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Dendrochronological Analysis of Oak and Pine Timbers

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ABSTRACT

Dendrochronological analysis of 133 oak timbers and 58 pine timbers from Stirling Castle has identified six distinct episodes of building activity. The bulk of the data relates to building activity throughout the 16th century but building episodes in the 17th and 18th centuries are also identified. The builders probably maintained a stockpile of old timber for recycling and in these re-used timbers can be detected the ghosts of earlier buildings for which we no longer have any material evidence. A small amount of native-grown oak is used in the earliest episodes but after that the building work is carried out solely with imported timber, oak boards from Poland, oak beams and pine boards from Scandinavia in the 16th century, Scandinavian pine beams in the 17th century and eastern Baltic pine beams in the 18th century.

1 INTRODUCTION

The surviving structural timberwork of Stirling Castle, both *in situ* and *ex situ*, has been comprehensively sampled in the course of three separate programmes of dendrochronological work carried out between 1995 and 2005. The purpose of this report is to draw together the results of that work and to present a comprehensive and coherent dendrochronological history of the timbers used throughout the Castle.

Both oak (*Quercus* sp.) and pine (*Pinus sylvestris*) timbers were sampled; however, because the physiological responses of each species to its environment differs their growth patterns are not comparable and they must therefore be analysed independently. Consequently, the results for each species are presented separately and then drawn together in a continuous narrative in Section 4.2.

2 DENDROCHRONOLOGICAL ANALYSIS OF THE OAK

2.1 INTRODUCTION

During building works throughout Stirling Castle in 1995-6 some 32 oak beams were sampled for dendrochronological analysis. These consisted mainly of timbers which had been re-used within the Great Hall and Chapel Royal, and *in situ* ceiling timbers in the King's and Queen's Bedchambers. This material was fully reported in a summary paper in which a number of site master chronologies for Stirling were presented (Crone & Fawcett 1998). The Stirling Heads were analysed in 2004; some 24

boards from ten of the Heads were sampled (Crone 2004a). A further 68 oak beams, all from the Palace, and nine oak boards (from three of the four surviving doors in the Palace) were sampled during the SPARC project in 2004-5. Analysis of this new material was undertaken on a room-by-room basis and interim reports were produced (Crone 2004b, 2005a, b, c, d, e). The results presented in those reports are drawn together here and integrated with the results of the earlier analyses.

The oak timbers from Stirling consists of two types, squared beams which make up the majority of the timber, and the radially-split boards used to make the Stirling Heads and the Palace doors. The evidence from each type is of a slightly different nature; and so, in the first instance, the results are presented below by type.

Analysis of the data has identified multiple episodes of building activity, the evidence for which is scattered throughout the Castle. To make sense of this evidence, the overall chronology is presented first, episode by episode. The evidence is then summarised by room so that the implications of the dating results can be reviewed in terms of the history of the building.

Finally, during the course of the analyses, three distinct sources of oak timber were identified, Scandinavia, the eastern Baltic and Scotland. The source of the timber will be mentioned as we proceed through the chronology but further discussion about the sources and what they mean in terms of woodland resources, the timber trade, *etc* will be presented in Section 2.4.

SAMPLING

In all, 133 oak timbers have been sampled throughout the Castle. The Stirling Heads and the Palace doors were selectively sampled, as were the timbers from the Great Hall and Chapel Royal. However, a blanket sampling strategy was applied to the oak beams still *in situ* throughout the Palace. The 1995-6 work had identified an early phase of building using native Scottish oak but it consisted of only a few timbers so, when a single native timber belonging to this early phase was identified during analysis of the joists over the Presence Chamber total sampling of the oak timbers was proposed to ensure that all surviving native oak was retrieved. This was not always possible in some areas where modern flooring or planking inserted to strengthen the beams restricted access to the timbers.

The method of sampling has varied. All the *in situ* beams have been sampled by coring while the beams that had been removed from the Great Hall and the Chapel Royal were sampled by sawing a slice from

one end. The Palace doors and the Stirling Heads were sampled by taking FIMO casts of the ring-patterns.

SAPWOOD AND THE FELLING DATE

The dendrochronological data is presented in Tables 2-7 and in Figures 1 and 2, and is organised in order of the quality of the date. This relates to the nature of the outermost ring present on the timber. If the bark edge is present then it is usually possible to determine both the year and season of felling. If the outermost rings have not survived but there is still some sapwood *in situ* then a span of years within which the tree is likely to have been felled can be estimated. The sapwood estimates used vary depending on the source of the timber. For Scandinavian oak, a sapwood estimate of 15-30 years is used (Niels Bonde pers comm); for Polish oak, 9-23 years is used (Wazny & Eckstein 1991); for British oak 10-46 years is used (EH 1997). These can also be applied if none of the sapwood has survived but the heartwood/sapwood boundary (h/s) is present. However, if there is no sapwood and an unknown number of heartwood rings may have been trimmed off the timber, then the most that can be provided is a *terminus post quem* (*tpq*) date, the minimum number of sapwood rings being added to the calendar date of the outermost surviving ring.

2.2 RESULTS; THE OAK BEAMS

A total of 100 oak beams were sampled, of which 71 have been successfully dated (Figure 1). Apart from the two beams from the Chapel Royal which represent building activity in the late 13th and late 15th centuries respectively all the dendrochronological evidence from the oak timbers at Stirling relates to building activity in the 16th century. As none of the recent work has any impact on the results from the Chapel Royal timbers and these have previously been reported fully (Crone & Fawcett 1998) no further comment is made on these early episodes.

The oak has provided dendrochronological evidence for four episodes of building activity in the 16th century. Table 1 lists the locations in which timber from each episode was found, the number of letters indicating where the greatest concentrations of timbers for that particular episode can be found.

EPISODES 1 & 2 (FIGURE 1; TABLES 2 & 3)

These episodes are discussed together because, apart from four sequences with absolute felling dates, the bulk of the sequences have not retained the bark edge and could therefore belong to either phase. The sapwood on most of these timbers was so worm-eaten that it either disintegrated or became detached during coring.

Some 24 timbers are ascribed to these episodes. The bulk of them are found in the King's and Queen's Bedchambers but there are five in the North Range, one in the South Range, one in the Princes Tower, and one in the attic space, A01. All the sequences ascribed to these episodes were cross-matched against each other to see whether any inter-relationships which emerged could clarify felling dates.

EPISODE 1

Only two timbers from this Episode retained the bark edge providing the felling date of 1500/01. KBSJ3 is imported timber used in the King's Bedchamber, while U10.5007 is native timber and was found in the North Range. Only four other timbers can be ascribed to this episode with any confidence. These are the four main beams from the King's Bedchamber which are also native oak, KBMJ1, KBMJ3, KBMJ4 and KBMJ5. They retain either little or no sapwood, although the heartwood/sapwood boundary was noted during sampling, so the British sapwood estimate was applied giving a wide felling range that encompasses Episodes 1, 2 and 3. However, they correlate well with U10.5007 (Table 3a), the only other native timber found throughout the entire Palace and logic suggests they belong to the same felling episode. Furthermore, U10.5007 is of similarly short length and has only 12 sapwood rings, suggesting that the lower range of the British sapwood estimate is best applied to these young native timbers.

It is probable that some of the other timbers listed in Table 2 also belong in Episode 1 but none of them display strong correlations with KBSJ3, the only imported timber clearly dated to this Episode and there are no other grounds on which to allocate them.

EPISODE 2

Only one sequence can be firmly ascribed to this episode. U30.5002, one of the joists in the Princes Tower, was felled in the spring/summer of 1505. However, it correlates very well (t = 6.52) with one other timber, U03.5036, one of the joists in the North Range. The outermost ring of this sequence is

dated to 1495 but there are a further 10 rings on a detached fragment of the sapwood which would place the year of felling in 1505 too. The bark edge survived intact on the sapwood fragment so it was possible to determine that the tree had also been felled in the spring/summer.

None of the other timbers listed in Table 2 display any correlation with U30.5002 and U03.5036 so it is possible that these are the only surviving representatives of this episode. However, given the likelihood of multiple sources for the timber (see below) this is not a strong argument for discounting the inclusion of other timbers in this episode. Certainly, on the basis of their estimated *termini post quem*, some of the timbers, such as QBMJ9, KBSJ6 and U09.5001, are more likely to belong to Episode 2 than Episode 1 and, on the basis of the strong correlations between these and other timbers (Table 3b) there are other likely candidates.

EPISODE 3 (FIGURE 1; TABLE 4)

The bulk of the timbers from Stirling were felled for this episode, 37 timbers in all. Episode 3 timbers are found mainly in the North and South Ranges, and the Queen's Bedchamber but two timbers re-used as lintels in the Great Hall also belong to this episode. This episode marks the construction of the Palace.

The bark edge was present on 50% of the timber from this episode but the sapwood was usually badly worm-eaten and did not stay intact. Consequently, there is often a hiatus in the ring-pattern at the heartwood/sapwood junction. However, where the sapwood had survived as a distinct fragment it was usually possible to measure the ring-pattern up to the bark edge, thus determining the season of felling and through cross-correlation with other chronologies, determining the felling date. The bulk of those timbers with surviving bark edge were clearly felled in the spring/summer of 1539. There are seven timbers that could have been felled in either the winter of 1538 or the early spring of 1539 and one timber definitely felled in 1538 but for which it was not possible to determine season because the outer rings were very compressed. The difference in season of felling may relate to different sources (see Section 2.4).

EPISODE 4 (FIGURE 1; TABLE 5)

There are eight timbers which can be ascribed to this episode, four from the Princes Tower and four re-used as lintels in the Great Hall. The bark edge survived on two of these timbers, producing two felling dates, 1591/2 and 1592/3. A further two timbers have felling ranges which span these felling dates while there are four timbers whose *termini post quem* places their felling in the last few decades of the 16th century. Of these M01.2 probably belongs with the 1592/3 felling episode as it correlates very strongly with M01.3 (t = 8.32) suggesting that they may have been part of the same batch of timbers.

UNDATED (TABLE 6)

Table 6 lists those 29 timbers which could not be dated. Three of the sequences from the King's Bedchamber were too short to be measured and their ring-pattern was simply counted. Similarly, the timbers in the joist holes above the King's Closet Stair (M03) were from young, fast-grown roundwood and were therefore not measured. The majority of the undated material is characterised by young, often fast-grown ring-sequences and this will have hindered dating.

SUMMARY BY ROOM

King's Bedchamber

In all 24 timbers in the ceiling of the King's Bedchamber have been sampled, of which 11 remain undated (Table 5). The 13 dated timbers all fall within Episode 1 or 2 (Table 2). One of the secondary joists was felled in 1500/1 and it is argued that the four main joists belong to this episode too. The other dated timbers in the King's Bedchamber were certainly felled in the first decade of the 16th century but cannot be clearly allocated to either Episode 1 or 2. However, on the balance of probabilities, it is most likely that they all belong to the former.

It is clear from the dendrochronological dates and the redundant joints and carpenter's marks displayed by many of the timbers in the King's Bedchamber that they were re-used there and came from an earlier building built in or shortly after 1501, which was subsequently dismantled some time between then and 1539, the date of the construction of the Palace. A mixture of native and imported timber was present in the Bedchamber, possibly indicating that two buildings had been dismantled.

Queen's Bedchamber

Nine of the main joists were sampled and all have been dated. Two retained the bark edge and were felled either in late 1538 or early 1539, and a further four timbers can be confidently ascribed to this felling episode (Table 4). The remaining three timbers have been placed in Episodes 1 & 2 (Table 2) on the basis of their estimated felling ranges. This would imply that, as in the King's Bedchamber, timber from an earlier structure was re-used, although the Queen's Bedchamber joists do not display any redundant features that would indicate re-use.

North & South Ranges

A total of 38 oak timbers were sampled throughout the North and South Ranges, of which only three remain undated. 29 timbers, 76% of the assemblage, belong to Episode 3. The North & South Ranges produced 15 timbers which had been felled in the spring/summer of 1539 and a further five sequences felled either late in 1538 or early in 1539 (Table 4). It is possible that this difference in season of felling relates to different sources (see Section 2.4).The weight of the dendrochronological evidence from the North & South Ranges confirms that the Palace was completed in or soon after 1539.

There are six timbers scattered throughout the North and South Ranges which belong to earlier episodes. U03/5.036 was probably felled in 1505 but the other five timbers could belong to either Episode 1 or 2. Although they must have been re-used in the Palace none of these timbers displayed evidence of re-use in the form of redundant joints or carpenter's marks.

The timbers sampled included both components of the four double beams, with the exception of U03.5009, the western element of which could not be sampled because of difficulties of access. One could not be dated but the results from the other beams shows that these were all part of the same episode of building and were not later insertions (Table 4).

Attic spaces

There were two oak timbers in A09 and four oak timbers in A01, all of which are diagonally-set horizontals, like the main joists in the King's Bedchamber. They were clearly re-used within the attic spaces, several of them displaying redundant mortice-&-tenon joints. The dendrochronological results are therefore not relevant to the construction of the existing roof.

Only one timber could be dated. A01.02 belongs to either Episode 1 or 2 (Table 2). There were no internal correlations within the group, suggesting a variety of sources – not unexpected as they were all re-used timbers. However, the absence of strong correlations with the now sizeable dataset from Stirling suggests that at least some of this group of timbers may have come from a building from which we have no other representative material.

Princes Tower

There were three oak beams in Room U30 and seven oak beams in the Mezzanine level of the Princes Tower, of which six could be sampled. The Mezzanine level timbers are different from the oak used elsewhere in the Palace in the way in which they have been converted from the original timber. The oak throughout the Palace has tended to be boxed heart baulks, i.e. complete tree trunks trimmed square. The Mezzanine level joists are all quarter baulks, so given their cross-sectional dimensions, the original timbers must have been very large. In Room U30, one timber U30.5001 was also quarter-sawn, while the other two timbers were boxed heart baulks.

Five of the nine sampled timbers could be dated, of which three yielded felling dates. M01.6 and M01.3 were felled in 1591/2 and 1592/3 respectively and another two of the dated timbers also belong to this episode (Table 5). It therefore seems more than probable that the Princes Tower was refurbished some time in or shortly after 1593.

Of the three timbers sampled in Room U30, one, U30.5001, belongs to Episode 4 and is presumably part of the late 16th century refurbishment, while the other dated timber, U30.5002 was felled in 1505 and provides the only secure felling date for Episode 2. This may reflect refurbishment of the Tower during the construction of the Palace, the timber coming from the same stockpile of re-cycled Episode 1 & 2 timber which was used throughout that building (see Section 2.4). The third timber from Room U30, U30.5003, is undated but it is a boxed heart beam rather than the quarter-sawn timbers of Episode 4, and may therefore belong to Episode 2.

Great Hall

All seven of the oak timbers sampled from the Great Hall had been re-used as lintels in that building (Crone & Fawcett 1998, 75) so the dendrochronological results are therefore not relevant to the construction of the existing structure. All but one of the timbers has been dated and all but one of the

dated timbers belongs to the late 16th century Episode 4 (Table 5). GHVI was felled in 1538/9 and belongs to Episode 3 (Table 4). This implies that buildings belonging to these episodes were dismantled or stripped of timbers during the 18th century modifications to the castle.

2.3 RESULTS; THE OAK BOARDS

THE PALACE DOORS (FIGURE 2; TABLE 7)

There are four early doors still *in situ* in the Palace, of which three were sampled. PD03 lies between the King's Guard Hall and the Presence Chamber , PE07 lies at the north end of the West Gallery, and PD09 lies between the Queen's Presence Chamber and the Queen's Bedchamber. All are double-skinned, with vertical boards on one face and horizontal boards on the other. Only the upper ends of the vertical boards not under the wide stone lintels were accessible for sampling. Small rolls of FIMO were applied to the surface and peeled off to 'capture' the ring-pattern.

PD03 has six vertical oak boards, of which four were sampled. PE07 has nine vertical oak boards, of which four were sampled. PD09 has six vertical oak boards but only the outermost board was sampled. The vertical boards on each door were numbered from the inner edge to the outer edge and each sample is referred to using the Historic Scotland reference number for the door followed by the vertical board (VB) number, i.e. PD03VB4.

All but one of the nine board sequences could be dated. All of the boards had been trimmed of their sapwood together with an unknown number of heartwood rings. As the statistical correlations indicate a Polish source (see Section 2.4) the sapwood estimate of 9 – 23 rings was used, the minimum number of sapwood rings, 9, being added to the calendar date of the outermost ring in order to calculate the *tpq* for the felling of the timbers. The latest date for each door provides the *tpq* for the construction of the door. Thus, PE07 was constructed sometime after 1533, PD03 sometime after 1520 and PD09 sometime after 1518. It is clear from the range of end dates for the boards, 1504 to 1524 for PE07 for instance, that a variable number of rings have been trimmed off, so it is not possible to refine the date of construction of the doors any further. However, it seems most likely that these doors were indeed made as part of the major building works on the Palace which began in 1539.

THE STIRLING HEADS (FIGURE 2; TABLE 8)

The majority of the Heads have four components, three boards butt-jointed together to create the width of the plaque, referred to in this report as the *Central board*, *Left board* and *Right board* (from the observer's point of view), and a fourth board which has been stuck to the central board to create the depth of relief for the carved faces, referred to here as the *Central ply*. Analysis of the ring-patterns revealed that, on the left and right boards the outermost rings of the sequence lay facing in towards the centre. This seems to have been a deliberate choice; there is only one exception amongst the Heads examined. This was very important from a dendrochronological view point because it meant that the outermost rings of the sequence, which are vital in dating the felling of the timber as closely as possible, usually lay along accessible and uninterrupted sections of the carving and not on the heavily carved outer edge. In all, 24 boards from a total of 10 Heads were sampled, of which 19 have been successfully dated (Table 8).

As with the doors, the boards were all trimmed, some more heavily than others, hence the apparently 'early' end-dates for some of the boards. For instance, the statistical correlation between D23CB and D23RB (t = 12.03) suggests that they were probably converted from the same tree but the difference between the dates of their outermost rings is 48 years. The *tpq* of D23CB has been estimated to reflect this relationship; although the outermost surviving ring of D23CB is 1473 it must have been felled after 1521, the date of the outermost surviving ring on D23RB (see Figure 2). Another two pairs also produced highly significant correlations between their ring-patterns (D22CB & D22CP t = 18.04; D25LB & D25RB t = 12.39) so their *tpq*s have been similarly adjusted.

In those instances where it is clear that a substantial number of heartwood rings have been trimmed off, the date of the outermost ring cannot contribute much towards determining the actual date of the Heads. However, in the case of some of the boards we can be more precise and provide an approximate felling range rather than just a *tpq*. As described above, in most cases it was possible to 'capture' the ring-pattern right up to the edge of the board, thus ensuring that the most complete ring-pattern that survived was recorded. As Figure 2 shows, the outer year-rings of eleven of the dated boards are remarkably synchronous, all lying within 12 years of each other, so it seems probable that they lie near to the heartwood/sapwood boundary. 12 year-rings amounts to about 15 - 20 mm of wood on these boards so it is easy to envisage that number of heartwood rings being trimmed off with the sapwood. Thus, for example the tree converted to make D23RB cannot have been felled before 1530 (1521 + 9) and, if the board has lost only a few heartwood rings, as argued above, then it may have been felled

sometime between then and 1544 (1521 + 23) or thereabouts. The chronological relationships between the dated boards and the synchroneity of the outermost year-rings suggest, therefore, that the trees used to make them were all felled towards the middle of the 16th century and that they were probably all part of a single event or phase. The approximate felling ranges for many of the boards straddles the Episode 3 felling date of 1539 and it therefore seems reasonable to assume that the Heads were commissioned as part of that major building programme.

2.4 OAK: DISCUSSION

The analysis of the oak timbers from Stirling has provided a series of felling dates for episodes of construction in the Castle (Figure 1). It has also provided insights into the way in which the building works were carried out, such as the recycling of timber, where the timber came from, and the nature of the timber trade at that time.

RECYCLING AND STOCKPILING

The builders at Stirling clearly recycled timbers (and probably other building materials as well). This is evident from both the redundant joints and carpenters marks seen on timber throughout the Palace and the dendrochronological results. None of the Episodes 1 & 2 timbers appear to be in their original positions; they are scattered throughout the Palace where they were used during the Episode 3 building in1539. This means that buildings which were constructed in 1501 and 1505 were either dismantled or substantially modified within 34 and 38 years of construction. Knocking down a building that had only been up for 38 years at most seems profligate but could be explained if these buildings lay on the footprint of the planned Palace and had to be cleared out of the way for this prestigious building project. There are documented records of building works within the Castle during these years, on the Great Hall in 1501 and 1503, and the 'Ald kyrk' in 1504-05 (Crone & Fawcett 1998, 70, 73). This latter building may be the early chapel which was truncated when construction of the Palace began (*ibid*). The ceiling of the King's Bedchamber was built entirely of these recycled timbers whilst a few were used in the Queen's Bedchamber, the North and South Ranges and the upper floor of the Princes Tower, along with imported beams specially bought for the purpose (the Episode 3 timbers). Is it possible that the ceiling of the King's Bedchamber was erected first, using up all but a few timbers from the recycling pile, which were then used alongside new timber throughout the rest of the Palace?

The bulk of the Episode 3 and 4 timbers do appear to be in their original positions, except for a handful which were re-used in the Great Hall at a much later date. As the Palace was much modified during the 18th century military occupation it is possible that those timbers re-used in the Great Hall came from the Palace itself, although other buildings, such as the new Chapel which was rebuilt in 1594 (Crone & Fawcett 1998, 73), may also have been a source.

There may have been a pile of timber for recycling but there is little evidence that timber was stockpiled over a number of years in preparation for a big building project, as for instance at Edinburgh Castle (Crone & Gallagher forthcoming). For Episode 3 at Stirling there is a single felling event in 1539; if the 1538/9 timbers do indicate a separate felling then it is only by a matter of months rather than years. This implies, perhaps, that plans for the construction of the Palace were not long in gestation. In contrast, the evidence from the Princes Tower of two felling dates, in 1591/2 and 1592/3 does imply a stockpile, although this could have been as much in the merchants' timber yard as in the Royal builders' timber yard. It is clear from the documentary sources that the Crown directly commissioned skippers to acquire timber for Royal projects. For instance, on at least two occasions, in 1508-9 and 1512 James IV wrote personally to ensure that his skipper could choose timber for ships masts in Norway (Hannay & Mackie 1953, 143, 240). In 1512 a skipper was sent to Norway in a ship hired by the King to 'bring hame gret tymmer', although for what purpose is not specified (TA Vol IV, 289). There may not have been any merchants or middlemen involved in these transactions. Certainly, in southern Norway in the mid-16th century Scottish skippers were able to trade directly with the farmers who owned the woods on the shores of the fjords (Lillehammer 1986, 101) so there was no need for stockpiling at the source.

It is notable that, where we have clear evidence of the use of recycled timber in later building works, i.e. in the Attic spaces and the Great Hall, the only felling episodes for which we find evidence are Episodes 1, 3 and 4. It is, of course, possible that some of the timbers for which we only have *tpq*'s could belong to some other episode but the absence of evidence does suggest that 1501, 1505, 1539 and 1593 do indeed represent the major building events of the 16th century at Stirling.

THE SOURCE OF THE TIMBER

As described in the introduction, two types of oak timber were used at Stirling, beams and boards. More often than not the oak beams are boxed heart baulks, complete tree trunks which have been trimmed square, often leaving some sapwood and/or waney edge at the corners. One or more faces have usually been trimmed more substantially than the others, leaving the pith lying offcentre within

the finished beam. Occasionally, as in the Mezzanine level of the Princes Tower, quarter baulks have been used; given their cross-sectional dimensions, the original timbers must have been very large and this may relate to different sources of timber.

SCOTTISH TIMBER

Of the 71 oak beams from Stirling that have been dated, only seven are Scottish in origin. These include the two large beams re-used in the Chapel Royal which represent building activity in the late 13th and 15th centuries, and the four main beams in the King's Bedchamber probably felled in 1500/01 (Crone & Fawcett 1998). The recent dendrochronological work has identified only one other native timber, in the ceiling over the Presence chamber in the North Range, which was also felled in 1500/01. Thus, the pattern identified in the earlier work, that Scottish timber was not available from the early 16th century, has not changed despite the analysis of substantially more timbers. The Chapel Royal timbers were massive in cross-section and one, CR1, produced a tree-ring sequence of 342 years spanning the years 1065 to 1406 AD, the longest retrieved at Stirling (Crone & Fawcett 1998, 76). In contrast, the Scottish timbers felled in 1500/01 were small and relatively young, with between 80 – 100 rings at most (Table 2). With the exception of a couple of imported beams most of the timber used in the King's Bedchamber was of a similar character, i.e. young and fast-grown, to the extent that a number of them were too short to be measured and very few could be successfully dated (Table 5). It seems probable that most of the undated timbers from this room are native, given the ease with which single imported timbers can now be dated against the Scandinavian master chronologies (e.g.. Crone 2005f).

'Scottis tymmer', is certainly recorded as being used at Stirling although there is no mention of the species and where it was used in the buildings. There are numerous references to timber being brought from Clackmannan to Stirling in 1531-2 (Paton 1957, 104, 107, 111) and in 1535-6 timber was transported to Leith from Lochaber for use in the Royal works at Stirling, Holyrood and Falkland (*ibid*, 182). In the same years 'Scotis ayk' (oak) was shipped from Stirling to Leith for use at Holyrood (*ibid*, 189) while 'vii gret akyn treis' were felled in the Torwood (near Stirling) for use at Linlithgow (*ibid*, 126). However, although supplies of native-grown timber were clearly still available in the early 16th century, Parliament was becoming increasingly anxious about the state of the native woodlands, passing Acts to protect them and encouraging landowners to plant woodland (Smout et al 2007, 45). The native oak used at Stirling shows that Parliament had reasons for concern; what was locally available was not of the quality or size required for major building works and the Palace builders had to rely on imported oak.

SCANDINAVIAN TIMBER

Some 90% of the dated beams are Scandinavian in origin. They have been dated individually against regional master chronologies from Scandinavia and against Scottish 'import' chronologies. Separate episode master chronologies were constructed on the assumption that all the timber felled in the same year was likely to have come from the same source; thus two episode masters were constructed for Episode 3 because it contained two felling dates, one in 1538/9 and one in 1539. The statistical correlations between the regional master chronologies from Scandinavia and the Scottish 'import' chronologies are presented in Table 9. This makes clear that the timber was being imported from either Denmark or Sweden; there were no correlations with Norwegian chronologies. In an attempt to determine provenance more exactly the episode masters were compared against site-specific chronologies from those countries; the results of the GIS mapping of the t-value statistics are presented in Figure 3 (for methodology see Daly 2007). The strongest correlations are mainly with chronologies from Sealand, in eastern Denmark but this distribution may be because there are fewer site-specific chronologies available for south-west Sweden (Aoife Daly pers comm). We can probably do no more with the data currently available than specify southern Scandinavia as the source of the timber.

The context for the timber trade between Scotland and southern Scandinavia was an alliance through royal marriage between Denmark and Scotland, a relationship which was further strengthened by a military treaty in 1492 (Ditchburn 1990). This treaty included a clause allowing freedom of trading between the two countries and as a consequence Scots began settling and trading in Danish towns such as Aalborg, Copenhagen and Elsinore. During the 15th and 16th centuries the southernmost provinces of modern Sweden, Halland, Scania and Blekinge, were under Danish rule and Scots also settled in this area, in towns like Malmo and Ystad (Dow 1965). One of the few direct references to Danish timber in the Scottish records must relate specifically to the building works on the Palace; in 1539 one Charles Murray was paid for buying timber in Denmark for use in the work at Stirling (*T*A VII, 159).

Strangely enough, given the volume of southern Scandinavian timber arriving in Scotland during the 16th century, Danish ports are rarely mentioned as the port of departure for west-bound Scottish ships when the Sound Toll Registers (the record of duties imposed on shipping passing through the Oresund, between Denmark and Sweden) first begin recording this information in 1557 (Riis 1986, 86). This suggests that timber was picked up to complete the cargo on the return journey back from the eastern Baltic to Scotland.

During this period Denmark and Sweden were intermittently at war with each other and so the alliance with Denmark was a hindrance to commercial relations between Sweden and Scotland (Dow 1969). Despite this, there are records of Swedish timber entering Scotland in the early 16th century (Paton 1957, 219) and trade picks up in the mid-16th century when the struggle between the two countries was resolved. Early trade with Sweden was almost exclusively out of the Swedish port of Lodose (near modern Goteberg); 'aiken tymmer of Lowdis' is mentioned in the Works Accounts in 1536 (Paton 1957, 95). The customs book for the port records 16 ships bound for Scotland in 1546, all loaded with timber (*ibid*, 73). Spruce, oak and a little lime are recorded, the oak being shipped as either boards or 'rough lengths', presumably undressed logs. The boxed heart baulks, half-baulks and quarter-baulks from Stirling could have been converted from such logs.

EASTERN BALTIC TIMBER

The boards used in the construction of the Stirling Heads and the Palace doors have all been dated, in the first instance, against either BALTIC1 or BALTIC2, master chronologies which were built using tree-ring sequences from the oak panels of medieval and Tudor paintings from collections throughout England (Hillam & Tyers 1995). Despite the fact that the paintings were executed in England, tree-ring analysis was able to demonstrate that the oak panels had been imported, probably from the eastern Baltic (Baillie *et al* 1985). Wazny (2002) has recently defined the likely source of the BALTIC1 oak as south and east Poland while the BALTIC2 oak probably came from the Baltic coast of Poland around the Hanseatic port of Danzig (modern Gdansk). These regions appear to have specialised in the production of fine, straight-grained timber which was particularly prized for boards which were going to be painted or carved. In Scotland examples of this type of material have so far been identified by dendrochronology in the painted ceiling from the Guthrie Aisle, Angus (Crone & Mills 2003) and in carved wooden panels from Perth (Crone *et al* 2000). This is the material described in contemporary English and Scottish records as 'Righolt' and 'Estland board' (Salzman 1952, 246: Paton 1957). There are specific references to this type of material being imported for use at Stirling at about the time of the Palace building programme; 'xxiiii wanscot burd' were brought from Leith in 1531-2 (Paton 1957, 108), 'ane dozane estland buirdis' were bought for the 'chapell dur' in 1537-8 (*ibid,* 228), and more 'estland burde' was bought in 1541 (TA VII, 456). Any of these shipments could have been for the Palace doors or the Heads.

The boards used in the Palace doors were made from oak from the BALTIC1 region; this has been confirmed by correlations with local Polish chronologies, the door sequences producing the strongest

correlations with chronologies from eastern Poland and the Vistula basin (Table 7). The majority of the boards used in the Heads also came from south and east Poland. However, three boards used in the Heads were made from oak from the Baltic coast region (Table 8). Head D22 contains oak from both regions. This suggests that the makers of the Stirling Heads were not obtaining the oak directly from source but used a merchant who shipped timber from the whole region. This is supported by the internal correlations within the assemblage. Many of the dated sequences match against only a few other sequences, suggesting that the timber is coming from a variety of sources.

This may also explain why some of the boards remain undated. From the late 13th century and throughout the later medieval period timber was exported in great quantities from the Hanseatic ports of the eastern Baltic, primarily Danzig and Riga. The timber exported via Danzig came from throughout the Vistula basin and further east in present day Belarus and the Ukraine (Wazny 1992). Similarly, the timber being exported via Riga was floated down the river Daugava from sources further east in Russia (Zunde 1999). Thus the possible sources for the oak being shipped out of the Baltic ports is vast and dendrochronological work is only just beginning to identify some of them (Wazny 2002). The undated boards may come from areas in Eastern Europe which still have no dendrochronological coverage.

3 DENDROCHRONOLOGICAL ANALYSIS OF THE PINE

3.1 INTRODUCTION

In all, 82 pine timbers have been sampled throughout Stirling Castle. The stubs of 12 pine joists embedded in the wall tops of the Great Hall were sampled as part of the 1995-6 works (Crone & Fawcett 1997) and during the recent investigations in the Palace a further 70 pine timbers were sampled. Almost all the pine joists throughout the North, South and East Ranges were sampled by coring, 62 joists in total. Finally, eight of the loose floor boards lying immediately over the oak beams of the Queen's Bedchamber were also sampled, slices being sawn off the exposed ends. The samples were assessed prior to full analysis, to weed out those samples which were too young and fast-grown, or where woodworm damage made it impossible to recover a complete ring-sequence. Woodworm damage was quite extensive and resulted in fragmentary cores, so that although in most instances the bark edge was present on the timber, it was not always recovered intact on the cores.

Only sequences with more than 60 rings were fully analysed (Tables 10-12). All the joists from the Great Hall and the floor boards over the Queen's Bedchamber had over 100 growth rings but the pine joists used throughout the Palace were very varied, particularly in the North Range where very young, fast-grown timber was found, as well as the oldest sequence, a joist with 269 rings. Of the 62 joists sampled, only 38 had complete sequences longer than 60 rings. In all, 58 pine timbers were considered suitable for dendrochronological analysis.

It was thought that each sampling locus probably represented different building episodes, in the early 17th century or earlier for the floor boards over the Queen's Bedchamber, the late 17th century for the joists throughout the Palace, and some time in the 18th century for the joists in the Great Hall. Analysis therefore proceeded initially within each locus, on the assumption that there was likely to be stronger agreement between material felled for the same building episode and this would facilitate chronology construction. The results have confirmed that each locus does indeed represent a distinct building episode and that, unlike the oak, timbers from different episodes have not been re-used in a variety of loci (Table 1). Consequently, the results are presented below by locus and episode simultaneously.

3.2 RESULTS

EPISODE 3; QUEEN'S BEDCHAMBER FLOOR BOARDS (FIGURE 4; TABLES 10-12)

A number of pine floor boards lay immediately over the oak beams of the Queen's Bedchamber. The floor boards were all rip-sawn and several had paired iron nails still *in situ*. They were tongue-and-grooved, a lath of oak being used for the tongue. Many were inaccessible and it was only possible to sample eight of them (Table 10).

Of the eight sequences, six correlated well with each other (Table 11) and a sub-master, QBCPINEx6, 166 years in length, was constructed. This sub-master was compared against all the pine data from Stirling but did not produce any significant correlations. It was also compared against a suite of regional and site chronologies and produced a number of significant correlations dating the chronology to AD1370 – AD1535 (Table 12). Of the six sequences in QBCPINEx6, two retained the bark edge (Figure 4). The bark edge was present on QBCp5 but the outermost rings were too compressed to be measurable and there were 10+ rings after the last measured ring, which dated to 1519; thus this timber would have been felled after 1529. The bark edge was also present on QBCp8 and as the outermost rings displayed no such compression we can be reasonably certain that this timber was felled in 1535.

The oak beams over which these floorboards lay have been dated to 1538/9, i.e. Episode 3 of the building activity identified by dendrochronology (Table 3). The felling date of 1535 for the floorboards suggests that these were part of the same episode, the pine timbers being stockpiled and seasoned in anticipation of the building works on the Palace. Thus, rather than being a later modification, as originally thought, the pine floorboards are part of the original fabric of the Renaissance Palace.

EPISODE 5; JOISTS IN THE NORTH, SOUTH AND EAST RANGES (FIGURE 5; TABLES 13-16)

Comparisons between the 38 sequences from the joists (Table 13) produced a group of 15 which correlated strongly with each other (Table 14). These were incorporated into a sub-master chronology, SPPINEx15, 196 years long, which was then compared against a suite of regional and site chronologies. Significant correlations against a number of these chronologies date SPPINEx15 to AD1476 – AD1671 (Table 15).

No further correlations were found amongst the remaining 23 sequences, except between one pair, U03.5025 and U03.5040, both from the North Range. The 23 sequences were also compared with SPPINEx15 but no further correlations were found.

Thus, of the 38 joists sampled throughout the Palace, 15 are dated (Table 16). The chronological relationships of the dated timbers are illustrated in Figure 5. Felling dates in 1664, 1665, 1667, 1670 and 1671 are indicated. The greatest number of timbers were felled in 1671; three were clearly felled in that year and U29.5024 is also likely to have been felled at the same time as U29.5022 (its outer rings were too compressed to measure although the bark edge was present, but its very high correlation with U29.5022 [t = 8.92] suggests that they may well have originated in the same woodland thus implying the same felling date). Only *termini post quem* can be provided for the rest of the dated material; the outer rings of many of the pine joists had suffered much woodworm damage and the cores were consequently very fragmented (the number of rings on some of the larger fragments has been added to the date of the outer ring to calculate the *tpq*).

EPISODE 6; THE GREAT HALL JOISTS (FIGURE 6; TABLES 17-19)

The analysis of 12 pine joists (Table 17) from the Great Hall in 1995 had not produced any results (Crone & Fawcett 1997, 80). As part of the recent investigations the sequences were re-examined; five correlated well with each other and a sub-master, GHPINEx5, 194 years in length, was constructed

(Table 18). This was compared against a suite of regional and site chronologies, including all the pine data from Stirling. This produced a number of significant correlations dating GHPINEx5 to AD1593 – AD1786 (Table 19). Of the five dated sequences from the Great Hall two retain the bark edge (Figure 6). GHP12 was felled in AD1783 and GHP3 was felled in AD1786. It is probable that the timber would not have arrived in Scotland until a few years after that date; the timber is thought to have come from as far afield as Russia (see Section 3.3) and it would sometimes take up to 2-3 years for timber to be rafted down the rivers to the ports (Maris Zunde pers comm.).

3.3 PINE: DISCUSSION

Dendrochronological analysis of the pine timbers from Stirling has successfully dated three building phases within the Castle which are summarised below:

Chronology	Date range	Timber type	Source region
QBCPINEx6	AD1370 – AD1535	pine boards	Scandinavia
SPPINEx15	AD1476 – AD1671	pine baulks	Scandinavia
GHPINEx5	AD1593 – AD1786	pine baulks	Eastern Baltic

The analyses have provided evidence about the source of the timber and, more indirectly, some insights into the way the timber trade was conducted.

THE SOURCE OF THE TIMBER

SCANDINAVIAN TIMBER

The regional and site chronologies against which QBCPINEx6 was dated (Table 12) are all from Sweden (the timber used in the German farmhouse was imported from Sweden (Sigrid Wrobel pers comm)); the correlations are not sufficiently high to specifically pinpoint this country as the source but they do indicate that southern Scandinavia was the probable source of the pine boards (Terje Thun pers comm).

The boards were probably imported into Scotland as such; sawmilling was not widely adopted in Scotland until the early 17th century (Shaw 1984, 95) (although locally sawn timber appears to have been used in the construction of the late 15th/ 16th century well in the Greyfriars Friary at Shuttle Street, Glasgow – Crone forthcoming a) but they had been sawmilling in Sweden since the 1460s and in

Norway from the early 16th century (Lillehammer 1986, 99-100). Furthermore, imported boards, or deals are frequently referred to in 16th century Scottish documents. There are numerous references to Swedish board in the Royal accounts between 1531 and 1540 (Dow 1969, 67); of particular interest in this instance is the reference to 'Swadyn …burdis' bought for use at Holyrood in 1535-6 (*Works Accts* 1, 181), the year in which the timber used to make the floorboards in Stirling was felled. However, the 1546 customs book from Lodose, on the west coast of Sweden records that the main types of timber being exported at that time were spruce and oak, both of which were shipped as boards (Dow 1969, 70); there is no mention of pine. It is possible that 'spruce' was a generic term to describe all types of softwoods but if this was an accurate description of the timber species being exported from Sweden then it would make it more likely that the pine was coming from southern Norway. There is certainly abundant documentary evidence for an active trade in timber between Scotland and Norway in the mid-16th century, enough to suggest that Scotland's bulk timber imports all came from Norway (Lythe 1960, 146; Smout 1963, 156). As an example, of 38 foreign ships visiting the Norwegian district of Ryfylke to buy timber in 1567, 28 were Scottish (Lillehammer 1986, 101).

In the 17th century pine beams, or baulks from the same region were used in the Palace. SPPINEx15 has produced correlations with a number of regional and site chronologies from around the Baltic, from Sweden, Latvia and even Russia (Table 15). However, again the strongest correlations are with Swedish chronologies indicating that southern Scandinavia is most probably the region from which the timber came. SPPINEx15 has also produced correlations with a number of English pine chronologies, including a particularly high correlation with a building in Co. Durham (Arnold *et al* 2006), also imported from the same region. Again, we cannot determine whether Norway or Sweden is the source of the pine. Scottish trade with Sweden began to expand in the early 17th century but oak still formed the bulk of the trade, Swedish pine deals being of poorer quality than those from Norway (Thomson 1991, 64). By contrast, some 91% of all the beams exported from the Norwegian district of Ryfylke in 1641-2 left in Scottish vessels; indeed, contemporary records refer to beams as 'skottebjelker', or Scottish beams (Lillehammer 1990, 104) while the predominance of Scottish buyers in the Norwegian timber trade at this time led to the 17th century being called 'the Scottish Period' (*ibid*, 100).

EASTERN BALTIC TIMBER

The regional and site chronologies against which GHPINEx5 has been dated are all from the eastern Baltic, from Latvia, Lithuania, Estonia and Poland, indicating that this is very clearly the source region (Table 19). GHPINEx5 also correlated well with another Scottish import chronology from Haddington,

East Lothian (Crone 1998), now known to be eastern Baltic in origin. As with the oak 'Estland boards' (see above), the pine exported out of the eastern Baltic ports could have come from anywhere within a huge hinterland which extended as far east as the Volga (Astrom 1988, 99; Zunde 1998, 73). The port of Riga initially supplied the demand for 'fir timber' ('fir' being the native Scottish word for pine; Smout 1997, 116)), most of the wood coming from the area of Belarus and Lithuania (Zunde 1998, 72). However, after 1764 the Prussian port of Memel (modern-day Klaipeda) quickly became Scotland's major source of pine baulks, to the extent that, by 1768 Memel supplied over 72% of Scotland's pine timber imports (Thomson 1991, 267). All the timber leaving Memel came from Russian forests (*ibid*, 212); as with the oak from this region there is much work to be done before pine can be more accurately dendroprovenanced.

STOCKPILING AND RAFTING

There are multiple felling dates amongst both the 17th century and 18th century pine beams (Figures 5 & 6), which generally implies that timber was being stockpiled. It is noteworthy that, of the pine beams used throughout the Palace to reinforce the floors in the 17th century, all the dated material comes from the South Range. This implies that the timber used in these rooms, U23, U27, U28 and U29, was all coming from the same general region and had probably arrived at Stirling as a single batch or load. The presence of a range of felling dates amongst this batch of timber suggests that it was probably being stockpiled by the merchant in the source region. As discussed above, rafting often meant that it could take 2-3 years after felling for timber to reach the ports and this could complicate the picture even further, with timber of varying age being mixed up in the river systems. If the timber had been stockpiled by the Palace builders, buying it in batches every year, one would have expected timber from the same source area to be scattered throughout the Palace. The lack of correlation between the timbers within the North and East Ranges implies that they were coming from a wide variety of sources, which were in turn different from the source of the timber in the South Range.

The likelihood that at least some of the timber was rafted is confirmed by features observed on two joists in the East Range. On U19.5006 and U19.5001 a single peghole was observed in cross-section at one end of each timber (Figure 7). The pegholes have been split by the sawing of the timber in half, so they clearly had no function in the construction. It is likely that they were drilled into the original trunks to hold pegs around which rope was tied to secure rafts of logs as they were floated down river. There are contemporary descriptions of this practice in southern Germany for example, where there were regional variations in the way the rafts were secured. These variations have been observed in

marks and pegholes surviving on medieval buildings in the region (Eissing 2003). Timbers in the harbour revetments at Riga had distinctive triangular holes characteristic of Russian rafting methods (Maris Zunde pers comm.). Although we cannot source these particular timbers because we have been unable to date them these features make it more likely that the timber was imported and was not homegrown. Timber was rafted down the major rivers of northern Europe but in Scotland rafting techniques were not introduced until the 1730s (Smout 1960) and probably only on rivers like the Spey. Generally logs were floated down singly or in loose lots because the rivers were not sufficiently wide or clear for large scale rafting.

4 SUMMARY

The dendrochronological work at Stirling Castle has made it possible to tie the surviving timberwork in the Castle into known episodes of building activity. It has proved possible to provenance the timber, thereby allowing us to gain insights into the mechanics of the timber trade which could not be gleaned from the documentary evidence alone. Finally, the scale of the dendrochronological works has enabled methodological advances, allowing us to refine sampling strategies for pine in particular, and providing a robust database as a basis for further dendrochronological work in Scotland.

4.1 BUILDING ACTIVITY

Dendrochronological analysis of 133 oak timbers and 58 pine timbers from Stirling Castle has identified six distinct episodes of building activity (excluding the early timbers re-used in the Chapel Royal). In summary, there is dendrochronological evidence for building activity spanning three centuries (Table 20). Most of the dendro-dated building episodes can be related to documented episodes of building activity. The re-used timber present in the Palace represents at least two episodes of building activity in the early years of the 16th century; these cannot be unequivocally attributed to documented building works but it is perhaps significant that there was work on the 'Ald kyrk' in 1504-05, which was probably demolished to make way for the Palace (Crone & Fawcett 1997). The bulk of the dendrochronological evidence, Episode 3, relates to the construction of the Renaissance Palace between *circa* 1538 -42 (Kirkdale 2005); there are clear felling dates in 1535, 1538 and 1539 while the oak used in the Stirling Heads and the Palace doors was felled at about this time. Episode 4 probably represents works done to the Palace in preparation for the arrival of James VI and his queen, Anna of Denmark, who gave birth to their son, Prince Henry, in Stirling in 1594 (Kirkdale 2005, 30). Episode 5 corresponds to the programme of renovation of the Palace undertaken by the Earls of Mar after the Restoration,

during which the upper floors were re-inforced by the insertion of pine joists between the old oak joists (Kirkdale 2005, 38). The 1671 felling dates accord with the documentary evidence which records the numerous shiploads of timber being brought up the Forth from Leith to Stirling during that and the following year (Gallagher & Harrison 2003). Finally, Episode 6 must relate to the modifications carried out by the Army to the Great Hall to create additional barrack accommodation, specifically the removal of the medieval hammerbeam roof and the erection of a simpler roof structure (Fawcett 1995, 103). It was during this episode that new windows and doorways were cut into the Great Hall, the lintels of which were re-used Episode 3 timbers.

4.2 PATTERNS OF TIMBER SUPPLY

The changing sources of timber used in the Castle reflect in microcosm the changing patterns of timber supply and trade between Scotland and Europe throughout the 16th to 18th centuries.

A small amount of native-grown timber has been identified and only in the earliest phases of building activity. These include the large oak baulks from the Chapel (Crone & Fawcett 1997) and some of the re-used Episode 1 timbers scattered throughout the Palace. While the late 13th and late 15th century oak baulks from the Chapel are singularly long-lived (*ibid*) the Episode 1 timbers are young and relatively fast-grown, reflecting the fact that native oak was in increasingly short supply by the end of the 15th century (*e.g.* Gilbert 1979, 237) and what was available was generally of poor quality (Crone & Mills 2000). Scandinavian oak baulks have been identified in several late 15th century Scottish buildings (Crone *et al* 2004; Crone forthcoming b) so it is no surprise to find that at the turn of the 16th century Scandinavian oak is being used to supplement supplies of native oak in the Castle. Throughout the 16th century southern Scandinavia remained the sole source for the oak baulks used throughout the Castle, corroborating the documentary evidence for timber imports from Denmark, Sweden and Norway during this period (Dow 1969; Ditchburn 1990; Lillehammer 1990).

Contemporary documents contain frequent references to 'eastland board' and examples of these boards have also been identified at Stirling in the 16th century. So far, the only eastern Baltic oak to be identified in Scotland has been found used in very particular circumstances, *i.e.* in the production of carved or painted panels (Crone *et al* 2000; forthcoming b) and this is also true at Stirling where it was used to make the Stirling Heads and the Palace doors. The fact that Scandinavian oak, which was readily available at the time, was not used in any of these examples suggests that 'Eistland...burdis' had qualities which set them apart from 'Swadyn…burdis' (*i.e. Works Accts* Vol 1, 108) and made them

preferable for use in fine woodwork where appearance was important, *i.e.* they were slow-grown, straight-grained, and wider than boards produced in Scandinavia.

Pine is rarely found in constructions of 16th century or earlier date in Scotland. This is not because it was unavailable; setting aside the uncertainties regarding a trade in native pine at so early a date (Lythe 1960, 143), pine was almost certainly being imported from Scandinavia, as both boards, or deals, and baulks. Its rarity is more probably because the elements for which pine deals were used, *i.e.* floorboards, shutters, sarking and paneling (Salzman 1952, 248), were those fittings of a building which could be readily refurbished. The floorboards over the Queen's Bedchamber are thus a rare survival of 16th century pine deals imported from Scandinavia. The panelling and cupboards in one of the bedchambers in the 16th century mansion at Newark Castle, Port Glasgow are another example of pine deals (Tabraham 2004, 23), as are the sawn pine boards shoring the well found during excavations of the Franciscan Friary at Shuttle St, Glasgow (Crone forthcoming a).

By the 17th century European oak supplies were becoming scarce. In 1602, for example, the export of Norwegian oak was forbidden because the remaining supplies were vital for the construction of the Danish/Norwegian fleet (Lillehammer 1986, 104). In Scotland pine replaced oak as the timber of choice for major structural purposes, such as rafters, joists, *etc*. There is little evidence of oak in 17th century and later buildings, at least in those buildings examined during dendrochronological research (Crone 2001; Crone & Mills 2005). The roof in the house at 68-74, High St, Brechin is a rare example of 17th century oak construction, and much of that consisted of re-used 15th century oak timbers (Crone *et al* 2004). Although the commercial exploitation of the native pinewoods of Scotland began during the 17th century (Smout 1960, 10) it appears to have been very small-scale and Scotland continued to rely on supplies of imported pine. That the late 17th century pine joists in the Palace are Scandinavian reflects the dominance of Norway and to a much lesser extent Sweden, in the supply of timber to Scotland at that time (Thomson 1991, 2, 65; Smout 1999).

By the late 18th century, when timber is required by the Army for alterations to the Castle, the pattern of trading had totally changed. During this period '… the balance of the Scottish import trade in timber switched from Norway, briefly to Sweden, and then decisively to the Baltic' (Smout 1999, 54). This change was due as much to governmental policy as to the better quality of timber from Russia, particularly the way in which the British government imposed import duties which encouraged the import of larger lengths of timber which only Baltic sources could supply (Thomson 1991, 266). Only three 18th century buildings in Scotland have so far been dendro-dated (42-44 Market St, Haddington

[Crone 1998], the Great Hall roof structure at Stirling Castle, and Elderslie House, Glasgow [Crone 2007a]) and they have all been provenanced to the eastern Baltic, providing material confirmation of the dominance of timber imports from Memel to Scotland in the last quarter of the 18th century (*ibid*, 267).

4.3 METHODOLOGICAL ADVANCES

The dendrochronological work at Stirling was some of the earliest undertaken in Scotland and has provided a substantial and robust dataset of oak chronologies which is proving to be an invaluable tool in the dating of imported timbers throughout Scotland. As a result of this and subsequent work it is now possible to date single timbers from 16th century structures with confidence, for example from John Knox House (Crone 2005f) and Tantallon Castle (Crone 2007b).

Pine dendrochronology in Scotland is still in its infancy. Dating of conifers has been commonplace in Europe for many years (*i.e.* Storsletten 1993) but in the UK it is only with the increasing interest in post-medieval and early modern building that attention has become more focused on the dendrochronology of conifers (Groves 1997; 2000). After a decade of research in England pine dendrochronology is now becoming mainstream (*ibid*). Work on developing both native and imported pine chronologies has begun in Scotland (Crone & Mills 2005) and the Stirling chronologies have provided the first successful building block. They represent the largest assemblage of pine yet to be analysed in Scotland. Prior to the Stirling Castle work the only other assemblage to be dated was that from 42-44, Market St, Haddington which produced a chronology containing five timbers (Crone 1998). However, the fact that this chronology was instrumental in dating the Great Hall timbers illustrates the progress that can be made as more and more buildings are successfully dated.

The work at Stirling has highlighted some of the problems surrounding the analysis of pine.
The 1671 felling dates accord with the documentary evidence which records the numerous shiploads of timber being brought up the Forth from Leith to Stirling during that and the following year (Gallagher & Harrison 2003). However, the very number of individual cargos of timber arriving in Stirling highlights the problem confronting the dendrochronologist. By the 17th century, timber was being imported into the country in vast quantities from multiple sources and it is quite likely that each cargo mentioned in the documents had arrived in Leith from anywhere around the Baltic or Scandinavia. The English Heritage research project on the development of conifer chronologies has tackled the problem of multiple sources by sampling as extensively as possible (Groves 1997; 2000) and this approach has paid dividends at Stirling. Of 58 timbers fully analysed, 26 have been dated; this amounts to 45% of the

assemblage, a proportion comparable to that now being achieved in the analysis of pine chronologies in England (*ibid*).

The character of the dated timbers at Stirling can be used to redefine guidelines for the sampling of pine in the future. Apart from two samples with sequences of 74 and 87 rings, all the dated samples had sequences with more than 100 rings; none of the shorter sequences could be dated. This suggests that the minimum number of rings required for successful analysis should be raised to at least 75 in large assemblages, and 100 in smaller assemblages. On the other hand, the very long sequences, those with 200+ rings, have not dated either. These sequences had very narrow rings throughout (average ring width 0.3 mm in comparison to 0.8 mm for the dated sequences) and while they appeared to be clear and measurable it remains possible that there are missing rings on some of the sequences. The experience at Stirling suggests that success in dating pine from buildings and periods where imported timber from multiple sources is expected will only be achieved with large assemblages, the bulk of which have ring-sequences between 100 and 200 rings.

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TABLES

	King's Bedchamber	Queen's Bedchamber	N&S Ranges	Princes Tower	Attic space	Great Hall	East Range
Episode 1 1500/01	OOO		O		O		
Episode 2 1505		O	O	O			
Episode 3 1538/9		OOO	OOO PPP			O	
Episode 4 1591 -3				OOO		OO	
Episode 5 1664 - 71			PPP				PPP
Episode 6 1783 - 6						PP	

Table 1: Building episodes and locations of dated timbers. O = oak, P = Pine (the number of letters indicates where the greatest concentrations of timbers for that particular episode are located)

Episode	Sample number	Number of rings	Sapwood	Bark edge	Season of felling	Date	Felling date/range
1	KBSJ3	138	25	S/B	?	1363 - 1500	1500/01
1	**U10/5.007**	**85**	**12**	**B**	**winter-cut**	**1416 - 1500**	**1500/01**
1	KBMJ1	86	h/s?	-		1404 - 1489	1499 - 1535
1	KBMJ3	81	2	-		1413 - 1492	1500 - 1536
1	KBMJ4	82	h/s?	-		1402 - 1483	1493 - 1539
1	KBMJ5	85	h/s?	-		1402 - 1486	1496 - 1532
2	U30.5.002	141	21	B	spring/summer	1365 - 1505	1505
2	**U03/5.036**	**144**	**3 +10**	**B**	**spring/summer**	**1356 - 1495**	**1505?**
2?	KBSJ6	85	h/s?	-		1407 - 1491	1506 - 1521
2?	QBMJ9	135	h/s?	-		1355 - 1489	1504 - 1519
2?	**U09/5.001**	**123**	**-**	**-**		**1367 - 1489**	***tpq* 1504**
1/2	U14.5.011	87	5	-		1402 - 1488	1498 - 1513
1/2	**U03/5.039**	**83**	**h/s?**	-		**1401 - 1483**	**1498 - 1513**
1/2	U14.5.022	98	hs?	-		1383 - 1480	1495 - 1510
1/2	QBMJ4	97	h/s	-		1382 - 1478	1493 - 1508
1/2	KBD1	76	h/s?	-		1401 - 1476	1491 - 1506
1/2	A01.02	68	h/s?			1402 - 1469	1484 - 1499
1/2	QBMJ2	75	h/s	-		1386 - 1460	1475 - 1490
1/2	KBSJ2	95	-	-		1391 - 1485	*tpq* 1500
1/2	U14.5.023	92	-	-		1392 - 1483	*tpq* 1498
1/2	**U29/5.005**	**68**	-	-		**1406 - 1473**	***tpq* 1488**
1/2	U14.5.005	70	-	-		1398 - 1467	*tpq* 1482
1/2	U12.5.012	61	-	-		1400 - 1460	*tpq* 1475
1/2	**U09/5.008**	**68**	-	-		**1380 - 1447**	***tpq* 1462**

Table 2: Episodes 1 & 2; dendrochronological data.

	U10/5_007	**KBMJ5**	**KBMJ1**	**KBMJ3**	**KBMJ4**
U10/5_007	*				
KBMJ5	4.91	*			
KBMJ1	4.02	-	*		
KBMJ3	4.86	3.95	3.97	*	
KBMJ4	4.31	4.92	5.03	4.07	*

Table 3a: t-value matrix for the Episode 1 native oak timbers

	29/5005	**QBMJ2**	**QBMJ9**	**U09/5001**	**U09/5008**	**QBMJ4**	**U12/5012**	**U14/5005**	**U14/5022**	**KBSJ6**
29/5005	*									
QBMJ2	5.63	*								
QBMJ9	5.16	5.79	*							
U09/5001	5.52	6.00	6.61	*						
U09/5008	/	5.00	/	3.74	*					
QBMJ4	/	5.24	6.95	3.95	5.34	*				
U12/5012	/	/	/	/	5.06	/	*			
U14/5005	/	5.64	/	/	3.61	4.07	4.55	*		
U14/5022	3.79	4.72	5.03	/	4.92	6.06	3.87	/	*	
KBSJ6	/	3.7	/	4.03	/	4.89	4.04	/	5.99	*

Table 3b: t-value matrix for some of the Episode 2 imported oak timbers.

Sample Number.	No. of rings	Sapwood	Bark edge	Season of felling	Date	Felling date/range
U23/5.005	102+ sap	25	B	spring/summer	1415 - 1516	1539
U26/5.005	138+ sap	24	B	spring/summer	1377 - 1514	1539
U27/5.005	117+ sap	14	B	spring/summer	1409 - 1525	1539
U28/5.005	179	24	B	spring/summer	1361 - 1539	1539
U28/5.016	129	14	B	spring/summer	1411 - 1539	1539
U29/5.001	103	15	B	spring/summer	1437 - 1539	1539
U29/5.002	140	18	B	spring/summer	1400 - 1539	1539
U29/5.004	81+	17	B	spring/summer	1459 - 1539	1539
U29/5.008	149	31	B	spring	1391 - 1539	1539
U29/5.010	83+ sap	22	B	spring/summer	1434 - 1516	1539
U29/5.011	76+ sap	16	B	spring/summer	1446 - 1521	1539
U29/5.026	111+sap	15	B	spring/summer	1413 - 1523	1539
U10/5.006	111+	20+	B	spring-cut	1406-1516	1539
U03/5.023	140	21	B	spring-cut	1400 - 1539	1539
U04/5.013	118	18	B	spring-cut	1422 - 1539	1539
U09/5.004	152	15	B	winter-cut	1387 - 1538	1538/9
U04/5.008	168	28	B	winter-cut	1371 - 1538	1538/9
U28/5.001	173	27	B	winter	1366 - 1538	1538/9
QBMJ6	140	15	B		1399 - 1538	1538/9
QBMJ8	155	17	B		1384 - 1538	1538/9
U09/5.011W	166	24	B	winter	1373 - 1538	1538/9
GHVI	157	15	B	winter	1382 - 1538	1538/9
U03/5.009E	122+ sap	25	B	?winter	1391 - 1512	1538
U03/5.019	140+	4+11	-		1387 - 1526	1537 - 1552
U03/5.042	150	H/S?	-		1375 - 1524	1539 - 1554
U03/5.028	107	5	-		1415 - 1521	1531 - 1546
QBMJ1	135	H/S?	-		1386 - 1520	1535 - 1550
QBMJ7	137	H/S?	-		1378 - 1514	1529 - 1544
QBMJ5	147	H/S?	-		1363 - 1509	1524 - 1539
QBMJ3	135	H/S?	-		1374 - 1508	1523 - 1538
U09/5.004E	150	-	-		1380 - 1529	*tpq* 1544
U03/5.032	99	-	-		1417 - 1515	*tpq* 1539
U03/5.004	55+ sap	7+	B	spring/summer	1471 - 1525	*tpq* 1532
GHV	132	-	-		1386 - 1517	*tpq* 1532
U10/5.009W	100	-	-		1408 - 1507	*tpq* 1522
U10/5.008	101	-	-		1397 - 1497	*tpq* 1512
U09/5.011	99	-	-		1395 - 1493	*tpq* 1508

Table 4: Episode 3; dendrochronological data.

Sample number	**No. of rings**	**Sapwood**	**Bark edge**	**Season of felling**	**Date**	**Felling date/range**
M01.3	158	19	B	winter?	1435 - 1592	1592/3
M01.6	185	24	B	winter?	1407 - 1591	1591/2
U30.5.001	149+ sap	1+ 6	-		1427 - 1575	1589 - 1604
GHVII	132	H/S	-		1440 - 1571	1586 - 1601
GHXVII	129	-	-		1441 - 1569	*tpq* 1584
GHXIX	171	-	-		1390 - 1560	*tpq* 1575
GHXIII	151	-	-		1408 - 1558	*tpq* 1573
M01.2	148	-	-		1405 - 1552	*tpq* 1567

***Table 5**: Episode 4; dendrochronological data.*

Sample number	**No. Of rings**	**Sapwood**	**Bark edge**	**Season of felling**
Kings bedchamber				
U12.5.016	47+	19	B	winter
U12.5.018	30	2	-	
U14.5.008	87	23	B	
U14.5.015	66	-	-	
KBMJ2	59	-	-	
KBSJ1	75	H/S?	-	
KBSJ4	63	-	-	
KBSJ5	53	19	S/B	
U16.5.008	unm (c 20)			
U14.5.012	unm (c 23)			
U12.5.022	unm (c 23)			
South range				
U28/5.009	58	-	-	
U28/5.013	53+	H/S?	-	
North range				
U10/5.009	109	19	B	winter-cut
Princes Tower				
M01.4	129	-	-	
M01.5	65	-	-	
M01.7	69	-	-	

Sample number	No. Of rings	Sapwood	Bark edge	Season of felling
U30.5.003	174+	17	B	spring/summer
Attic space				
A01.01	79	H/S?	-	
A01.03	90	H/S?	-	
A01.04	97	-	-	
A09.01	124	H/S?	-	
A09.02	87	-	-	
Great Hall				
GHXVI	113	17	S/B	
GHCORE1	52	-	-	
GHNW1	111	-	-	
King's Closet Stairs				
U13B2.013	unm			
UB13B2.015	unm			
U13B2.016	unm			

Table 6: Undated timbers; dendrochronological data.

Door	Board	No. of rings	Date	*tpq* (+9 rings)	Correlation with BALTIC 1	Vistula Basin	East Poland
PE07	VB1	128	1377 - 1504	1513	6.47	3.69	5.31
	VB4	185	1337 - 1521	1530	4.44	/	/
	VB5	237	1270 - 1506	1515	6.27	/	3.92
	VB8	238	1287 - 1524	1533	9.24	3.99	4.98
PD03	VB3	231	undated				
	VB4	240	1272 1511	1520	9.3	4.96	3.71
	VB5	170	1337 - 1506	1515	4.29	3.27	/
	VB6	177	1325 - 1501	1510	7.4	3.69	/
PD09	VB6	227	1283 - 1509	1518	9.99	5.40	5.04

Table 7: The Palace doors; dendrochronological data.

Board	No. rings	Date	*tpq*	BALTIC 1	BALTIC 2
D1CB	246	undated			
D2CB	145	1368 - 1512	1521	8.28	
D2CP	195	undated			
D5CB	104	1409 - 1512	1521		4.83
D5LB	214	1273 - 1486	1495	5.48	
D9CB	109	undated			
D9CP	89	1368 - 1457	1466	9.04	
D16CB	114	undated			
D16CP	109	1358 - 1466	1475	4.17	
D18LB	160	1350 - 1509	1518	3.87	
D18RB	158	undated			
D18CB	144	1367 - 1510	1519	6.95	
D22LB	139	1298 - 1436	1445		
D22RB	114	1304 - 1417	1426	8.24	
D22CP	135	1372 - 1513	1522		7.95
D22CB	138	1372 - 1509	1518		6.45
D23LB	138	1378 - 1515	1524	5.07	
D23RB	139	1383 - 1521	1530	7.28	
D23CB	114	1360 - 1473	1482	7.42	
D25LB	111	1390 - 1500	1509	10.35	
D25RB	125	1389 - 1513	1522	8.97	
D25CB	130	1383 - 1512	1521	7.58	
D26CB	101	1405 - 1505	1514	7.06	
D26LB	94	1398 - 1491	1500	6.35	

Table 8: The Stirling Heads; dendrochronological data

	EP21505	EP31538/9	EP31539	EP41592
Regional chronologies				
2X900001 (830 - 1997 AD) Sealand, Denmark	10.44	11.34	13.26	10.22
81M00004 (1350 - 1480 AD) N Jutland, Denmark	11.82	9.71	9.43	10.05
JUTLAND6 (846 - 1793 AD) Jutland, Denmark	8.29	9.06	11.21	11.81
SM00005 (1274 - 1974 AD) Skaane - Blekinge, W Sweden	9.24	9.95	12.00	7.54
SM000012 (1125 - 1720 AD) W Sweden	9.21	9.75	9.69	11.44
SM00001 (1310 - 1539 AD) SW Sweden	6.53	6.81	9.28	8.24
Scottish 'import' chronologies				
FTMAS1 (1366 - 1547 AD) Fenton Tower, East Lothian	9.02	7.58	7.94	10.20
FTMAS2 (1318 - 1572 AD) Fenton Tower, East Lothian	6.98	6.02	6.00	6.47
EDINCAS2 (1358 - 1509 AD) Edinburgh Castle	6.21	5.76	5.78	4.86
BRECHIN1 (1359 - 1470 AD) 68-74 High St, Brechin, Angus	7.08	5.48	5.71	6.55
GAROOF2 (1350 - 1458 AD) Guthrie Aisle, Angus	8.85	8.11	9.42	6.42
MIDHOPEx2 (1265 - 1505 AD) Midhope Castle, West Lothian	8.80	5.80	7.93	5.44
OSU1NEWx2 (1391 - 1520 AD) Old Students Union, St Andrews, Fife	6.33	4.99	5.43	5.28
TC1x1 (1383 - 1484 AD) Tantallon Castle, East Lothian	5.69	5.43	5.03	4.77
375HSMNx2 (1338 - 1570 AD) 375, High St, Edinburgh	5.69	4.74	3.92	3.68
STPCMNx3 (1410 - 1552 AD) barrel, Cowgate, Edinburgh	5.60	7.54	8.60	8.35

Table 9: Correlations between the Episode masters and regional and site chronologies

Sample no.	No. of rings	Bark edge	Comments
QBCP1	151	/	
QBCP2	103	/	
QBCP3	90	/	
QBCP4	110	/	
QBCP5 (P07.6/25)	134 +	B	outer 10+ rings compressed & unm
QBCP6 (P07.6/25)	160	/	
QBCP7(P07.6/24)	120	/	
QBCP8 (P07.6/24)	123	B?	

Table 10: Pine floor boards over the Queen's Bedchamber; dendrochronological data**.**

	QBC4	QBC7	QBC3	QBC2	QBC5	QBC8
QBC4	*	5.16	4.80	5.16	4.42	4.69
QBC7	*	*	4.05	-	-	-
QBC3	*	*	*	-	3.99	-
QBC2	*	*	*	*	4.57	4.87
QBC5	*	*	*	*	*	-
QBC8	*	*	*	*	*	*

Table 11: Matrix of t-values for QBCPINEx5

Regional/site chronology	***Starts***	***Ends***	***t-value***	**Description of chronology**
SWED_DAL	1001	1852	5.86	Dalarna, Sweden (TB pers comm)
SWED_HL1	1001	1861	5.99	Helsingland, Sweden (TB pers comm)
K010301S	1395	1706	6.18	Farmhouse Lower Saxony (Wrobel pers comm)
SE Norway	871	1986	6.84	Standing buildings, SE Norway (Thun 2005)
3epgag01	1297	1448	6.73	Cistercian convent, Tallinn, Estonia (Alar Laanelaid pers comm)

Table 12: QBCPINEx6 correlations with master chronologies

Sample	No. rings	Bark edge	Comments
NORTH RANGE			
U03/5.013	269	B?	
U03/5.025	171	B	
U03/5.034	126	B?	
U03/5.040	160+	B	Outer 2-3 mm worm-eaten
U03/5.041	140	B	
U03/5.045	64	B	
U09/5.010	69	-	Outer rings worm-eaten
U10/5.010	105+	B	In 2 sections not overlapping
U10/5.012	101+	-	Outer rings worm-eaten
SOUTH RANGE			
U23.5.006	138 +	/	Outer rings worm-eaten
U27.5.004	79 +	/	+ 48 r on worm-eaten fragments
U27.5.006	152 +	/	+ 21 r on bark frag. Winter cut
U27.5.007	185	B	spring/summer cut
U28.5.003	110 +	/	outer rings too worm-eaten to measure
U28.5.004	101 +	/	+ 46 rings on worm-eaten fragments
U28.5.007	160	B	
U28.5.011	102 + 83	B	spring/summer cut
U28.5.015	74	/	Outer rings worm-eaten
U29.5.012	134	B	winter cut
U29.5.013	84 +	/	47+ on worm-eaten fragment
U29.5.014	143	B	winter cut
U29.5.015	100	B?	
U29.5.016	196	/	spring/summer cut
U29.5.017	113	B	spring/summer cut
U29.5.019	133	/	Outer rings worm-eaten
U29.5.022	136	B	
U29.5.024	139	B	Outer rings worm-eaten & compressed
U29.5.025	114 +	/	+ 9 rings on fragment with bark edge - spring/summer cut
U29.5.027	87 +	/	35 + rings on worm-eaten fragment
EAST RANGE			
U18.5.007	260 +	B	outer rings too compressed to measure - est 10-15 more rings
U18.5.008	121 +	/	*circa* 5 mm wood worm-eaten – est. 8 rings lost
U18.5.009	111 +	/	

Sample	No. rings	Bark edge	Comments
U19.5.002	158 +	/	Outer rings worm-eaten
U19.5.003	118 +	/	*circa* 20 mm wood worm-eaten - est 70-80 rings lost
U19.5.004	80	B	spring/summer cut
U19.5.005	65 + 63 +	B	outer rings too compressed to measure - est 5-6 more rings
U19.5.006	158	B	*rafting peghole present
U24.5.005	75 +	/	*circa* 7 mm wood worm-eaten - est 7+ rings missing

Table 13: Joists in the North, South and East Ranges with sequences greater than 60 rings; dendrochronological data.

	U295024	**U295019**	**U295022**	**U295027**	**U295025**	**U295012**	**U295016**	**U295014**	**U285004**	**U275007**	**U295015**	**U285007**	**U235006**	**U295017**	**U285015**
U295024	*	6.85	8.92	4.83	6.13	4.47	-	4.26	4.59	-	3.46	5.38	-	3.06	-
U295019	*	*	6.86	5.29	7.31	5.87	5.28	5.18	6.07	6.23	4.40	5.82	-	4.45	-
U295022	*	*	*	4.52	5.62	4.37	4.15	3.53	4.40	3.04	3.67	5.74	4.90	4.73	3.85
U295027	*	*	*	*	7.12	5.41	4.84	-	7.35	3.37	3.30	3.68	3.02		-
U295025	*	*	*	*	*	5.83	3.72	-	3.62	4.98	5.88	3.55	-	3.43	-
U295012	*	*	*	*	*	*	3.62	4.43	3.31	4.62	-	3.49	-	5.30	-
U295016	*	*	*	*	*	*	*	*	5.08	-	-	-	4.86	3.75	-
U295014	*	*	*	*	*	*	*	*	3.64	-	3.51	-		3.42	-
U285004	*	*	*	*	*	*	*	*	*	5.92	*	4.60	4.13	-	3.84
U275007	*	*	*	*	*	*	*	*	*	*	*	4.57	4.14	-	3.79
U295015	*	*	*	*	*	*	*	*	*	*	*	*		3.80	*
U285007	*	*	*	*	*	*	*	*	*	*	*	*	3.15	*	*
U235006	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
U295017	*	*	*	*	*	*	*	*	*	*	*	*	*	*	5.46
U285015	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 14: matrix of t-values for SPPINEx15

Regional/site chronology	***Starts***	***Ends***	***t-value***	**Description of chronology**
SWED_STK	1127	1671	6.36	Stockholm/Uppland [TB pers comm 1994]
SWED_GRV	1469	1840	5.36	MK Gravsten [TB pers comm 1994]
SWED_MAL	1083	1992	5.22	Malardalen Gotland Sweden [Alf Brathen]
LAT_DANN	1445	1694	4.79	Dannensterna House Riga Latvia [Zunde 1999]
RUSS017	1471	1993	4.53	Paajarv2 Russia [M. Lindholm/J. Merilainen]
MRGASQ05	1528	1681	8.26	Co. Durham Middridge Grange Heighington [Arnold 2006]
DANSON1	1489	1758	4.77	Danson House Bexley Kent [Groves 2002]
JEMGRP03	1367	1710	4.51	London-Westminster 107 Jermyn Street [Groves 2005]
RANGR-P2	1551	1663	4.25	Rangers House Greenwich Park London [CG 2004]

Table 15: Correlations between SPPINEx15 and other sites and regional chronologies

	Dated sequence starts	**Dated sequence ends**	**Outer rings**	**Felling date or tpq**
U295022	AD1536	AD1671	B	1671
U295016	AD1476	AD1671	B	1671
U295017	AD1559	AD1671	B	1671
U275007	AD1486	AD1670	B	1670
U295024	AD1531	AD1669	+ 1-2	1671
U285007	AD1508	AD1667	B	1667
U295014	AD1523	AD1665	B	1665
U295012	AD1531	AD1664	B	1664
U295019	AD1528	AD1660	/	tpq 1660
U295025	AD1545	AD1658	+ 9	tpq 1666
U295015	AD1552	AD1651	/	tpq 1651
U285015	AD1571	AD1644	/	tpq 1644
U235006	AD1488	AD1625	/	tpq 1625
U295027	AD1537	AD1623	+ 35	tpq 1658
U285004	AD1505	AD1605	+ 46	tpq 1651

Table 16: Dated pine joists in the Palace listed according to end date..

Sample no.	No. of rings	Bark edge
2W	113	/
3W	159	B
5W	160	B
6W	153	/
7W	122	B
8W	158	B
9W	165	B
10W	85	/
12E	162	B
13E	153	B?
14E	75	B
18E	162	/

Table 17:Pine joists from the Great Hall; dendrochronological data.

							t-values against
		GHP12	**GHP9**	**GHP2**	**GHP3**	**GHP18**	**HADDINGTON**
GHP12	**AD 1622 - 1783**	*	9.28	6.56	3.55	4.14	/
GHP9	**AD 1609 - 1773**	*	*	3.78	5.84	3.80	6.39
GHP2	**AD 1593 - 1705**	*	*	*	*	*	/
GHP3	**AD 1627 - 1786**	*	*	*	*	7.53	6.05
GHP18	**AD 1606 - 1767**	*	*	*	*	*	5.04

Table 18: Matrix of t-values for GHPINEx5

Regional/site chronology	***Starts***	***Ends***	***t-value***	**Description of chronology**
lat-bskd	1583	1751	4.4	Bauska Holy Spirit Church, Latvia (Maris Zunde pers comm)
ZP06PSC4	1672	1903	7.7	historic buildings - Vilnius, Lithuania (Rutile Pukiene pers comm)
BZGUDZC1	1486	1798	5.68	Historic churches -Lithuania (Rutile Pukiene pers comm)
3ep242av	1516	1998	6.31	Historic buildings - Estonia (Alar Laanelaid pers comm)
			6.65	Gdansk, Poland (Thomasz Wazny pers comm)
HADDINGTON			6.01	42 Market St, Haddington (Crone 1998)

Table 19: Correlations between GHPINEx5 and other site and regional chronologies.

Episode	**Felling date/s**	**Species**	**Location**	**Timber type**		**Source region**
Episode 1	1500/01	oak	King's Bedchamber	baulks	*re-used*	Scotland & Scandinavia
		oak	N&S Ranges	baulks	*re-used*	Scotland & Scandinavia
		oak	Attic space	baulks	*re-used*	Scandinavia
Episode 2	1505	oak	Queen's Bedchamber	baulks	*re-used*	Scandinavia
		oak	Princes Tower	baulks	*re-used*	Scandinavia
		oak	N&S Ranges	baulks	*re-used*	Scandinavia
Episode 3	1538/9	oak	Queen's Bedchamber	baulks		Scandinavia
		oak	N&S Ranges	baulks		Scandinavia
		oak	Stirling Heads	boards		Poland
		oak	Palace doors	boards		Poland
		oak	Great Hall	baulks	*re-used*	Scandinavia
	1535	pine	Queen's Bedchamber	boards		Scandinavia
Episode 4	1591-3	oak	Princes Tower	baulks		Scandinavia
Episode 5	1664-71	pine	N&S Ranges	baulks		Scandinavia
Episode 6	1783-6	pine	Great Hall	baulks		Eastern Baltic

Table 20: Summary of dendrochronological evidence from Sterling.

FIGURES

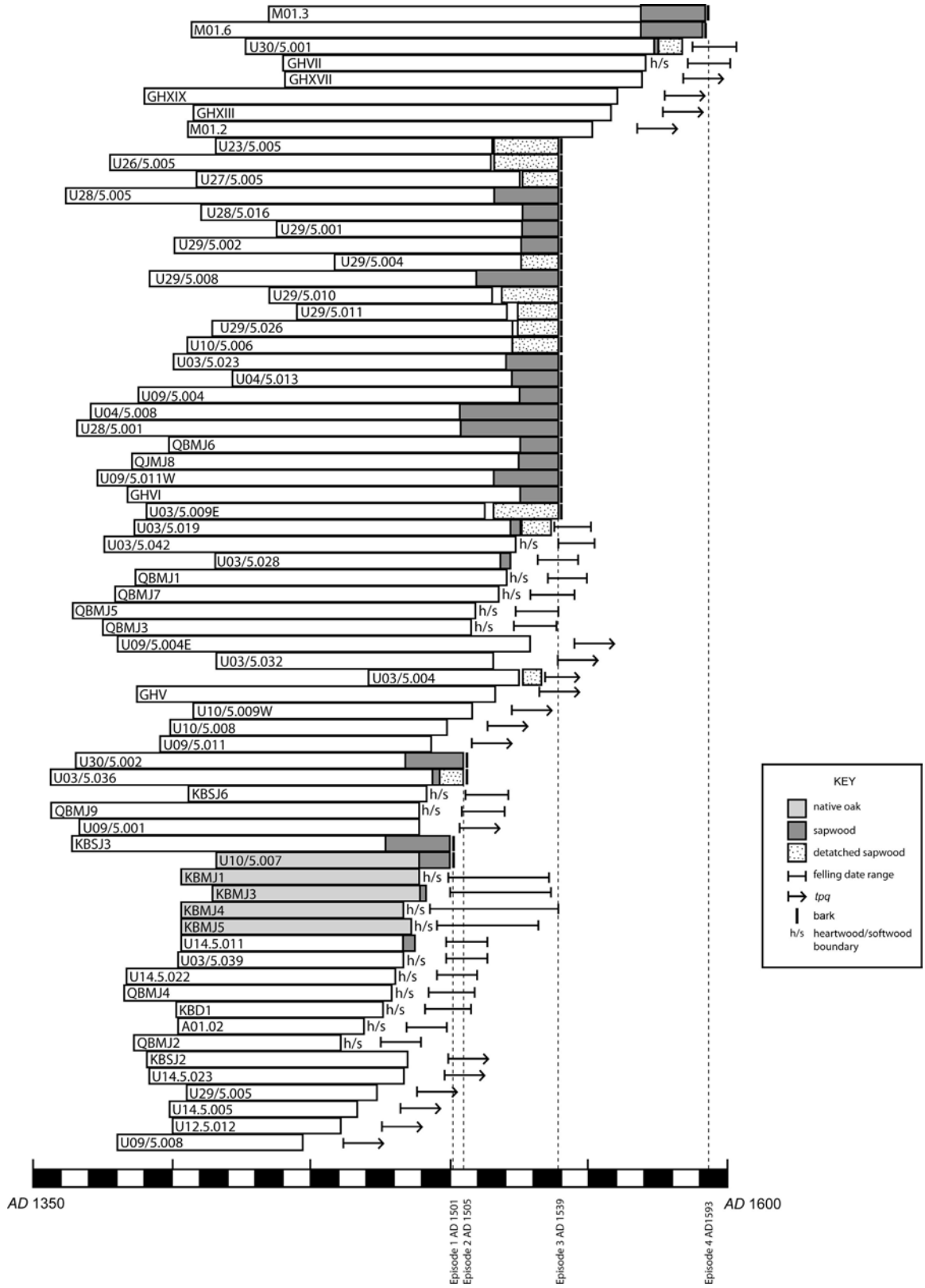

***Figure 1*: Bar diagram showing the chronological relationships of all the dated oak beams from Stirling Castle.**

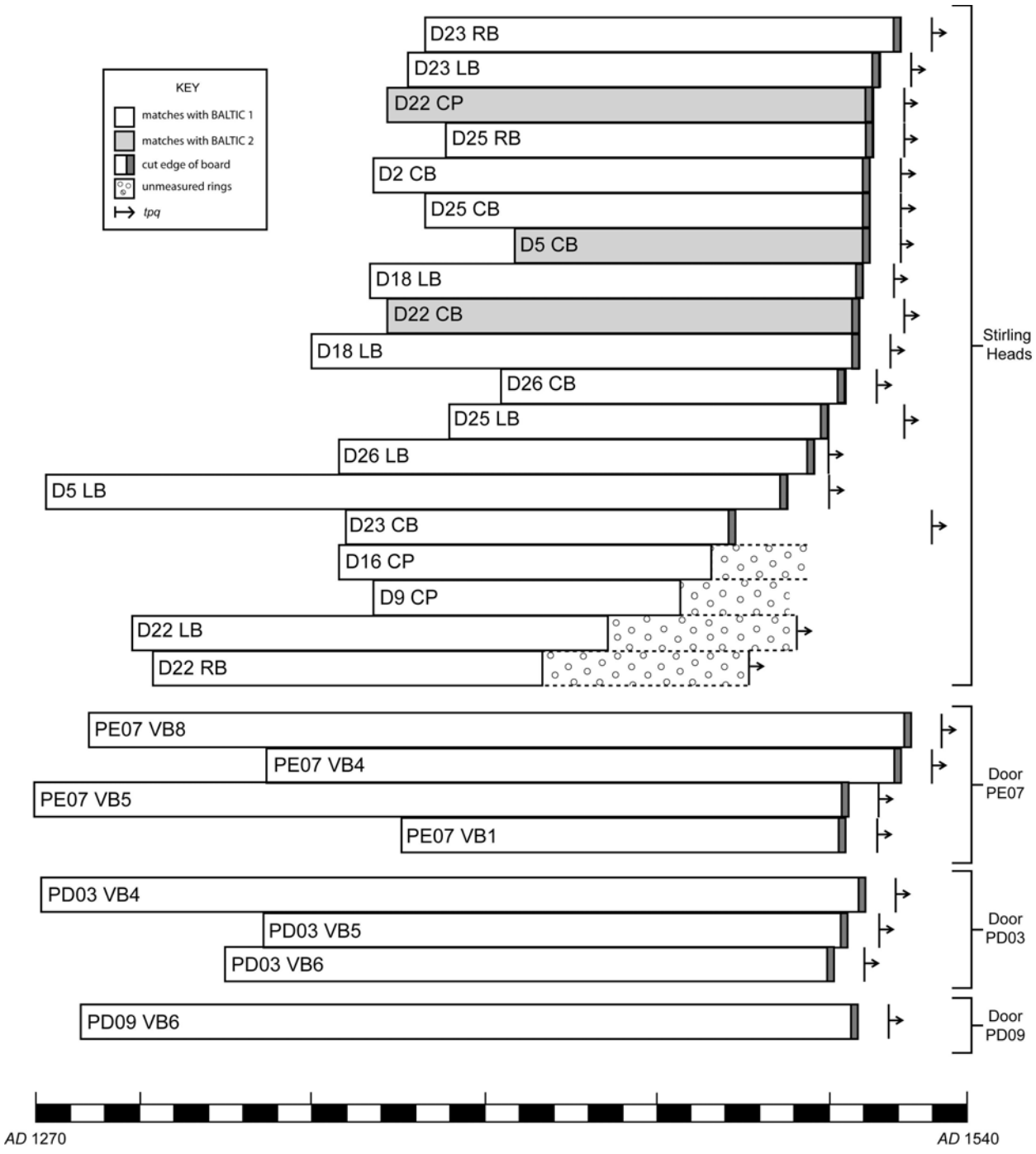

Figure 2: Bar diagram showing the chronological relationships of the boards used in the Stirling Heads and the Palace doors.

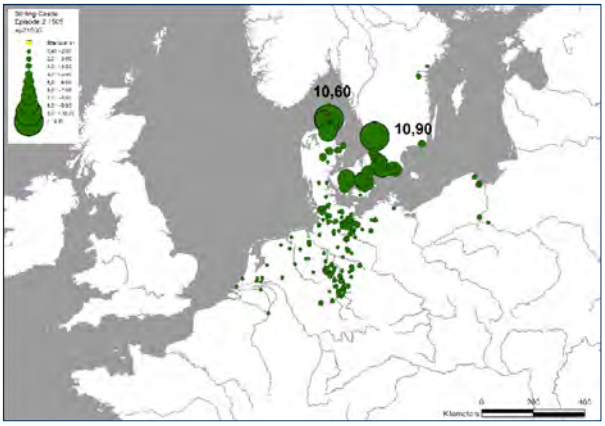

Figure 3a: Episode 2 1505

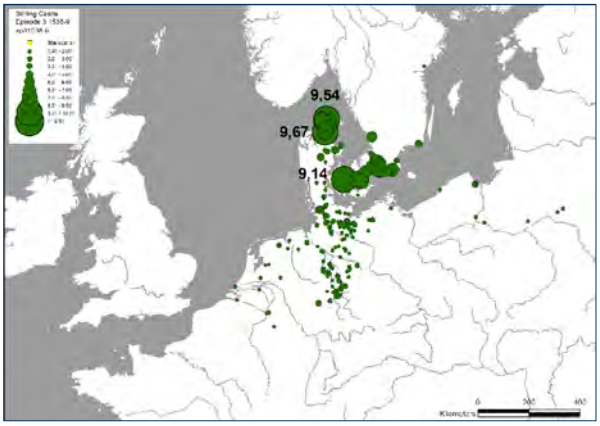

Figure 3b: Episode 3 1538/9

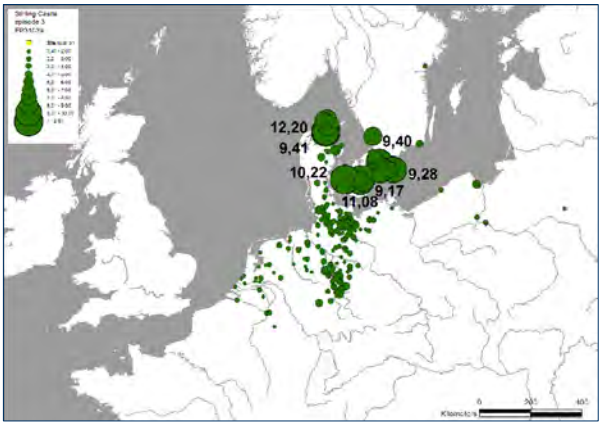

Figure 3c: Episode 3 1539

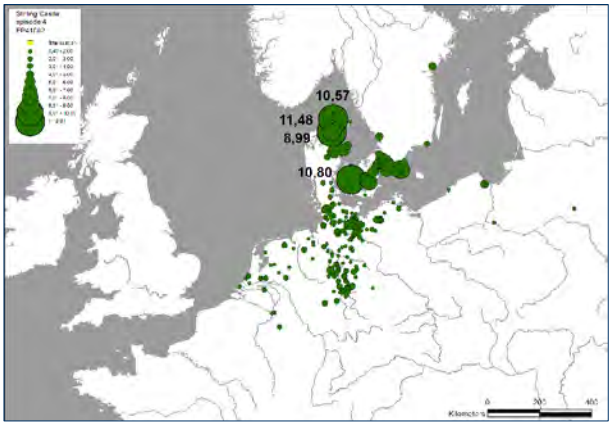

Figure 3d: Episode 4 1592

Figure 3: Distribution of correlation values between the episode masters and site chronologies for northern Europe.

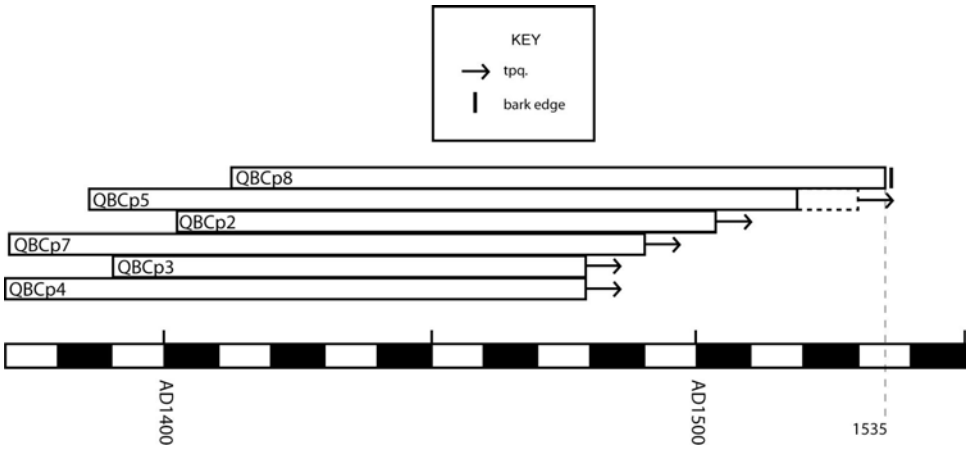

Figure 4: Bar diagram showing the chronological relationships between the dated pine floorboards from the Queen's Bedchamber.

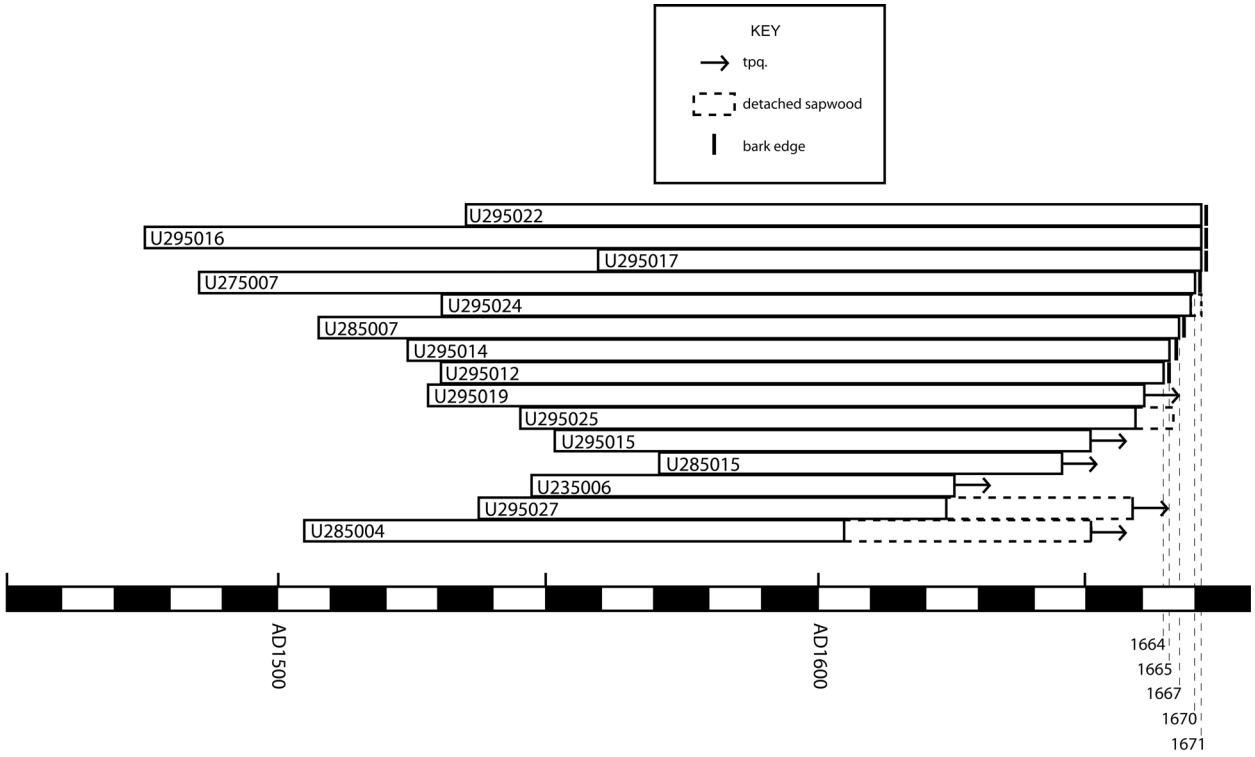

Figure 5: Bar diagram showing chronological relationships of dated pine timbers in the North Range.

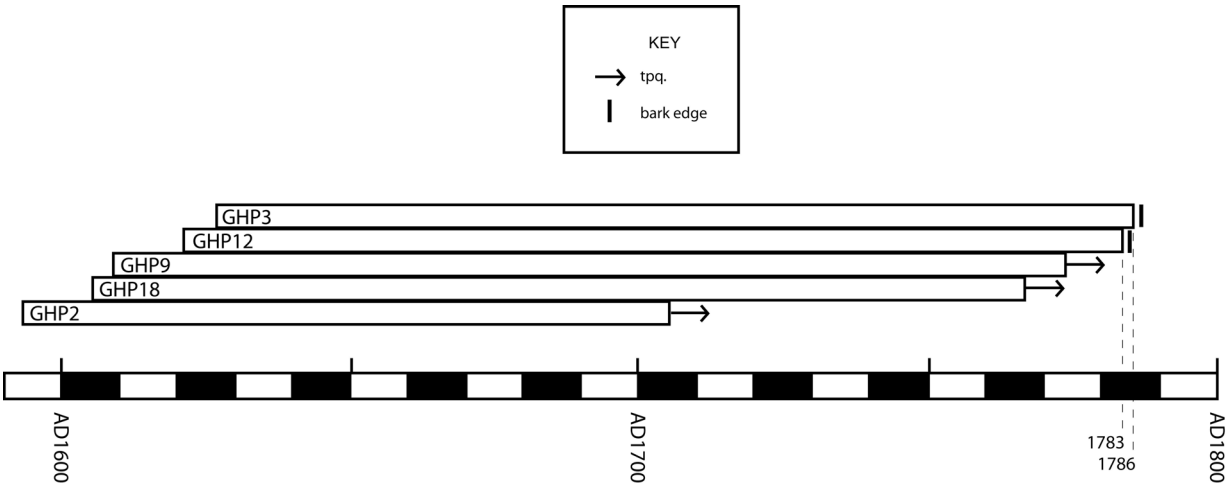

Figure 6: Bar diagram showing chronological relationships of dated pine timbers from the Great Hall.

Figure 7: Rafting peghole in U:19.5.001.