CCA Report 13

June 2013

Dendrochronological analysis of samples from timbers and cargo from the Vasa, Stockholm, Sweden – a case study

Chronology, Culture and Archaeology

MARIE CURIE ACTIONS

UCD DUBLIN

CCA report 13 (June 2013)
Dendrochronological analysis of samples from timbers and cargo from the *Vasa*, Stockholm, Sweden – a case study.

Aoife Daly, Ph.D.

Marie Curie funded project: Chronology, Culture and Archaeology, based at the School of Archaeology, University College Dublin. The main theme of the project is the analysis of short tree-ring sequences but other themes are also addressed, namely maritime timber, digital data sharing and non-destructive analysis. The analysis described in this report is within the maritime timber theme, and is in collaboration with Fred Hocker, The Vasa Museum, Swedish National Maritime Museums, Sweden. In the interest of access to data and to enable researchers to utilise this material in the future, all measurements will be submitted to the Digital Collaboratory for Cultural Dendrochronology (DCCD, www.dendrochronology.eu).

A case study of a very small portion of barrel staves and timbers from *Vasa* was carried out in spring 2013. This was with a view to demonstrating the potential for information about wood procurement that an extensive dendrochronological analysis might produce, of the already firmly dated *Vasa*. *Vasa*, built in Stockholm in 1626-1628, sank in Stockholm harbour the first time she set sail (Cederlund & Hocker 2006). The ship was raised in 1961 and is now housed in the custom-built Vasa Museum. Historical records show that timber for the ship was purchased in Riga, Königsberg (Kaliningrad), Amsterdam and Småland and Uppland (south and northwest of Stockholm respectively) (Cederlund 1966, Hocker 2011, 41-42). Timbers for *Vasa* can have therefore grown in a wide variety of geographic locations throughout Northern Europe. Likewise, barrels from the ship's cargo might indicate the source of the material they contained. For this case study priority was given to analysis of a small selection of barrel staves, one of *Pinus sp*., pine and the remainder of *Quercus sp*., oak. This was in light of a new archaeological study of the *Vasa* barrels that has recently been completed (Ratcliffe 2012). However, as pieces of some oak timbers from the actual ship were also readily available (they had been extracted during the opening of ventilation holes in the hull to control humidity levels in the ship) these were also included in the study.

Planks Group 1	Z092002a	Z092001a	Z092003a
Z092002a	*	7,46	\
Z092001a	7,46	*	11,04
Z092003a	\	11,04	*

Planks Group 2	Z092004a	Z0920059
Z092004a	*	5,38
Z0920059	5,38	*

Table 1. The table shows the correlation, at their cross-matched position, between the tree-ring curves from the ship planks from *Vasa*. Two separate groups have thus been identified.

Measuring

All samples were taken from the objects by sawing, chiefly from staves that were already in an incomplete state. The sawn samples were prepared along the transverse section, making all preserved tree-rings clearly visible. The ring widths were then measured using a Leica stereo microscope and a measuring table designed by Ian Tyers at the University of Sheffield. For calculation of the t-value (”t-test”) ”CROS” (Baillie & Pilcher, 1973) was used, embedded in the program ”DENDRO” (Tyers, 1997).

Results

Ship timbers

Five ship timbers are analysed in this case study. They are all from planking in the hull, and were removed to make ventilation holes in the ship. Three are from the starboard side, while two are from the port side of the ship. The tree-ring curves from these planks show that they form two distinct groups. Group 1 consists of three of the planks, two from starboard, one from port side (see fig. 1, table 1 and catalogue). The two from the starboard side 23804 (Z092003A) and 23801 (Z092001A) might be from one and the same plank, as the samples are taken where the ventilation holes have coincidentally been cut, and this possibility needs to be confirmed. The tree-ring curves from these two show a very high correlation between each other, but it cannot be said with certainty, from the dendrochronological analysis alone, that these are indeed the same tree (the visual comparison shows that these diverge slightly from each other). The mean curve, formed from averaging the tree-ring widths from the three samples (Z092M001) is 215 years in length. The second group consists of the remaining two planks, and its mean curve (Z092M002, group 2) is just 94 years in length. No significant correlation between these two groups appears, so this might indicate that these two timber groups are from two distinct geographical sources.

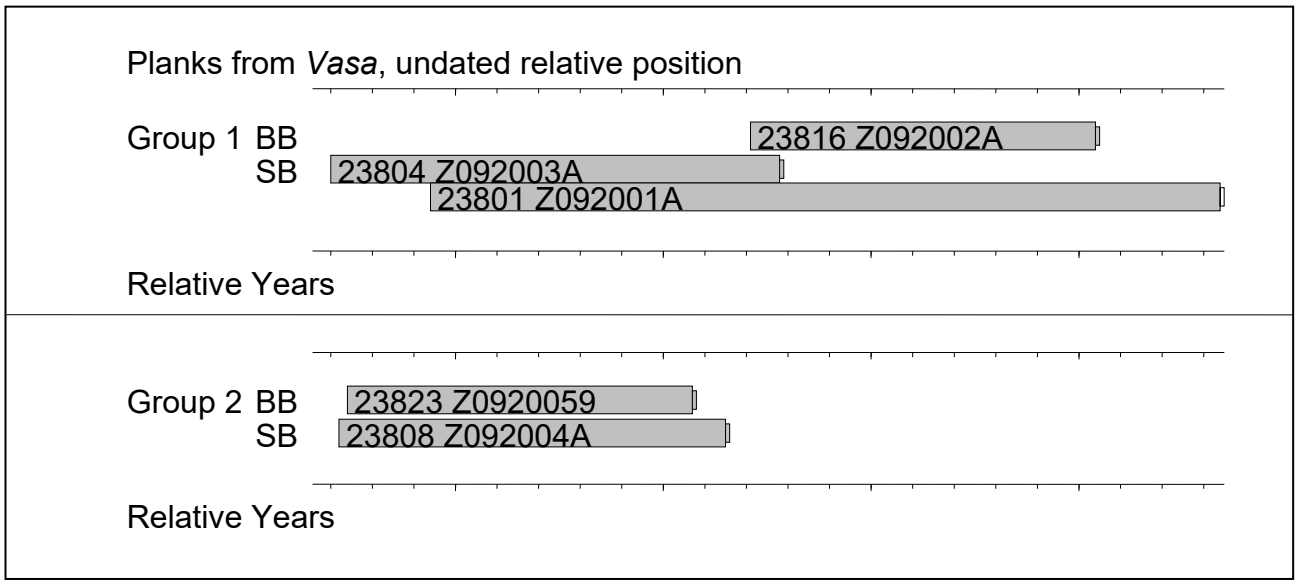

Fig. 1. The diagram shows the relative position of the tree-ring curves from the ship timbers. Two groups are identified, but no significant correlation between the groups has emerged.

In spite of attempts to find correlation for the tree-ring curves from the ship timbers through comparison with a large network of site and master chronologies covering a wide Northern European geographical region, these samples are not yet dated. There can be several reasons for this. One is that in spite of the extensive network of tree-ring data that exists for oak for Northern Europe, chronologies for the region, where the trees used for these planks grew, might not be fully developed for the period which they cover. On the other hand, the number of samples is very few. As the five planks form two groups, and the material produces averages with a depth of only two trees (see fig. 1), the replication is very low. It is always more difficult to date single or low numbers of samples, as the individual growth of the trees can mask the regional climate signal, which is the requirement for successful dating. Given that the timbers for building *Vasa* were collected from many sources throughout Northern Europe, a more extensive dendrochronological analysis will be necessary to unravel the complicated story of the timber procurement for the ship.

Barrels

A total of 17 staves from barrels from the ship were selected for analysis (fig. 5). As mentioned above, one stave is pine while the remainder are oak. For this small case study incompletely preserved staves made from slow-grown trees were prioritised. This was, on the one hand, to minimise damage to fully preserved objects while maximising the number of tree-rings the object contained, thus increasing the possibility for dating this potentially diverse material. Fourteen of the barrels staves can currently be dated. The correlation results in this analysis suggest several groupings and these are therefore described individually.

		Z093003A	Z093011A	Z093001A	Z093005A	Z093010A	Z093012A	Z093004A	Z093016a	Z093015a	Z093017a	Z0930149	Z093006A	Z093007A	Z093002A
	Z093003A	*	2.77	1.81	\	1.55	1.37	-	\	\	0.86	\	\	\	\
Gr. 5 Z093 M003	Z093011A	2.77	*	3.17	1.24	2.69	0.27	0.59	1.77	1.39	1.1	1.47	2.3	0.53	-
	Z093001A	1.81	3.17	*	\	1.57	0.37	1.68	0.92	1.28	0.86	2.12	1.96	2.26	1.35
Group 3 Z093M001	Z093005A	\	1.24	\	*	\	\	\	\	\	2.45	\	\	\	\
	Z093010A	1.55	2.69	1.57	\	*	2.44	0.62	\	\	3.45	1.46	\	\	0.08
	Z093012A	1.37	0.27	0.37	\	2.44	*	2.9	\	\	3.98	1.47	\	\	-
	Z093004A	-	0.59	1.68	\	0.62	2.9	*	5.22	4.18	4.51	0.08	1.75	1.7	1.28
	Z093016a	\	1.77	0.92	\	\	\	5.22	*	10.53	5.34	3.33	0.56	2.96	2.03
	Z093015a	\	1.39	1.28	\	\	\	4.18	10.53	*	6.94	3.32	0.13	2.77	2.34
	Z093017a	0.86	1.1	0.86	2.45	3.45	3.98	4.51	5.34	6.94	*	2.61	0.23	2.05	1.75
Group 4 Z093M002	Z0930149	\	1.47	2.12	\	1.46	1.47	0.08	3.33	3.32	2.61	*	0.75	1.27	0.71
	Z093006A	\	2.3	1.96	\	\	\	1.75	0.56	0.13	0.23	0.75	*	4.01	2.31
	Z093007A	\	0.53	2.26	\	\	\	1.7	2.96	2.77	2.05	1.27	4.01	*	2.01
	Z093002A	\	-	1.35	\	0.08	-	1.28	2.03	2.34	1.75	0.71	2.31	2.01	*

Table 2. The correlation (t-value) between the tree-ring curves from the dated barrel staves from *Vasa*. The grey tone highlights the high t-values. (The symbols \ = overlap less than 30 rings and - = t-value less than 0.00)

The main group (group 3)

Seven staves form the main group of barrel staves. Three of these are from a single barrel that was used for transport and storage of gunpowder (Fred Hocker pers comm.). Highly significant correlation appears between the tree-ring curves of the three gunpowder barrel staves. Through statistical and visual comparison with each other and with a range of chronologies, the tree-ring curves from four other oak staves can be added to this group (table 2). The tree-ring curves from all seven staves are averaged to form a mean curve (Z093M001, group 3) of 195 years in length. The mean curve covers the period AD 1420-1614 and as shown in table 3 achieves high correlation with site and master chronologies for Northern Germany, and highest with a chronology built from historical timbers from Lübeck (built at Hamburg University). Given the high internal agreement between the tree-ring curves from the three staves from the gunpowder barrel, it could be suggested that the barrel itself, as opposed to the timber raw product, was an imported item. There is reference in Swedish records that empty casks were bought for kitting ships, and the gunpowder barrels are larger than the other oak barrels in *Vasa* (Fred Hocker pers comm.), so these might be a specialised product from the Lübeck region.

Filenames	-	-	**Z093M001**	
-	start	dates	AD1420	
-	dates	End	AD1614	
Chronologies				
DM100008	AD457	AD1723	**12,50**	Lübeck (Hamburg University)
DM100007	AD1080	AD1967	8,77	Hamburg (Hamburg University)
DM200005	AD915	AD1873	7,90	Niedersachsen, Nord (Göttingen University)
DM100003	AD436	AD1968	7,74	Schleswig-Holstein (Hamburg University)
DM200006	AD914	AD1873	7,74	Lüneburger Heide (Göttingen University)
9M456781	109BC	AD1986	6,54	Jylland/Fyn (National Museum of Denmark)
ZEALAND0	AD452	AD1770	6,44	Zealand, Denmark (Daly unpubl.)
Ships				
Z0442M02	AD1412	AD1628	**9,35**	Kanonvraget Fehmern (Daly 2013 unpublished)
Z043M002	AD1394	AD1589	7,80	FPL 77 4AM wreck (Daly 2011)

Table 3. The results of the calculation of correlation between the mean curve (Z093M001) from a group of seven barrel staves from *Vasa* (group 3) and a diverse selection of site and master chronologies are shown. The source of the chronologies is given. The grey tone highlights the high t-values.

Group 4

A slightly smaller group of the barrel staves can also be identified. These are all oak and though they do not have a very high internal correlation, they all are dating with Scandinavian datasets. The tree-ring curves for the four (see table 2) are therefore averaged to form a mean curve (Z093M002) which is 111 years long. The correlation values achieved between this mean curve and diverse site and master chronologies for Northern Europe is shown in table 4. While it is clear that the group is dating against Norwegian and Swedish datasets, the values are not high enough to allow a confident statement on the provenance of the trees forming this group (see discussion of the parameters for confident provenance determination in Daly (2007b). Knowing that *Vasa* was built in Stockholm harbour, it is of course not unlikely that oaks from the eastern Swedish region were used in the manufacture of both the ship and some of the barrels in her cargo. These barrel staves assigned to group 4 could conceivably represent material from Eastern Sweden, for which chronologies for oak from the period are not available.

Filenames	-	-	Z093M002	
-	start	dates	AD1454	
-	dates	end	AD1564	
Chronologies				
Snorwayships	AD1304	AD1895	5,04	South Norway ships 63 timber mean (Daly unpubl.)
ZEALAND0	AD452	AD1770	4,84	Zealand, Denmark (Daly unpubl.)
SM000012	AD1125	AD1720	4,78	Sverige Vest (Bråthen 1982)
4077M001	AD1310	AD1540	4,47	Nyborg slot (Daly 1999)
Ships				
Z065M003	AD1355	AD1617	5,22	Bjørvika ship 'Kenneth' Oslo (Daly 2011c)
Z0309M01	AD1395	AD1561	4,93	Barcode ship BC09 (Daly 2010)
00652M02	AD1405	AD1607	4,89	B&W vrag 2 (2 timbers) (Daly 2000)
Z071m004	AD1304	AD1595	4,70	Barcode ship 08 (Daly 2011d)
Z0302&7	AD1429	AD1587	4,64	barcode ships BC02 & BC07 (Daly unpubl)
Scandinavian timber in Scotland				
EP41592	AD1390	AD1592	5,02	Stirling Castle Scotland imported timbers (Episode 4) (Crone 2008)
EP31539	AD1361	AD1539	4,84	Stirling Castle Scotland 15 imported timbers (Episode 3) (Crone 2008)

Table 4. The results of the calculation of correlation between the mean curve (Z093M002) from a group of four barrel staves from *Vasa* (group 4) and a diverse selection of site and master chronologies are shown. The source of the chronologies is given. The grey tone highlights the high t-values.

Two staves, group 5

Of the remaining three dated barrel staves, two can be discussed together, due to the findings of this analysis. They are both oak, and though they do not achieve highly significant correlation between each other (t-value = 3.17) they might come from the same broad region. The staves 07923 (Z093001A) and 14847 (Z093011A) contain 109 and 158 tree-rings respectively, and the dating position of their tree-ring curves is indicated in fig. 3 and is listed in the catalogue. As the table of correlation values for the mean curve from these two oak staves shows (table 5), the

highest t-values are achieved with chronologies from northern Poland and with a chronology named “Baltic 1” which is based on tree-ring data from fine-art paintings, whose wood source is taken to be the Southern Baltic region. Even with this very preliminary study the results indicate that the trees used in the manufacture of these barrel staves grew in the Southern Baltic region. Given that the timbers for the building of *Vasa* were acquired from many regions, including purchases in Riga and Königsberg, it is not inconceivable that other timber items like barrel making material also were purchased here. Trade in planks, panels and even stave wood from this region is documented both through historical sources like the Danish Sound Toll Records and in the evidence from dendrochronology. The appearance of barrel material from the Southern Baltic in the *Vasa* inventory can be seen in the context of this trade.

Fig. 2. One of the gunpowder barrel staves of oak, sampled in this study (find no. 17492, Z093017A). (Photo Henrik Kiær).

Filenames	-	-	Z093M003	
-	Start	dates	AD1425	
-	Dates	end	AD1593	
Site and master chronologies				
0M040004	AD1156	AD1597	7,80	Baltic 1 (Hillam & Tyers 1995)
21013M01	AD1305	AD1682	5,53	B&W-grunden, Copenhagen (Daly 1997a & b)
PP11201M	AD1447	AD1570	5,52	PL Gdansk-Lipce (Tomasz Wazny pers comm)
0691006S	AD1375	AD1599	5,30	PL-Oliwa/Kathedrale (Tomasz Wazny pers comm)
midtjy17	AD536	AD1980	5,23	Midtjylland (Kjeld Christensen pers comm)
SNorwayships	AD1304	AD1895	5,04	S. Norway ships 63 timber mean (Daly unpubl.)
0684002S	AD1463	AD1647	5,02	PL Starzyno-Kirche (Tomasz Wazny pers comm)
6094M002	AD1450	AD1660	4,71	Funder kirke later material (Daly 2002)
OLUN0020	AD621	AD1723	4,65	Lund Oak (Olafur Eggertsson pers comm)
ZEALAND0	AD452	AD1770	4,60	Zealand Denmark (Daly unpubl.)
JUTLAND6	AD846	AD1793	4,59	Jutland Denmark (Daly unpubl.)
PM670108	AD725	AD1985	4,56	Pl Gdansk (Tomasz Wazny pers comm)
0684001S	AD1463	AD1647	4,53	Starzyno (Tomasz Wazny pers comm)
Baltic timber in Scotland				
MPD03VB3	AD1249	AD1479	7,27	Stirling doors Baltic timber source (Crone 2008)
HEADSx11	AD1304	AD1521	5,78	Stirling heads Baltic timber source (Crone 2008)
Barrels & ships of Baltic timber				
1HA00M01	AD1450	AD1590	7,46	Haarlem Wilsonplein barrel (Sjoerd van Dalen pers comm)
B019M002	AD1374	AD1574	5,73	Helsingør Kulturværft two barrels (Daly 2009)
Z064M002	AD1313	AD1481	4,57	Sørenga 9 (Daly 2011b)

Table 5. The results of the calculation of correlation between the mean curve from two of the barrel staves from *Vasa* (Z093M003 group 5) and diverse site and master chronologies are shown. The source of the chronologies is given. The grey tone highlights the high t-values.

A single dated stave

One other of the barrel staves analysed here, number 14838 (Z093003A), can be dated. It has 2 rings of sapwood preserved, and contains 67 rings. As the table of correlation indicates (table 6) the tree used to make this oak stave might have grown in the Lower Saxony or Dutch region, but additional analyses of more barrel material from the *Vasa* cargo should be carried out to confirm this.

Filenames	-	-	Z093003A	
-	Start	dates	AD1550	
-	Dates	end	AD1616	
nlwf1040	AD1040	AD1972	5,31	Nederland. Westfalen (H.Tisje unpublished)
DM200005	AD915	AD1873	5,07	Niedersachsen, Nord (Göttingen University)
DM200006	AD914	AD1873	5,05	Lüneburger Heide (Göttingen University)
LUNQSP01	AD621	AD1769	4,45	Lund (Thomas Bartholin pers comm)
PM670108	AD725	AD1985	4,11	Gdansk (Tomasz Wazny pers comm)

Table 6. The results of the calculation of correlation between the tree-ring curve from a single barrel stave from *Vasa* (Z093003A) and diverse site and master chronologies are shown. The source of the chronologies is given. The grey tone highlights the high t-values.

The undated barrel staves

Three of the barrel staves analysed are currently not dated. The two undated oak staves contain rather few rings: stave 14868 (Z093009A) has 45 while 14100 (Z093013A) contains just 41 tree-rings. The pine barrel stave on the other hand contains 139 rings, but finding the date for this piece has not been possible. Again, dendrochronological dating of single samples can often be problematic, and analysis of additional pine objects from the ship and its inventory will provide insight into the diversity of the procurement also of this timber type for the *Vasa*.

Given the possibility that the barrel cargo of the *Vasa* were made from wood from diverse sources, and as some of the regions from which oaks for *Vasa* grew might be underrepresented in the Northern European dendrochronological dataset, it is suggested that an extensive analysis of more material from both the ship itself and its cargo would increase the success of the dating and provenance determination of this material.

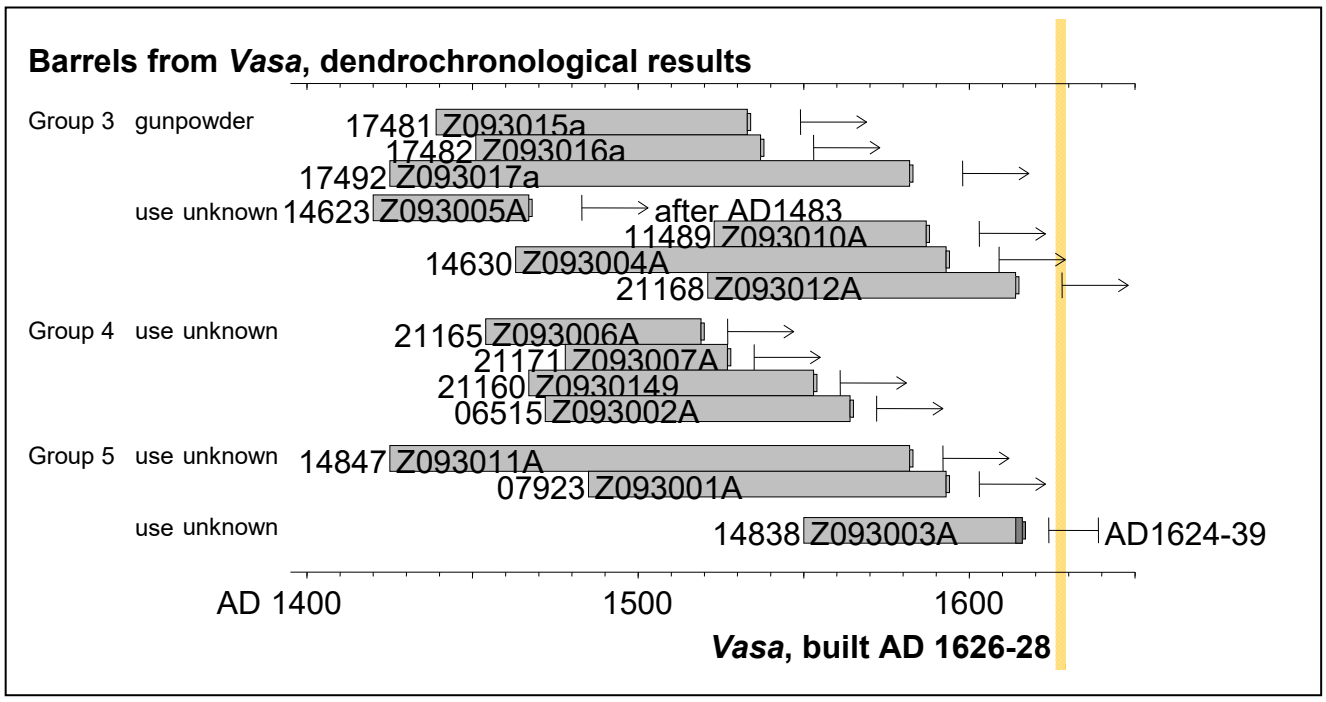

Fig. 3. The diagram shows the chronological position of the 14 dated samples from the barrel staves from *Vasa* (see text below for an explanation of the diagram).

The dendrochronological dating of the barrels from *Vasa*

The illustration in fig. 3 shows the dated position of the 14 dated objects. The grey bars represent the chronological position of the tree-ring measurements, with heartwood in light

grey, sapwood in dark grey. The lines to the right of these represent the estimated felling date for the trees that the timbers were made from. The yellow vertical line indicates the years during which *Vasa* was built, that we know historically. The estimated felling dates for the trees used to make the dated barrel staves here agree, not surprisingly, with the historical date. As the analysis indicates different regions of origin for the different groups identified here, different sapwood statistics are applied when estimating the felling date of the oaks used. As can be seen in the map below (fig. 4) oaks in Northern Europe have varying numbers of sapwood rings in what seems to be an east-west gradient; more in the west and fewer to the east. For the barrel staves from group 3 the sapwood statistic for Northern Germany is used which suggests that oaks have 20 (-5 +10) sapwood rings (Hollstein 1980). The slightly shorter sapwood estimate for Northern Poland (Wazny 1990) is used for the group 5 staves. For the four trees making up group 4 it is decided that, in light of the possibility that these are Scandinavian trees, a sapwood estimate for Norway (Christensen & Havemann 1998) is applied here.
The sapwood estimates can be more finely adjusted to take account of the growth rate of the tree. It has been widely recognised that fast-grown oaks generally have fewer sapwood rings (Hillam et al 1987, Daly 2007a), In an analysis of oaks from Danish material with complete sapwood to bark preserved it was found that faster-grown mature oaks, with average ring-width of 1-2 mm, have predominantly *c* .13-26 sapwood rings (Daly 2006, 28 & Daly 2007a, 157). When this estimate is used for the dating of stave no. 21168 (Z093012A) whose average ring width is 1.1 mm, the felling of the tree used can be placed at after *c*. AD 1628.
The only stave in this study that has sapwood preserved (find no. 14838 (Z093003A)) is from an even faster-grown tree. It has an average ring width of 1.7mm, so a sapwood estimate of *c*.15 rings (-5/+10) is more appropriate for this tree, so that it's felling date is estimated to lie within the years AD1624-39. This is in full agreement with the historical dating of the *Vasa*.

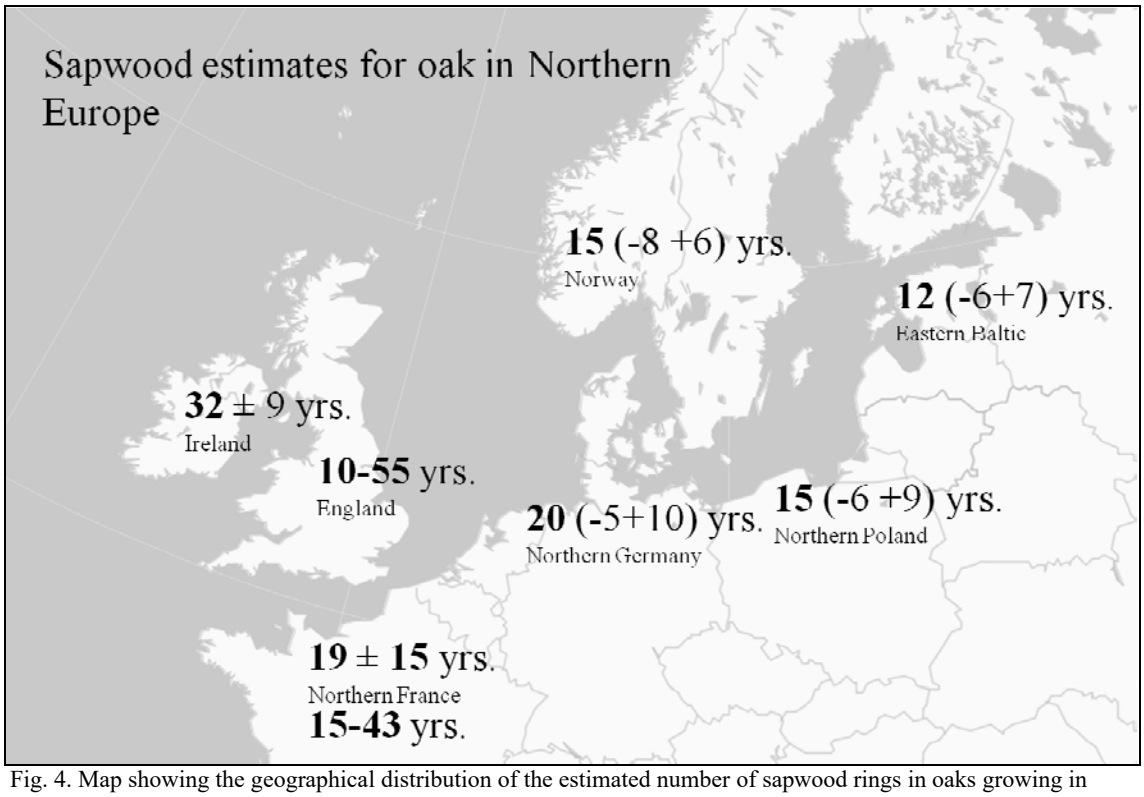

Fig. 4. Map showing the geographical distribution of the estimated number of sapwood rings in oaks growing in Northern Europe: Norway (Christensen & Havemann 1998), Ireland (Baillie 1995), England (Hillam et al 1987), Northern France (Lambert 2006, Pilcher 1987), Northern Germany (Hollstein 1980), Northern Poland (Wazny 1990) and Eastern Baltic (Sohar et al 2012).
(Background map from http://en.wikipedia.org/wiki/File:Europe_polar_stereographic_Caucasus_Urals_boundary.svg#filelinks)

Conclusion

As stated at the beginning of this report, this small case study of material from the *Vasa* ship and inventory is just a very preliminary exercise. While some very useful results have emerged from this analysis, it also serves to demonstrate that the story of the timber procurement for *Vasa*, and the wooden inventory within her, is not a simple one. Just as timbers for building the ship were acquired from a range of sources the provenance determination of the wood for the barrels might both indicate the source of the barrel's contents or the origin of raw material for barrel making. Ratcliffe points out that Stockholm was considered an exporter of barrels (Braun and Hogenberg 1955: 125, referred to in Ratcliffe 2012, 65), and it is highly likely that some of the Vasa barrels were made from trees of local provenance. The analysed examples here labelled group 4 might indeed represent barrels made from local oaks. In a more detailed study, it would be important to analyse several components from more complete barrels, so that the tree-ring study can show whether barrels are made from wood from a single or diverse sources. If the barrels are made of timber from mixed sources we can argue that we are dealing with traded wood. If however single barrels are made from staves whose tree-ring patterns match very well, then we can suggest that the source of the trees is also an idicator for the source of the barrel. The conclusions of the dendrochronological study can then be compared to details of the barrel dimensions and other details of manufacture, to point out details that are specific to certain regions. Clearly a wealth of details are still waiting to be discovered about the timber used to build and equip *Vasa*.

Fig. 5. Selecting suitable barrels staves from *Vasa* for dendrochronology and provenance analysis. (Photo Henrik Kiær).

Acknowledgements

Thanks to Fred Hocker for allowing me the opportunity to analyse this material, to Emma Hocker for facilitating the sampling of the objects and to Henrik Kiær for assistance during sampling. Thanks are also extended to colleagues and institutions in Northern Europe for the generosity they have shown in making their tree-ring data available. Thanks also to the UCD School of Archaeology for hosting me during my Marie Curie IEF research project.

Literature

Baillie, M.G.L. and Pilcher, J.R., 1973: A simple crossdating program for tree-ring research. *Tree-Ring Bulletin* 33, 7-14.

Baillie, M.G.L., 1995. *A Slice through Time: Dendrochronology and Precision Dating.* London 1995.

Braun, G., & Hogenberg, F., 1955. *Old European Cities: Twenty-Four 16th-Century City Maps and Texts from the Civitates Orbis Terrarum*. Thames and Hudson, London.

Bråthen, A., 1982: Dendrokronologisk serie från västra Sverige 813-1975. *Rapport Riksantikvarieämbetet och Statens historiska museer* 1982:1. Stockholm.

Cederlund, C.O., 1966. *Stockholms skeppsgård 1605-1640. Personalens struktur och organisation*. SSHM internal report

Cederlund, Carl Olof & Fred Hocker (ed), 2006. *Vasa I The Archaeology of a Swedish Warship of 1628*. National Maritime Museums of Sweden, Stockholm, pp. 491.

Christensen, K. & Havemann, K. 1998. Dendrochronology of oak (*Quercus sp*.) in Norway. *AmSVaria* 32, Stavanger, 59-60.

Crone, B.A., 2008. 'Dendrochronological analysis of oak and pine timbers', in *Stirling Castle Palace: archaeological and historical research* 2004-2008; http://sparc.scran.ac.uk/publications

Daly, A., 1997a. Dendrokronologisk Undersøgelse af tømmer fra 'B&W grunden', Strandgade 3A, Christianshavn, tidligere Grønnegaard Havn. I: Bolværk, bedding mm. *Nationalmuseets Naturvidenskabelige Undersøgelser* rapport 1/1997, Copenhagen.

Daly, A., 1997b. Dendrokronologisk Undersøgelse af tømmer fra 'B&W grunden', Strandgade 3A, Christianshavn, tidligere Grønnegaard Havn. III: Bolværk. *Nationalmuseets Naturvidenskabelige Undersøgelser* rapport 18/1997, Copenhagen.

Daly, A., 1998. Kirker i Vendsyssel - alder og funktion. Dendrokronologisk del. *Nationalmuseets Naturvidenskabelige Undersøgelser rapport nr.* 36, 1998. København.

Daly, A. 1999: Dendrokronologisk undersøgelse af tømmer fra Nyborg slot, Fyns Amt. *Nationalmuseets Naturvidenskabelige Undersøgelse* rapport nr. 1999 : 25.

Daly, A., 2000. Dendrokronologisk undersøgelse af tømmer fra B&W grunden, Skibsvrag 2 og 5. *Nationalmuseets Naturvidenskabelige Undersøgelser rapport nr*. 2000 : 26.

Daly, A., 2001. Dendrokronologisk undersøgelse af tømmer fra Suså, Næstved, Storstrøms amt. *Nationalmuseets Naturvidenskabelige Undersøgelser rapport nr.* 31, 2001. København.

Daly, A., 2002. Dendrokronologisk undersøgelse af tømmer fra Funder kirke, Århus amt. *Nationalmuseets Naturvidenskabelige Undersøgelser rapport nr*. 2002 : 19.

Daly, A. 2006. The dendrochronological dating of timber crossings in west Jutland, Denmark. *Journal of Wetland Archaeology* **6**, 19-48.

Daly, A. 2007a. The Karschau Ship, Schleswig-Holstein: Dendrochronological Results and Timber Provenance. *International Journal of Nautical Archaeology* **36**.1, 155-166.

Daly, A., 2007b. *Timber, Trade and Tree-rings. A dendrochronological analysis of structural oak timber in Northern Europe, c. AD 1000 to c. AD 1650*. Ph.D. thesis submitted February 2007, University of Southern Denmark.

Daly, A., 2009. Kulturværft Helsingør. *dendro.dk rapport* nr. 2009 : 21

Daly, A., 2010. Barcode ship 9. *dendro.dk rapport nr.* 2010 : 37

Daly, A., 2011a. Dendro-geography – mapping the Northern European historic timber trade. P Fraiture (ed.), 2011, *Tree Rings, Art, Archaeology*, Brussels, coll. Scientia Artis 7, 107-124.

Daly, A., 2011b. Sørenga 9, Oslo. *dendro.dk rapport nr*. 2011 : 16, København.

Daly, A., 2011c. Oslo Bjørvika "Kenneth". *dendro.dk rapport nr*. 2011 : 18, København.

Daly, A., 2011d. Barcode vrag 5, vrag 8 og vrag 14, Oslo. *dendro.dk rapport nr*. 2011 : 24, København.
Hillam, J., Morgan, R.A. and Tyers, I., 1987. Sapwood estimates and the dating of short ring sequences. in R.G.W. Ward (ed), *Applications of Tree-ring Studies: Current Research in Dendrochronology and Related Subjects*, BAR International Series 333, 1987, pp. 165–185.
Hillam J. & Tyers I., 1995. Reliability and repeatability in dendrochronological analysis: tests using the Fletcher archive of panel-painting data, *Archaeometry* 37, p. 395–405.
Hollstein, E. 1980. *Mitteleuropäische Eichenchronologie.* Trierer Grabungen und Forschungen 11. Mainz am Rhein.
Lambert, G.N., *Dendrochronologie, histoire et archéologie, modélisation du temps. Le logiciel Dendron II et le projet Historic Oaks.* Thèse de doctorat, 2006, Habilitation à Diriger les Recherches, Université de Franche-Comté. 2vol.
Pilcher, J. R., 1987, A 700 year dating chronology for northern France. Applications of tree-ring studies. Current research in dendrochronology and related subjects. *BAR International Series* 333: 127-139.
Ratcliffe, J.E., 2012. *The casks from Vasa*. A thesis presented to the faculty of the Department of History, East Carolina University in partial fulfilment of the requirements for the degree master of arts in maritime studies.
Sohar, K., Vitas, A. & Läänelaid, A., 2012. Sapwood estimates of pedunculate oak (Quercus robur L.) in eastern Baltic. *Dendrochronologia* 30 (2012) 49–56.
Tyers, I.G., 1997. Dendro for Windows Program Guide, *ARCUS Report* 340, Sheffield.
Wazny, T., 1990. *Aufbau und Anwendung der Dendrochronologie für Eichenholz in Polen*. PhD Thesis. Universität Hamburg, pp. 213.

Catalogue

Catalogue format:

Filename
Title and sample number
Tree species (QUSP = *Quercus sp*., oak, PISY = *Pinus sp*., pine, PCAB = *Picea abies*, spruce) and number of years measured
Chronological position of the tree-ring curve
Number of sapwood years, presence of bark
Felling date
The measurements start at the innermost preserved ring

Barrel staves

Z093001A
Vasa ship laggstav 07923 65849
Raw Ring-width QUSP data of 109 years length
Dated AD1485 to AD1593
0 sapwood rings and no bark surface
Average ring width 121.26 Sensitivity 0.20
Interpretation after AD1603

188	289	270	229	210	234	144	81	83	105
131	126	112	123	84	89	106	91	117	97
95	92	141	99	88	134	160	119	130	149
150	179	155	107	142	72	119	120	139	146
156	194	198	147	97	102	119	93	85	116
120	112	97	88	108	113	103	122	129	165
173	136	98	140	155	98	144	111	135	108
128	121	81	123	98	159	139	114	145	107
146	88	99	103	130	133	156	108	108	102
93	79	94	111	104	114	83	82	63	64
96	109	85	101	83	68	71	72	50	

Z093002A
Vasa ship laggstav 06515 65850
Raw Ring-width QUSP data of 93 years length
Dated AD1472 to AD1564
0 sapwood rings and no bark surface
Average ring width 142.34 Sensitivity 0.25
Interpretation after AD1572

121	93	87	141	100	127	137	127	99	79
79	85	131	93	126	98	77	95	153	142
122	128	127	154	155	187	158	131	140	134
157	151	131	143	128	87	108	141	85	133
170	201	143	165	288	296	304	233	125	223
318	224	115	225	158	205	165	169	114	171
164	160	145	128	93	137	119	148	94	143
122	117	101	172	127	81	138	83	91	178
255	155	181	158	120	104	68	110	137	127
127	142	111							

Z093003A
Vasa ship laggstav 14838 65851
Raw Ring-width QUSP data of 67 years length
Dated AD1550 to AD1616
2 sapwood rings and no bark surface
Average ring width 175.60 Sensitivity 0.20
Interpretation AD1624-39

351	442	379	489	152	173	223	250	157	165
232	263	252	296	191	236	203	233	201	196
237	211	215	239	220	173	182	191	221	167
109	96	126	84	76	132	145	154	154	188
118	146	143	157	160	91	96	120	163	104
90	75	114	114	116	123	101	143	152	110
110	141	152	164	110	110	138			

Z093004A
Vasa ship laggstav 14630 65852
Raw Ring-width QUSP data of 131 years length
Dated AD1463 to AD1593
0 sapwood rings and no bark surface
Average ring width 94.97 Sensitivity 0.15
Interpretation after AD1609

103	82	78	82	91	120	116	78	90	111
114	128	134	98	107	144	153	150	128	85
116	114	119	141	141	95	84	100	71	76
113	115	106	109	95	74	96	96	117	92
75	59	93	82	92	90	82	67	99	85
98	90	61	94	63	64	71	68	89	102
88	101	66	97	109	121	71	80	108	81
110	85	115	118	145	111	117	115	92	74
71	64	71	88	82	76	107	83	82	77
82	96	97	87	102	93	84	93	96	114
98	124	93	93	83	77	82	91	76	94
112	99	93	83	94	101	96	85	98	89
92	92	98	91	91	69	80	80	88	79
85									

Z093005A
Vasa ship laggstav 14623 65853
Raw Ring-width QUSP data of 48 years length
Dated AD1420 to AD1467
0 sapwood rings and no bark surface
Average ring width 225.73 Sensitivity 0.26
Interpretation after AD1483

392	230	289	259	248	390	311	406	173	234
221	195	190	144	163	178	279	322	252	359
278	162	154	144	121	161	185	270	202	275
215	313	246	128	165	211	231	195	262	355
162	208	121	148	183	176	177	152		

Z093006A
Vasa ship laggstav 21165 65854
Raw Ring-width QUSP data of 66 years length
Dated AD1454 to AD1519
0 sapwood rings and no bark surface
Average ring width 157.36 Sensitivity 0.14
Interpretation after AD1527

97	150	147	184	172	182	212	196	179	177
167	220	198	227	204	206	199	161	175	196
182	223	250	210	197	184	158	156	146	177
174	191	205	195	125	155	173	150	110	103
133	117	140	175	172	147	135	185	150	130
109	139	86	122	124	120	116	99	109	97
112	97	118	126	122	93				

Z093007A
Vasa ship laggstav 21171 65855
Raw Ring-width QUSP data of 50 years length
Dated AD1478 to AD1527
0 sapwood rings and no bark surface
Average ring width 200.58 Sensitivity 0.14
Interpretation after AD1535

349	282	233	280	275	268	243	193	260	378
217	221	199	187	144	157	204	215	227	200
219	208	221	241	208	175	169	204	120	178
139	164	153	165	209	186	200	167	181	176
176	162	135	142	160	166	150	182	181	160

Z093008A
Vasa ship laggstav 14849 65856
Raw Ring-width PISY data of 139 years length
Undated
0 sapwood rings and no bark surface
Average ring width 67.46 Sensitivity 0.23

85	93	80	103	113	115	105	95	64	47
64	92	116	87	86	97	78	46	40	63
91	83	96	85	68	65	76	66	118	154
96	83	72	63	105	76	76	49	30	43
40	48	33	29	33	47	53	48	64	64
66	74	87	45	32	24	21	23	25	36
43	18	10	12	20	42	59	69	76	69
71	71	58	73	88	65	59	66	87	69
53	61	28	29	21	29	40	41	57	82
89	80	64	48	89	69	56	63	51	56
111	102	66	52	66	81	67	57	70	102
120	106	101	108	118	115	88	119	81	77
93	137	121	99	77	55	28	37	29	25
44	56	46	41	45	46	65	65	74	

Z093009A
Vasa ship laggstav 14868 65857
Raw Ring-width QUSP data of 45 years length
Undated
0 sapwood rings and no bark surface
Average ring width 232.04 Sensitivity 0.18

377	442	268	372	313	346	281	223	296	276
223	326	269	201	243	231	253	322	244	165
181	268	202	237	283	247	235	194	235	166
161	158	141	159	138	166	138	167	194	206
199	191	172	139	194					

Z093010A
Vasa ship laggstav 11489 65858
Raw Ring-width QUSP data of 65 years length
Dated AD1523 to AD1587
0 sapwood rings and no bark surface
Average ring width 179.00 Sensitivity 0.21
Interpretation after AD1603

340	293	289	310	343	286	231	221	262	274
250	237	228	195	162	260	247	202	170	179
161	120	143	130	182	233	235	159	136	163
181	120	175	156	129	290	262	222	206	209
176	110	147	110	192	165	114	147	116	130
217	138	79	109	140	152	102	74	73	73
73	67	77	156	107					

Z093011A
Vasa ship laggstav 14847 65859
Raw Ring-width QUSP data of 158 years length
Dated AD1425 to AD1582
0 sapwood rings and no bark surface
Average ring width 65.80 Sensitivity 0.22
Interpretation after AD1592

54	81	79	45	65	62	67	106	108	93
78	76	91	82	76	100	101	101	122	99
109	67	62	72	80	59	94	110	121	99
121	97	62	67	84	118	83	69	45	93
78	53	75	84	98	84	114	93	39	42
73	82	45	44	31	57	50	48	67	74
41	55	50	55	60	65	38	30	32	37
37	37	60	51	41	40	67	51	36	31
38	47	57	44	61	68	52	51	37	70
79	84	78	57	44	53	43	37	39	50
43	42	37	49	36	38	27	32	28	30
36	46	70	67	114	90	106	89	124	129
112	90	77	114	93	52	51	48	98	42
99	94	68	81	70	76	68	85	88	68
62	57	68	57	67	81	51	32	36	37
35	31	36	49	40	43	38	37		

Z093012A
Vasa ship laggstav 21168 65860
Raw Ring-width QUSP data of 94 years length
Dated AD1521 to AD1614
0 sapwood rings and no bark surface
Average ring width 110.74 Sensitivity 0.18
Interpretation after AD1628

147	131	164	144	111	141	152	172	139	141
111	81	107	72	56	66	53	86	94	88
103	113	114	77	127	110	111	142	206	106
145	117	152	155	119	117	154	170	133	121
129	127	119	99	91	87	90	89	66	63
72	78	96	78	104	80	104	106	112	90
124	109	142	95	130	126	127	73	104	102
117	127	136	111	100	102	170	105	120	96
78	87	95	88	85	88	98	126	110	107
84	109	96	115						

Z093013A
Vasa ship laggstav 14100 65861
Raw Ring-width QUSP data of 41 years length
Undated
0 sapwood rings and no bark surface
Average ring width 243.49 Sensitivity 0.25

116	111	223	231	233	273	205	188	136	175
147	137	189	155	138	124	179	92	111	138
282	211	276	313	227	231	269	322	515	477
255	317	322	490	420	279	265	418	418	177
198									

Z0930149
Vasa ship laggstav 21160 65862
Raw Ring-width QUSP data of 87 years length
Dated AD1467 to AD1553
0 sapwood rings and no bark surface
Average ring width 118.43 Sensitivity 0.20
Interpretation after AD1561

163	164	211	224	267	233	153	84	154	134
97	171	170	97	119	211	158	192	186	159
204	178	146	149	153	115	129	162	145	117
123	124	118	75	153	105	104	102	148	171
149	123	80	92	114	87	88	62	109	81
64	72	99	60	63	66	78	71	61	49
62	63	57	91	80	102	103	96	90	95
78	120	118	82	80	96	107	92	92	86
87	88	85	112	140	161	104			

Z093015a
Vasa ship laggstav 17481 65863
Raw Ring-width QUSP data of 95 years length
Dated AD1439 to AD1533
0 sapwood rings and no bark surface
Average ring width 134.21 Sensitivity 0.18
Interpretation after AD1549

279	250	205	175	219	154	140	121	200	187
212	161	236	218	135	135	139	181	181	238
195	178	157	140	160	194	165	207	203	224
198	134	154	211	156	182	238	161	127	183
147	136	138	141	132	186	118	147	176	113
75	97	96	77	85	96	99	144	83	94
94	88	106	91	75	69	100	105	80	82
78	81	101	112	94	98	129	105	87	87
112	96	114	113	69	68	57	74	76	72
77	63	74	55	55					

Z093016a
Vasa ship laggstav 17482 65864
Raw Ring-width QUSP data of 87 years length
Dated AD1451 to AD1537
0 sapwood rings and no bark surface
Average ring width 143.76 Sensitivity 0.20
Interpretation after AD1553

235	246	156	126	182	197	145	194	239	183
208	209	254	253	210	250	284	325	293	190
259	367	284	270	309	200	142	233	219	203
207	180	212	260	214	213	294	198	136	184
132	97	144	133	116	109	80	81	72	87
103	82	52	54	86	89	105	95	85	68
75	89	67	55	74	60	38	44	59	63
75	90	62	63	63	77	66	69	76	53
60	44	57	47	44	38	66			

Z093017a
Vasa ship laggstav 17492 65865
Raw Ring-width QUSP data of 158 years length
Dated AD1425 to AD1582
0 sapwood rings and no bark surface
Average ring width 87.61 Sensitivity 0.19
Interpretation after AD1598

200	166	138	115	182	129	139	95	97	81
79	88	102	108	120	149	122	117	123	98
117	105	101	97	129	123	130	92	66	80
94	124	93	98	60	67	50	48	54	74
81	57	54	84	85	85	103	143	119	165
147	91	89	126	162	114	103	100	91	116
90	119	152	75	87	88	75	48	57	50
51	61	42	37	53	46	55	62	56	59
78	96	86	67	54	61	89	89	70	60
91	66	81	62	77	86	98	92	72	78
68	92	127	106	97	86	92	73	95	83
70	65	74	104	122	87	74	57	47	51
81	92	93	111	81	68	62	71	78	77
70	84	105	115	120	109	99	139	109	82
50	51	47	68	58	53	51	80	76	53
51	45	72	68	52	49	59	62		

Ship timbers
Z092001a
Vasa ship bordläggning venthål 1 SB 23801 65866
Raw Ring-width QUSP data of 191 years length
Undated
0 sapwood rings and no bark surface
Average ring width 101.28 Sensitivity 0.19

114	95	109	186	124	136	126	108	123	112
99	82	59	68	77	97	128	123	85	82
83	55	94	80	78	92	50	81	112	75
117	101	109	118	51	76	126	100	105	77
68	138	120	131	106	119	108	110	85	50
73	56	61	93	96	101	103	87	65	73
104	108	112	124	101	62	105	100	74	78
71	72	85	83	71	115	116	110	111	92
78	79	81	69	65	75	75	68	97	94
74	66	123	115	150	131	133	116	157	146
149	132	158	161	137	102	90	79	62	65
67	96	71	101	87	65	74	93	103	119
87	76	70	63	50	69	96	94	98	92
123	90	102	100	82	94	114	99	82	102
109	128	161	125	136	146	130	131	98	85
132	125	106	101	91	85	103	110	79	86
127	102	126	103	131	127	125	123	94	98
125	82	84	132	150	95	158	120	117	126
144	117	116	97	123	116	117	108	136	107
115									

Z092002a
Vasa ship bordläggning venthål 5 BB 23816 65867
Raw Ring-width QUSP data of 84 years length
Undated
0 sapwood rings and no bark surface
Average ring width 128.52 Sensitivity 0.19

132	132	142	124	132	92	97	90	83	102
117	132	150	108	86	133	141	182	150	152
152	147	124	143	114	166	155	143	136	112
110	87	93	84	145	119	179	145	123	89
121	127	170	136	106	81	99	79	82	105
129	125	113	148	140	138	83	95	128	175
128	120	125	134	143	248	162	161	153	176
187	112	103	146	147	134	168	125	94	99
146	100	150	112						

Z092003a
Vasa ship bordläggning venthål 4 SB 23804 65868
Raw Ring-width QUSP data of 109 years length
Undated
0 sapwood rings and no bark surface
Average ring width 119.63 Sensitivity 0.22

95	91	76	80	99	87	53	42	80	122
124	180	121	130	155	138	161	110	111	154
191	129	138	215	130	106	90	118	109	128
115	142	134	128	114	81	58	67	86	114
144	112	130	140	136	129	163	129	133	148
76	121	164	104	173	163	170	170	98	93
167	169	152	110	98	145	115	148	117	136
154	157	143	80	94	79	104	120	122	146
114	106	81	104	131	123	118	146	134	86
158	114	78	118	97	116	86	104	90	133
112	108	125	144	115	111	91	66	77	

Z092004a
Vasa ship bordläggning venthål 8 SB 23808 65869
Raw Ring-width QUSP data of 94 years length
Undated
0 sapwood rings and no bark surface
Average ring width 177.01 Sensitivity 0.20

167	193	83	134	171	176	235	110	137	153
231	238	206	161	171	112	168	158	133	214
215	366	197	229	195	260	215	199	160	208
247	295	216	179	124	135	199	222	219	231
196	205	195	221	188	233	168	228	229	219
168	143	180	123	160	130	152	130	300	235
231	188	237	213	313	239	203	200	188	223
161	152	148	129	117	120	124	115	132	107
115	109	92	88	89	133	98	147	130	135
107	112	131	148						

Z0920059
Vasa ship bordläggning venthål 12 BB 23823 65870
Raw Ring-width QUSP data of 84 years length
Undated
0 sapwood rings and no bark surface
Average ring width 195.05 Sensitivity 0.15

287	247	355	322	394	355	322	255	243	302
322	288	298	338	338	349	276	295	237	309
212	245	188	230	215	220	196	230	222	278
180	170	127	168	196	212	190	200	181	170
160	196	165	181	142	224	200	161	132	119
161	127	152	148	133	122	143	121	166	142
166	148	182	173	129	141	146	176	135	100
102	109	116	126	113	135	124	116	102	110
112	125	122	119						

Chronology, Culture and Archaeology (CCA).
Funded through a Marie Curie Intra-European Fellowship (IEF) and based at the School of Archaeology, University College Dublin, the project is concerned with the precise dating of timber and wood from archaeological or historical contexts. As dating results emerge these are dissemminated to project collaborators through this CCA report series. Full publication of the extensive material and methodological advancements will be prepared during the course of the project and submitted to peer review journals.

Filename	sample title and number	rings	start yr.	End yr.	Conversion	pith	sapwood	bark?	group	extra start	extra end	interpretation / felling
	Barrel staves											
Z093001A	Vasa ship laggstav 07923 65849 QUSP	109	AD1485	AD1593	R	G	-	-	-	-	H1	after AD1603
Z093002A	Vasa ship laggstav 06515 65850 QUSP	93	AD1472	AD1564	R	G	-	-	-	-	H1	after AD1572
Z093003A	Vasa ship laggstav 14838 65851 QUSP	67	AD1550	AD1616	R	G	2	-	-	-	S1	AD1624-39
Z093004A	Vasa ship laggstav 14630 65852 QUSP	131	AD1463	AD1593	T	G	-	-	3	-	H1	after AD1609
Z093005A	Vasa ship laggstav 14623 65853 QUSP	48	AD1420	AD1467	R	G	-	-	3	-	H1	after AD1483
Z093006A	Vasa ship laggstav 21165 65854 QUSP	66	AD1454	AD1519	R	G	-	-	4	-	H1	after AD1527
Z093007A	Vasa ship laggstav 21171 65855 QUSP	50	AD1478	AD1527	R	G	-	-	4	-	H1	after AD1535
Z093008A	Vasa ship laggstav 14849 65856 PISY	139			T	G	-	-	-	-	H1	Undated
Z093009A	Vasa ship laggstav 14868 65857 QUSP	45			R	G	-	-	-	-	H1	Undated
Z093010A	Vasa ship laggstav 11489 65858 QUSP	65	AD1523	AD1587	R	G	-	-	3	-	H1	after AD1603
Z093011A	Vasa ship laggstav 14847 65859 QUSP	158	AD1425	AD1582	R	G	-	-	-	-	H1	after AD1592
Z093012A	Vasa ship laggstav 21168 65860 QUSP	94	AD1521	AD1614	R	G	-	-	3	-	H1	after AD1628
Z093013A	Vasa ship laggstav 14100 65861 QUSP	41			R	G	-	-	-	-	H1	Undated
Z0930149	Vasa ship laggstav 21160 65862 QUSP	87	AD1467	AD1553	R	G	-	-	-	-	H1	after AD1561
Z093015a	Vasa ship laggstav 17481 65863 QUSP	95	AD1439	AD1533	R	G	-	-	3	-	H1	after AD1549
Z093016a	Vasa ship laggstav 17482 65864 QUSP	87	AD1451	AD1537	R	G	-	-	3	-	H1	after AD1553
Z093017a	Vasa ship laggstav 17492 65865 QUSP	158	AD1425	AD1582	R	G	-	-	3	-	H1	after AD1598
	Ship timbers											
Z092001a	Vasa ship bordläggning venthål 1 SB 23801 65866 QUSP	191			T	G	-	-	1	-	H1	Undated
Z092002a	Vasa ship bordläggning venthål 5 BB 23816 65867 QUSP	84			T	G	-	-	1	-	H1	Undated
Z092003a	Vasa ship bordläggning venthål 4 SB 23804 65868 QUSP	109			T	G	-	-	1	-	H1	Undated
Z092004a	Vasa ship bordläggning venthål 8 SB 23808 65869 QUSP	94			T	C	-	-	2	-	H1	Undated
Z0920059	Vasa ship bordläggning venthål 12 BB 23823 65870 QUSP	84			T	V	-	-	2	-	H1	Undated
	Barrel averages											
Z093M001 Group 3	Vasa barrels 7 timber mean QUSP Z093004A, Z093005A, Z093010A, Z093012A, Z093015a, Z093016a & Z093017a	195	AD1420	AD1614								
Z093M002 Group 4	Vasa barrels 4 timber mean QUSP Z093002A, Z093006A, Z093007A & Z0930149	111	AD1454	AD1564								
Z093M003	Vasa barrels 2 timber mean QUSP Z093001A & Z093011A	169	AD1425	AD1593								
	Ship averages											
Z092M001 Group 1	Vasa 3 timber mean QUSP Z092001a, Z092002a & Z092003a	215										Undated
Z092M002 Group 2	Vasa 2 timber mean QUSP Z092004a & Z0920059	94										Undated

Conversion: R = radial split plank, T = tangential plank, W = whole timber, S = squared whole timber, H = half timber, Q = quarter timber, O = other conversion.
Pith: C = centre, V = less than 5 rings, F = 5 – 10 rings, G = greater than 10 rings.

Aoife Daly, ph.d. 4th June 2013