33	Floor joist 13	62	No h/s	------	------	------
LNC-A34	Window lintel 1 (rear, or east, window)	64	No h/s	------	------	------
LNC-A35	Window lintel 2 (front, or west, window)	101	No h/s	------	------	------
LNC-A36	South upper purlin	211	No h/s	------	------	------
LNC-A37	South lower purlin	119	No h/s	------	------	------
LNC-A38	North purlin	nm	---	------	------	------

Table 2: Results of the cross-matching of site sequence LNCASQ01 and a selection of relevant reference chronologies when the first-ring date is AD 1627 and the last-ring date is AD 1754. Reference chronologies known to be based on imported timbers are indicated

Reference chronology	*t*-value	Span of chronology	Reference
House Mill, Bromley by Bow, London, England (imported)	10.5[1]	AD 1608–1801	Groves 2000
Warleigh House, Tamerton Foliot, Devon, England (imported)	6.6[1]	AD 1670–1806	Howard *et al* 2006
Elderslie House, Glasgow, Scotland (imported)	6.3[1]	AD 1580–1774	Crone 2007
North Germany 1 (imported)	8.1[2]	AD 1519–1858	Eckstein and Schubert pers comm
West coast, Germany (imported)	6.0[2]	AD 1519–1858	Wrobel pers comm
Stralsund, Germany	9.9[2]	AD 1558–1840	Leuschner pers comm
Brandenburg, Germany	7.2[3]	AD 799–2009	Heußner pers comm
Mecklenburg, Germany	9.2[3]	AD 1086–2007	Heußner pers comm
Torun, Poland	9.5[2]	AD 1168–1991	Zielski pers comm
Gdansk, Poland	11.1[4]	AD 1157–1990	Wazny 2001

[1] - *t*-values provided by C Tyers (University of Sheffield)

[2] - *t*-values calculated by S Wrobel (University of Hamburg/Federal Research Centre for Forestry and Forest Products)

[3] - *t*-values calculated by C-U Heußner (German Archaeological Institute Berlin)

[4] - *t*-values calculated by T Wazny (Cornell University)

Table 3: Results of the cross-matching of site sequence LNCASQ02 and a selection of relevant reference chronologies when the first-ring date is AD 1551 and the last-ring date is AD 1733. Reference chronologies known to be based on imported timbers are indicated

Reference chronology	*t*-value	Span of chronology	Reference
Danson House 1, Bexley, Kent, England (imported)	7.41	AD 1489–1758	Groves 2002
Oxburgh House, Norfolk, England (imported)	5.41	AD 1554–1748	Tyers 2004
Warleigh House, Tamerton Foliot, Devon, England (imported)	4.41	AD 1543–1759	Howard *et al* 2006
Denmark (imported)	3.62	AD 1380–1853	Bartholin pers comm
North Germany 1 (imported)	4.12	AD 1519–1858	Eckstein and Schubert pers comm
Stralsund, Germany	4.32	AD 1558–1840	Leuschner pers comm
Mecklenburg, Germany	4.82	AD 1555–1750	Wrobel pers comm
Estonia	5.92	AD 1516–1998	Läänelaid pers comm
Dannensterna House, Riga, Latvia	6.21	AD 1445–1694	Zunde 1998
River Daugava revetment, Latvia	4.81	AD 1546–1745	Zunde pers comm

[1] - *t*-values provided by C Tyers (University of Sheffield)

[2] - *t*-values calculated by S Wrobel (University of Hamburg/Federal Research Centre for Forestry and Forest Products)

Table 4: Results of the cross-matching of site sequence LNCASQ03 and a selection of relevant reference chronologies when the first-ring date is AD 1605 and the last-ring date is AD 1737. Reference chronologies known to be based on imported timbers are indicated

Reference chronology	*t*-value	Span of chronology	Reference
Danson House 2, Bexley, Kent, England (imported)	4.3[1]	AD 1545–1767	Groves 2002
House Mill, Bromley by Bow, London, England (imported)	4.4[1]	AD 1608–1801	Groves 2000
North Germany 2 (imported)	4.1[2]	AD 1362–1809	Wrobel pers comm
Stralsund, Germany	4.8[2]	AD 1558–1840	Leuschner pers comm
Brandenburg, Germany	5.3[3]	AD 799–2009	Heußner pers comm
Mecklenburg, Germany	5.4[3]	AD 1086–2007	Heußner pers comm
River Odra, Germany	5.3[3]	AD 954–2005	Heußner pers comm
Uckerk, Germany	4.9[3]	AD 1044–2005	Heußner pers comm
Torun, Poland	5.6[2]	AD 1168–1991	Zielski pers comm
Gdansk, Poland	6.1[4]	AD 1157–1990	Wazny 2001

[1] - *t*-values provided by C Tyers (University of Sheffield)

[2] - *t*-values calculated by S Wrobel (University of Hamburg/Federal Research Centre for Forestry and Forest Products)

[3] - *t*-values calculated by C-U Heußner (German Archaeological Institute Berlin)

[4] - *t*-values calculated by T Wazny (Cornell University)

FIGURES

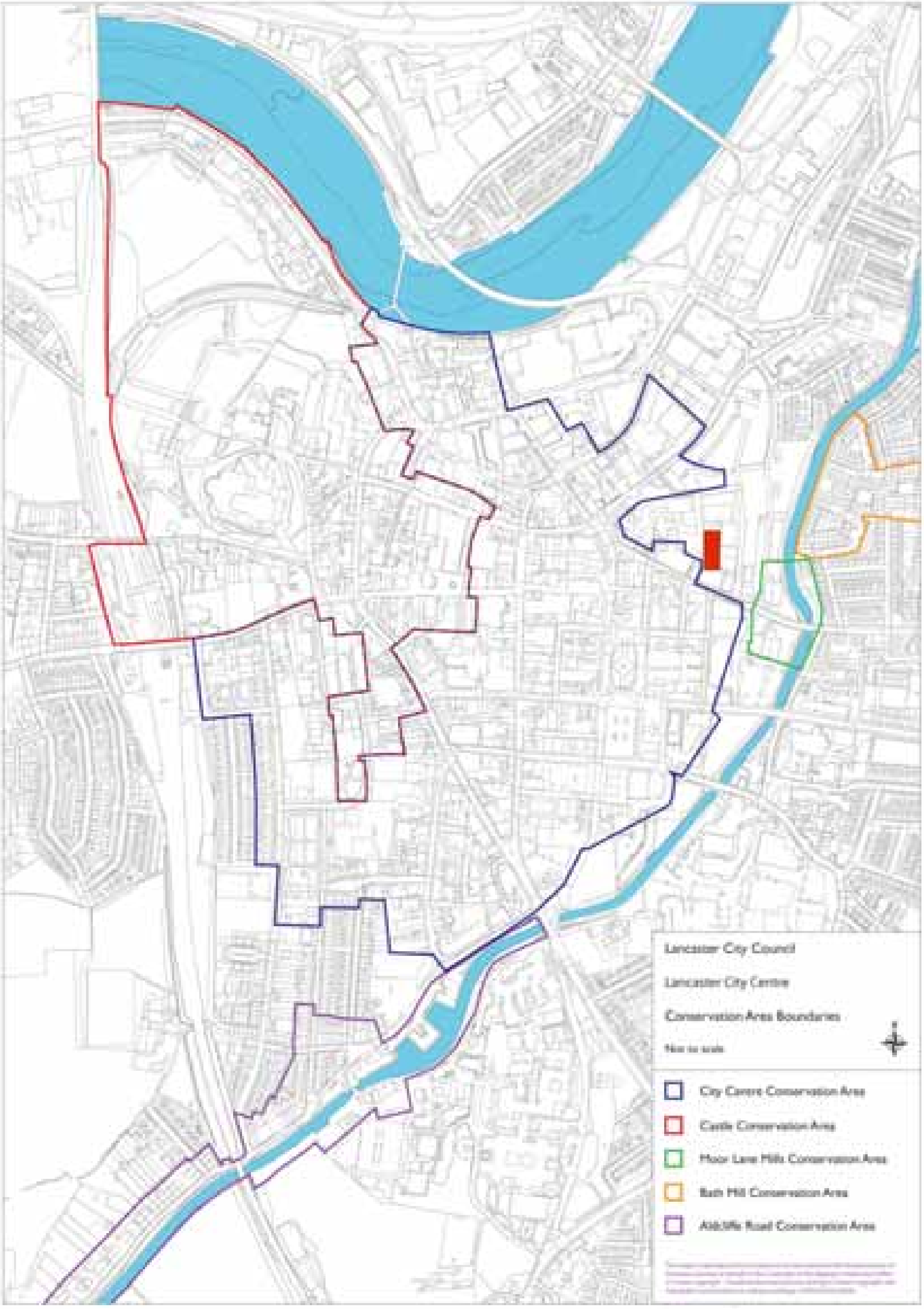


Figure 1: Location of Mitchell's Brewery (blocked in red)

Figure 2: Map showing the location of the buildings (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

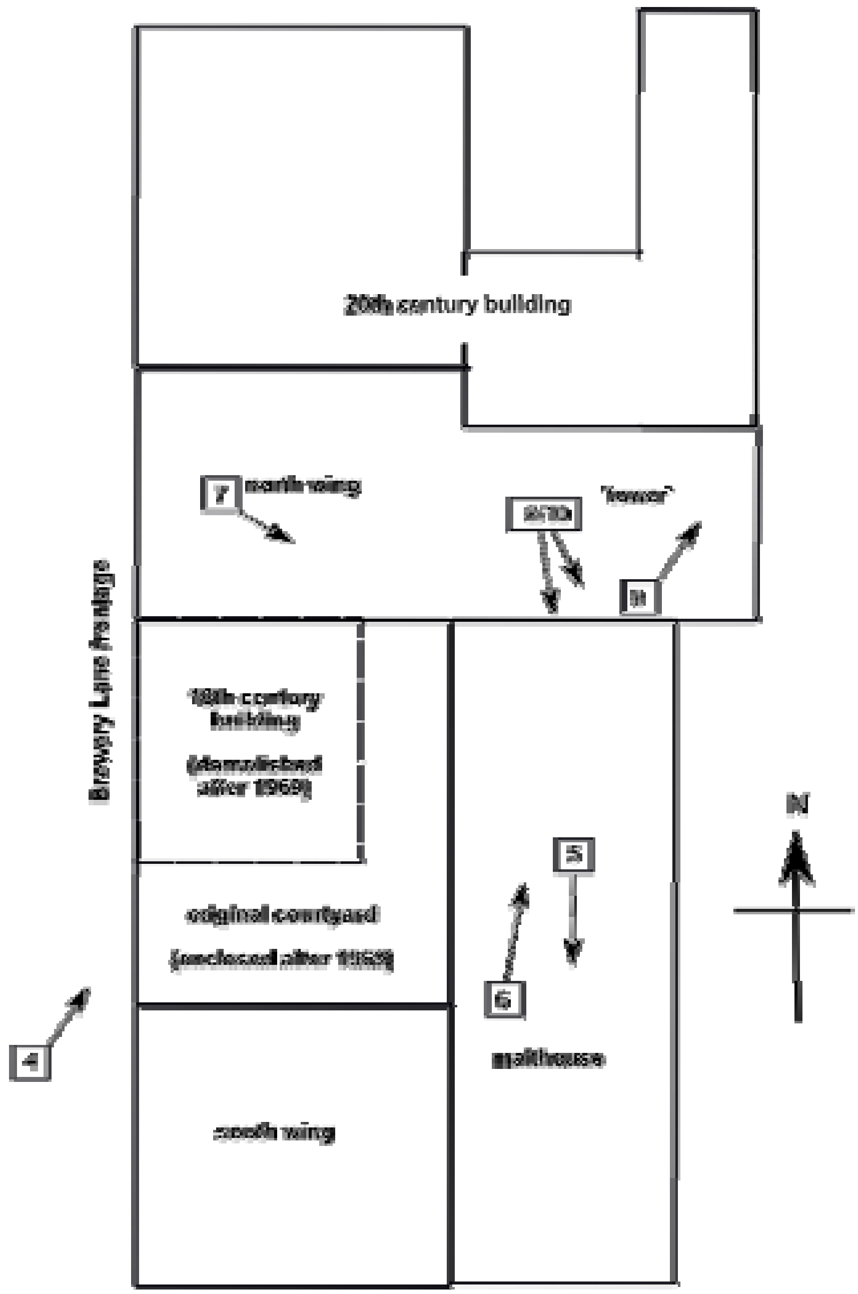


Figure 3: Schematic plan of Mitchell's Brewery complex showing position and direction of photographs used in Figures 4–10

Figure 4: View of Mitchell's Brewery from Brewery Lane. To the left (north) rises the brick-built, partially stone-fronted, nineteenth-century building. In the middle, with its arched double door, is the stone-built north wing. To the rear of this rises the 'tower', the west window of which is just visible. To the right is the position of the eighteenth-century stables and the former courtyard, demolished and then enclosed in 1969 by the stone-block and rendered building

Figure 5: View of the main beams of the frame to the first floor

Figure 6: View of the roof trusses to the malthouse

Figure 7: View of the roof trusses to the north wing

Figure 8: View of the south slope to the roof of the 'tower'

Figure 9: View of the north slope to the roof of the 'tower' (the blocked east window behind the black downpipe)

Figure 10: View of the remains of the third-floor frame of the 'tower'

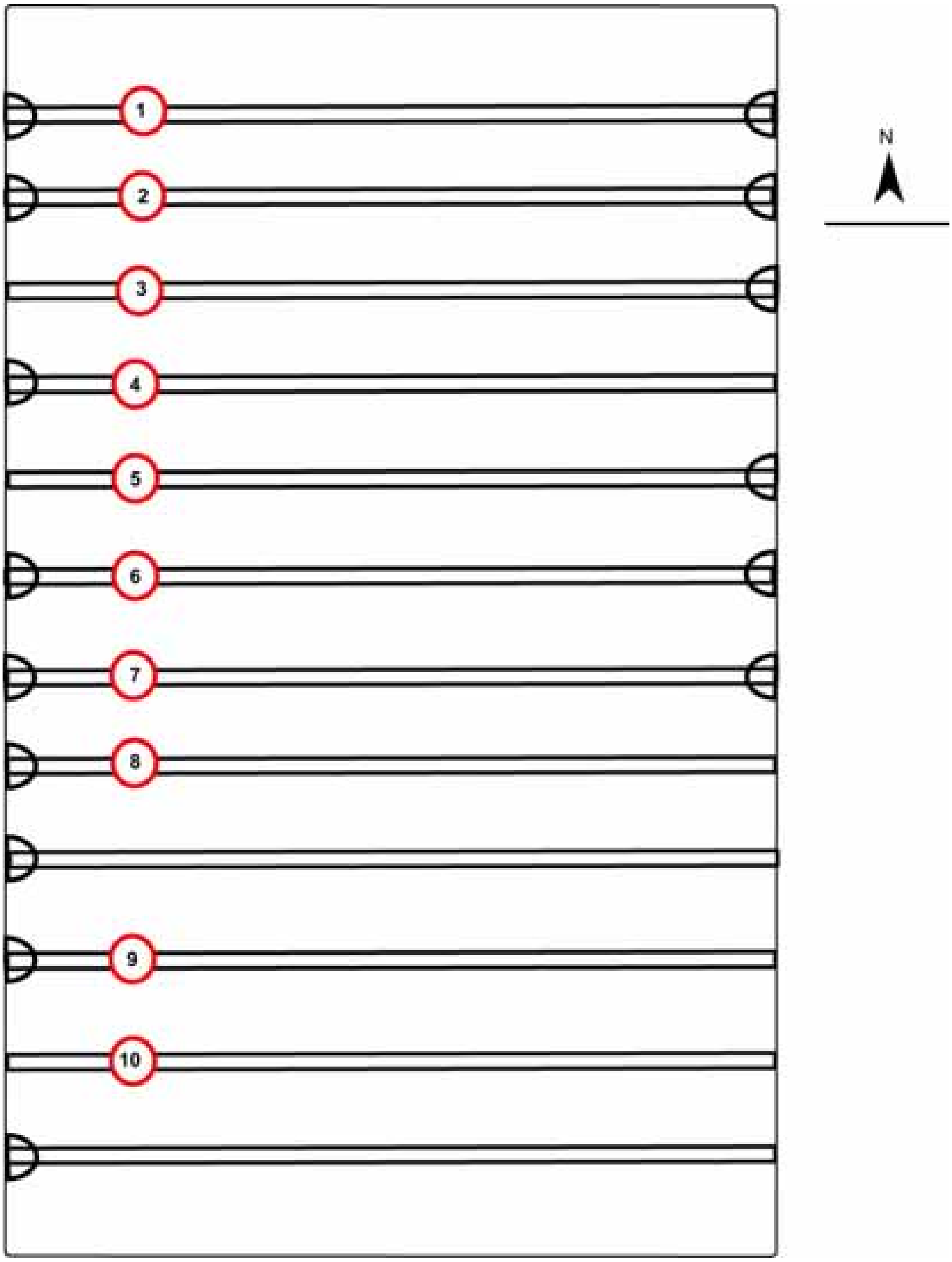


Figure 11a: Plan of first floor of the malthouse to show sampled timbers

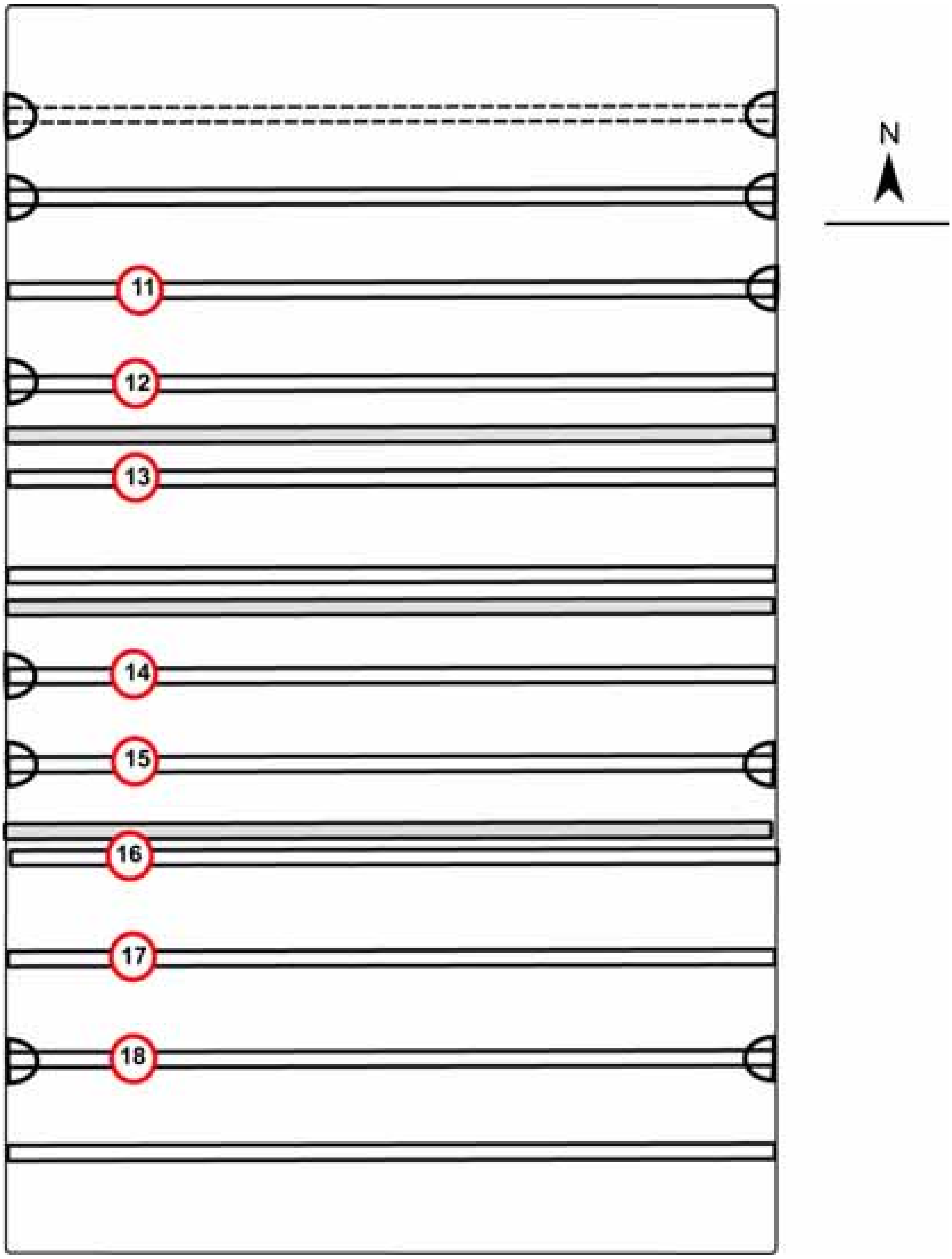


Figure 11b: Plan of the second floor of the malthouse to show sampled timbers (inserted steel joists shown shaded)

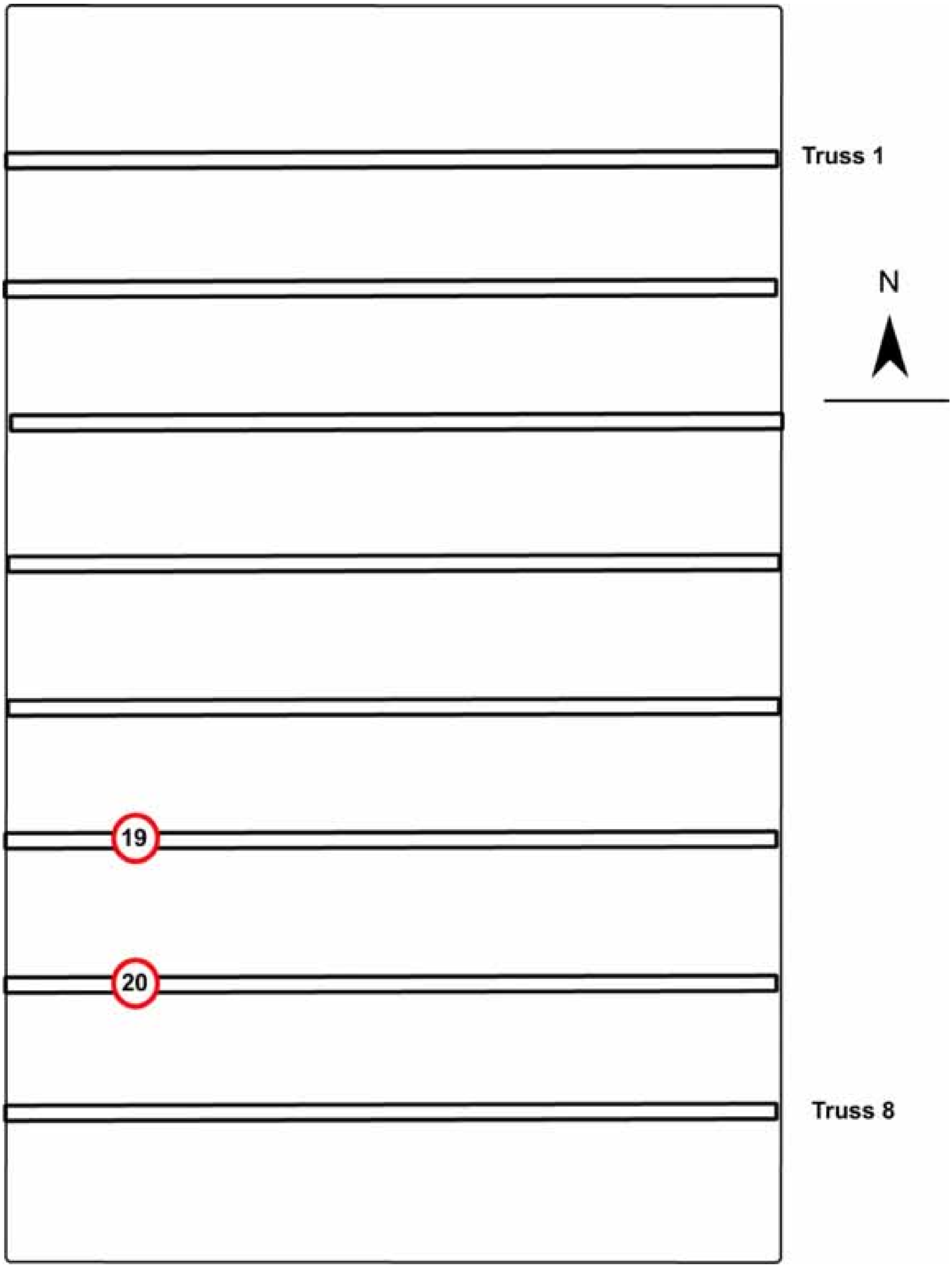


Figure 11c: Plan of the roof of the malthouse to show sampled timbers

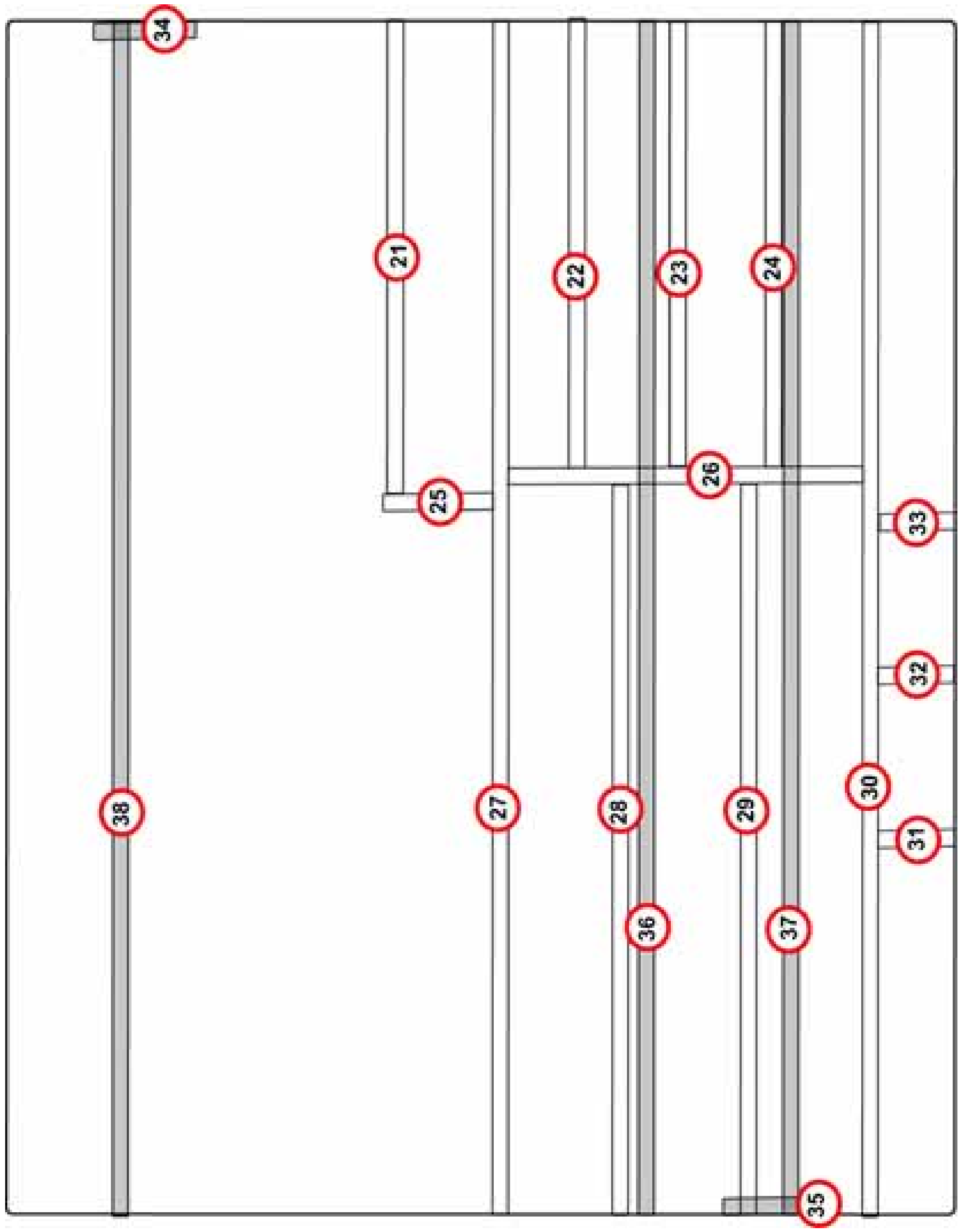
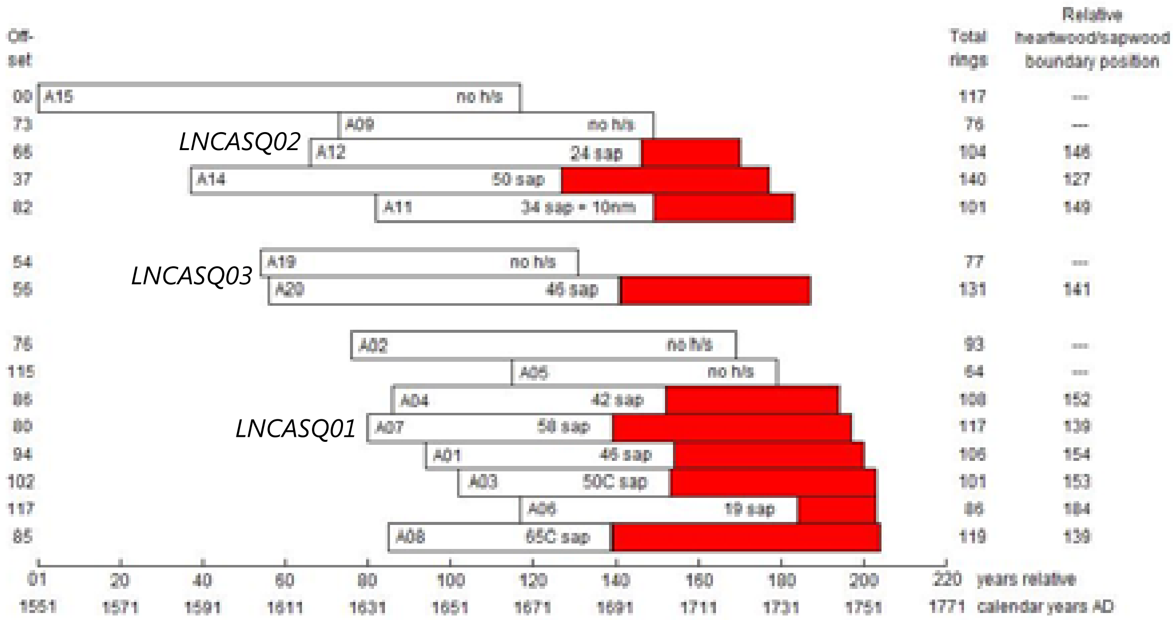
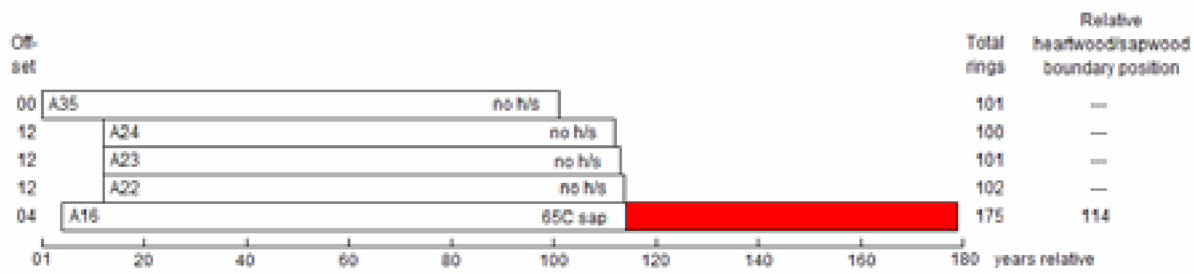


Figure 11d: Plan of the third floor frame of the 'tower' with the roof timbers and lintels shaded





White bars [ ] *= heartwood rings, shaded bars* [ ] *= sapwood rings*
h/s = the last ring on the sample is at the heartwood/sapwood boundary (only the sapwood rings are missing)
C = complete sapwood is retained on the sample. Where dated this is the felling date of the tree represented

Figures 12a–c: Bar diagrams of the samples in site chronologies LNCASQ01–SQ05 (top to bottom)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

LNC-A01A 106
296 317 209 213 256 233 208 203 163 139 252 261 191 221 184 241 231 257 235 163
156 132 147 123 105 150 42 27 29 72 67 82 90 142 191 249 131 103 92 131
135 174 204 218 134 156 149 161 194 187 162 148 127 120 112 148 129 155 152 144
81 95 30 71 83 156 150 161 199 167 161 109 157 156 112 126 141 157 183 179
164 154 123 124 86 119 71 136 134 148 127 130 132 97 87 76 80 66 116 94
113 123 110 83 65 96
LNC-A01B 106
272 306 267 155 196 252 200 202 168 147 232 260 210 205 179 210 247 239 212 171
154 133 146 118 115 154 42 27 20 71 69 83 94 142 200 257 128 114 92 135
144 166 207 222 148 156 142 167 193 198 148 145 130 125 112 144 138 157 148 139
85 97 31 72 82 155 144 167 193 172 167 105 153 154 117 126 139 158 179 176
175 147 130 123 91 126 74 125 121 143 129 137 116 95 87 81 75 68 113 96
108 123 115 79 70 101
LNC-A02A 93
299 340 313 325 206 161 257 211 285 327 257 276 300 284 222 222 182 180 312 269
267 308 256 304 286 215 138 171 181 184 62 62 78 100 163 207 227 248 211 108
116 216 198 160 198 178 274 161 127 71 77 167 129 129 66 129 150 108 110 184
114 113 69 37 55 58 55 75 95 100 77 55 34 48 62 55 41 45 65 64
63 136 129 135 136 114 137 145 93 75 111 89 119
LNC-A02B 93
308 345 304 321 203 162 260 212 275 312 255 266 285 290 228 219 175 182 302 261
277 295 249 308 300 221 127 170 195 193 66 65 79 98 159 209 232 261 176 75
100 202 191 166 200 221 287 163 129 62 65 170 130 119 59 116 146 111 121 183
124 113 71 37 67 63 53 68 94 122 73 60 35 48 64 48 47 40 61 75
67 135 126 123 136 117 137 142 90 75 104 98 111
LNC-A03A 101
169 166 180 230 196 202 171 238 418 423 328 271 267 197 151 132 152 204 58 28
66 97 102 105 150 206 200 335 211 154 202 162 207 283 252 217 148 178 170 191
220 181 148 162 173 156 133 152 140 205 261 180 130 91 62 101 99 183 191 192
213 180 148 161 179 185 145 161 164 179 199 198 220 157 122 106 80 110 47 87
105 114 126 125 109 98 86 62 79 75 101 93 101 102 98 65 75 75 77 100
123
LNC-A03B 101
172 172 171 246 195 209 164 243 463 423 329 290 262 181 144 138 142 217 54 37
48 90 86 113 132 214 198 335 223 163 196 182 208 282 251 216 153 175 171 186
217 188 152 149 179 163 134 148 141 215 260 189 124 96 62 96 98 174 179 206
210 170 145 168 178 171 162 153 179 182 211 197 225 166 129 109 82 109 47 92
106 121 126 123 134 102 76 70 70 83 109 79 98 117 92 73 70 73 73 109
133
LNC-A04A 108
129 146 156 159 127 162 139 135 226 188 209 206 207 264 254 219 170 169 181 219
139 157 103 92 124 160 206 206 227 129 89 142 153 108 99 99 154 102 103 82
73 79 93 142 109 133 114 127 133 179 154 156 131 125 131 122 105 123 100 90
82 61 37 74 77 119 174 103 90 56 95 112 120 123 114 129 127 131 99 78
129 134 106 103 112 114 112 108 112 93 100 120 135 165 124 139 150 183 230 177
168 174 111 61 96 108 161 157
LNC-A04B 108
124 146 163 165 120 162 142 133 231 190 207 211 214 278 272 223 169 161 193 211
136 165 103 82 130 164 202 216 230 129 97 139 147 105 92 104 158 104 112 85
79 94 88 155 113 122 109 114 121 174 151 153 128 127 138 113 108 129 100 100
81 62 34 67 82 115 172 108 88 60 87 120 109 125 116 128 134 125 96 84
125 135 108 105 110 108 111 105 99 97 105 125 147 161 122 132 164 185 225 169
168 170 126 67 81 113 150 171
LNC-A05A 64
601 554 740 607 531 534 558 475 401 281 223 260 350 265 417 250 224 279 256 242

293 290 243 147 100 208 199 304 351 206 153 133 141 129 173 181 209 156 137 144
98 116 182 223 330 218 249 252 225 169 161 210 236 169 101 139 186 227 174 168
124 119 153 129
LNC-A05B 64
617 555 732 611 539 501 550 504 416 281 222 255 350 270 431 249 206 294 244 238
304 311 243 156 99 200 198 301 361 210 148 130 137 120 168 186 199 156 132 146
100 109 174 221 333 235 261 238 223 154 161 233 256 165 101 126 175 229 167 173
117 109 152 147
LNC-A06A 86
510 370 360 315 319 334 241 218 174 249 300 279 323 186 221 244 214 233 270 294
202 178 84 168 185 166 188 151 127 101 144 134 143 152 172 146 104 137 85 135
178 166 206 194 170 167 145 125 116 189 202 165 87 148 179 204 146 127 84 90
132 148 178 94 146 121 133 118 124 65 46 81 80 117 118 128 112 117 108 118
59 82 86 147 161 196
LNC-A06B 86
508 373 375 315 328 324 260 203 174 257 302 281 308 198 222 228 210 254 270 300
210 162 89 177 186 163 194 147 132 110 145 138 141 159 167 139 103 129 85 134
181 163 197 199 173 173 136 125 121 184 208 160 78 153 177 208 144 125 90 85
122 150 175 99 142 120 132 119 122 65 50 85 79 116 116 130 111 114 107 121
61 77 95 138 154 208
LNC-A07A 117
296 353 482 410 369 435 440 368 402 346 306 402 409 414 465 462 304 190 210 366
370 296 179 158 188 194 93 144 49 127 333 361 309 236 220 120 78 103 111 77
62 55 143 91 75 62 81 95 77 116 74 62 76 77 94 125 95 84 74 48
79 89 116 115 63 56 50 68 69 94 98 117 77 82 85 57 15 50 51 106
71 90 94 92 102 85 88 90 67 65 91 128 136 93 75 82 73 71 64 54
46 38 54 78 85 81 120 124 42 58 59 55 70 44 87 97 102
LNC-A07B 117
322 358 463 414 370 429 439 372 379 342 320 392 407 415 458 460 291 178 218 370
350 296 179 145 174 175 100 139 44 113 295 370 336 249 209 124 81 99 122 83
69 55 147 94 68 66 89 112 72 109 77 61 100 56 87 120 98 82 71 55
69 88 113 121 55 67 51 71 61 94 105 108 76 83 89 54 16 46 50 112
64 102 97 85 99 77 90 90 62 67 97 125 124 97 78 85 70 70 62 59
33 42 49 77 91 77 125 121 44 52 63 52 48 49 100 106 120
LNC-A08A 119
344 348 353 333 406 381 393 351 362 588 364 250 207 234 322 294 221 164 156 160
165 79 99 30 66 238 209 183 246 236 115 105 119 117 82 67 53 127 108 86
85 89 98 61 110 92 74 78 86 126 167 127 118 79 55 75 98 133 116 66
40 47 54 47 66 67 75 68 64 60 21 9 30 35 53 56 62 60 61 71
55 66 98 50 67 90 108 121 93 93 109 108 82 74 70 66 73 92 154 139
98 159 173 71 79 97 132 135 132 156 211 144 43 75 145 106 120 138 137
LNC-A08B 119
387 346 366 331 413 380 378 347 359 593 337 263 229 242 306 289 222 168 159 166
168 82 93 35 69 213 219 185 234 244 109 106 120 112 78 59 60 133 103 80
77 93 106 70 104 101 66 84 79 133 183 128 111 82 60 69 104 133 116 66
46 36 62 52 71 70 73 68 62 51 17 10 38 36 58 53 73 54 54 72
55 72 93 58 70 82 108 122 82 102 107 113 89 72 67 54 75 93 166 128
99 153 175 78 74 115 126 143 130 155 190 133 45 72 143 100 118 135 156
LNC-A09A 76
328 282 225 296 397 301 212 206 261 300 279 270 291 212 168 176 178 157 142 203
197 251 255 140 214 212 189 188 218 169 165 150 156 166 189 186 155 138 124 91
126 108 127 117 91 93 117 95 76 76 78 88 129 101 87 64 129 83 119 119
111 110 125 97 98 136 144 140 83 76 199 156 162 158 127 126
LNC-A09B 76
320 283 234 273 368 307 228 191 262 317 282 270 289 221 158 169 177 152 150 190
198 256 257 159 238 208 182 205 221 162 170 149 152 184 175 186 164 155 122 85
130 113 131 117 87 94 119 95 74 82 74 96 129 111 81 57 149 88 128 120
108 101 127 95 98 132 140 141 78 86 206 148 151 167 126 126
LNC-A10A 97
120 150 199 149 101 131 161 211 211 185 299 264 172 126 171 196 119 143 151 217
169 138 225 256 150 159 250 168 104 175 203 151 164 132 115 105 99 99 122 132

179 101 137 169 164 89 89 126 148 126 121 82 98 74 68 78 150 265 225 191
163 161 207 304 152 83 92 130 141 122 81 85 89 90 90 108 48 96 132 222
161 176 156 188 121 67 128 107 150 180 221 215 236 207 228 384 205
LNC-A10B 97
121 141 222 156 88 149 157 204 215 187 294 272 180 125 161 200 114 144 142 225
169 141 212 254 148 158 248 166 109 172 197 154 169 129 111 113 89 110 119 124
176 110 148 170 166 97 97 123 148 129 123 80 98 72 74 75 149 270 222 201
157 153 190 306 148 88 93 132 146 125 87 78 105 84 98 103 48 97 128 218
160 174 172 181 127 74 128 109 149 188 207 202 246 204 220 377 214
LNC-A11A 101
141 111 144 163 153 152 163 172 89 86 82 126 131 126 152 154 185 162 186 152
180 202 166 225 202 164 163 135 129 138 147 179 180 181 139 161 139 128 131 121
108 127 130 152 141 152 135 183 203 190 132 150 153 186 189 108 114 82 134 88
57 119 88 97 86 100 88 84 78 90 91 122 137 103 123 120 92 89 77 86
82 138 112 84 107 112 114 113 118 100 124 119 92 82 94 80 61 97 79 107
140
LNC-A11B 101
158 125 139 152 157 140 171 166 102 82 84 118 131 132 156 152 189 162 183 171
177 207 170 234 208 160 170 136 134 141 148 181 180 182 139 158 138 132 126 135
113 119 135 156 141 150 136 187 214 193 129 151 158 163 201 111 114 83 133 88
57 111 96 94 79 106 83 90 76 91 96 124 129 110 129 102 106 75 75 88
88 124 105 91 106 110 121 111 123 108 127 123 89 89 87 73 64 89 86 120
138
LNC-A12A 60
162 150 131 183 164 177 138 151 136 156 178 136 136 137 116 150 131 124 118 152
143 137 117 113 111 149 141 89 90 73 121 82 58 85 78 77 65 77 65 70
89 112 85 106 114 88 104 98 75 70 66 66 75 84 71 52 68 90 70 75
LNC-A12B 60
159 148 124 176 167 182 141 154 142 145 169 138 138 127 119 141 122 118 116 155
125 135 121 114 117 145 136 87 93 82 119 96 48 97 68 78 62 76 57 74
85 113 90 101 111 87 108 96 72 73 64 69 79 89 63 61 72 84 67 86
LNC-A12C 75
179 144 106 118 134 145 154 118 129 124 125 165 150 146 114 129 112 110 130 138
153 164 203 177 107 90 83 110 133 95 132 146 161 167 159 154 183 183 177 200
175 133 161 132 141 152 103 182 159 172 150 149 129 139 166 139 116 122 127 149
127 129 122 167 140 136 132 139 117 148 148 98 88 74 129
LNC-A12D 75
174 138 92 129 126 156 168 146 134 130 116 153 167 155 113 126 112 114 111 144
155 167 195 177 110 92 83 118 137 101 121 150 160 163 157 156 190 179 164 198
179 137 159 133 144 155 117 167 181 178 147 150 134 152 164 139 117 114 121 164
133 128 123 162 151 125 133 142 108 152 148 104 89 74 142
LNC-A13A 113
445 358 316 158 222 389 380 271 280 165 275 304 436 389 405 245 373 255 245 333
210 256 247 193 182 286 237 299 272 185 147 171 178 138 273 140 124 182 174 185
169 161 132 115 173 138 115 116 107 113 134 126 110 149 184 110 92 96 98 150
155 92 86 89 89 105 122 140 86 99 142 90 100 80 108 105 79 107 91 55
63 56 73 69 73 56 58 61 31 45 59 56 52 74 112 78 64 64 74 42
65 47 41 49 24 20 28 48 44 55 47 69 80
LNC-A13B 113
431 358 345 160 219 417 440 259 275 153 269 318 435 403 389 266 371 256 245 328
223 249 262 190 178 285 244 298 270 184 140 184 177 145 265 126 127 181 175 188
161 157 135 119 166 145 114 127 110 116 151 114 122 153 187 109 94 98 98 148
163 91 95 82 87 110 119 126 83 102 139 92 94 82 104 105 83 115 86 52
68 64 65 68 68 54 64 63 24 48 65 60 52 68 112 78 55 63 83 36
69 51 43 52 22 18 28 46 53 54 44 72 81
LNC-A14A 140
135 135 107 131 142 102 116 128 128 105 131 119 126 117 154 122 151 136 139 156
125 164 153 145 153 150 124 120 174 137 88 79 119 80 86 102 86 87 80 94
124 131 86 70 96 113 95 117 145 106 96 85 122 71 47 59 87 88 94 87
98 101 80 79 109 132 112 94 138 99 89 59 106 90 97 79 88 79 102 88
95 78 72 72 86 61 57 77 79 64 58 59 94 101 78 69 77 92 102 80

75 95 76 70 28 45 88 52 34 29 47 61 73 67 62 52 58 72 54 81
84 58 51 54 50 59 49 39 33 48 57 57 53 61 55 43 28 36 53 49
LNC-A14B 140
167 139 99 142 154 114 121 110 138 108 142 116 122 106 148 129 145 140 144 151
132 172 170 137 143 140 126 130 166 132 88 84 117 85 89 97 90 85 85 97
121 127 91 79 86 123 104 115 135 106 96 86 123 77 52 56 84 97 92 90
102 104 75 92 104 135 115 85 145 98 86 65 101 93 94 86 91 77 96 94
94 72 71 82 82 66 56 79 79 79 52 56 100 98 72 74 75 101 93 86
76 94 90 73 38 41 103 54 26 33 51 62 79 60 59 46 58 71 59 84
90 62 58 47 53 59 48 44 41 46 67 49 54 65 51 43 34 35 40 65
LNC-A15A 117
79 88 102 100 110 76 68 72 116 119 135 139 113 153 137 162 196 134 105 112
140 125 123 133 111 125 154 156 178 197 183 167 168 140 177 195 148 231 149 138
170 194 157 143 127 126 106 144 127 118 103 147 119 131 136 112 123 107 108 110
101 124 148 114 117 172 102 63 69 104 93 63 100 92 78 55 67 82 81 59
61 80 114 106 116 147 98 93 92 129 72 29 54 90 122 107 113 144 109 116
86 87 104 103 110 113 82 59 53 99 96 76 67 88 92 84 81
LNC-A15B 117
87 88 95 100 113 70 75 73 118 119 160 156 110 148 133 167 198 138 100 112
137 119 121 141 125 131 153 155 171 200 161 153 172 175 172 204 160 229 155 140
175 197 158 139 136 141 97 173 118 119 108 142 107 140 134 118 112 111 115 105
101 120 160 108 116 173 110 64 64 101 95 67 100 89 78 54 72 82 91 48
58 85 112 98 122 149 96 84 94 130 71 31 61 82 123 109 99 149 104 114
89 92 107 107 90 128 82 58 53 96 104 69 61 99 93 90 83
LNC-A16A 175
382 322 296 343 376 262 135 126 108 152 201 221 206 256 191 218 181 177 158 167
152 196 123 138 125 117 121 115 144 169 186 159 184 166 140 168 132 144 151 124
110 129 88 87 115 119 131 51 23 10 9 41 24 31 31 28 37 51 58 83
104 121 97 75 58 74 69 65 68 92 72 87 90 77 90 84 86 129 84 76
59 67 65 87 82 74 75 78 56 67 77 58 69 71 62 55 79 110 79 85
92 106 96 95 69 69 56 94 90 65 63 65 61 73 58 54 62 68 46 45
54 63 46 47 49 64 74 48 70 72 57 47 52 59 59 58 50 46 51 61
59 83 85 76 63 71 83 63 74 75 99 72 62 50 88 74 40 41 31 59
57 51 59 69 69 45 49 61 57 27 37 43 54 64 63
LNC-A16B 175
411 344 296 333 363 285 136 130 107 148 218 196 213 277 195 225 189 189 151 178
167 204 134 141 122 121 117 119 154 169 165 159 182 177 142 158 136 133 148 136
107 129 91 84 123 114 126 57 21 8 8 42 27 28 26 26 43 53 53 72
109 129 96 72 61 74 68 62 73 88 85 86 83 79 83 84 85 139 81 70
72 58 71 78 87 73 71 77 63 65 70 62 66 60 73 51 88 105 85 82
90 99 98 91 72 67 62 93 82 65 69 59 66 65 69 48 67 68 45 47
59 63 41 36 47 73 70 48 72 71 56 50 55 67 54 60 54 44 52 60
50 82 90 81 67 76 73 78 67 80 92 84 60 56 88 71 46 37 42 52
58 52 62 56 80 41 47 62 60 25 31 51 53 60 72
LNC-A17A 149
559 472 407 345 364 412 488 415 407 360 354 400 349 253 278 264 284 265 306 273
291 290 290 297 228 109 113 82 93 122 135 141 156 131 161 123 120 106 111 101
127 115 153 129 107 106 78 106 97 103 99 116 112 127 112 98 92 122 100 112
130 90 86 85 105 83 51 39 21 20 20 35 53 40 59 95 73 102 103 126
109 91 97 83 100 73 84 74 92 85 102 94 103 103 101 95 68 76 53 68
73 78 100 106 91 80 75 66 65 61 76 91 58 62 80 110 100 102 91 147
115 109 94 86 81 118 117 69 84 65 78 86 64 76 80 67 73 70 55 88
82 83 64 98 111 71 83 93 85
LNC-A17B 149
537 494 396 361 353 424 474 401 413 364 344 422 344 252 249 283 282 254 314 283
292 279 289 293 231 113 120 82 88 106 158 136 156 136 161 120 126 101 115 97
125 118 151 131 105 110 79 108 103 98 100 117 111 127 113 102 109 115 100 96
127 92 90 87 99 98 54 29 26 13 22 38 46 38 66 102 75 86 104 142
118 98 93 83 99 69 92 76 87 84 104 90 105 105 95 100 74 69 62 60
75 77 106 113 92 73 77 59 65 63 82 92 53 61 82 110 95 102 100 143
111 114 96 83 83 115 119 70 74 72 84 90 60 73 81 61 69 68 60 88

85 83 64 104 103 75 80 94 93
LNC-A19A 77
372 356 416 289 341 375 429 285 256 272 279 205 182 208 184 247 173 235 277 201
177 144 211 237 243 280 201 174 197 191 185 200 178 176 159 165 124 158 141 129
248 181 170 136 143 196 263 213 153 104 132 175 113 144 181 145 205 202 202 152
121 59 78 76 108 96 101 134 188 141 68 55 69 98 105 91 91
LNC-A19B 77
378 348 417 290 338 378 446 288 261 301 267 195 190 195 203 252 169 247 283 198
184 136 220 243 224 282 213 159 204 200 182 193 193 159 155 155 123 158 122 133
252 201 168 125 146 181 261 230 139 121 123 184 114 148 188 130 212 208 199 154
108 69 68 89 104 105 103 128 203 135 55 56 67 104 95 97 114
LNC-A20A 131
323 208 251 253 336 262 229 238 249 193 190 206 251 350 159 222 259 179 191 195
297 287 204 241 191 198 235 215 208 191 185 201 172 147 143 170 152 166 240 174
157 115 139 190 200 132 123 69 100 101 106 165 132 85 157 139 160 134 116 86
78 80 72 71 74 122 144 96 56 55 53 72 88 146 101 90 98 90 97 125
167 134 101 137 114 84 84 108 69 71 56 64 45 50 61 35 24 29 32 32
19 9 20 46 52 45 59 75 56 48 78 96 61 56 60 88 156 92 103 112
95 70 82 64 35 52 64 102 88 91 76
LNC-A20B 131
340 208 245 249 329 249 220 248 251 191 180 202 274 340 167 228 259 176 192 201
264 282 221 229 190 201 235 219 197 196 175 189 181 143 142 169 159 155 240 171
158 120 129 188 192 123 128 66 93 105 110 158 141 83 144 139 158 133 113 83
70 87 74 72 78 128 143 91 53 54 59 68 79 155 100 79 91 104 94 131
167 139 108 131 106 63 88 105 75 74 66 59 42 48 58 37 31 25 33 33
17 14 18 42 60 43 52 62 53 61 71 111 59 55 56 86 153 90 104 109
88 78 84 59 33 66 69 97 83 87 76
LNC-A22A 102
170 184 232 240 214 199 155 168 125 152 130 136 128 150 155 144 149 161 146 144
161 175 159 171 183 237 242 225 182 217 212 199 238 240 172 198 220 205 183 117
63 27 21 35 48 93 109 92 110 120 123 126 123 124 151 173 162 180 218 186
169 171 172 138 119 117 105 84 103 126 94 101 73 73 86 88 96 118 129 118
105 87 101 86 94 70 69 75 91 87 91 99 90 119 93 94 101 82 116 143
136 111
LNC-A22B 102
177 184 234 241 228 206 147 156 127 127 136 126 132 154 159 139 152 155 148 145
176 158 157 183 176 241 231 250 207 214 209 199 241 232 179 204 196 218 175 117
64 37 20 29 49 95 107 91 114 111 126 125 125 120 158 174 167 180 211 182
170 169 169 144 122 119 102 88 100 126 94 97 77 74 81 90 103 115 128 126
101 86 101 86 88 72 64 84 89 89 87 101 94 119 94 92 107 86 111 130
142 103
LNC-A23A 101
131 132 173 183 154 135 123 120 113 119 137 133 136 154 152 153 169 145 125 129
154 160 180 183 178 221 227 278 282 237 212 193 243 246 194 204 218 212 177 129
61 24 21 35 50 105 112 127 132 104 118 119 167 183 158 172 148 184 246 220
173 165 170 149 136 113 110 97 116 132 98 104 97 81 106 120 111 150 189 150
150 114 114 103 105 71 72 93 81 97 101 129 108 128 109 91 103 95 114 134
128
LNC-A23B 101
135 132 173 180 151 131 122 123 109 119 140 128 139 157 150 153 116 150 127 121
157 167 179 183 181 221 227 277 277 239 217 180 253 248 193 202 217 214 170 130
62 29 18 37 43 94 122 130 128 100 119 119 158 178 160 172 157 180 235 221
179 162 177 154 128 116 103 101 119 133 96 104 100 92 101 116 117 145 172 172
154 111 117 106 102 79 79 77 89 98 117 115 116 119 100 83 94 89 108 133
132
LNC-A24A 100
66 142 228 220 213 225 178 163 156 132 147 159 139 133 159 155 110 143 136 133
149 140 138 143 143 166 159 176 145 134 157 137 161 162 145 164 175 148 134 100
60 36 27 44 36 61 90 105 108 127 109 124 111 117 166 187 120 132 144 135
119 103 108 90 92 63 50 40 55 64 57 83 73 86 86 95 90 106 105 94
113 102 94 87 72 59 70 73 75 73 73 74 87 77 74 61 71 58 67 78

LNC-A24B 100
86 136 241 214 222 213 180 155 158 133 151 154 131 136 161 166 101 141 132 136
151 141 137 141 144 167 162 174 148 137 157 131 162 170 139 157 182 151 130 105
58 36 23 39 35 70 87 106 107 113 121 116 119 110 125 151 108 123 155 137
119 107 106 91 88 67 47 47 49 63 67 78 77 84 87 95 92 106 103 96
111 103 102 78 77 59 74 69 73 82 83 66 82 77 71 62 69 55 65 76
LNC-A25A 57
140 316 329 387 375 345 293 312 328 305 269 264 212 201 238 186 113 109 106 103
140 161 200 193 162 165 153 120 138 115 132 139 131 126 153 149 129 125 146 152
168 152 151 174 189 182 177 157 162 148 173 169 145 163 141 112 171
LNC-A25B 57
139 316 318 399 369 355 296 305 332 311 283 264 214 213 225 195 115 104 108 95
136 166 194 192 171 154 158 132 124 114 136 143 131 125 153 155 130 129 133 14
168 159 163 180 173 189 178 151 162 160 157 189 143 157 144 115 169
LNC-A27A 115
167 86 230 225 261 227 140 69 164 206 205 170 232 115 143 174 185 151 165 154
179 179 155 166 121 131 115 106 114 97 98 111 97 114 87 71 62 58 55 52
60 69 71 75 88 114 87 83 93 82 112 101 92 95 111 79 107 86 86 51
64 71 78 79 56 67 54 49 55 67 83 68 81 83 78 58 58 71 75 102
99 103 105 96 138 106 82 105 91 99 109 120 118 84 108 82 92 58 46 40
37 51 73 63 55 61 70 84 89 78 84 72 72 47 37
LNC-A27B 115
163 85 230 217 272 220 134 72 161 218 201 190 222 110 152 174 183 147 164 148
182 177 156 160 128 142 109 103 113 100 109 103 90 103 86 74 63 52 57 59
60 77 60 85 88 119 81 88 85 79 96 95 97 94 111 87 106 99 72 57
66 74 77 81 53 66 56 49 51 71 81 63 80 80 81 65 56 69 76 102
94 108 102 104 134 101 93 102 90 95 109 118 123 85 102 85 91 64 38 45
42 43 76 62 51 67 71 82 84 82 82 77 72 44 35
LNC-A28A 82
234 208 224 237 191 222 183 181 169 139 141 149 133 109 99 115 85 103 64 56
70 39 20 25 36 27 40 48 68 78 125 143 140 149 133 94 97 107 88 93
162 175 172 151 162 136 162 206 241 226 190 155 170 148 141 89 86 87 95 84
89 147 185 238 181 307 170 210 184 128 137 72 55 104 66 89 70 65 68 76
55 79
LNC-A28B 82
239 209 230 248 193 220 185 178 167 144 142 151 130 109 101 105 85 96 68 55
70 40 22 29 26 32 39 45 68 89 104 116 147 157 144 97 99 105 75 110
146 156 163 166 160 135 158 189 249 219 196 153 170 152 136 92 88 73 102 67
96 155 174 205 186 310 168 219 172 140 133 72 63 95 71 84 73 60 70 68
52 76
LNC-A29A 79
282 398 293 209 311 353 328 271 292 298 282 237 254 274 206 216 242 231 236 206
190 237 239 217 230 230 204 257 226 203 186 154 131 112 152 158 167 153 133 149
165 150 137 129 110 109 135 117 77 68 92 104 81 80 89 101 80 94 84 91
81 86 86 100 112 127 111 100 90 91 74 99 73 60 79 94 97 89 160
LNC-A29B 79
288 376 346 188 293 313 289 267 290 311 296 249 227 291 226 204 233 206 220 218
179 262 248 230 230 229 211 239 246 191 186 148 133 119 144 155 175 147 133 147
156 149 115 140 101 117 140 117 77 68 84 110 83 85 89 98 85 89 86 92
84 89 89 100 114 129 102 109 89 91 71 101 77 61 86 86 100 88 161
LNC-A30A 119
193 175 170 149 174 197 214 230 173 172 175 168 193 161 131 107 103 127 117 94
122 115 137 106 114 101 106 109 130 101 103 95 114 117 91 98 96 72 114 117
88 68 99 122 115 110 99 102 109 103 99 126 110 124 78 74 61 90 68 71
59 63 90 91 86 96 113 103 104 91 157 154 196 136 123 127 97 96 119 72
85 81 72 89 73 74 92 97 77 96 148 125 120 106 98 88 85 75 113 100
76 70 83 80 89 70 52 50 57 67 91 77 89 71 63 66 97 82 113
LNC-A30B 119
188 185 171 144 170 198 220 222 177 178 177 169 190 156 130 108 102 129 115 100
123 104 142 107 113 95 110 113 122 110 101 95 110 114 96 104 82 77 111 121
85 75 98 119 116 110 103 100 105 106 98 126 114 123 79 76 59 86 71 72

57 65 87 90 79 103 112 98 114 97 151 157 193 129 125 132 88 100 121 68
86 83 69 86 78 72 92 105 67 99 156 125 112 108 98 87 80 79 102 110
73 75 84 76 92 65 46 57 58 59 96 84 84 77 59 69 95 84 115
LNC-A31A 57
185 137 151 144 156 121 116 80 81 52 62 108 123 125 134 147 123 108 118 119
132 143 226 179 146 142 155 155 126 122 115 107 74 80 66 77 84 65 70 63
96 90 92 103 100 81 78 87 83 76 80 77 64 75 84 85 89
LNC-A31B 57
179 136 143 151 160 138 110 90 74 55 61 104 126 128 126 138 128 110 113 117
124 138 216 156 156 137 164 156 124 114 108 102 74 89 63 89 86 70 69 76
99 92 96 103 110 66 78 86 83 77 80 74 67 77 82 86 89
LNC-A33A 62
210 185 176 139 146 118 125 115 78 63 51 61 86 91 123 99 127 150 120 128
123 125 135 216 174 150 133 161 165 130 142 159 124 102 112 86 127 147 101 113
104 145 126 137 117 129 113 132 141 120 119 96 113 93 104 114 108 97 86 94
103 119
LNC-A33B 62
218 182 158 140 152 92 127 110 73 71 48 61 84 105 106 109 120 139 116 127
125 120 128 204 170 153 131 163 161 110 138 159 125 94 114 87 124 145 99 110
103 150 117 140 123 125 117 125 139 123 118 98 111 95 111 113 127 100 86 96
100 119
LNC-A34A 64
373 483 578 604 660 503 440 181 441 341 290 641 428 271 319 338 291 293 415 310
247 305 268 312 402 258 215 245 230 295 268 119 138 215 175 244 182 282 318 248
214 225 206 273 419 224 184 175 269 254 149 174 200 203 234 312 316 359 269 191
176 237 314 236
LNC-A34B 64
368 468 570 607 647 516 429 196 407 324 231 601 410 280 340 318 301 286 420 308
253 304 270 314 405 244 231 242 236 295 256 120 143 205 176 247 182 287 316 243
166 243 204 279 457 230 194 182 270 256 148 165 215 191 236 301 326 340 280 189
186 242 314 230
LNC-A35A 101
123 91 100 95 120 107 126 108 133 129 91 119 151 107 154 186 177 157 170 149
122 155 176 179 158 172 162 189 180 159 166 135 197 152 180 114 178 120 104 124
106 146 135 97 96 118 108 121 143 134 111 102 27 18 17 26 32 29 41 44
49 67 82 62 76 92 117 78 55 68 81 137 119 101 135 117 84 92 92 78
73 68 62 77 81 97 126 129 73 97 84 98 70 68 69 81 85 99 130 157
177
LNC-A35B 101
110 91 94 106 116 104 119 108 140 112 102 112 157 105 159 186 164 167 181 154
129 149 161 178 162 187 173 209 178 158 168 133 211 140 146 123 156 119 88 126
115 142 143 91 92 115 103 128 143 120 112 98 29 19 17 28 25 33 38 49
53 83 81 93 92 84 110 74 57 66 83 128 113 95 120 115 92 86 95 70
81 64 65 78 79 96 120 121 80 99 90 97 66 72 67 86 86 102 126 157
177
LNC-A36A 211
90 145 142 112 139 167 198 136 121 100 66 79 61 31 46 70 102 115 127 140
160 158 160 133 194 297 209 242 185 112 156 127 136 147 150 184 181 159 173 134
158 221 179 167 166 122 153 172 189 150 179 200 186 146 204 161 158 205 161 140
178 205 229 274 137 120 159 128 141 129 165 151 126 196 150 138 152 124 143 129
135 168 138 162 140 135 124 83 53 64 93 111 102 117 103 138 99 88 101 68
62 72 63 62 69 74 76 58 68 67 54 74 49 48 49 53 60 66 57 61
63 60 67 39 21 16 23 24 28 41 51 55 38 37 30 54 43 49 51 71
65 54 53 69 58 62 57 59 66 57 62 50 49 32 55 48 54 47 63 53
49 46 59 57 67 74 60 71 51 60 66 64 73 61 61 43 40 46 42 29
44 35 37 42 39 52 41 41 27 35 42 32 22 29 34 30 42 47 40 36
43 50 47 42 35 28 37 33 45 47 52
LNC-A36B 211
114 146 132 112 137 166 177 135 122 103 63 79 66 25 42 75 101 161 121 131
159 165 158 127 186 296 201 241 180 117 149 142 132 135 160 184 194 159 167 131
157 232 183 159 169 122 152 174 201 143 183 193 197 146 181 173 152 170 151 146

193 192 216 258 138 119 165 136 144 121 171 155 130 191 148 139 156 124 136 132
135 156 141 169 134 132 127 83 53 69 96 109 102 123 97 127 94 96 96 67
79 59 68 67 65 72 76 62 64 62 54 64 46 56 48 48 61 70 67 56
65 61 65 36 20 18 20 29 25 44 49 60 35 38 32 47 46 59 46 71
61 57 59 59 59 65 53 63 61 56 67 48 47 32 57 48 53 48 63 50
55 36 57 61 67 74 63 68 52 62 65 66 71 59 57 50 36 45 42 30
47 37 36 38 39 53 43 38 33 34 38 32 20 27 34 35 39 45 41 35
45 47 49 40 39 31 37 37 48 46 52

LNC-A37A 119

420 546 444 551 402 483 532 377 298 197 163 235 173 151 190 199 157 122 38 32
80 90 109 157 124 96 80 52 78 67 75 66 47 47 61 71 74 82 106 106
97 103 62 64 59 71 51 60 75 51 58 71 48 49 42 45 49 46 40 38
44 56 47 64 78 144 112 86 135 124 125 87 117 75 91 86 103 90 105 113
81 77 69 45 56 55 53 52 103 79 73 55 74 83 57 42 37 36 74 75
71 81 86 59 84 73 63 69 63 39 65 72 83 100 92 123 117 78 119

LNC-A37B 119

371 540 430 565 408 487 532 374 299 197 163 227 174 149 196 198 158 120 38 37
74 93 113 152 121 91 89 48 76 66 77 61 45 54 59 75 72 83 99 110
100 93 66 67 66 65 55 61 63 55 52 69 55 44 54 45 44 46 38 36
36 60 48 70 74 143 115 84 136 125 132 89 114 80 82 85 109 85 106 111
80 81 71 43 62 54 48 48 103 78 78 55 74 84 51 49 46 29 69 67
73 77 87 63 86 71 64 71 59 45 59 73 84 102 88 120 103 87 122

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

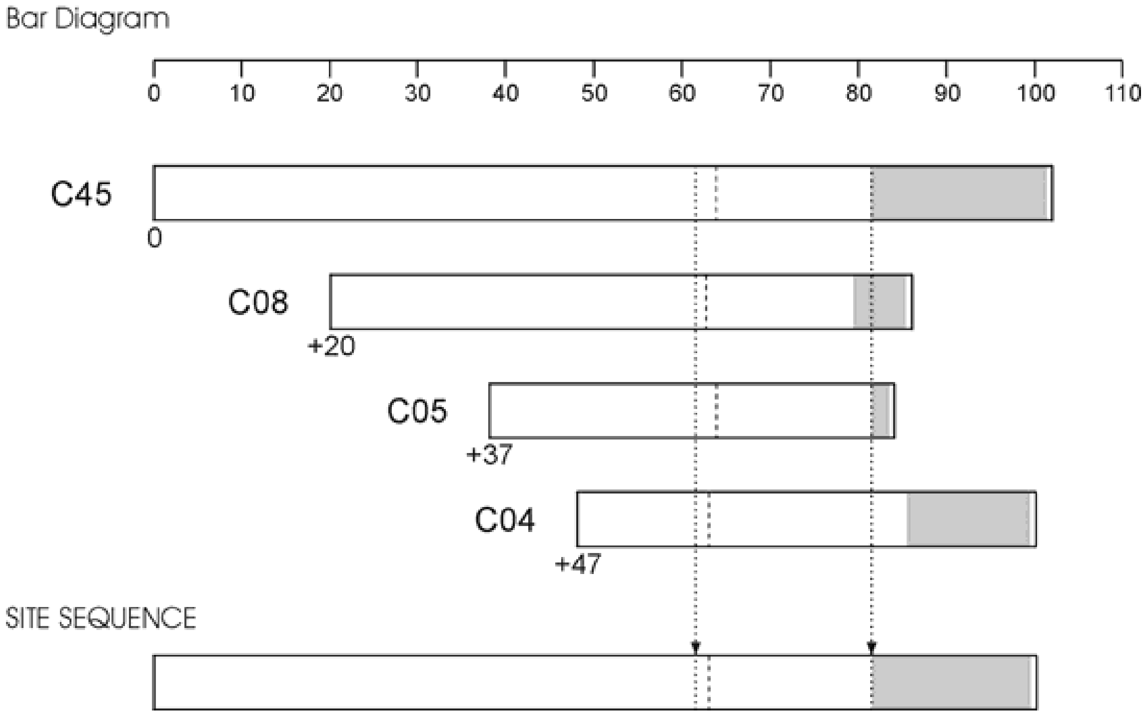


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

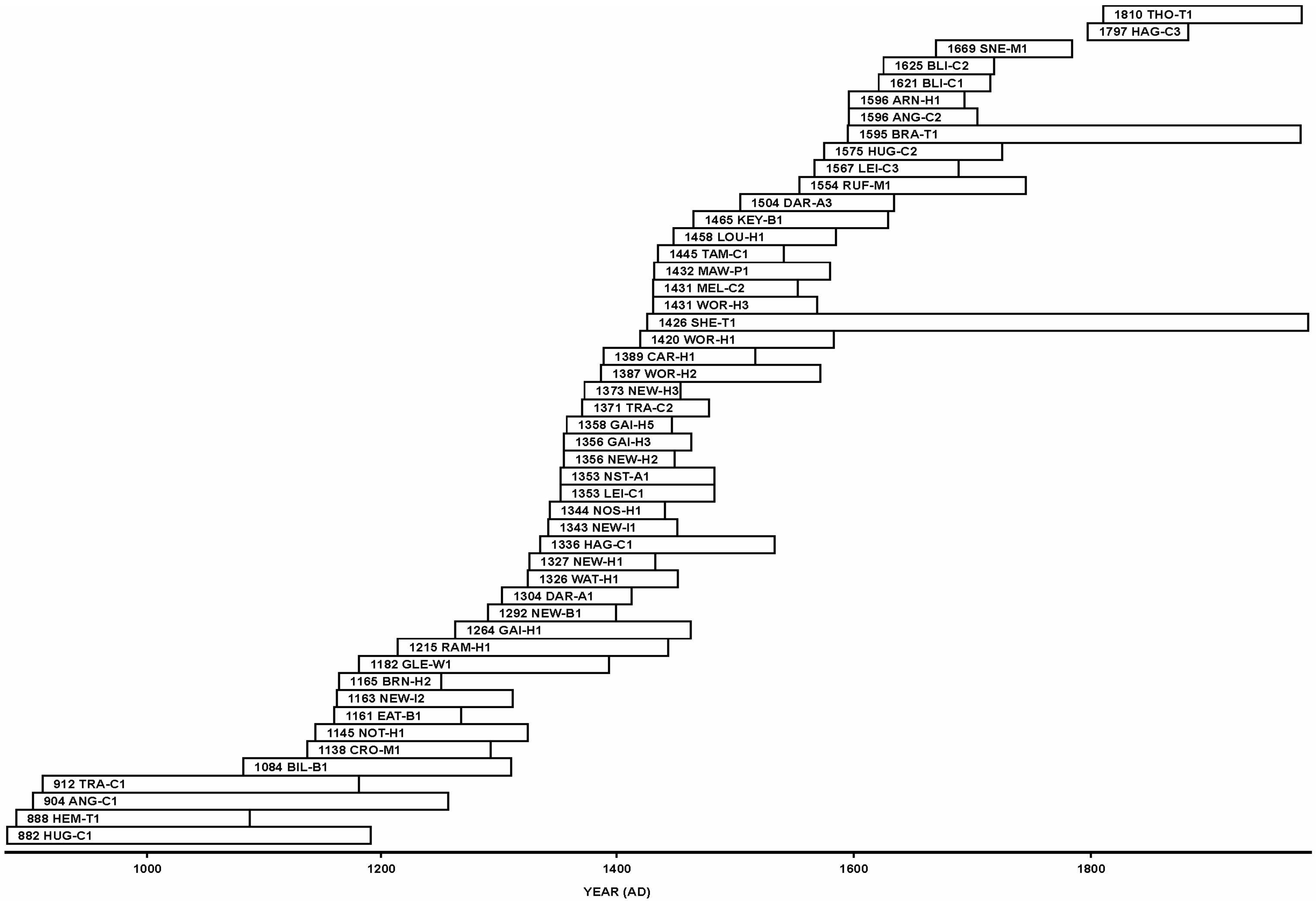
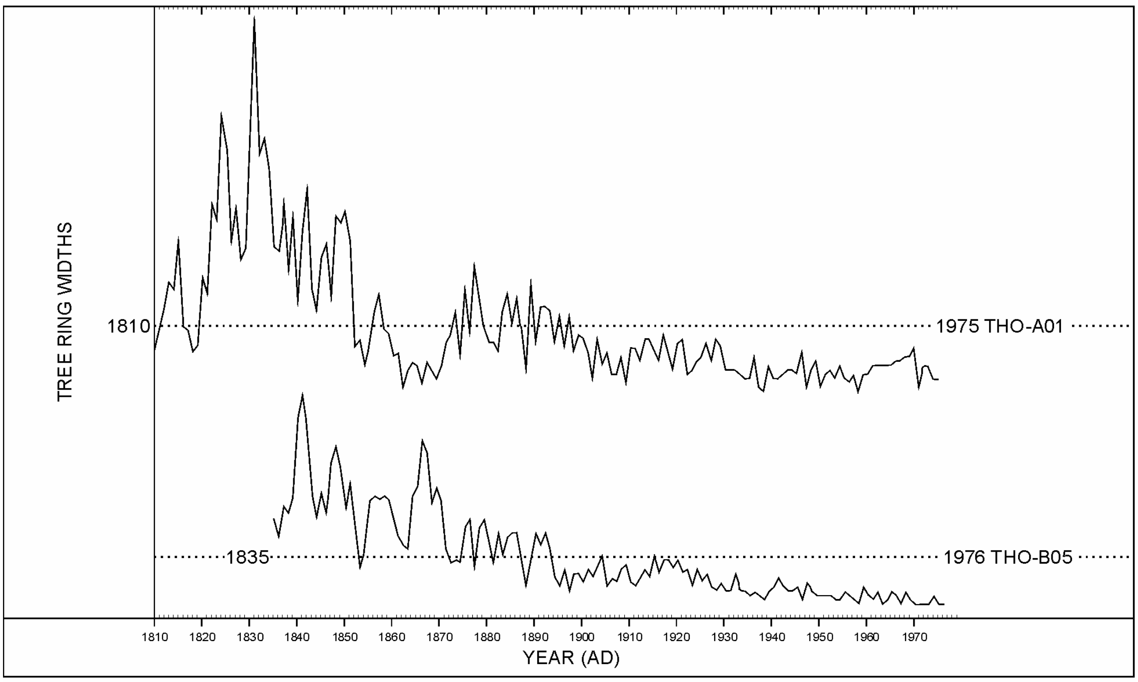


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

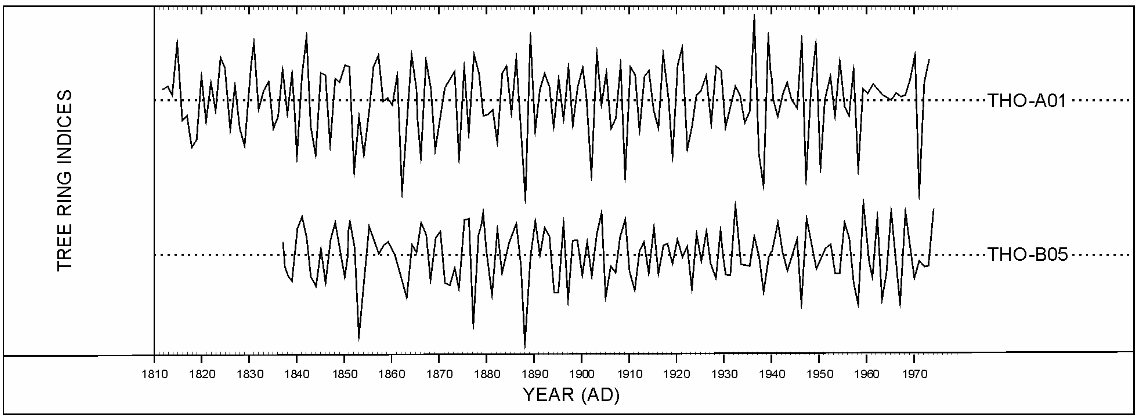


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, 33, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, 3, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, 15–26

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, 8, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, 22, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, 33, 90–8

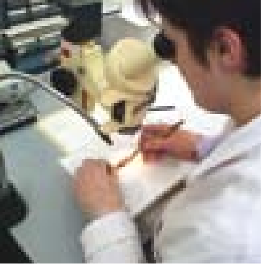
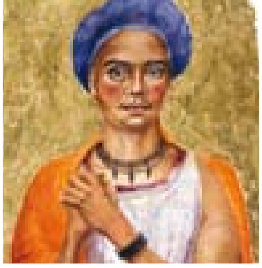
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*, 18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, 28, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

- *Aerial Survey and Investigation*
- *Archaeological Projects (excavation)*
- *Archaeological Science*
- *Archaeological Survey and Investigation (landscape analysis)*
- *Architectural Investigation*
- *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
- *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE