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TREE-RING ANALYSIS OF OAK TIMBERS FROM BILLINGSGATE LORRY PARK, CITY OF LONDON: THE PERIOD VIII-XVII TIMBERS.

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Summary

The tree-ring analysis and dating of 116 oak timbers from periods VIII to XVII are described. The results provide a dating framework for the development of the Billingsgate waterfront during the late 12th/13th century.

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TREE-RING ANALYSIS OF OAK TIMBERS FROM BILLINGSGATE LORRY PARK, CITY OF LONDON: THE PERIOD VIII-XVII TIMBERS

Introduction

The analysis and dating of the oak timbers from periods II to VII have already been described (Hillam 1987a,b; 1988a,b; 1990; Hillam & Groves 1985). The results of these analyses provided a dating framework, often precise to the year, for the development of the waterfront structures at Billingsgate throughout the 11th and 12th centuries. This framework had allowed the archaeological interpretation to be revised and refined. The most recent timbers to be examined prior to this study are from phase VII.13, and these were felled in the period 1172-1187. The aim of the present study is to outline the waterfront chronology during periods VIII to XVII.

Period VIII saw the construction of a new waterfront and new dumps across the whole site. The tree-ring samples are mostly from the VIII.2 north-south revetment at the south east of the site which had front bracing to the west. Another revetment was constructed in period IX.1 with primary dumping behind the new revetment in IX.2. Few primary timbers were available for analysis although some may have been robbed for use in phase X.1. Phase X.2 is represented by the construction of a building, whilst in phase X.4 there was the construction of a north-south extension to the VIII.2 revetment. Period XI saw the construction of a new front-braced revetment in the extreme south of the site. A substantial section of this east-west revetment was excavated and conserved for display. The revetment was repaired from time to time as shown by the timbers from phases XI.2 to XI.7. The final timbers from period XI come from a timber drain which was added behind the refaced revetment.

The archaeological phasing of the final periods of the site's history has not yet been completed, but the analysis of the five timbers from periods XIII-XVII have been included for completeness.

The samples

The 32 samples from period VIII were divided into one from VIII.1 and 31 from VIII.2. A further two samples (5293, 6009) supposedly belonging to VIII.1 were also examined but these are now thought to be mislabelled. 4192 from VIII.1 was a random stake found in dumping associated with a possible front-braced post and plank revetment. Many of the VIII.2 samples were structural timbers from the north-south revetment. 5667, 5669, 5670, 5673, and 5742 were horizontal planks which had been pegged onto the revetment. 5675-5680 were from vertically set uprights which had been tenoned into the baseplate 5721. Two piles (5684, 5724) and a wedge (5723) were driven in along the west side of the baseplate to prevent displacement to the west. The baseplate was underpinned by several reused structural timber fragments (5725, 5729, 5731-2, 5735-6). Other samples came from a subsidiary brace baseplate 5711, which was associated with retaining pile 5606, a brace 5683, and an upright post 6877. A group of discarded structural timbers from the dumping behind the revetment were also sampled (5530-1, 6470).

Four timbers were sampled from period IX although 5754 from IX.3 appears to have been mislabelled (see below). Of the others, 4571 from IX.1 was from a timber which possibly underpinned the robbed baseplate of the revetment, and 2678A/B were plank fragments from the dumps behind the revetment.

None of the five timbers which were sampled from X.1 are likely to have been *in situ*, and some may have been robbed from the dismantled period IX revetment. All were found within a dump to the south of the period IX revetment. 4729, 4731-2 were planks, 4319 a squared timber and 4586 a possible brace.

The samples from the phase X.2 central building came from two planks from the west wall (4759, 5203) and a horizontally laid timber pad 5686 at the corner of the west and north walls.

Six timbers were sampled from the phase X.4 extension of the VIII.2 revetment. 2645A/B were squared tenoned uprights set into a baseplate, whilst 2646, 5630-1 and 5633 were planks which were fixed onto the uprights as cladding.

A total of 41 timbers were examined from the XI.1 revetment. The majority were sampled during excavation and sent to Sheffield for analysis but four (cladding timbers - 6190-1, upright - 6204, secondary baseplate - accession no 3269) were examined as part of a separate study on timbers which were being preserved for conservation. Full details of all the conservation samples are given elsewhere (Hillam & Groves 1985), although a summary of the results for the above four timbers will be included here.

The east-west XI.1 revetment is divided into a western and eastern section. The western section consists of two reused baseplates 3865-6 into which are fitted reused uprights (2656, 2658, 2663-4, 2672, 2675 pegged to 3865; 2668A/B, 3301, 3560 attached to 3866). This section may have been the western part of the period IX revetment which had been dismantled and re-erected. Other timbers sampled from the western section were plank fragments attached to the uprights above the cladding (2659, 2683A/B, 2686A/B, 3338, 3369, 3381, 3408, 3652, 4737). Whilst the cladding was thought to be primary, the planks were either reused or a later repair. 6154 and 6156 were from north-south timbers serving as a lever beneath a baseplate, and 3875 was a pile retaining baseplate for a front brace.

The eastern section of the XI.1 revetment had one baseplate 4998 (not sampled) with no evidence of reused material. At the junction of the two sections, 4999 was reused as a baseplate. It had originally been part of a house stud timber. In the eastern section the upright 4978 was sampled as were the planks pegged to the uprights (4676, 4895-7). A plank fragment 2651 and a top plate 2660 pegged to tenons on top of some of the uprights were also sampled. The final timber associated with the XI.1 revetment (3770) may have been a chopping block.

The phase XI.2 timber 4927 was one of a series of vertically set reused planks which were used to repair the gap between the period IX revetment and the period X extension. The phase XI.3 timbers 2837-8 were stray timbers on the surface of the main dump behind the XI.1 revetment. The phase XI.6 timber 3208 was a pile driven in to provide replacement bracing for the eastern section of the XI.1 revetment. In the western section, 3690 was also reused to replace the original XI.1 bracing (phase XI.7). Other XI.7 timbers (4146-7, 5453), found in front of the revetment, were of uncertain function.

The ten timbers from XI.8 were all from or associated with a timber drain. The drain was planked on the bottom and sides, and covered by a lid. It was supported crossways underneath the base by cradling timbers. Samples were taken from the lid (4956), east side (5181, 5210), west side (4959-60), base (5182, 5211) and cradling timbers (5142A/B).

The final five samples were 2722, possibly from period XIII, 2383 from XIV.1, 2491-2 from XIV.3, and 4603 from period XVII. (Approximately forty other tree-ring samples from Billingsgate were stored at Sheffield but since no information about them is available, they have been discarded.)

Methods

The samples were prepared by freezing them for at least 48 hours and then cleaning their cross-sections with a surform plane. The ring widths of those samples with more than 50 rings were measured on a travelling stage connected to an Apple II microcomputer (Hillam 1985, Fig 4). (Ring patterns with less than 50 rings are unlikely to be unique and might not produce reliable dates - see Hillam et al 1987 for further details.) The ring sequences were plotted as graphs using a graphing program on the Prime mainframe (Okasha 1987). The graphs were then compared with each other on a light box to check for any similarities between the ring patterns which might indicate contemporanity. For crossmatching purposes, the ring width data were also transferred to an Atari ST microcomputer with hard disk. The tree-ring software for the Atari was written and developed by Ian Tyers of the Museum of London. The

crossmatching routines are based on the Belfast CROS program (Baillie & Pilcher 1973; Munro 1984), and all the *t* values quoted in this report are identical to those produced by the first CROS program (Baillie & Pilcher 1973). Generally t values of 3.5 or above indicate a match provided that the visual match between the tree-ring graphs is acceptable (Baillie 1982, 82-5).

Dating is achieved by crossmatching ring sequences within a site or structure, combining the matching sequences into a site master, and then testing that master for similarity against dated reference chronologies. A site master is used for dating whenever possible because it enhances the general climatic signal at the expense of the background noise from the growth characteristics of the individual samples. Any unmatched sequences are tested individually against the reference chronologies. However since dated master curves made up from period IV-VII timbers, already exist for Billingsgate, the period VIII-XI sequences were first tested against these. Other reference chronologies which were frequently used were City Med (Hillam unpubl), Southwarkmed (Tyers pers comm), and Ref 6 (Fletcher 1977).

If a sample has bark or bark edge, the date of the last measured ring is the date in which the tree was felled. A complete outer ring indicates that the tree was felled during its dormant period in winter or early spring. This is referred to as "winter felled". If the ring is incomplete, felling took place during the growing season in late spring or summer (referred to as "summer felled"). In the absence of bark edge, felling dates are calculated using the sapwood estimate of 10-55 rings. This is the range of the 95% confidence limits for the number of sapwood rings in British oak trees over 30 years old (Hillam *et al* 1987). Where sapwood is absent, felling dates are given as *termini post quem* by adding 10 years, which represents the minimum number of missing sapwood rings, to the date of the last measured heartwood ring.

At this stage of the study, factors such as reuse, stockpiling, or repairs have also to be taken into account. Thus whilst the tree-ring dates for the

measured rings are precise and independent, the interpretation of these dates often requires other archaeological evidence.

Results

The results of the tree-ring analysis are described briefly phase by phase below. Details of the samples and the tree-ring dates are given in Table 1, and rough sketches of the cross-sections in figure 1. The results are also shown as bar diagrams in figures 2-4.

Period VIII

Phase VIII.1. Of the two mislabelled samples, 5293 remains undated and the ring sequence of 6009 dates to 905-1009, suggesting that the timber came from an earlier phase.

The stake 4192, possibly associated with a revetment, dates to 1073-1168 with a heartwood-sapwood transition dating to 1151. Using the 10-55 sapwood estimate, a probable felling date range of 1168-1205 is obtained.

Phase VIII.2. Thirteen samples were rejected, mostly because they had less than 50 rings. The measured samples had 46-211 rings. (5678 with 46 rings was measured because it had bark edge but it did not date.) Two of the samples (5669, 5670) were almost identical and their ring patterns could be crossmatched before measurement. They must have come from the same tree and therefore their ring widths were averaged so as not to bias any master chronology. This sequence plus ten others were dated (Fig 2).

5531B from the dump behind the revetment has a heartwood-sapwood transition dating to 1026. This gives a felling date of 1035-1080. Two uprights (5675, 6877) end in 1160 and 1164, and were felled after 1170 and 1174 respectively. Of the four dated horizontals, 5669/5670 from the same tree ended in 1182, giving a *terminus post quem* for felling of 1192; 5667 was felled after 1193, and 5742 with a heartwood-sapwood transition of 1185 was felled in the period 1194-1249. Two of the timbers found beside the baseplate were dated and both had sapwood. The pile 5724 ended in 1204 and had a sapwood transition of 1181.

This gives a felling date range of 1204-1235. The wedge 5723 ended in 1206 and 9 unmeasured rings were counted between the last measured ring and the bark edge, giving a felling date of 1215/1216. The same felling date was obtained for two of the reused structural timbers, 5725 and 5731. (The ring sequence of the latter ends in 1207 but an extra 8 rings were counted up to the bark edge.) The exact season of felling was difficult to determine for these timbers because the outer rings tended to be very narrow.

Period IX

The mislabelled 5754 was felled in about 1040, suggesting that it was probably a period IV timber. 2678B from IX.2 was rejected because it was very knotty, and the other IX.2 sample 2678A remains undated. 4571 from IX.1 was dated and had a heartwood-sapwood transition of 1160, giving a felling date range of 1169-1214.

Period X

Phase X.1. Two of the samples (4319, 4732) were rejected because of insufficient rings. The other three had 65-173 rings. 4731 remains undated but 4586 and 4729 end in 1175 and 1162, giving *termini post quem* for felling of 1185 and 1172 respectively.

Phase X.2. All the three X.2 samples had sapwood but 4759 was rejected and 5686 could not be dated. 5203 from the west wall of the central building had 12 sapwood rings and its heartwood-sapwood transition dates to 1197. Its probable felling date range is 1208-1251.

Phase X.4. 5630 was rejected because of insufficient rings. The remaining five samples had 53-12 rings. Two of the cladding planks (2646, 5631) dated although neither had sapwood. They ended in 1197 and 1153, and were therefore felled after 1207 and 1163 respectively.

Period XI

Phase XI.1. Thirteen samples were rejected either because they were knotty

(eg 2656) or because they had less than 50 rings (eg 2660).

Four of the conservation samples were dated (Hillam & Groves 1985). 6190 and 6191 were both X-rayed and successfully dated (Tyers 1985). 6190 ended in 1177 whilst 6191 had a sapwood transition of 1179. The latter therefore gives a felling date range of 1188-1233. The core from 6204 ends in 1142 and the small section from the timber with accession number 3269 ends in 1159.

Fourteen other samples were dated. The reused baseplate at the junction of the two sections of revetment had a possible heartwood-sapwood transition dating to 1152. This would give a probable felling date range of 1162-1207. From the western section, the upright 3301 had 27 sapwood rings and ended in 1211 at what was thought to be bark edge. The retaining pile 3875 ended in 1172 and was felled after 1182. Five of the fragments attached to the uprights above the primary cladding were dated. The only one with sapwood had a sapwood transition date of 1215 and ended in 1243. This produces a felling date range of 1243-1269. The other four samples end in 1100, 1154, 1165, and 1197, the *termini post quem* for felling being 10 years later in each case.

On the east side, the upright 4973 had bark edge and its outer ring dated to 1220. The timber was winter felled indicating that it was felled in 1220/1221. Three of the planks that were pegged to the eastern uprights were also dated. 4895 and 4897 ended in 1195 and 1201, giving *termini post quem* for felling of 1205 and 1211 respectively, whilst 4896 had a probable bark edge which dated to 1225. A plank fragment 2651 and a timber possibly used as underpinning (6039) ended in 1154 and 1168, and were therefore felled after 1164 and 1178.

In addition to these dated samples, a group of four ring sequences (2658, 2663, 2672, 2675) crossmatched each other to produce a single sequence of 170 years (Table 2). However they did not crossmatch any of the dated Billingsgate sequences or any reference chronology, and the 170 year sequence remains undated.

Phases XI.2, XI.3 and XI.6. The only measurable sample from this group was 2837. It has 98 heartwood rings and dated to 948-1045. It was therefore felled after 1055.

Sample 4927 from XI.2 was broken and unmeasurable, 2838 from XI.3 was knotty, and 3208 from XI.6 was a sample of beech (*Fagus sylvatica* L) with only 31 rings.

Phase XI.7. 5433 with 25 rings was rejected. 3690 and 4147 had 55 and 57 rings; 4146 had over 70 rings but they were very narrow. None of the three measured ring patterns could be dated.

Phase XI.8. The four samples from the base of the XI.8 drain were rejected. The lid 4956 had 70 heartwood rings with an average ring width of 4.2mm. The planks from the east and west sides of the drain had similar cross-sectional dimensions to 4956 but by contrast they had average ring widths of 0.9-1.2mm and therefore contained over 200 rings. (4960 contained a band of unmeasurable narrow rings and had to be measured in two sections - see 4960A and 4960B in Table 1). These five ring sequences from the sides of the drain crossmatched each other extremely well (Table 3), and it is possible that some, if not all, are from the same tree. Their ring widths were combined to give a single sequence of 293 years (Table 4). There is no similarity between it and the ring sequence from the lid. In addition, the drain master has been tested against all the tree-ring reference data available to the laboratories at Sheffield and London, including chronologies from other parts of Europe, but no reliable dating has been found.

Periods XIII-XVII

All the five samples from these later periods were rejected, either because they were knotty or they did not have enough rings.

The timbers

Since not all the excavated timbers were sampled for dendrochronology and the

excavated assemblage itself is only a small part of what must have been used at 13th century Billingsgate, this section is limited to a few general remarks. Many of the timbers from the XI.1 revetment, for example, were not sampled but kept instead for conservation and display.

As would be expected in an assemblage which includes timbers used for different purposes, the size, age and growth rate of the timbers was very variable. Since some of the phases are represented by only as few samples, the three largest groups are selected for discussion.

The 31 timbers from VIII.2 include ten, often with bark edge, which come from trees under about 50-60 years old when felled (Table 1). The trees would have been 200-250mm in diameter or less. Other timbers have been split into planks or hewn into shape from larger and older trees. 5731, for example, is a rectangular cross-section which has about 220 rings and comes from the outside of a tree well over 200 years old when felled.

The 37 timbers from the XI.1 revetment (excluding the four conservation samples for which the full cross-sections are not available) contain only four which come from 50-60 year old trees. The timbers were noted to be generally knotty and wavy-grained, reflecting the use of poor quality timber, especially compared to the timber used in the XI.8 drain or even the VIII.2 extension. Photographs of the many timbers which were not sampled confirm that the XI.1 revetment contains timber of very inferior quality.

Only eight timbers had sapwood (21.6%) as compared to fourteen timbers from the VIII.2 extension (45.2%). This might indicate that there was more reuse amongst the XI.1 timbers.

The ten timbers from the XI.8 drain fell into three groups. The four base timbers came from relatively small trees with less than 50-60 rings. The lid 4956 was of similar dimensions to the timbers used for the side planks but it came from a much faster grown tree. The side planks which were split tangentially, had cross-sectional dimensions of approximately 330x90mm. All

contained over 200 rings and none had sapwood or the centre rings. The trees (or tree) used to produce these planks would probably have been over 300 years old when felled with a diameter of 1m or more. The fact that the 293 year ring sequence from these planks does not date may indicate that the timber came from a different woodland source, perhaps some distance from the London area.

The chronology of periods VIII-XI

Phase VIII.1 is represented by only one dated timber which has a felling date range of 1168-1205. However, since this period represents new building activity across the site, this date must be later than that for the phase VII.13 timbers which were felled during 1172-1187. The modified felling date range for VIII.1 therefore becomes 1172-1205 (Table 5).

Three of the timbers from the VIII.2 revetment have bark edge and all were felled in 1215/1216. Five other timbers appear to be contemporary with them (Fig 2), leaving only 5675 and 6877 which could have been felled slightly earlier. Although some of the timbers were thought to be reused (eg 5725, 5731), the VIII.2 timbers seem to be a much more homogeneous group than the timbers from the XI.1 revetment, for example. 5723, 5725 and 5731 in particular match each other with t values greater than 8.0 and sometimes greater than 10.0, which suggests that they may be from the same tree. Tree-ring analysis therefore indicates a 1215/1216 felling date for the VIII.2 revetment with construction following soon afterwards.

The only IX.1 timber to be dated is 4571 which has a felling date range of 1169-1214 (Fig 3). The X.1 timbers from the dismantled IX.1 revetment however were felled after 1172 and 1185, which refines the IX.1 revetment date to 1185-1214. (Some of the timbers from the western section of the XI.1 revetment, for example, 3301 which was probably felled in 1211/1212, may also have been from the period IX revetment, which would place the construction date at the younger end of the felling range.) The tree-ring results therefore suggest that the period IX revetment is either broadly contemporary

with the VIII.2 revetment or slightly earlier in date.

The dated plank from the central building was felled during the period 1208-1251. Its heartwood-sapwood transition is 1197 which is the same as the last measured ring of 2641, one of the planks used as cladding in the X.4 extension of the VIII revetment. Although the felling date for this timber can only be quoted as a *terminus post quem* of 1207, it is possible that it is contemporary with the X.2 timber.

The tree-ring dates for the XI.1 revetment are complex (Fig 4). There are three timbers with bark edge. 3301, a reused upright from the western section, was probably felled in 1225; 4978, an upright from the eastern section, was felled in the winter of 1220/1221, and 4896, a plank pegged to an eastern upright was probably felled in 1225. However a reused fragment from the western section (3338) has a later felling date than any of these since it was felled some time during 1243-1269. The only other timbers with sapwood from IX.1 are 6191, a cladding timber, which has a felling date range of 1188-1233, and 4999, the reused baseplate at the junction of the two sections. The latter has a possible heartwood-sapwood transition of 1152, which would give a felling range of 1162-1207.

Since there was no evidence of reuse amongst the timbers from the eastern section, it is possible that the revetment was constructed during 1220-1225. Even then, there are at least two possible interpretations:

1. The revetment was constructed in or just after 1220/1221 as indicated by the date of the upright 4978, and repaired in 1225 when the planks were pegged to the upright.

2. The revetment was constructed in or just after 1225 incorporating reused or stockpiled timber.

Whichever interpretation is correct (if either), the felling date range of 1243-1269 for the "reused" timber 3338 from the western section indicates

that the revetment was probably repaired at least once. It is hoped that other archaeological evidence will help to clarify the tree-ring dates for this revetment.

Dendrochronological implications

Of the 116 samples submitted for analysis from periods VIII-XVII, 44 were rejected because they were unsuitable for dating, 39 were dated and 33 remain undated. This resulted in the production of a 247 year dated tree-ring chronology for the period AD997-1243 (Table 6). This master curve matches extremely well with other London chronologies (Table 7). It also gives high t values with reference chronologies from elsewhere in England. It will therefore be useful as a reference curve for dating timbers from other sites in England.

There are two undated master sequences. One is 170 years long and is from the XI.1 revetment; the other is 293 years long and is made up from five of the XI.8 drain sequences. The ring width data for these two curves are given in Tables 2 and 4. (The data from all the individual ring sequences are stored at the Sheffield Dendrochronology Laboratory where they can be consulted on request.) The lack of dating for these two sequences is unusual. The quantity of British Isles tree-ring data for the historic period is such that if a replicated tree-ring sequence can be produced, then there will normally be no problem in dating it. A possible explanation is that the timber came from outside the London area or from an environment where growth conditions were very different to those affecting the majority of the timber trees used at Billingsgate.

Conclusion

Although many of the samples were not dated, either because they were unsuitable for dating or because their ring sequence was undatable, the 39 dated samples have produced a 247 year chronology for the period AD997-1243. The individual tree-ring dates have provided a series of dates for the development of the Billingsgate waterfront during periods VIII-XI. This

chronology appears to be more complicated than that for the earlier periods. A date range of 1172-1205 is obtained for the VIII.1 dumps, and a felling date of 1215/1216 for the period VIII.2 revetment. The period IX revetment has a felling date range of 1185-1214. If some of these timbers were reused in the XI.1 revetment, it may be possible to refine this date to 1211/1212. The periods VIII.2 and IX revetments therefore may be broadly contemporary. A precise date is not available for the period X timbers. A date range of 1208-1251 was produced for X.2, and a *terminus post quem* of 1207 for X.4. The XI.1 revetment was built from inferior quality timbers, many of which were reused. This makes interpretation of the tree-ring results very difficult. The most likely interpretation is that the revetment was constructed around 1220-1225 and repaired at least once in 1243-1269. No date was obtained for the period XI.8 drain, although an undated chronology of 293 years was produced. The samples from periods XIII-XVII proved unsuitable for tree-ring dating.

Acknowledgements

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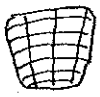
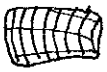
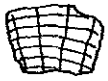
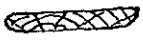
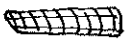
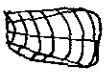
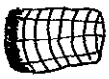
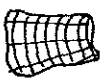
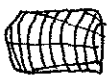
Fig 1: Sketches of cross-sections (not to scale)

Context	Sketch	Size
4192		110x65
5293		190x160
6009		165x120
5530		250x225
5531A		230x160
5531B		140x100
5531C		100x30
5606		85x85
5667		245x30
5669		230x40
5670		385x40
5673		175x40
5675		175x150
5676		170x165
5677		130x125
5678		180x175
5679		130x100

Context	Sketch	Size
5680		170x165
5683		210x180
5684		150x150
5711		120x90
5721		230x190
5723		130x35
5724		230x210
5725		125x90
5729		165x130
5731		180x120
5732		175x135
5735A		190x145
5735B		190x145
5736		230x185
5742		210x40
6470		100x70
6877		180x65

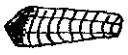
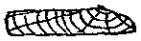
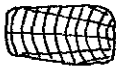
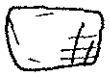
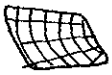
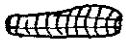
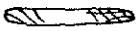
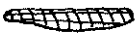
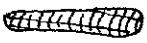
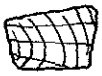
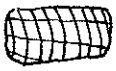
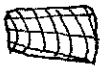
Context	Sketch	Size
4571		145x45
2678A		480x95
2678B		345x100
5754		110x55
4319		140x140
4586		205x35
4729		180x40
4731		250x65
4732		120x25
4759		170x65
5203		275x65
5686		305x110
2645A		210x180
2645B		210x190
2646		320x60
5630		150x35
5631		175x50

Fig 1: Sketches of cross-sections (not to scale)

Context	Sketch	Size
5633		180x35
2651		270x45
2656		275x100
2658		335x115
2659		245x45
2660		120x105
2663		300x85
2664		295x100
2668A		250x130
2668B		300x175
2672		120x120
2675		255x80
2683A		110x25
2683B		95x30
2686A		125x50
2686B		130x50
3301		265x75

Context	Sketch	Size
3338		85x80
3369		200x15
3381		200x20
3408		270x30
3560		290x130
3652		170x20
3770		100x100
3865		285x135
3866		250x135
3875		100x95
4676		190x75
4737		130x80
4895		205x45
4896		375x115
4897		190x25
4978		155x145
4999		175x55

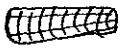
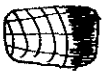
Context	Sketch	Size
5152		190x190
6039		150x40
6154		240x105
6156		180x170
2637		175x60
2638		195x65
3208		115x50
3690		145x80
4146		110x110
4147		115x85
5453		170x65
4956		310x45
4959A		325x85
4959B		320x90
4960A		360x100
4960B	-	360x100
5142A		175x95

Fig 1: Sketches of cross-sections (not to scale)

Context	Sketch	Size	Context	Sketch	Size	Context	Sketch	Size
5142B		105x70						
5181		360x90						
5182		175x50						
5210		355x90						
5211		215x45						
2722		115x75						
2383A		190x125						
2383B		120x35						
2492		150x80						
4603		470x115						

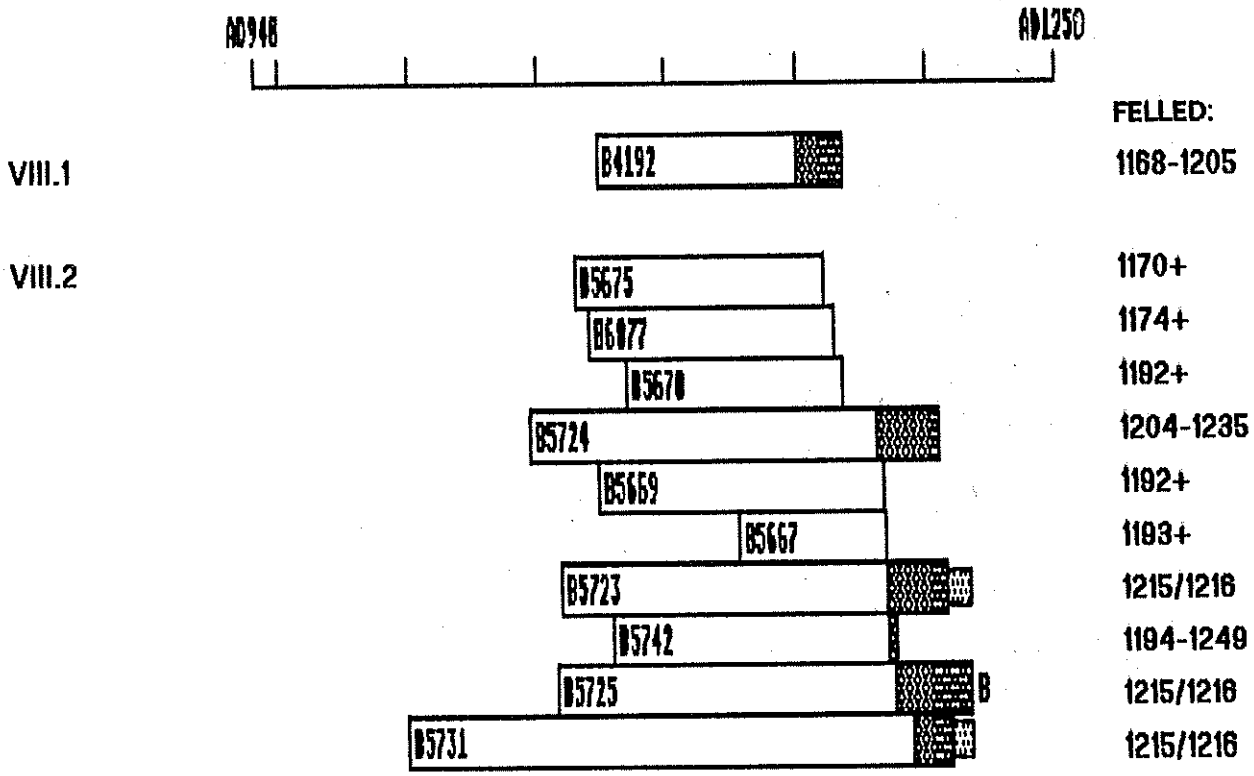


Figure 2: Bar diagram showing the relative positions of the period VIII ring sequences. White bars - heartwood rings; shaded bars - sapwood; B - bark edge.

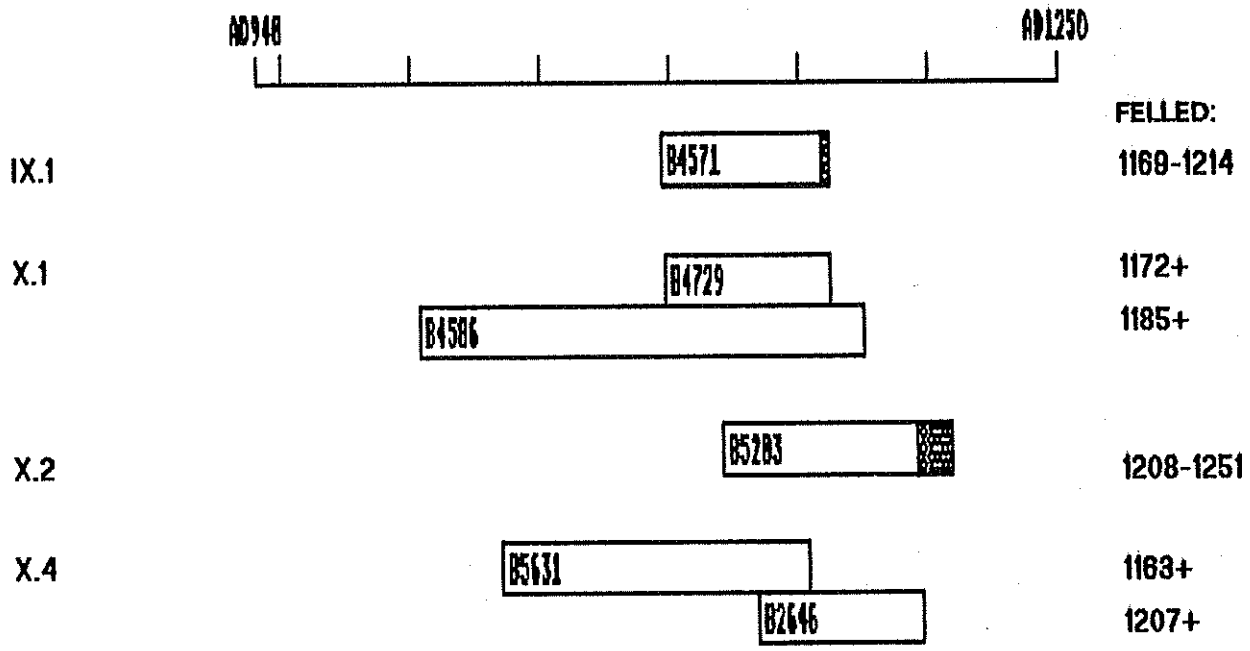


Figure 3: Bar diagram showing the relative positions of the ring sequences from periods IX and X.

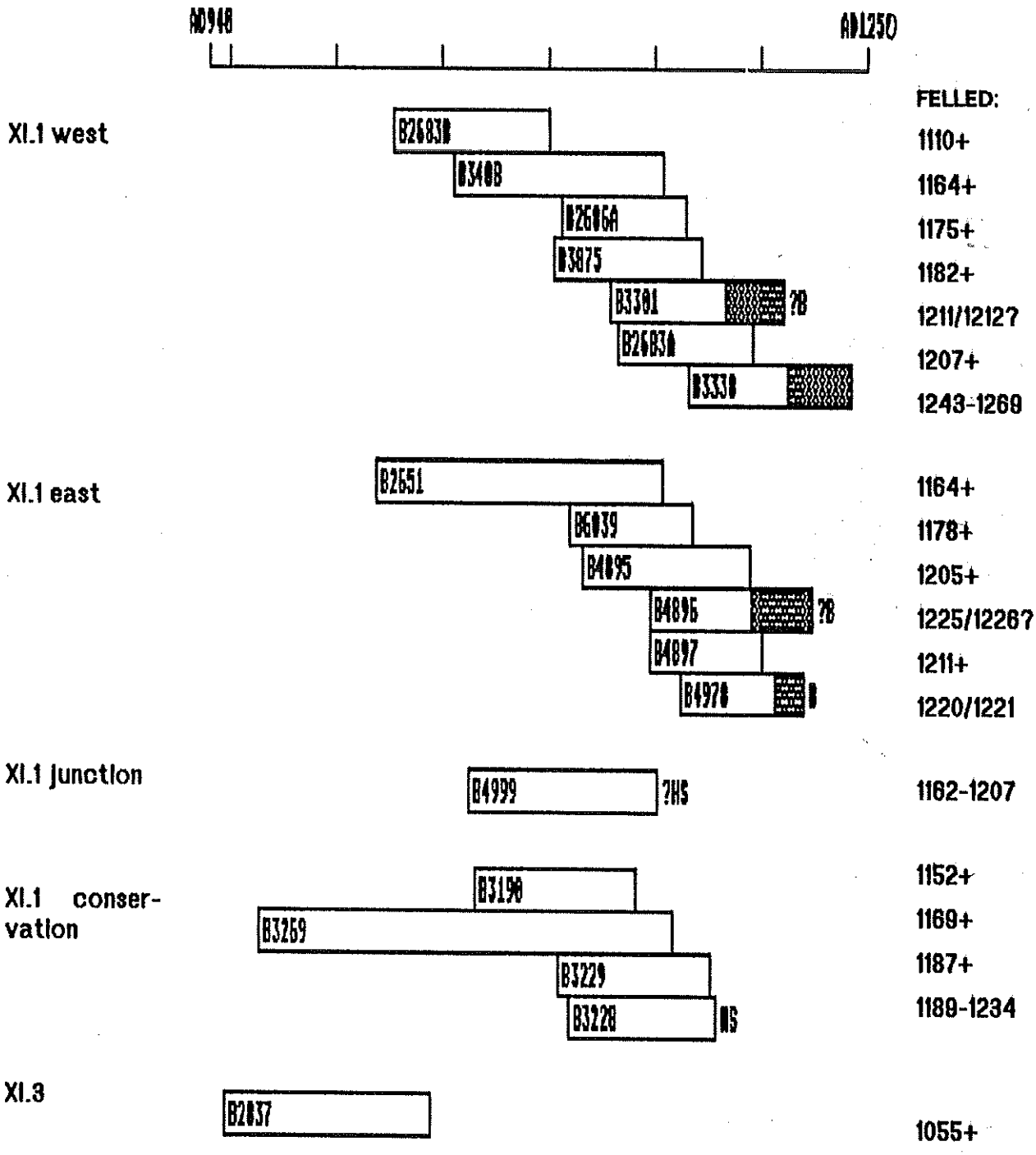


Figure 4: Bar diagram showing the relative positions of the period XI ring sequences.

Table 1: Details of the tree-ring samples. Dates of heartwood-sapwood transitions, if present, are given after the date span. Sketches of the cross-sections are given in fig 1.

CONTEXT	ACCN	PHASE	ACTION	TOTAL RINGS	SAPWD	AV. WIDTH (MM)	SIZE 1 (MM)	SIZE 2 (MM)	DATE SPAN (AD)	COMMENT
4192	3312	8.1	dated	96	18	1.22	110	65	1073-1168(1151)	
5293	4964	8.1	undated	74	0	2.26	190	160		
6009	4422	8.1	dated	105	0	1.54	165	120	905-1009	
5530	4371	8.2	reject	45	0		250	225		
5531A	4344	8.2	undated	82	0	1.81	230	160		
5531B	4345	8.2	dated	83	1	1.62	140	100	944-1026(1026)	
5531C	4512	8.2	undated	64	0	1.28	100	30		
5606	3316	8.2	reject	21	9		85	85		bark edge?
5667	4605	8.2	dated	58	0	2.04	245	30	1126-1183	
5669	4525	8.2	dated	111	0	1.9	230	40	1072-1182	same tree as 5670
5670	4717	8.2	dated	85	0	1.88	385	40	1083-1167	
5673	4333	8.2	reject	48	0		175	40		
5675	4960	8.2	dated	97	0	1.08	175	150	1064-1160	
5676	4986	8.2	reject	33	10		170	165		
5677	4524	8.2	reject	42	6		130	125		
5678	4662	8.2	undated	46	13	2.94	180	175		bark edge?
5679	4660	8.2	reject	41	16		130	100		bark edge?
5680	3320	8.2	reject	27	8		170	165		
5683	3322	8.2	reject	29	11		210	180		
5684	4347	8.2	reject	41	9		150	150		
5711	4388	8.2	reject	28	0		120	90		
5721	4642	8.2	reject	0	0		230	190		knotty
5723	4532	8.2	dated	150	23	.85	130	35	1057-1206(1184)	c9 rings to bark
5724	4805	8.2	dated	159	24	.83	230	210	1046-1204(1181)	near bark edge?
5725	4712	8.2	dated	161	29	.7	125	90	1055-1215(1192)	bark edge?
5729	4918	8.2	reject	35	0		165	130		knotty; bark edge?
5731	4545	8.2	dated	211	15	.81	180	120	997-1207(1195)	c8 rings to BE
5732	4714	8.2	undated	53	16	2.13	175	135		
5735A	4521	8.2	undated	123	0	1.11	190	145		knotty
5735B	4582	8.2	reject	43	0		190	145		
5736	4035	8.2	undated	97	0	1.68	230	185		
5742	4040	8.2	dated	111	3	1.8	210	40	1077-1187(1185)	
6470	4272	8.2	undated	83	0	1.1	100	70		knotty
6877	4934	8.2	dated	96	0	1.64	180	65	1069-1164	bad condition; + ?sapwood
4571	4529	9.1	dated	66	3	1.03	145	45	1097-1162(1160)	
2678A	4343	9.2	undated	62	0	6.79	480	95		+ c57 narrow rings
2678B	4472	9.2	reject	0	0		345	100		knotty
5754	4391	9.3	dated	67	2	1.17	110	55	963-1029(1028)	+ c11 rings to bark
4319	4338	10.1	reject	39	12		140	140		
4586	4500	10.1	dated	173	0	1.11	205	35	1003-1175	
4729	4552	10.1	dated	65	0	1.18	180	40	1098-1162	
4731	4573	10.1	undated	67	0	2.39	250	65		
4732	4499	10.1	reject	39	0		120	25		
4759	4342	10.2	reject	45	13		170	65		
5203	4497	10.2	dated	89	12	2.9	275	65	1120-1208(1197)	
5686	5612	10.2	undated	72	12	4.11	305	110		bark edge
2645A	4387	10.4	undated	53	1	2.27	210	180		
2645B	4715	10.4	undated	66	21	2.27	210	190		
2646	4621	10.4	dated	65	0	2.49	320	60	1133-1197	knotty
5630	3369	10.4	reject	28	0		150	35		
5631	4611	10.4	dated	120	0	1.36	175	50	1034-1153	
5633	4795	10.4	undated	94	0	1.53	180	35		
2651	4303	11.1	dated	136	0	1.97	270	45	1019-1154	
2656	4477	11.1	reject	0	0		275	100		
2658	4558	11.1	undated	170	0	1.88	335	115		
2659	4554	11.1	undated	55	0	2.37	245	45		
2660	4290	11.1	reject	24	0		120	105		
2663	4622	11.1	undated	57	0	1.91	300	85		
2664	4553	11.1	undated	67	0	2.28	295	100		HS?

2668A	4575	11.1	reject	0	0		250	130		knotty
2668B	4951	11.1	reject	0	0		300	175		knotty
2672	4530	11.1	undated	55	0	2.47	120	120		
2675	4551	11.1	undated	81	0	2.03	255	80		
2683A	4538	11.1	dated	65	0	1.66	110	25	1133-1197	
2683B	4627	11.1	dated	74	0	1.26	95	30	1027-1100	
2686A	4501	11.1	dated	60	0	1.99	125	50	1106-1165	
2686B	4511	11.1	reject	0	0		130	50		knotty
3301	3321	11.1	dated	83	27	1.48	265	75	1127-1211(1185)	sapwood = 24-30; bark edge?
3338	4515	11.1	dated	78	29	.75	85	80	1166-1243(1215)	
3369	3311	11.1	reject	0	0		200	15		knotty
3381	4486	11.1	reject	40	0		200	20		
3408	4570	11.1	dated	100	0	1.43	270	30	1155-1154	inner third not measd
3560	4513	11.1	undated	51	0	2.8	290	130		
3652	4526	11.1	undated	57	0	2.77	170	20		
3770	4488	11.1	undated	60	12	1.79	100	100		
3865	3270	11.1	reject	47	0		285	135		
3866	4716	11.1	reject	0	0		250	135		knotty
3875	4386	11.1	dated	71	0	1.36	100	95	1102-1172	
4676	4514	11.1	undated	109	0	1.65	190	75		last 35 = sapwood; +10 rings
4737	4566	11.1	reject	46	0		130	60		
4895	4713	11.1	dated	80	0	2.38	205	45	1116-1195	
4896	4518	11.1	dated	78	28	1.57	375	115	1148-1225(1198)	knotty; bark edge?
4897	4489	11.1	dated	54	0	2.98	190	25	1148-1201	
4978	4469	11.1	dated	59	13	1.85	155	145	1162-1220(1208)	felled winter
4999	3318	11.1	dated	90	0	1.85	175	55	1063-1152(1152?)	HS? errors in last decade?
5152	3315	11.1	reject	28	10		190	190		felled summer
6039	4052	11.1	dated	59	0	2.39	150	40	110-1168	
6154	4395	11.1	reject	29	6		240	105		felled winter
6156	4368	11.1	reject	30	4		180	170		
6190	3229	11.1	dated	73	0				1105-1177	X-ray
6191	3228	11.1	dated	70	1				1110-1179(1179)	X-ray
6204	3190	11.1	dated	77	0	1.37			1066-1142	core
	3269	11.1	dated	196	0	1.2			964-1159	end
4927	4468	11.2	reject	0	0		0	0		
2837	4531	11.3	dated	98	0	1.66	175	60	948-1045	
2838	4616	11.3	reject	0	0		195	65		knotty
3208	4495	11.6	reject	31	0		115	50		
3690	4548	11.7	undated	55	0	2.56	145	80		
4146	4549	11.7	undated	70	45	.67	110	110		HS very variable; + c15 rings
4147	4581	11.7	undated	57	45	1	115	85		bark edge?
5453	4663	11.7	reject	25	9		170	65		
4956	4519	11.8	undated	70	0	4.17	310	45		
4959A	4550	11.8	undated	243	0	1.01	325	85		nr HS?
4959B	4569	11.8	undated	236	3	.85	320	90		
4960A	3324	11.8	undated	150	0		360	100		+ inner rings; c40 to 4960B
4960B	3324	11.8	undated	45	0		360	100		
5142A	4878	11.8	reject	0	0		175	95		knotty
5142B	4962	11.8	reject	0	0		105	70		bark edge
5181	3317	11.8	undated	246	0	.82	360	90		
5182	4527	11.8	reject	40	14		175	50		
5210	4510	11.8	undated	251	0	1.16	355	90		
5211	4711	11.8	reject	30	0		215	45		
2722	4228	13	reject	26	10		115	75		
2383A		14.1	reject	0	0		190	125		knotty
2383B	4485	14.1	reject	45	0		120	35		
2492	4304	14.3	reject	29	17		150	80		bark edge?
4603	4509	17	reject	0	0		470	115		knotty

Table 2: Ring width data for the undated chronology made up from 2658, 2663, 2672 and 2675 from phase XI.1. (Crossmatching within the group gives t values of 5.0 to 7.1.)

years	ring widths (0.02mm)										no. of samples									
1	336	293	158	245	175	188	169	213	159	219	1	1	1	1	1	1	1	1	1	1
	146	99	140	120	214	126	142	106	124	129	3	3	3	3	3	3	3	3	3	3
	96	128	76	95	129	105	162	120	166	125	3	3	3	3	3	3	3	3	3	3
	119	157	146	191	109	113	114	81	96	122	3	3	3	3	3	3	3	3	3	3
	140	134	142	109	78	116	121	110	112	93	3	3	3	3	3	3	3	3	3	3
51	74	76	88	75	106	111	84	63	98	94	3	3	3	3	3	3	3	3	3	3
	104	122	96	76	79	99	67	72	92	84	3	3	3	3	3	2	2	2	2	2
	131	142	96	71	59	51	58	123	120	120	2	2	2	2	2	2	2	2	2	3
	154	138	165	124	112	130	85	80	137	94	3	3	3	3	3	3	3	3	3	3
	121	119	126	114	120	74	62	58	99	109	3	2	2	2	2	2	2	2	2	2
101	102	95	80	68	60	73	89	113	77	68	2	2	2	2	2	2	2	2	2	2
	67	65	54	59	59	88	97	86	65	81	2	2	2	2	2	2	2	2	2	2
	76	70	54	73	78	67	65	76	78	76	2	2	2	2	2	2	2	2	2	2
	67	55	66	64	71	71	42	50	60	53	2	2	2	2	2	2	1	1	1	1
	56	57	49	50	49	46	45	52	65	44	1	1	1	1	1	1	1	1	1	1
151	57	51	50	41	52	46	38	47	59	60	1	1	1	1	1	1	1	1	1	1
	50	46	50	31	52	44	29	62	61	62	1	1	1	1	1	1	1	1	1	1

Table 3: t value matrix for the matching sequences from the XI.8 drain. (The inner part of 4960 is only 45 years long and is not included.)

	4959A	4959B	4960A	5181	5280
4959A	x	13.0	6.8	9.0	9.5
4959B		x	6.8	11.5	7.9
4960A			x	8.1	6.2
5181				x	7.1
5280					x

Table 4: The undated chronology from the Billingsgate XI.8 drain.

years	ring widths (0.02mm)										no. of samples									
1	252	334	262	275	241	188	134	186	146	242	1	1	1	1	1	1	1	1	1	1
	243	265	228	166	210	208	222	191	198	112	1	1	1	1	1	1	1	1	1	1
	157	121	73	107	106	96	130	89	102	80	1	1	1	1	1	1	1	1	2	2
	104	114	119	80	81	75	67	92	97	104	2	3	3	3	3	3	3	3	3	3
	131	92	91	122	83	119	88	131	100	115	3	3	3	3	3	4	4	4	4	4
51	108	92	63	108	109	110	86	51	55	57	4	4	4	4	4	4	4	4	4	4
	67	40	68	56	77	69	55	74	77	72	4	4	4	4	4	4	4	4	4	4
	80	79	78	68	90	91	71	85	67	59	4	4	4	4	4	4	4	4	4	4
	67	68	62	54	51	59	58	62	46	56	4	4	4	4	4	4	4	4	4	4
	66	52	48	59	56	44	35	54	47	48	4	4	4	4	4	4	4	4	4	4
101	47	54	56	44	53	52	55	54	56	57	4	4	4	4	4	4	4	4	4	4
	57	49	47	39	63	38	51	41	56	49	4	4	4	4	4	4	4	4	4	4
	56	41	39	30	43	43	48	36	51	44	4	4	4	4	4	4	4	4	4	4
	44	51	35	57	50	56	45	42	36	35	4	4	4	4	4	4	4	4	4	4
	27	51	43	37	41	41	41	28	45	29	4	4	4	4	4	4	4	4	4	4
151	35	27	34	29	39	27	44	31	38	28	4	4	4	4	4	4	4	4	4	4
	28	35	29	35	29	34	34	38	29	28	4	4	4	4	4	4	4	4	4	4
	34	30	28	24	32	31	31	28	22	26	4	4	4	4	4	4	4	4	3	3
	25	18	20	19	20	19	19	22	17	21	3	3	3	3	3	3	3	3	3	3
	22	26	19	22	21	22	20	18	22	19	3	3	3	3	3	3	3	3	3	3
201	25	21	26	22	21	29	25	24	25	25	3	3	3	3	3	3	3	3	3	3
	29	20	23	19	25	23	20	25	18	22	3	3	3	3	3	3	3	3	3	3
	22	22	22	26	27	23	20	22	31	24	3	3	3	3	3	3	3	3	3	3
	34	28	23	30	22	45	42	31	38	42	3	3	3	3	3	3	3	3	3	3
	48	31	67	32	43	29	43	45	23	41	3	3	3	3	3	3	3	3	3	3
251	33	47	32	50	23	46	30	47	34	47	3	2	2	2	2	2	2	2	2	2
	37	42	41	31	44	40	48	55	51	45	2	2	2	2	2	2	2	2	2	2
	49	61	29	61	61	53	55	44	53	40	2	2	2	2	2	2	2	1	1	1
	78	45	61	50	59	41	55	43	55	41	1	1	1	1	1	1	1	1	1	1
	55	43	51								1	1	1							

Table 5: The chronology of the Billingsgate waterfront during periods VIII-XI as indicated by the tree-ring dates.

phase	context	date
VIII.1	dumps	1172-1205
VIII.2	N-S front-braced revetment	1215/1216
IX.1	revetment	1185-1214 (1211/1212?)
X.1	dismantled revetment	1185+
X.2	central building	1208-1251
X.4	extension to VIII.2 revetment	1207+
XI.1	E-W front-braced revetment - construction - repair	1220-1225 1243-1269
XI.3	dump behind XI.1 revetment	1055+
XI.8	drain behind XI.1 revetment	no date

Table 6: The Billingsgate period VIII-XI tree-ring chronology, AD997-1243; data from 31 samples are included.

years	ring widths (0.02mm)										no. of samples									
AD997							105	126	179	118							1	1	1	1
AD1001	93	106	88	132	99	113	134	114	98	73	1	1	2	2	2	2	2	2	2	2
	90	96	82	57	74	46	49	47	74	71	2	2	2	2	2	2	2	2	3	3
	121	137	152	91	54	75	77	62	67	96	3	3	3	3	3	3	4	4	4	4
	81	55	71	59	75	58	91	62	63	62	4	4	4	5	5	5	5	5	5	5
	63	69	81	68	77	66	80	53	61	38	5	5	5	5	5	6	6	6	6	6
AD1051	56	70	57	47	69	62	49	66	57	54	6	6	6	6	8	8	9	9	9	9
	56	60	80	73	67	69	77	86	70	60	9	9	10	11	11	11	11	11	12	12
	60	70	84	84	77	88	78	83	92	84	12	13	14	14	14	14	15	15	15	15
	62	88	104	79	99	101	68	69	78	64	15	15	16	16	16	16	16	16	16	16
	66	87	88	71	73	76	79	81	69	81	16	16	16	16	16	16	17	18	18	18
AD1101	55	53	73	68	62	61	64	70	76	60	17	18	18	18	18	19	19	19	19	20
	65	59	68	67	80	74	73	78	72	78	20	20	20	20	20	21	21	21	21	22
	60	77	84	98	77	60	63	75	70	83	22	22	22	22	22	23	23	23	24	24
	73	76	74	85	87	67	53	66	60	99	24	24	26	26	26	26	26	26	26	26
	83	66	61	72	82	76	68	85	102	82	26	26	26	26	26	26	26	28	28	28
AD1151	79	63	98	87	87	101	88	77	93	103	28	28	27	26	24	24	24	24	24	24
	92	87	81	104	96	88	81	86	115	82	23	24	22	22	21	21	21	20	18	18
	94	77	77	84	79	72	54	71	85	61	18	18	17	17	17	16	16	16	16	16
	68	86	88	52	70	70	78	45	47	62	16	16	15	14	14	14	14	13	13	13
	52	46	96	65	75	85	72	72	62	65	13	13	13	13	13	12	12	10	10	10
AD1201	78	59	76	51	52	50	49	79	43	52	10	9	9	9	8	8	7	6	5	5
	40	40	41	36	44	67	48	43	47	50	5	4	4	4	4	3	3	3	3	3
	47	31	42	46	33	48	15	33	56	40	2	2	2	2	2	1	1	1	1	1
	48	23	34	32	30	21	32	27	25	22	1	1	1	1	1	1	1	1	1	1
	23	25	19								1	1	1							

Table 7: Dating the chronology from periods VIII-XI. *t* values with a selection of dated reference chronologies from London and elsewhere in England.

chronology	*t* value
Beverley, Eastgate (Groves 1987)	7.9
Bristol, Dundas Wharf (Nicholson & Hillam 1988)	7.2
Carlisle (Baillie & Pilcher pers comm)	5.0
Droitwich, Upwich 2 (Groves & Hillam 1990)	9.2
East Midlands (Laxton & Litton 1988)	8.9
England (Baillie & Pilcher pers comm)	11.0
London: Billingsgate periods IV-VII (Hillam unpubl)	11.4
Fennings Wharf (Tyers pers comm)	15.1
Merton Priory (Tyers pers comm)	10.3
Seal House (Hillam unpubl)	14.2
Swan Lane (Groves & Hillam 1987)	11.2