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The Danish royal flagship gribshunden – Dendrochronology on a late medieval carvel sunk in the Baltic Sea

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ABSTRACT
The Royal flagship Gribshunden carried the Danish King Hans on its way to the city of Kalmar in Sweden when the ship sank in the summer of 1495. The ship caught fire while anchored north of the Stora Ekò Island and sank to the seafloor, where it lies to this day. The wreck was rediscovered in the 1970s and is remarkably well preserved. Since 2001, scientific investigations have been performed on the wreck by various organizations. In total, 13 dendrochronological samples from different parts of the ship construction have been collected and analyzed with standard dendrochronological methods with respect to age and provenance. The results show that all dated samples could have been felled during the winter season of 1482/83, although only one sample contains sapwood and waney edge. The highest correlations are obtained from reference chronologies that originate from the River Meuse drainage area, with correlations peaking around the city of Namur in Belgium. Most likely, the ship was constructed in a shipyard close to the mouth of the River Meuse in the southern Netherlands. It seems King Hans realized the potential of the new ship type represented by Gribshunden, but his shipwrights did not have the knowledge to build such a ship in Denmark. Instead, he purchased the ship from abroad. This study highlights late medieval economic and political connections throughout northern Europe.

1. Introduction

Dendrochronological studies of wood from Baltic Sea archaeological sites provide accurate and precise dating of the features, and often the provenance of the trees. Dendrochronology can be used by social scientists to expose patterns of cultural contact, economic transactions and even aspects of political power through time. The Baltic Sea is an exceptional preservative environment for wood primarily due to the absence of marine borers such as the shipworm, Teredo navalis, which cannot reproduce in this sea’s low salinity. As a result, archaeological sites remain on the seafloor for hundreds or even thousands of years (Fors et al., 2012; Rönby, 2001). It is estimated that the Baltic holds more than 100,000 underwater cultural heritage sites including Stone Age features, coastal fortifications, and particularly shipwrecks (Olsson, 2006; Eriksson and Rönby, 2012).

One of the most important shipwrecks yet investigated in the Baltic Sea is the flagship of King Hans, who ruled Denmark 1481–1513. Gribshunden sank in 1495 north of Stora Ekò Island in the Blekinge archipelago (Eriksson, 2015) (Fig. 1). Recreational divers discovered the wreck during the 1970s, and around 2001 archaeologists under the auspices of Kalmar County Museum determined that the wreck was medieval. Maritime historians subsequently linked the wreck to written sources from Denmark and Lübeck, and identified it tentatively as Griffen or Gribshunden (Einarsson and Wallbom, 2001; Rönby, 2015).

This ship appears in documents held in the Danish royal archives, with the first mention in a letter written by King Hans aboard the vessel in May 1486 (Sjöblom, 2015). Gribshunden quickly became an instrument to exercise Hans’ political and military will; in 1487 Gribshunden helped suppress a potential revolt on the Danish-held island of Gotland. In the early summer of 1495 King Hans was on his way to the city of Kalmar, a Swedish city close to the then-border of Denmark and Sweden, where he was to meet the Swedish regent Sten Sture the Elder (ca 1440–1503). King Hans wanted to re-establish the Nordic Union between Denmark, Norway, and Sweden by being elected king of Sweden (Eriksson, 2020; Sjöblom, 2015). On his way to Kalmar, the king took shelter close to the city of Ronneby in the Blekinge archipelago, then Danish territory. While anchored north of Stora Ekò Island the ship caught fire and sank, with many casualties. King Hans had disembarked prior to the fire, and later continued his journey to Kalmar.

resulted in recovery of wooden gun carriages, dendrochronological samples, and hundreds of individual artifacts (Einarsson and Wallbom, 2001, 2002; Einarsson and Gainsford, 2007; Einarsson, 2012). Between 2013 and 2015 Gribshunden was part of the Södertörn University project ‘Ships at War’, resulting in the recovery of the ship’s wooden figurehead (Eriksson, 2020; Rönby, 2015). During the summer of 2019 a new effort involving Lund University, Blekinge Museum, and Södertörn University excavated a trench amidships to reveal the hull construction and to assess the archaeological potential of the site (Fig. 2).

This dendrochronological study is part of a multi-disciplinary effort on the Gribshunden shipwreck aiming at a better understanding of late medieval ship construction, life aboard a royal ship, and everyday commodity use practices in late medieval Scandinavia. The specific aims with this dendrochronological study are to determine the time of felling and source area of the timber used to build the ship. This will aid understanding of political, military, and economic connections throughout Europe in the later medieval period. Specifically, it will provide insight into Hans’ connections across Europe, and the development of ships like Gribshunden: the first purpose-built warships capable of carrying naval artillery.

2. Methods

The samples, all of oak, were collected by divers during several field campaigns at the wreck site. Samples 55236–55245, consisting of available loose parts of the hull in direct vicinity of the wreck on the seafloor, were collected in the late summer of 2001 (Einarsson and Wallbom, 2001). The exact find spots were not recorded. Samples 55609–55610, found disarticulated on the seafloor 2.5 and 9.8 m either side of the absolute stern of the wreck, were collected in the autumn of 2011 (Einarsson, 2012). Sample 55,881 was sampled in the summer of 2019 and consists of a section of hull plank sawn from the intact hull 1 m below the sediment surface in an excavation trench located starboard amidships (Rönby, 2020) (Fig. 2).

The samples were analyzed at the National Laboratory of Wood Anatomy and Dendrochronology at the Department of Geology, Lund University. The samples were prepared by cutting the surface with an industrial razor blade to make the rings clearly visible. Chalk was applied to better distinguish the earlywood-latewood border. The tree ring-widths were measured with a precision of 0.01 mm using a stereo microscope and the CATRAS software (Aniol, 1983). Between two and four radii for each sample were measured, in order to detect missing

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**Fig. 1.** Map of the locations discussed in this paper. (A) A map showing the position of the Gribshunden shipwreck position (red circle) in southeastern Sweden. Basemap © EuroGeographics. (B) Location of the Stora Ekön Island and the Gribshunden shipwreck, marked by the red rhomb, north of the Island. Topography data © Lantmäteriet. (C) Map over parts of northwestern Europe. Cities are marked by black circles and names in italics. Names of rivers in the area are marked by normal letters. The beige area represents the drainage area of the River Meuse. Basemap © EuroGeographics.
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rings or possible measurement errors, and merged into tree-ring width series. Comparisons between the tree-ring series were performed by statistical and visual methods (Pilcher, 1990), in order to construct tree-ring width chronologies. The ring-width measurements and chronologies were quality controlled using the COFECHA software (Holmes, 1983). In order to obtain calendar ages and to determine the provenance of the wood, the ring-width chronologies, and the individual samples, were matched against the vast network of reference chronologies representing different geographical areas across Europe harbored at the National Laboratory of Wood Anatomy and Dendrochronology. The matching was performed in the TSAPWin software (Rinn, 2003) using the Baillie-Pilcher t-value (Baillie and Pilcher, 1973) and the gleichläufigkeit (glk) (*, ** or *** representing 95 %, 99 % or 99.9 % significance, respectively) (Schweingruber, 1988) statistical parameters, as well as visual inspection of the chronology cross correlation.

3. Results

The oak samples are from deck and hull planks, knees, deck beam, and futtocks of the ship. The number of rings in each sample varies from 22 to 108, with a mean ring width ranging from 1.1–4.5 mm. Only one sample has sapwood and/or waney edge preserved (Table 1). Two ring-width chronologies, 20552384 and 20552415, were constructed based on the internal correlations of the samples (Table 2). The 20552384 chronology consists of four samples and the 20552415 chronology consists of five samples. One sample, 55,241, occurs in both chronologies, whereas sample 55239 does not belong to any of the chronologies. Furthermore, a third ring-width chronology, 20552389, containing all nine dated samples was constructed.

The results show that the 20552389 chronology is dated to 1482 (Fig. 3). Statistical matches between the three Gribshunden chronologies, with and without a valid time series of ring 1–100, and the highest correlating reference chronologies are presented in Table 3. Of the thirteen measured samples, nine could be confidently dated to a calendar year, while four have not been possible to date. One sample, 55,241, has preserved sapwood and waney edge and is dated to the winter season of 1482/83. The other dated samples lack sapwood, and therefore a number of years have been added to the outermost ring to determine the oldest possible year of felling, a so-called terminus post quem dating (Table 1).

4. Discussion

4.1. Dating of the Gribshunden timber

The 20552389 chronology is dated to 1482 (Table 3). The best
correlation is to the Meuse Valley chronology with a t-value of 6.0 and a glk of 69***. However, the sample depth of the 20552389 chronology decreases and the ring-width curve starts to vary greatly after 1455 and the visual match against the reference chronology is low (Fig. 3). In order to get a more representative chronology and a better statistical match, the years 1456–1482 were subsequently left out of further statistical analysis. This led to an increase in both t-value and glk with most reference chronologies, with the South East England chronology being

### Table 2
Statistical correlations between the Gribshunden samples. The statistics are presented as t-value; gleichläufigkeit with *, ** or *** representing 95 %, 99 % or 99.9 % significance, respectively. Sample matches forming chronology 20552384 are coloured in orange, while sample matches forming chronology 20552415 are coloured in blue. Note that sample 55,241 is included in both chronologies and is therefore coloured blue on the horizontal axis and orange on the vertical axis.

<table>
<thead>
<tr>
<th>Sample Depth</th>
<th>20552384</th>
<th>20552384 VT 1–100</th>
<th>20552415</th>
<th>20552415 VT 1–100</th>
<th>20552389</th>
<th>20552389 VT 1–100</th>
</tr>
</thead>
<tbody>
<tr>
<td>55236</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55237</td>
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<tr>
<td>55238</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55239</td>
<td>4.6; 68**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55240</td>
<td></td>
<td>5.0; 79***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55241</td>
<td></td>
<td>6.8; 78***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55243</td>
<td>4.6; 63*</td>
<td></td>
<td>5.6; 79***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55244</td>
<td></td>
<td>3.2; 63**</td>
<td>4.4; 75***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55245</td>
<td></td>
<td></td>
<td>5.1; 78**</td>
<td></td>
<td>6.0; 81***</td>
<td></td>
</tr>
<tr>
<td>55609</td>
<td></td>
<td>4.1; 65**</td>
<td>3.8; 18*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55610</td>
<td></td>
<td>3.9; 64**</td>
<td>3.0; 59*</td>
<td>4.6; 77**</td>
<td>4.3; 63**</td>
<td>4.0; 67**</td>
</tr>
<tr>
<td>55881</td>
<td>3.1; 69**</td>
<td>5.6; 74***</td>
<td>3.5; 73***</td>
<td></td>
<td>3.2; 65**</td>
<td>4.5; 71***</td>
</tr>
</tbody>
</table>

Fig. 3. Visual and statistical correlation between the 20552389 chronology (black curve) and the BBMEUSE2 chronology (red curve). The grey box represents the area omitted from the valid time span when correlating with the reference chronology. The sample depth of the 20552389 chronology is presented in the top of the figure.

### Table 3
Statistical correlation parameters between Gribshunden chronologies and reference chronologies for the year 1482 CE. t-value; gleichläufigkeit with *, ** or *** representing 95 %, 99 % or 99.9 % significance, respectively. The reference chronologies are sorted by the t-value of the ‘20552389’ chronology.

<table>
<thead>
<tr>
<th>Ref. chronology</th>
<th>Year AD</th>
<th>Location</th>
<th>20552384</th>
<th>20552384 VT 1–100</th>
<th>20552415</th>
<th>20552415 VT 1–100</th>
<th>20552389</th>
<th>20552389 VT 1–100</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBMEUSE2</td>
<td>674–1989</td>
<td>Meuse Valley</td>
<td>6.1; 67***</td>
<td>5.4; 69***</td>
<td>5.8; 71***</td>
<td>5.4; 74***</td>
<td>6.0; 69***</td>
<td>6.2; 73***</td>
</tr>
<tr>
<td>BBDBHSTD</td>
<td>1311–1550</td>
<td>Hertogenbosch</td>
<td>5.2; 63**</td>
<td>4.9; 64**</td>
<td>5.9; 65***</td>
<td>6.0; 67***</td>
<td>5.8; 63**</td>
<td>6.3; 65**</td>
</tr>
<tr>
<td>00000081</td>
<td>1989</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENGQ0001</td>
<td>413–1899</td>
<td>South East England</td>
<td>5.7; 68**</td>
<td>4.4; 65**</td>
<td>4.2; 61**</td>
<td>3.7; 63**</td>
<td>5.1; 66**</td>
<td>5.3; 72***</td>
</tr>
<tr>
<td>BBMJKSTD</td>
<td>1191–1457</td>
<td>Maastricht</td>
<td>4.3; 69**</td>
<td>5.2; 69**</td>
<td>4.2; 69**</td>
<td>4.7; 70***</td>
<td>4.9; 69**</td>
<td>5.5; 70**</td>
</tr>
<tr>
<td>BBNAMUR1</td>
<td>1363–1638</td>
<td>Namur</td>
<td>4.8; 63**</td>
<td>3.7; 63**</td>
<td>4.1; 69**</td>
<td>3.5; 72***</td>
<td>4.7; 67**</td>
<td>4.7; 70***</td>
</tr>
<tr>
<td>00000884</td>
<td>1322–1973</td>
<td>Mosel Valley</td>
<td>3.9; 65**</td>
<td>3.9; 63**</td>
<td>4.6; 66**</td>
<td>3.5; 65**</td>
<td>4.3; 66**</td>
<td>3.6; 66***</td>
</tr>
<tr>
<td>BBARDEN2</td>
<td>1120–1986</td>
<td>The Ardennes</td>
<td>3.7; 55**</td>
<td>3.9; 58*</td>
<td>3.7; 57**</td>
<td>4.3; 65**</td>
<td>4.0; 55**</td>
<td>4.9; 60*</td>
</tr>
<tr>
<td>00000078</td>
<td>1036–1972</td>
<td>Holland</td>
<td>3.0; 63**</td>
<td>3.9; 64**</td>
<td>2.6; 58**</td>
<td>4.0; 66***</td>
<td>3.1; 63**</td>
<td>4.6; 64**</td>
</tr>
<tr>
<td>0M010006</td>
<td>1000–1655</td>
<td>Cologne</td>
<td>2.7; 59*</td>
<td>3.3; 64**</td>
<td>3.4; 60**</td>
<td>4.2; 61**</td>
<td>3.3; 59*</td>
<td>4.7; 60*</td>
</tr>
</tbody>
</table>
Correlations between the reference chronologies used in this study within the time span 1300–1500.

One sample, 55,241, has been possible to date to the winter season of 1482/83. The growth season of an oak tree starts in late April to early May and continues until the end of August, hence the term winter season is defined as September to April. The dating of the individual timber sample when it was cut down. The normal amount of sapwood rings in oak from Belgium older than 100 years is 11. For the respective ship part. The 20552384 chronology contains one

The reference chronologies used for the dating and provenance have not been constructed by the laboratory at Lund University and therefore the origin of the samples which were used in the chronologies is unclear. For chronologies which have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some chronologies have descriptions of cities in their data header, it is assumed that the trees grew in the vicinity of that city. However, some...
to better determine the source area of the respective reference chronology. The Namur, Hertogenbosch, and Maastricht chronologies are assumed to contain timber which grew close to the respective city. The Meuse Valley chronology potentially contains samples from a large area. However, the Meuse Valley chronology has a high similarity to the Namur chronology for the time span of 1363–1500 (Table 4), suggesting that they share several samples and therefore the Meuse Valley chronology could represent a source area close to the city of Namur (Fig. 4).

The Western Germany chronology correlates well with the Holland, Cologne, Meuse Valley, and Hertogenbosch chronologies, suggesting that the Western Germany chronology contains samples from many localities. However, the highest correlation is to the Meuse Valley chronology, especially with regards to glk, possibly indicating that the borderland to Belgium and Holland is a good provenance for the Western Germany chronology (Table 5).

The South East England chronology correlated very well with reference chronologies from the European mainland and this raised the possibility that the South East England chronology might contain timber from the European Mainland. However, the t-value is sensitive to the length of the overlapping chronologies (Baillie and Pilcher, 1973). When correlating only the 1300–1500 window, the correlation between the South East England and the European mainland chronologies decreases considerably indicating that the timber from the South East England chronology, at least for the time period 1300–1500, is sourced from England. Another aspect to consider when comparing chronologies is that during its construction a chronology might have been dependent on already existing chronologies that could explain some similarity.

4.3. Provenance of the Gribshunden timber

Where did the Gribshunden timber grow? The highest correlations were found in the northwestern part of Mainland Europe (Fig. 5). The highest correlation to the 20552389 chronology was with the Meuse Valley, followed by the Hertogenbosch, Western Germany, and South East England chronologies. The high correlation with the South East England chronology posed a problem due to the distance from England to the other reference locations. But by excluding the outermost 27 rings the correlation with the South East England chronology markedly decreased, clearly indicating that the source of the Gribshunden timber was not England. A similar decrease can be seen in the correlation to the Mosel valley chronology, excluding that source area as well.

An increased correlation when applying the valid time span can be seen in all the reference chronologies in the Meuse River drainage area. Matching ring-width extremes and long overlaps increases the t-value,
whereas the glk is less sensitive to these factors. Therefore, correlations with a high t-value but a low glk should be used with caution when determining provenance. For instance, despite the high t-value the Gribshunden timber is unlikely to have been sourced close to the city of Hertogenbosch. Instead, the most likely source area is further upstream along the Meuse valley, where we find reference chronologies with both high t-value and glk. An area west and north of the Ardennes Mountains, limited by the city of Maastricht to the north and its southern limit somewhere south of the city of Namur represents the most likely source area for the Gribshunden timber. (Fig. 5). Possibly the source area could stretch as far south as northernmost France, but the limited possibility to float timber through the Ardennes should also limit the source area.

The mean ring width of the trees stretches from 1.1–3.1 mm with an average mean ring width of 1.8 mm, excluding sample 55242 containing a high average mean ring width of 1.8 mm, whereas Gribshunden timber can be compared with mean ring widths of other shipwrecks from the Netherlands and northwest Germany. A compilation of mean ring widths from five shipwrecks dated from the 14th to the 17th century show ring widths around 1.5–2 mm, similar to Gribshunden, whereas three ships show ring widths of around 2.8 mm and one ship 1.3 mm (Von Arbin and Daly, 2012; Leméé, 2006). Together the data indicate that the relatively open forest type the Gribshunden timber originated from was common in northwest mainland Europe, suggesting that these forests had already been thinned out by this time. Consistently, the inflow by the 14th century of southern Baltic timber into Europe, found in e.g. ships and panel paintings, further indicates the lack of local timber resources (Von Arbin and Daly, 2012).

4.4 Ship construction site and Danish procurement

Gribshunden represents the first generation of a vessel type that Iberian shipbuilders developed in the 15th century. It was an amalgamation of Mediterranean and Northern European styles, featuring a “balanced rig” combined with a carvel hull capable of carrying a heavy deck load including artillery (Adams, 2013). It is possible that King Hans recognized the advantages this ship type offered, but despite having forests of suitable timber in his realm, he did not have the requisite construction expertise in his own shipyards to build this new ship. This is supported by large sample volumes of 15th-century oak from churches from the then-Danish province of Scania harbored at the National Laboratory of Wood Anatomy and Dendrochronology, suggesting that timber was readily available for ship construction within King Hans’ dominion.

As a remedy, he purchased the ship from a builder in Belgium or the Netherlands. Information about the shipyard location has not been preserved through history, but with the timber provenance we can suggest the shipyard’s construction locality. Assuming that the timber was floated down the River Meuse towards the Rhine-Meuse-Scheldt delta in present-day Netherlands, towns such as Rotterdam and Antwerp could be possible construction locations for Gribshunden.

Hans was likely the first and only owner of the ship. If the trees were felled in the winter of 1482/93, they would have been “seasoned” and allowed to dry for a year or more before construction commenced. Building and fitting-out would have taken perhaps another year, making 1485 the earliest year of delivery. Hans possessed the ship at least as early as May 1486, as evidenced by a letter he wrote while aboard the vessel (Eitting et al., 2020).

5. Conclusions

Gribshunden is a remarkably well-preserved and historically significant shipwreck. Written accounts provide the date and circumstances of the sinking, providing a terminus ante quem for the dendrochronological analysis described here. The possibility that this new ship type was Dutch-built suggests that Hans not only sought technological advantage but had the trans-European political and economic connections to obtain the vessel. Continued excavation will reveal details of the construction. Additional elements of the ship will be the subject of future dendrochronological studies, to trace ship usage and repair. Combined with the authors’ studies now underway of wooden barrels contained in the hold, dendrochronological analysis will provide new views of the medieval economy and political connections in the late medieval period.

Declaration of Competing Interest

The authors report no declarations of interest.

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