Timber, Trade and Tree-rings.

A dendrochronological analysis of structural oak timber
in Northern Europe, *c.* AD 1000 to *c.* AD 1650.

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Summary

In this study we set out to describe and refine the method by which we determine the origin of ancient oak timber using dendrochronology. Many aspects needed to be discussed, from the point of view of developing a method to determine provenance to a more local level than previously. The development of the method is initiated on the basis of tree-ring data from living trees, where a set of procedures and rules could be defined. However in the subsequent application of the method of determining the origin of the timber from ancient structures, consideration has to be taken of problems of the historical and/or archaeological context. A series of case studies is presented where the dendrochronological analysis of oak timber from shipwrecks and barrels found in an archaeological context are described, and an attempt is made to determine the origin of the timber. A varying level of detail is applied in each case, depending of the number of samples that are analysed, and depending on the nature of the results that emerge. In some cases a clear provenance to a local level can be attained, while in other instances we can identify the timber origin only to the regional level.

The main points that have emerged can be summed up as follows. It has been shown that we can refine the provenance determination technique by testing the tree-ring curve from a structure at three levels. The first level test checks the curve against master chronologies. The second level test is where we test the tree-ring curve with site chronologies. At the third level we check the curve with single tree-ring measurements or indices.

In the dendrochronological provenance determination exercise, just as *t*-values of greater than 3.5 are interesting when looking for the date of an object, *t*-values greater than *c*. 9.00 are interesting when looking for the provenance of the object. But more importantly, as in dendrochronological methodology, where a date for a tree-ring curve is also checked visually before a position is accepted, the distribution of the correlations and the overlap and replication of the well matching sites is examined before a provenance is suggested. In other words we must look at the geographical distribution of the correlation results in every test. In keeping with a dendrochronological term where an undated chronology is called a ‘floating

chronology', we might refer to the dated but transported chronologies (the panel painting data, the Norwegian timber abroad, site chronologies identified as not native to the area in which they are found) as 'geographically floating'.

We know that timber transport increased over the period dealt with here, but forests, woodland and trees still grew and were utilised locally. It is this combination of usage of local and imported timbers for different uses that allows us to be able to map the movement of timber. As oak timber is easier to work while still 'green', preparation at source is necessary, and thus the decision as to what use the timber will be put to might already have been made at source. While the market for the oak panelling that we see in the 14th and 15th centuries might be reliable and regular enough that the production of this timber product could have been a standard activity, it is possible that the preparation of timber for shipbuilding was carried out to fill specific orders, and not as a routine timber product. We can begin to conclude that the transport of bulk oak has to go hand in hand with other lighter timber species, especially when rafting, as the oak timber alone will not float. Oak worked into planks and boards etc make them far more easy to handle, and thereby possible to export on a large scale, while substantial oak timbers, transported over long distances, are a relative rarity. All in all it is logical that if oak is available nearby chances are that it is used, rather than going to all the trouble and expense of using long-distance transport. So the conclusion is that the predominant practice was the use of local oak. Imported oak being the exception, not the rule. It is not until the 16th century that we begin to see the necessity for the transport of oak, and this occurs for those regions which run out of native resources. In this period also we see the increasing dominance of conifer as the main structural timber for building.

For the purposes of identifying the occurrence of the transport of timber, as a raw material for shipbuilding, it is shown that the analysis of samples from several timbers of varying form and function in a ship's structure, bring us nearer the true picture of the timber origin, and the region where the ships were built, which are, by the 15th century, not necessarily one and the same thing! Indeed the pattern emerging seems to point towards the start of the 15th century as the point where, at least in the archaeological record, we see that timber for ship building is shipped to a ship building site some distance from the site where the timber was harvested.

In light of the frequent appearance of ancient oak from archaeological sites and from panels and inventory in historic buildings in Western Europe, which shows by dendrochronology to have an eastern Baltic origin, more tree-ring data for oak from the Polish but also from the other Eastern Baltic countries would allow more detailed information of this extensive historic timber trade (Ważny 2002; Haneca et al 2005). Clearly, continuing cooperation with dendrochronology laboratories from the underrepresented regions will be an enormous asset for the provenance determination of ancient oak.

It can be seen here that when sampling for dendrochronological analysis there is enormous potential for the recording of the types of timber utilised over time, in historical buildings and in the remains of construction found in archaeological excavations. With the possibility of precise felling dates and a review of the quality, dimensions, conversion and tree-age of timbers, we would come towards a detailed picture of the timber in terms of resource availability through time. Not only could we identify instances of imported timber by provenance determination, we could also identify trends in the availability of building timber. This discourse would though have to take into account the different status or social context of the buildings or other constructions, for which the timber is used. Account should be taken for the possibility that the type of timber used in any construction is not necessarily reflecting timber availability, but rather the choice of specific materials with specific qualities.

Resumé (Summary in Danish)

Denne afhandlings formål er at beskrive og raffinere den metodik, hvormed oprindelsesområdet for gammelt egetræstømmer kan identificeres, ved anvendelse af den dendrokronologiske metode. Det har været nødvendigt at undersøge mange forskellige aspekter med henblik på udvikling af en metode, der kan identificere proveniensen til et mere lokalt niveau, end tidligere er blevet gjort. Udviklingen af metoden er begyndt på basis af årringsdata fra nu-levende træer, hvor et sæt procedurer og regler kan defineres., Ved den efterfølgende anvendelse af metoden til bestemmelsen af oprindelsesområdet for tømmer fra gamle konstruktioner, er det imidlertid vigtigt, at problemer, som opstår i materialet med hensyn til dets historisk eller arkæologisk kontekst, tages i betragtning. Der præsenteres en række case studies, i forbindelse med hvilke den dendrokronologiske undersøgelse af egetræ fra et udvalg af skibsvrag og tønder, som er fundet i arkæologiske kontekster, beskrives, og det forsøges at bestemme oprindelsesområdet for tømmeret. En varierende detaljeringsgrad anvendes fra sag til sag afhængigt af antallet af prøver, der er undersøgt samt afhængigt af karakteren af de resultater, som kommer frem. Ved nogle af eksemplerne opnås et klart billede af tømmerets oprindelse til det lokale niveau, mens det ved andre eksempler kun er muligt at identificere tømmerets oprindelse til et regionalt niveau.

Resultaterne af denne afhandling kan opsummeres som følgende: Det er bevist, at metodikken hvormed et oprindelsesområde kan identificeres, kan raffineres ved at teste årringskurven fra en konstruktion på tre niveauer. På det første niveau sammenlignes årringskurven med grundkurver. På andet niveau testes hvor årringskurven ligger sammenlignet med lokalkurver. På det tredje niveau sammenlignes årringskurven med hver enkelt årringskurve i datasættet.

I forbindelse med udførelse af den dendrokronologiske bestemmelse af oprindelsesområdet gælder det, at hvor *t*-værdier højere end 3,5 er interessante, når vi skal finde dateringspositionen for årringskurven fra en egetræsgenstand, er *t*-værdier, som er højere end ca. 9,00, interessante, når vi vil finde oprindelsesområdet for egetræet. Imidlertid er det endnu vigtigere, at ligesom ved den dendrokronologiske metodik, hvor en mulig dateringsposition for en årringskurve

også verificeres visuelt, før en datering er accepteret, så undersøges både den geografiske spredning af korrelationsværdierne samt overlapningen og replikationen af de lokalkurver, som giver højeste overensstemmelse, før oprindelsesområdet bliver forslået. Man bør med andre ord se på den geografiske spredning af korrelationresultaterne for hvert test-niveau. Hvor det viser sig, at lokalkurver ikke kommer fra det sted, hvor de er endt i det arkæologiske materiale, bør vi ikke inkorporere disse i regionale grundkurver - hverken for fundområdet eller oprindelsesområdet. Hvis vi derimod holder os til en dendrokronologisk terminologi, hvor en årringskurve, som ikke er dateret, kaldes for en "flydende grundkurve", kan vi beskrive lokal- eller grundkurver, som er dateret, men som består af transporteret tømmer (f.eks. de kunsthistoriske egetræspaneler, norsk egetømmer fundet udenfor Norge eller andre lokalkurver, der er identificeret som ikke hjemhørende til det sted, hvor de blev fundet) som "geografisk flydende".

Fra den periode, som behandles her, ved vi at transport af tømmer øgedes, men også at træ fra skove, skovpartier og enkelt-voksende træer stadigvæk blev benyttet lokalt. Det er denne kombination af brugen af lokalt samt importeret tømmer til forskellige formål, der gør, at vi kan kortlægge tømmertransport. Da egetømmer er nemmere at bearbejde i ulagret tilstand, er for-bearbejdning ved fældningen nødvendig, og derfor kan beslutningen, om hvilken anvendelse tømmeret skal bestemmes til, være blevet taget på forhånd ved tømmerets kilde. Mens markedet for egetræspaneler, som vi ser i det 14. og 15. århundrede, kan have været stabilt nok til at produktionen af dette tømmerprodukt var en standard tømmer-forarbejningsaktivitet, mener jeg, at forberedelsen af tømmer til skibsbyggeri blev udført for at opfylde specifikke ordrer og ikke som et rutine tømmerprodukt. Jeg er nået frem til den konklusion, at transporten af egetræ i massive størrelser skal gå hånd i hånd med andre lettere tømmerarter, især i forbindelse med tømmerflådning, fordi egetømmer alene ikke flyder. Egetræ, der er bearbejdet til planker og paneler, er langt nemmere at håndtere og bliver derfor muligt at transportere i større skala, imens stort massivt egetømmer, transporteret over lange distancer, er en relativ sjældenhed. Alt i alt er det logisk, at hvis egetræ er tilgængeligt lokalt, er det mest sandsynligt at man bruger det, i stedet for at have ulejlighed og omkostninger ved at benytte lang-distance transport. Så konklusionen er, at den dominerende praksis er anvendelse af lokalt tømmer. Importeret egetræ er undtagelsen - ikke reglen. Det er ikke før det 16. århundrede, at vi begynder at se nødvendigheden af transport af egetræ, og dette sker for de regioner, som løber tør for lokale ressourcer. I denne periode ser vi også en øget brug af nåletræ som almindelig konstruktionstømmer i byggeri.

Med det formål at identificere tilfælde af transport af tømmer som råmateriale specifik til *skibsbyggeri*, demonstrerer nærværende arbejde, at en analyse af prøver fra adskillige tømmerstykker af et udvalg af former og funktioner i skibets konstruktion giver et bedre billede af tømmeroprindelsen og af regionen, hvor skibet er bygget, hvilket, når vi når til det 15. århundrede, ikke er en og samme ting! Det billede, som begynder at tegne sig, peger på begyndelsen af det 15. århundrede som tidspunktet, i hvert fald i det arkæologiske materiale, hvor tømmer til skibsbyggeri er blevet transporteret til en skibsbyggeplads en vis afstand fra det sted hvor tømmeret blev fældet.

Set i lyset af hyppigheden af forekomsten af egetræ i arkæologiske kontekster samt i paneler og inventarium i historiske bygninger i det vestlige Europa, som ved hjælp af dendrokronologi viser sig at have en oprindelse i den sydlige eller østlige Østersøregion, vil yderligere årringsdata for eg - både fra Polen og andre af de baltiske lande - betyde muligheden for at tegne et meget mere detaljeret billede af denne omfattende historiske tømmerhandel (Ważny 2002; Haneca et al 2005). Fortsat samarbejde mellem dendrokronologiske laboratorier fra underrepræsenterede regioner vil være nødvendig for bestemmelse af oprindelsesområde for gammelt egetræ.

Det kan endvidere påpeges, at når der tages prøver til en dendrokronologisk undersøgelse, er der et stort potentiale for dokumentation af de typer tømmer, som er anvendt, over tid, i historiske bygninger og i resterne af konstruktioner fundet på arkæologiske udgravninger. Med muligheden for præcise fældningsdatoer og med en gennemgang af kvaliteten, størrelsen, form og alderen på tømmeret, vil vi kunne nærme os et detaljeret billede af tømmerressourcens tilgængelighed og tilstand gennem tid. Vi vil være i stand til ikke bare at identificere tilfælde af importeret tømmer ved hjælp af proveniensbestemmelse, men også til at identificere udviklingen i tilgængeligheden af bygningstømmer. I forbindelse med denne diskurs vil det dog være nødvendigt at tage hensyn til forskelle i status eller social kontekst, som de bygninger, eller andre konstruktioner i hvilke tømmeret er brugt, har tilhørt. Ligeledes bør der tages hensyn til muligheden for, at den type tømmer, som er benyttet i en konstruktion, ikke nødvendigvis afspejler tømmerets tilgængelighed, men måske snarere specifikke valg af materialer med specifikke egenskaber til forskellige formål.

Introduction

Dendrochronology is the study of the pattern of wide and narrow tree-rings in timber, with a view to identifying the date of felling for trees. The basic tool for the analysis is the master chronology: an index of tree-ring widths, year for year, over often many centuries, for a particular region. The master chronology is built using first living trees, where the actual calendar year in which each tree-ring was formed is known, and extending back in time using historical timber. Eventually a long sequence is formed, which is then averaged to form the master chronology.

Due to several decades of dendrochronology studies in Northern Europe by different researchers, a network of these regional master chronologies for oak, *Quercus sp.*, now exist. These chronologies have been used for dating ancient oak of unknown age as a very precise dating technique for the archaeological and historical disciplines. Furthermore this network of master chronologies has enabled the identification of the region of origin of ancient oak.

Unfortunately, in that the master chronologies for oak are built of data from wide regions, only long-distance timber transport is detected in the dendrochronological provenance determination exercise. It could be concluded, for example, that an ancient ship had been built from oak which grew in Western Denmark, or in countries on the Southeast Baltic coast.

In this study, we wish to move away from using the master chronology for provenance determination, to see if it is possible to identify the origin of oaks to a more local level. To do this, it is necessary to go back to the original measurements of oak, and assemble them in smaller local groups, so that the Northern European region would be covered in a network of local tree-ring chronologies, instead of the regional masters. Putting it another way, the task for this study was to begin from the beginning.

This entailed the re-examination of the original raw tree-ring measurements for every site or structure where oak measurements were available. The resource for this study consists of raw tree-ring measurements for oak for 2,304 sites from Northern Europe. This data was assembled by the cooperation of dendrochronologists from laboratories in several countries, during a EU-funded project in the 1990s entitled “Climate from tree-rings”. After checking for errors and various features in the data for each site, measurements were grouped within the site, to form a site chronology: an average of the tree-ring widths from the site. All this data is connected, through their map coordinates, to a geographical information system, so that the correlation, calculated between tree-ring data from structures of unknown origin (ancient shipwrecks for example), and the raw measurements and site chronologies from these sites, can be displayed geographically. The maps produced then are the basic tool in the interpretation of the provenance of the ship’s timbers to a more local level than has previously been possible.

Structure of the Thesis

Section I

In the first section, the background and methodology of the technique is discussed, beginning with a description of dendrochronology, including a short history, a description of the dataset that has been analysed in this study and continuing with an outline of the various aspects of the dendrochronological technique, from statistics to problems of data coverage. Finally, a number of test cases are presented, using the living tree data, to outline aspects of the technique where the provenance parameters are known.

Section II

The second section presents a series of case studies of the application of the dendroprovenance technique. The case studies are of dendrochronological analyses of a selection of ancient shipwrecks and barrel parts, chiefly from the medieval period.

Section III

The third and final section discusses the implications of the technique for our interpretation of timber trade in the past, and for the analysis and interpretation of ship technology in the past. Aspects of the discoveries made in this study are looked at in the context of trade, ship design and the timber resource.

Appendices

Papers prepared during the course of this study have been submitted to various publishers. Two were submitted to peer review journals and are included here (appendix 1 and appendix 2) as two case studies. Both papers are now published.

Appendix 1. Daly, A., 2006. The dendrochronological dating of timber crossings in west Jutland, Denmark. *Journal of Wetland Archaeology* **6**, 2006, 19-48.

Appendix 2. Daly, A., 2007. The Karschau Ship, Schleswig-Holstein: Dendrochronological Results and Timber Provenance. *International Journal of Nautical Archaeology* 36.1, (March 2007), 155-166.

Section I

1 Chapter 1: Background

The development of dendrochronology as a dating technique is described elsewhere (Baillie 1982) and its initiation in Europe was to a large part to develop a check on the 14C methodology, that is to gather material to enable the calibration of the radiocarbon timescale. The development of chronologies for oak in Ireland and in Germany from sub-fossil trees for the prehistoric period enabled precise dating for oak structures in the archaeological record. The application of dendrochronology in the historic period especially though, has had enormous impact on the archaeological discipline, allowing in many cases dates to within a single year, which in turn allows direct comparison of archaeological discoveries with historical events.

Early on in the development of the technique, consideration was taken of the context of the timber being dated, such that ship timbers, for example, were not included in regional chronologies, as the probability that these were of an exotic origin was high. The possibility of using dendrochronology to identify the origin of ship timbers was also acknowledged quite early (Baillie 1977). Ship timbers, reused in Viking Dublin, had been dated using the tree-ring series from oak from primary contexts, leading to the comment that it at the very least showed that shipbuilding *was* taking place in the Viking town: "work has shown a strong possibility that the majority of ship derived timbers from the Dublin sites were in fact local in origin" (Baillie 1977, 15). Baillie goes on to write that chronologies constructed using locally grown oaks: "can ultimately be used not only for dating purposes but for possible attribution of 'exotic' ship timbers found in excavation contexts in Ireland or elsewhere" (Baillie 1977, 19). Baillie's prediction proved strikingly correct, when the Dublin chronology he describes in that paper became the key chronology in the provenance determination of the oak from Skuldelev 2 from Roskilde, Denmark (Bonde and Crumlin-Pedersen 1990) (see below).

In an analysis of barrels from predominantly 8th century wells, found in Dorestad in the Netherlands, it was expected that the oak tree-ring series would date with Dutch chronologies but this was found not to be the case. The many barrels (34 wells were dated) gave the highest agreement with chronologies from Mainz, up the Rhine River in Germany (Eckstein 1978). In the description of the origin of the oak, a map is shown showing the sites for which chronologies existed at the time (24 early medieval series). On the map, circles are drawn to indicate which sites the barrels match with best (Eckstein 1978, 311). Although the actual correlation values are not given, a clear indication is apparent of a central zone of highest agreement, and decay with distance of the degree of correlation.

In analysis of three ships from the Netherlands it was pointed out that the dendrochronological method could be used to identify the origin of the timber (van Holk 1987). Using the few master chronologies available at the time, van Holk found that the timber for all three ships were made of timber that had not grown in the Netherlands.

The similarity of the tree-ring curve from a boat, dating to 1548, from Stockholm, to a southwest Skania chronology (Sweden) also prompted the suggestion that dendrochronology could be used to show where a tree had grown (Bartholin 1988, 286).

So several researchers over the decades were pursuing the possibilities of provenance determination. The possibility though of identifying the origin of ships' timber was really only actively pursued when the dating of the longship, Skuldelev 2, found in Roskilde Fjord, Denmark, was being analysed. Failing to achieve a date with Scandinavian references, and prompted by the information that features of the ship construction could point towards England, Niels Bonde, from the Danish National Museum, found that the ship dated using English and Irish chronologies, and found that it matched best with Baillie's chronology from Viking Dublin (Baillie 1995, 133). A short note of the finding was published in 1990 (Bonde and

Crumlin-Pedersen 1990). A ship, whose date was subsequently refined to the spring or summer of 1042 (Crumlin-Pedersen 2002, 185), found in Roskilde Fjord at Skuldelev, had been built of Irish oak. This dramatic finding became the catalyst for dendrochronological research into timber origin especially in Denmark, where soon the identification of the provenance of the timbers from medieval shipwrecks became as important as the date. The term dendroprovenance was coined, and published in Bonde et al 1997. Over the next decade or so then, provenance determination was attempted for archaeological material, but no real analysis of the mechanisms of the techniques being used, nor any full publication of dendroprovenancing as a technique, was forthcoming. Articles outlining specific results have been published (Bonde 1994, 1995; Crone and Fawcett 1998), as have papers with particular reference to the Baltic timber trade (Bonde et al 1997; Ważny 2002). Aspects of the technique have also been published, for example with a view to examining the possibilities of provenance determination within Britain (Bridge 2000). More frequently though, the dating and provenance results of dendrochronological analyses are disseminated in report form (for example Bartholin 1998; Bonde 1999; Crone 2000; 2002; Daly 1999b; 1999d etc, Hanraets 1999 etc.). In Bonde et al (1997), it is suggested that the further development of the technique of dendroprovenancing should deal with the remaking of smaller chronologies for the Northern European region and that, in essence, is exactly the task in this study.

2 Chapter 2: Dendrochronological data

There are some basic concepts and techniques in dendrochronology, which are described elsewhere (for example Baillie 1982; 1995) but some aspects are dealt with here, as they have a direct bearing on the study. The dataset which is analysed in this study is also described, including the way in which it is organised and some of the problems that have to be dealt with. Only oak data is included in the study. There are several reasons for this. The durable nature of oak timber combined with its longevity makes it the most valued structural timber over history. Its durability ensures its survival in many historical buildings and underground structures, available for study. Its longevity, and its growth behaviour (oak almost always forms a tree-ring every year, even under stressful growth conditions) make it a perfect species for the dendrochronological technique. This combination of factors means that the most successful dendrochronological analyses in Northern Europe are with this species, resulting in a wide network of chronologies for oak for the region. Analyses of other species have also been successful, especially of conifers where chronologies are being built for example for much of Scandinavia. Other species have sometimes been successfully dated against oak references, for example beech (Uwe Heußner pers. comm.) and ash (Daly 1998a) but work with these species is beyond the scope of this study.

2.1 *The master chronology*

The basic tool of the dendrochronologist when dating a tree-ring curve is the master chronology. A master chronology is built by averaging, at every year, the ring widths for many trees together to form a single continuous curve, representing, year for year, the variation of tree-ring widths in a region. The basic master chronology is begun by first taking ring-width measurements from living trees, and cross-matching the tree-ring curves. Samples are then taken from ancient timbers in buildings, or from archaeological sites where the preservation of timbers has occurred, and this material is cross-matched with the living tree data, thus lengthening the period of time for which tree-ring widths are recorded. As the felling (or sample extraction) year of the living trees is known, identification of the exact year each tree-ring was formed can be controlled. By building up a large dataset of tree-ring measurements for a region, all linked through cross-matching, back to the living trees, the exact calendar year for each tree-ring, back into antiquity, is known. When the large continuous dataset is collected, the master chronology can be built.

Laboratories in several countries have, since the 1970s, been working in their regions, building master chronologies for dating purposes. The map (Fig. 1) indicates the regions covered by master chronologies for oak over Northern Europe. The map shows just a selection of the chronologies that have been made over the past 40 years or so. There is no sharp boundary between chronologies. Indeed master chronologies are not static things. Dendrochronologists in many laboratories are constantly generating additional tree-ring measurements, as the need for dating analyses from the archaeological and architecture-historical disciplines is nearly constant. Master chronologies can exist therefore in many versions, where new data is added to the region, and new masters are built. For dating oak from Northern Europe a very useful network of chronologies is available to dendrochronology. These chronologies were exchanged between certain laboratories and have formed the basis of the initial provenance determination tool.

An initiative to assemble a database of chronologies by Tom Levanic (Biotechnical faculty, Ljubljana, Slovenia) resulted in a web-based searchable catalogue where no less than 48 laboratories have submitted lists of their chronologies (Hillam 1997). The idea with this catalogue is that contact can be made to the relevant laboratories to gain further information. A world tree-ring database is also running, the International Tree-Ring Data Bank, but for Europe the oak data consists chiefly of living tree data, and is not by any means complete. Provenance determination requires that a full suite of chronologies is available over the region being studied.

Timber which has travelled long distances, will stand out, in the cross-matching exercise, as being very different from the native timber, as in the case of the Baltic oak panels in western Europe. Timber which has been transported shorter distances is not so readily identifiable, and in chronology building therefore, can very easily have been included in these large regional master chronologies. In major towns with their speedy growth in the medieval period, timber for more robust construction like prestigious buildings, waterfronts etc, might have quite quickly exhausted the local structural timber supply and will have required the transport of timber from greater distances than buildings in rural areas. The large amount of timber for example, which has been analysed for Gdansk, and used to build a master chronology for the Pomerania region of Poland, had its source further up the Vistula River. Indeed the early portions of such a large master might be of more local timber, but increasingly where the master chronology covers later time periods the master represents a wide region climatically. This might mean that if we try to make direct comparison of correlation between a single site and a network of master chronologies, the varying properties of the different masters, determined by the varying history of the sources of the timber, which make up the master, will affect the correlation levels in the analysis. A master from the timbers in Gdansk, which by the late medieval period was a major exporter of so-called wainscots and other timber products, rafted down the Vistula River from inland forests in what is now Poland, could reflect a large region climatically, giving very high correlations with ancient ship timbers, barrels and painting panels, leading to the assumption that everything came from Gdansk. Care has though also been taken to construct chronologies in Poland of large beams in constructions from eastern Pomerania, far from the Vistula River, thereby avoiding timbers tied in with the Gdansk timber trade, allowing more confident identification of timber from the Pomeranian area (Bonde et.al. 1997, 202-3). The picture now emerging from research into provenance determination of oak in the west, which has a Southern Baltic origin, is that many different sources will in the future be identified (Haneca et al 2005).

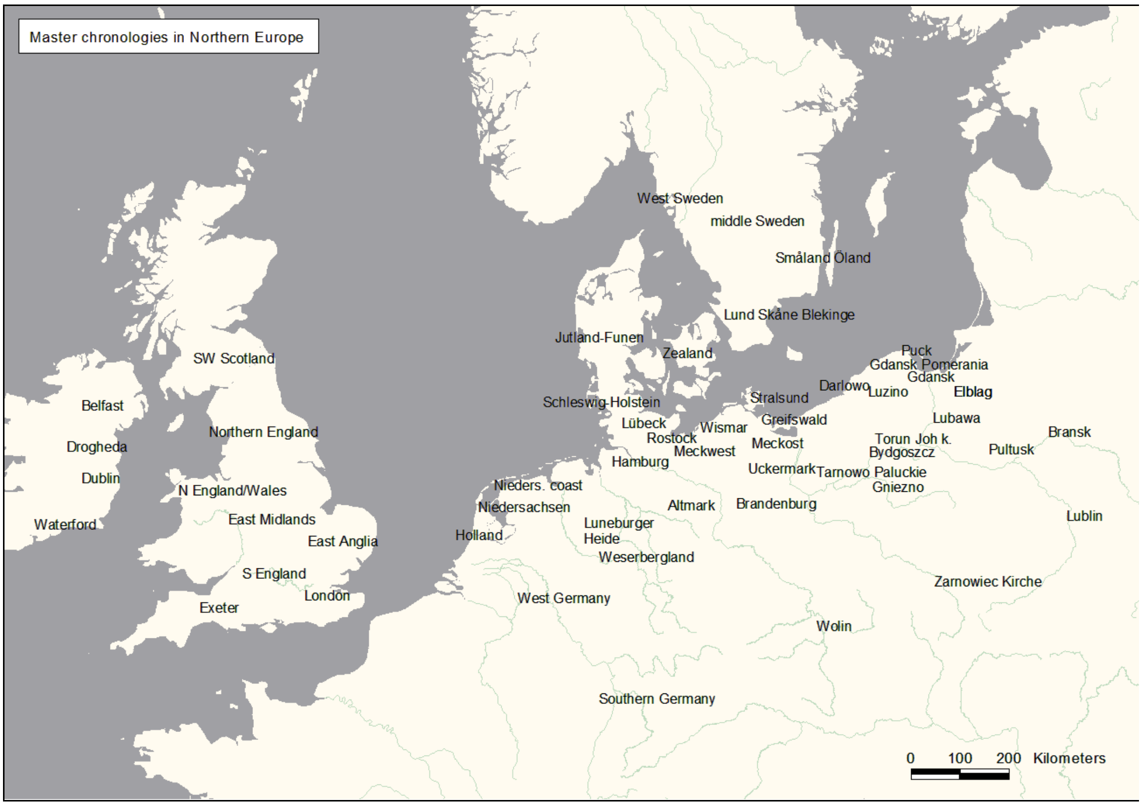


Fig. 1. Map of master chronology coverage over Northern Europe. The map indicates the regions covered by master chronologies for oak over Northern Europe. The map shows just a selection of the chronologies that have been made over the past 40 years or so.

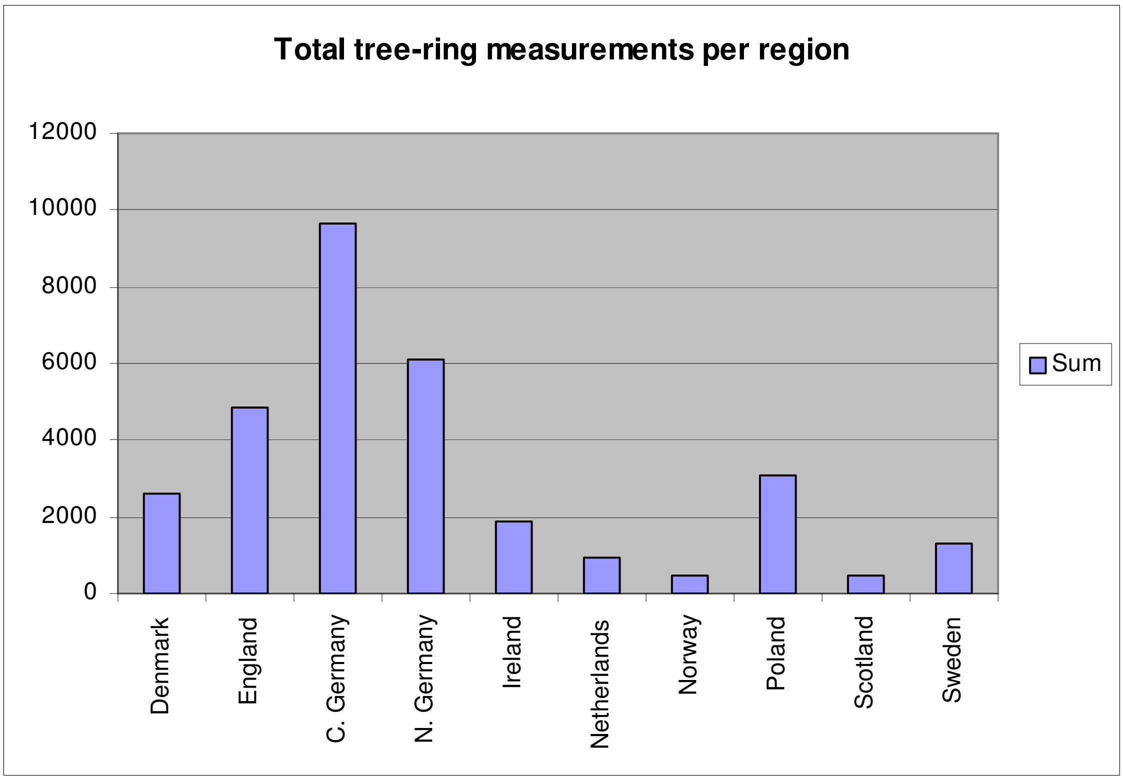


Fig. 2. The number of samples in the dataset, by region. Having removed cockchafer affected tree-ring series the resulting dataset of single sample measurements consist of 16,912 samples.

In the literature these imports of oak in the west are often called Baltic timber, which can be misleading, as many parts of Scandinavia also have Baltic coasts. For example, in his conclusion of the origin of the timber of the Bossholmen cog, Thomas Bartholin determined the ship's timber origin to the south-western part of Scandinavia (Cederlund 1990, 194). This is quoted in Crumlin-Pedersen (2000, 237) as W. Baltic, which is quite a different thing to the "Baltic timber" referred to in terms of panel paintings and other historic objects of south or south-eastern Baltic provenance.

2.2 *The oak tree-ring data*

In the 1990's, an EU-funded project involving a number of dendrochronology laboratories throughout Northern Europe was set up, entitled *Tree-ring Evidence of Climate Change in Northern Eurasia During the Last 2000 Years*, and this was extended to *Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia – the last 10 000 years*. Results are published in *Holocene* 12.6, 2002 where a whole volume is devoted to a presentation of the work (the oak results are presented for example in Kelly et al 2002; Leuschner et.al. 2002; Spurk 2002). For the climate reconstruction analysis, tree-ring data from the dendrochronology laboratories involved was shared. The data submitted by the laboratories consisted not of chronologies, but of the original individual sample measurements, for living trees and for historical material. Of course for the purposes of this provenance study, this data is invaluable, as it enables the re-working of the provenance determination tool from scratch.

As mentioned, the data consists of measurements of individual samples from 2,304 sites, both modern, living-tree sites and historical or archaeological sites, from the last 2000 years. The number of measurements from each site varies considerably, from a single sample to several hundred in some cases. In addition to the data from the EU-project, measurements of oak from various sites in Denmark, analysed by the author since the end of the EU project, were also included in the dataset.

It was found that all the data had to be checked for errors before grouping the measurements into chronologies. This could only be done by a visual check of the data by plotting the tree-ring curves for each site on screen. This process is described below (chapter 4). It was also found that a number of the mapping coordinates that were attached to the measurements were wrong, and in view of the reliance of the provenance technique, in this study, on the mapping of the results, this was also an important problem needing to be rectified. A third aspect that was to be dealt with was screening for cyclical patterns in the data. The tree-ring growth of oak can be affected by the cockchafer beetle, causing a very narrow ring every three, four or five years (Christensen 1987). While other cyclical patterns can exist in the data these can be of a less regular nature and are not so easy to find the cause. One cyclical pattern can for instance be anthropogenic, in timber which has been pollarded regularly, narrow rings are produced as the tree recovers (Rackham 1990, 17). The way in which the data is screened for cockchafer is described in chapter 4.

Having then removed cockchafer affected tree-ring series the resulting dataset of single sample measurements consist of 16,912 samples. To summarise this data, the diagram (fig. 2) shows the number of measurements in relation to region. Clearly most of the data is from the central German region, those measurements from the dendrochronology laboratory in Göttingen University. The data for Northern Germany (tree-ring data from the Dendro. Lab. at Hamburg University) is the second largest dataset, while the English data is third. A summary of the makeup of this data is organised further, in relation to the time period which the data covers, in 50-year intervals, to gain an idea of the temporal distribution of the data (fig. 3). The diagram shows, for every 50-year interval, from 1950 to the present, 1900 to 1950 etc, the number of samples that cover at least 30 years of that half-century. For the data as a whole it can be seen that there are periods which are well represented, namely the 20th century, (the living tree data) the 16th to early 18th centuries and the 12th and 13th centuries and there are periods with fewer data 1750-1850, the 14th century and as we come further back in time from the 10th or 11th century. In the diagram only some of the series are highlighted with colour, for simplicity. The orange and red colours indicate the number of samples from the two German regions, Northern Germany and Central Germany, while the yellow indicates the Polish data. It is readily apparent from the diagram that certain regions dominate the dataset in different periods throughout the timescale shown. The central German data is present throughout almost the whole of the last 1000 years, though dominating from 1400 to the present. The Northern German data is not large for the modern period but is numerous in the 11th and 12th centuries and particularly in the 15th and 16th centuries and to a certain extent in the 17th century. The Polish data is interesting here, in that the period where it is dominant is in the 13th and early 14th centuries. It can be noted too that the English data dominates in the 10th to early 12th centuries.

The diagram clearly illustrates that all periods are not equally covered geographically and this will of course have a bearing on the final provenance determination, and may be helpful in discovering the reasons for eventual weak provenance results. The distribution map of sites from which the oak tree-ring data used in this study come (fig. 4) also clearly shows the different density of sites geographically, for different regions. There is a dense distribution of sites in the Northern and Central German regions, and for the Danish region, while the relatively few Polish sites, coupled by the size of that region, means that a rather thin density is represented here. As can be seen on the map, there are regions which are not covered in this oak dataset. It was not in the remit of this research to try to fill up these gaps, as the main point of the study is the methodological development and analysis. For the Swedish region, access was given to a number of site chronologies built by Olafur Eggertsson, which have been of help in this research. Additionally, for the Northeast German region, comparison of a suite of tree-ring data for shipwrecks and barrels in this study with regional chronologies from Northeast Germany was carried out by Karl-Uwe Heußner from the Dendrochronology Laboratory in Berlin.

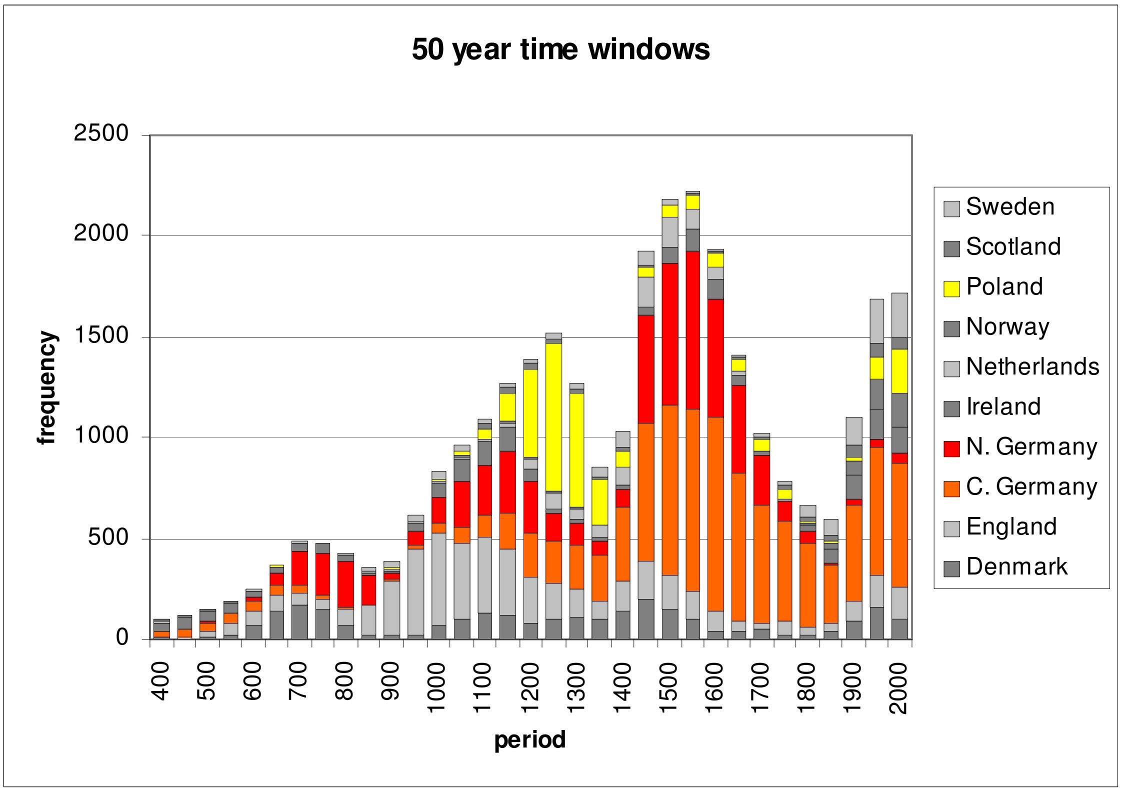


Fig. 3. A summary of the makeup of the EU tree-ring dataset, in relation to the time period which the data covers, in 50-year intervals. The diagram shows, for every 50-year interval, from 1950 to the present, 1900 to 1950 etc, the number of samples that cover at least 30 years of that half-century. It is readily apparent from the diagram that certain regions dominate the dataset in different periods throughout the timescale shown. For the data as a whole it can be seen that there are periods which are well represented and there are periods with fewer data.

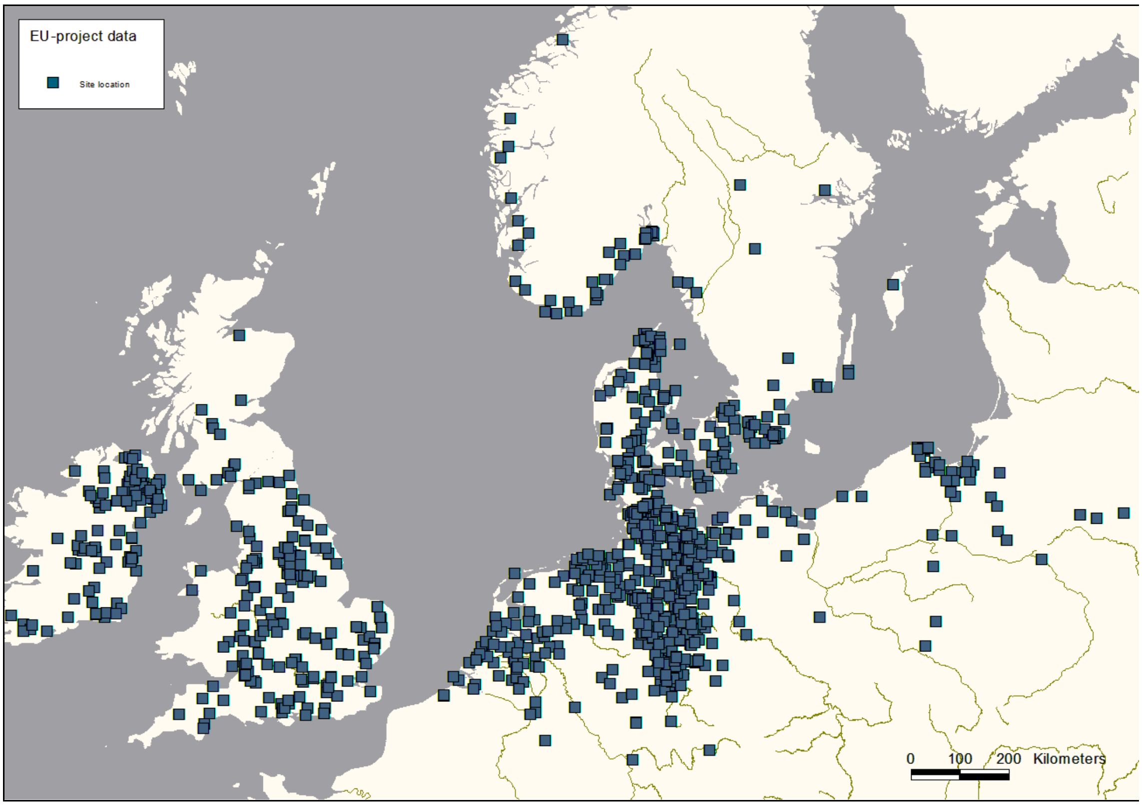


Fig. 4. Distribution map of sites from which the oak tree-ring data used in this study come. The map clearly shows the different density of sites geographically, for different regions.

2.3 *GIS*

One of the key developments in this research is the connection of the tree-ring data to a geographic information system (GIS). With map coordinates for every site in the material any analysis results can be readily mapped, allowing an immediate visual illustration of the results. This is invaluable not only in the analysis process but also for the demonstration of the results in an illustrative format. The maps allow the accessibility of the results not only to peer audiences in dendrochronology but also to audiences in the related fields of archaeology and history, and even to a general audience.

As mentioned above though, some revision of the coordinate information was necessary. These mistakes were spotted when plotting correlation tests at quite an early stage, as it was easily apparent that some of the Danish sites were positioned wrong. The author's familiarity with the material from many of the sites and with the various placenames was because it was the author's role in the EU-project in 1995-1996 to find the coordinates for the Danish sites, and it could be seen, from mapping of the Danish sites for which dendrochronology has been carried out, that the coordinates were not originally incorrect. The mistakes happened in the data at a later stage in the process.

All the coordinate data needed therefore to be checked. The way in which the EU-data was organised though is extremely well structured, and was a great help in this matter. The numbering system for the tree-ring data is organised in relation to geographical regions, for the whole of the dataset. Each tree has an eight-digit filename (fig. 5). The first digit describes which laboratory the data is from. The next two digits indicate the region in which the site lies. The fourth and fifth is the label for the site within that region, while the last three digits give the numbering of the individual samples. It was possible then to map the sites for each region, using the filenames as the search criteria, and see which sites fell outside that region. The coordinates could then be corrected. The new coordinate system should ideally be inserted into the actual tree-ring series files but as this would be a time-consuming process, it was chosen to make a single file, listing the correct coordinates for all the tree-ring series. (It is very possible that a routine could be composed to automatically insert the updated coordinates into the individual tree-ring text files but such a job would have brought the study at hand somewhat off track.) When plotting the numerous statistical results the sites are then linked to the coordinate file through the filename or sitecode system, allowing GIS mapping of the statistics.

2.4 *Choice of correlation statistic.*

In most dendroprovenance literature it is the *t*-value that is used as the indicator for the degree of correlation between site means and master chronologies. There are however several versions of this statistic, which are incorporated into the different tree-ring analysis programs. In the DENDRO program by Tyers (1997) the original *t*-value calculation developed by Baillie and Pilcher (1973) is the *t*-value calculation version used in its routines. It is possible to test, in DENDRO, using a second version of the *t*-value calculation (CROS84) (Munro 1984) and using the percentage agreement statistic (Eckstein and Bauch 1969) in the ‘looking for a date’ routine, but when running the date check routines it is the original CROS73 which is applied. It is therefore Baillie and Pilcher’s CROS73 which is used for the correlation matrixes for each site, for the comparison of site means, including the test cases with the living tree data and the numerous ancient shipwreck and barrel data, against the regional master chronologies, against the site chronologies and against the single timbers’ tree-ring curves. What is most important in this context is to be consistent. It can become problematic if we begin to use slightly different *t*-value calculation versions in the same comparison of correlations.

To investigate the different correlation methods I began to check data correlation with several other correlation calculations. Another tree-ring analysis program called TSAP can be used to produce several correlation statistics between tree-ring series. It calculates percentage agreement (Eckstein and Bauch 1969) and CROS73 (Baillie and Pilcher 1973) and it also calculates a “cross-date index” which combines the percentage agreement and the *t*-value. It was discovered in this exercise though that even when the two programs purport to use the same *t*-value (Baillie and Pilcher), if you test the same two curves using DENDRO (Tyers 1997) and TSAP (Rinn and Jäkel 1997) different results appear. This is due to the different filters that are applied to the series before the correlation statistic is calculated. Knobben forest in Germany (this site is discussed in more detail below) matches best with a second forest in the area with a *t*-value of 9.48 using DENDRO, CROS73. When the same two site chronologies are compared using TSAP, t = 7.4 is the result, and using DENDRO, CROS84 the *t*-value is just t = 5.84. When Knobben is checked with another site, with which it gives a high correlation, again the *t*-values are different. DENDRO, CROS73 gives t = 9.20, DENDRO, CROS84 gives 6.02, while TSAP gives t = 7.7. Clearly there is a lot of variation. A full analysis of what causes these differences, and their significance, is needed. This is not carried out as part of this study, but should be tackled by a statistician. In conclusion, for this study, only one *t*-value calculation is used; CROS73, and this is most important. Consistency in the *t*-value calculation means that *t*-values can be directly compared in the maps of the results.

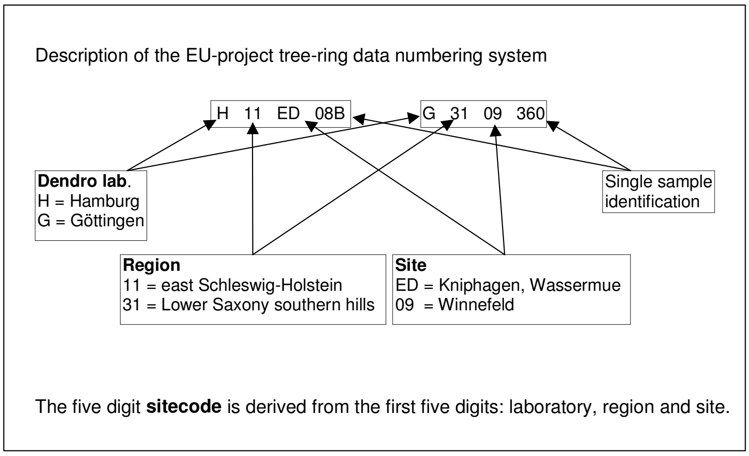


Fig. 5. Diagram describing the numbering system of the tree-ring dataset. The numbering system for the tree-ring data is organised in relation to geographical regions, for the whole of the dataset. Each tree has an eight-digit filename. The first digit describes which laboratory the data is from. The next two digits indicate the region in which the site lies. The fourth and fifth is the label for the site within that region, while the last three digits give the numbering of the individual samples.

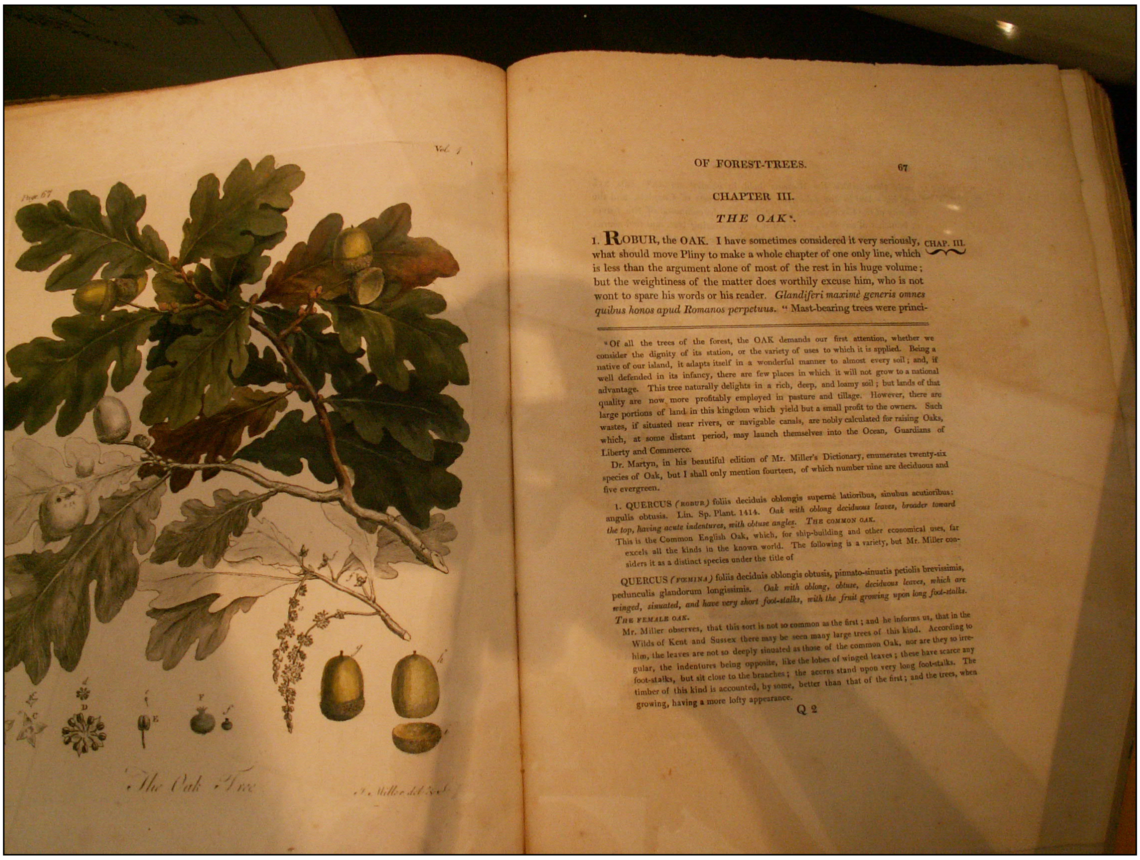


Fig. 6. Photo of the oak page from Evelyn's 'Silva or a discourse on forest trees' (first published in 1664). The text in the notes seems not to be the prose of Evelyn but seems attributed to Dr. Martyn in Miller's dictionary, which was first published in 1731.

3 Chapter 3: Towards a new provenance determination method

3.1 *Grouping the tree-ring data*

In pre-industrial Europe, woodland in some form existed in local areas, exploited locally for fuel and domestic building needs. Historic maps from the late 18th and early 19th centuries, which depict forest cover, show that large or small scale forestry was still to be found. In Denmark, certain areas show a lack of trees, while extensive woodland can be seen in other parts. Pollen analysis of deposits in small lakes in Denmark, have shed interesting light on aspects of forest cover in Denmark over the historic period. The pollen information from small lakes tends to reflect local vegetation cover. Lakes in areas with forest, and in areas with no forest, were chosen for analysis, to compare aspects of vegetation history in the contrasting landscapes. The general conclusion that was reached was that the pattern of forest distribution on the late 18th century maps was detectable in the pollen deposits also further back in time, into the medieval period (Odgaard and Rasmussen 2000). The continuity of forestry in certain areas is linked to the dominating landscape in those areas. Land which is particularly suitable for arable cultivation, will remain forest free whereas in those areas where cultivation is less optimal, the forestry will be allowed to remain. Neither was forestry just a vacant place, which could shrink or grow depending on peoples' cultivation needs. It was an important resource: not just for building materials, but also for fuel, for berries, fungi and nuts and for grazing of domestic animals.

> "Of all the trees of the forest, the OAK demands our first attention, whether we consider the dignity of its station, or the variety of uses to which it is applied. Being a native of our island, it adapts itself in a wonderful manner to almost every soil; and, if well defended in its infancy, there are few places in which it will not grow to a national advantage. This tree naturally delights in a rich, deep, and loamy soil; but lands of that quality are now more profitably employed in pasture and tillage. However, there are large portions of land in this kingdom which yield but a small profit to the owners. Such wastes, if situated near rivers, or navigable canals, are nobly calculated for raising

> Oaks, which, at some distant period, may launch themselves into the Ocean, Guardians of Liberty and Commerce." Miller's dictionary (Fig. 6).[1]

What if historic maps of vegetation, showing forest cover, could be used to help in defining smaller areas into which the tree-ring data could be grouped? Well this possibility was explored in this study. We have the Danish Videnskabernes Selskabskort showing forest cover and these are digitised (described for example in Dam 2003), but it would be quite a job to locate similar maps for the whole of Northern Europe for this purpose. There is a series of maps though, showing forest cover, at a scale of 1:1,000,000 covering most of continental Europe (Gottholt 1807). Of course at this scale, small local woodlands are omitted, but large forests are depicted. Comparison of the sheets, which cover the Danish region with Videnskabernes Selskabskort, showed that the large Danish forests were included, and it might thus be assumed that an accurate general picture of the extent of forestry in Northern Europe at the beginning of the 1800s can be gained. Taking the evidence mentioned above of the continuity of woodland distribution from the Medieval period until these 18th and 19th century maps of vegetation, and taking the narrative from the 18th century concerning the placement of oaks on marginal land, we might take even the less detailed Gottholt map as a broad indication of forest cover in earlier times.

The reason for this investigation into the geographical distribution of Northern European forestry was initiated with the hope that it could be of use in the choice of smaller areas, within which the tree-ring data could be grouped, for the building of chronologies. Regions lacking forest historically could be taken as boundaries to these areas, thus grouping tree-ring data from a well defined region. Problems with this approach include the following: Due to the random nature of the distribution of sites for which tree-ring data exists, some areas would be well

[1] The text was found in what I think is Hunter's 1786 version of Evelyn's 'Silva or a discourse on forest trees' (first published in 1664 (Rackham 1990, 92)). I saw the book, open at the beginning of the chapter about oak, at an exhibition. The text is in the notes, and is not the prose of Evelyn but seems attributed to Dr. Martyn in Miller's dictionary, which was first published in 1731.

represented while others would have gaps in the tree-ring data. Additionally, for much of north-central Europe, very large tracts of forest were depicted, such that choosing boundaries within these large forests could not be done from the historic mapping alone. An additional problem was the assumption that the areas where forestry was not marked contained no trees. What was the definition of a forest when included in mapping, real vegetation cover or administratively defined forestry? And what of the occurrence of trees outside of the mapped forests or woodlands? Clearly another approach was needed.

Instead of choosing areas for chronology building, the approach that was chosen was to keep the data separate for each site and only group tree-ring data within each site. This would result in a dense network of so-called site chronologies, over Northern Europe. the way in which this was done is described in detail below. The next step then would be to carry out provenance determination using these site chronologies, and showing the results in maps, where the distribution of the correlation values could be plotted. The making of these site chronologies is very time consuming, involving an analysis of each site, one by one, until one finally arrives at a point where a large region is covered.

Another, simpler approach grew out of an investigation into other possibilities in the data, for provenance determination. This initially was in preparation for a conference at quite an early stage of the project, where some results might be presented. Having cleaned the data of those with the cockchafer cycle we were left with the large set of single-tree data, as summarised above. What result might emerge if a shipwreck for example, was tested against every single tree in the Northern European dataset? Single-tree data had never been used in a provenance determination exercise. Perhaps, to some extent because sufficiently large volumes of data haven't been assembled until now, and perhaps also that the power of computing and of computer mapping is really only now ready to handle these large calculations.

The logic behind this idea is that, where trees within a forest can have correlation values as high as t = 10 or higher, then if the forest from which a shipwreck's oaks come is represented in the historical/archaeological building timber data, the single trees may give a very high correlation. This analysis, when mapped for the Kollerup cog, gave very satisfactory results (fig. 57). The test of correlation between the average of samples from the Kollerup Cog and every single tree in the Northern European dataset produced a distribution of highest *t*-values with tree-ring data from sites in Southwest Jutland. Clearly this test was showing a significant result.

3.2 *The method*

As a result of the study of the possibilities in the execution of this study, a procedure was finally arrived at, which has then been consistently utilised in the analysis of the provenance of oak. The provenance of an oak structure is tested at three levels: The first level test is where the average tree-ring curve for the structure being examined is tested against large regional master chronologies. At the second level test the average is tested against existing site chronologies, thus allowing a more refined provenance determination in many cases. The third test is where the average for the structure being tested is run against all single-tree measurements in the dataset. This serves as a control on the second level test.

Throughout the whole process, many maps with various sized circles are produced, as many as three for each averaged group is possible, one for the first level, one for the second level and one for the third level provenance test.

To aid the readability of the illustrations there is a consistency in the choice of colours. When the map illustrates the first level provenance test, blue circles are always used. For the second level test, green circles appear. For the third level test the results appear in red. Therefore, the reader will know immediately which test level is illustrated.

Blue dots	**Master chronologies**	**first level test**
Green dots	**Site chronologies**	**second level test**
Red dots	**Single trees**	**third level test**

In some instances it is helpful to highlight specific results, and here we can give the highlighted circles a lighter shade than the others to make them stand out. The site being tested in each map is also always indicated, by a little, yellow square.

3.3 *Mapping*

Choosing how to depict the correlation results had also to be considered. The plan originally of plotting results on a map of Northern Europe proved to be one of the strongest advantages of this methodology. The maps of correlation results provide a visual illustration of the results achieved, which is extremely useful in communicating the results. However careful considerations of how to depict the results were made. It was found that the simple process of choosing the size of the circle is an extremely important step in the procedure. If quite large circles are chosen for *t*-values of 6.00 for example, with increasing circle diameter for higher values, a large spread of large circles will result, leading to a conclusion that the tree-rings' climate signal is of a wider regional character (fig. 7). Indeed analyses where *t*-values as 'low' as circa 6.00 are used to achieve provenance determination should be treated with scepticism. Consistency again is necessary here. The circle size in every map of *t*-values always indicates the same *t*-value range.

3.4 *Data screening*

The data was, for the EU-project analyses, assembled in long text files, one for each contributing laboratory. The conversion of this file format to the format used in DENDRO meant that a folder, in which each measurement is a text file within that folder, in the DENDRO format, represents each site. There were several details which needed checking after the conversion. The many different computer programs which have been developed independently of each other, for the measuring, cross-dating and manipulation of tree-ring data, all use different file formats. Conversion from the one format to the other causes problems. In the CATRAS program for example (Aniol 1983), tree-rings which are identified while measuring, but which

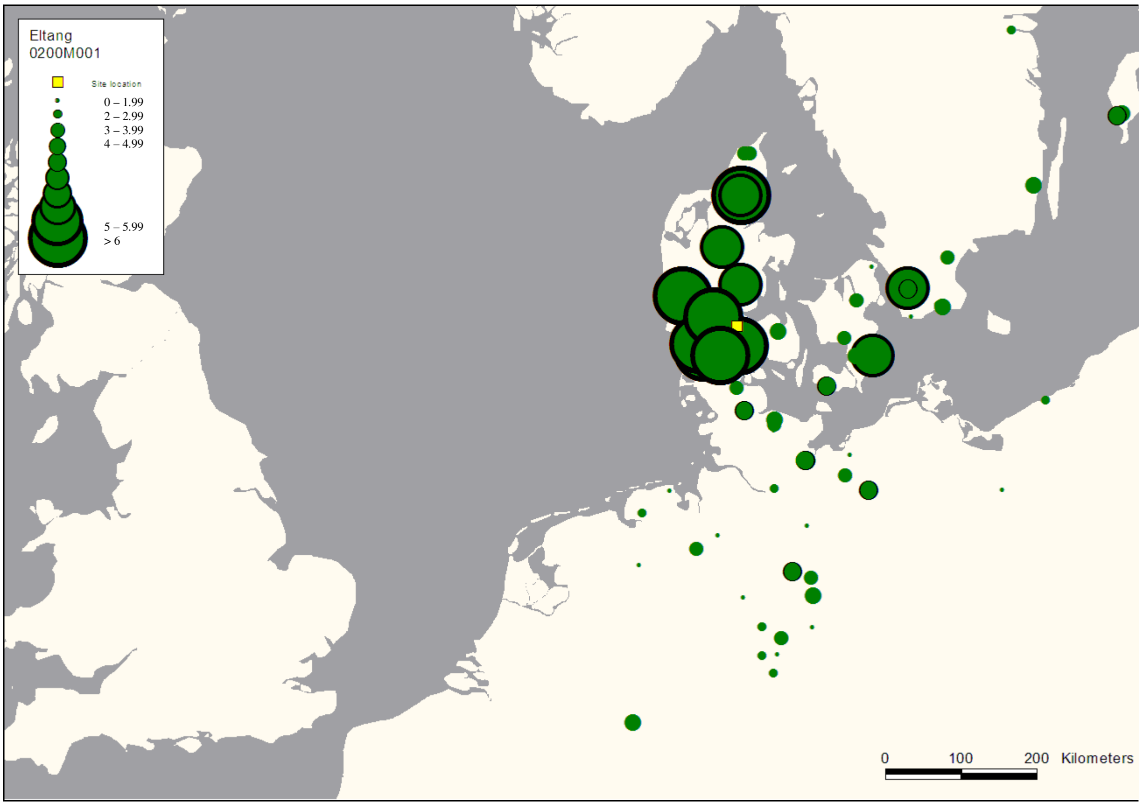


Fig.7. Map of northern Europe, showing the result if a different circle size is chosen. The example is the correlation between the Eltang ship's tree-ring average and available site chronologies. The simple process of choosing the size of the circle is an extremely important step in the procedure. If quite large circles are chosen for t-values of 6.00 for example, with increasing circle diameter for higher values, a large spread of large circles will result, leading to a conclusion that the tree-rings' climate signal is of a wider regional character.

	H111M0G0	H111M010	H111M030	H111M04A	H111M060	H111M020	H111M0JA	H111M08A	H111M0F0	H111M0H0	H111M0BA	H111M0CA	H111M0IA	H111M0KA
H111M0G0	*	3	3,3	3,5	-	-	-	-	3,2	-	4,7	3,6	-	4,7
H111M010	3	*	8,8	5,8	5,8	5,2	5,3	5,6	-	-	3,2	4,3	3,3	4,3
H111M030	3,3	8,8	*	9,2	7,5	7,2	7,3	6,4	4,7	3,7	-	5,2	4,5	4,7
H111M04A	3,5	5,8	9,2	*	6,2	6,6	6	4,5	-	-	-	3,8	4,1	3,7
H111M060	-	5,8	7,5	6,2	*	6,4	7,5	6,7	6,4	6,5	3,3	4,2	-	4,5
H111M020	-	5,2	7,2	6,6	6,4	*	9	8,5	6,6	3,5	4,5	6,2	6,2	3,5
H111M0JA	-	5,3	7,3	6	7,5	9	*	6	3,6	-	3,8	4,9	4,1	3,9
H111M08A	-	5,6	6,4	4,5	6,7	8,5	6	*	5,6	3,8	5	5,7	4,8	4,3
H111M0F0	3,2	-	4,7	-	6,4	6,6	3,6	5,6	*	3,3	4,4	4,4	5,3	4,8
H111M0H0	-	-	3,7	-	6,5	3,5	-	3,8	3,3	*	3,8	3,8	-	3,8
H111M0BA	4,7	3,2	-	-	3,3	4,5	3,8	5	4,4	3,8	*	6,2	4	3,9
H111M0CA	3,6	4,3	5,2	3,8	4,2	6,2	4,9	5,7	4,4	3,8	6,2	*	6,7	3,2
H111M0IA	-	3,3	4,5	4,1	-	6,2	4,1	4,8	5,3	-	4	6,7	*	-
H111M0KA	4,7	4,3	4,7	3,7	4,5	3,5	3,9	4,3	4,8	3,8	3,9	3,2	-	*

Fig. 8. Matrix of the results of a correlation test between tree-ring measurements from a single site.

are incomplete, or display some kind of anomaly such that the dendrochronologist wishes the ring to be counted, while the measurement will not be used in calculations, inserts a minus to indicate the invalid measurement. If an average of say two radii from a single sample is made, the value at this ring becomes –9999 (although in some measurements the value became –4711). These kinds of values are included in the EU-project data, and in the conversion to DENDRO format, these values were imported, but without the minus, creating dangerous anomalies in the data. These extreme values are easy to spot however when the tree-ring series is plotted, and were readily removable, though this was of course time consuming. Partial measurements of for example the partially preserved first or last measured ring of a sample occurred also, and these also needed to be removed. These would occur when we are dealing not with an average curve of two measured radii, but with a single radius measurement. These were of course less easy to identify, but a comparison of the original data, where the minus was given, allowed identification of these partial ring-widths. In some instances if a very narrow last ring was seen, though there was no minus in the original text file indicating that it was indeed a partial measurement, this was deleted to be on the safe side. This just meant that the final usable tree-ring measurement was that little bit shorter.

Some series had mistakes in the measurements, like in the middle of a tree-ring curve a value of "1" or "0" could occur. Obviously, these samples could not be included in further analysis. So for every site represented in the EU-project data, firstly it was necessary to plot the tree-ring curves on screen, to check for obvious anomalies, which could then be removed from the text file. In some instances there was no minus in the original file attached to anomalous measurements so development of an automated procedure for this time-consuming task was not attempted.

3.5 *The procedure*

Instead of trying to choose areas for building local chronologies as described above, it was decided instead to keep the data separated, at the site level. It was decided to build site chronologies. To try to exclude imported timber from each site chronology, only tree-ring sequences, which match to form a homogeneous group, are included. That is, only tree-ring measurements, which match well together, are included in the site chronology. The resulting chronology then should represent trees from a reasonably small area, thus containing local growth patterns. This procedure does not rule out the possibility that a site contains a large number of imported timber, such that the site chronology could theoretically consist of a group of imports, but this is apparent after the site chronology is made and can be tested as to whether it is local or not. In practice, instead of testing every single site chronology for provenance, what we achieve in keeping these groupings separate is a constant check on how the results look. In that way we not only locate these exotic groups in the provenance determination test of historical material, we also reveal links in the archaeological or historical material, which might not otherwise emerge.

The process consists of comparing each sample with each other using the *t*-value calculation built into the DENDRO program as described above, forming a matrix of the results, as shown in the example in fig. 8. Organising this information into groups can be done by hand, simply by grouping the measurements according to the *t*-values. For sites with many measurements this can take a considerable time. However, David Browne Rønne, working at the Danish National museum's Environmental Archaeology Unit in 2001 (David Browne Rønne, pers. comm.) made a procedure in Microsoft Excel which organises this matrix in relation to the groupings that the *t*-values indicate, easing the process of defining groups considerably. Groupings within each site can be readily viewed, and this forms the basis for deciding which measurements will be included in the site chronology.

So for each individual site in the dataset, the first step is to check the measurements for anomalies, then calculate the correlation between all tree-ring curves in a site at the dated position. This then results in a matrix of correlation values, which needs to be organised according to the values achieved (higher values being grouped together). From this matrix, it becomes very obvious which samples agree well with each other and which fall outside the main group or groups. Those which do not achieve any significant correlation with the rest of the material were checked to see if a reason for this can be found, like for example that the timber in question was dated by chronologies outside the region of the site, indicating an imported timber. In some instances though it was found that the error lay in either a missing/extra ring or that the tree-ring curve was placed in the wrong dating position. These are quite serious errors to be detected in tree-ring data. It has not been in the remit of this study, to go back to original records in the dendrochronology laboratories to trace these errors. Are these sequences wrongly positioned in the initial dating analysis, which would have a bearing on the archaeological conclusions such wrong dates might cause? It is very possible though with the several conversions that have been necessary from many different data formats that errors crept in (some measurements were still only on a punch-card system at the initiation of the EU-project).

3.6 *Cluster analysis*

Other researchers have formulated other ways of automating the chronology building process by using cluster analysis (Hans-Hubert Leuschner, pers. comm.) producing groups of timbers at varying levels of agreement, so that the Northern European tree-ring data could on a large scale be divided into just two groups, a maritime and a continental, while at another level, 11 growth regions were defined. For the purposes of this research, definition of such large regions was not the focus of the analysis. On the contrary, the task of this project was to test to what degree provenance determination could be carried out on the very local level.

Another method of grouping data was used by Esther Jansma and further developed by Ronald Visser at Ring dendro lab Lelystad, The Netherlands. He was analysing Roman period tree-ring data from the Netherlands, building chronologies. To group the data he developed a procedure where a mean is made of all the measurements, and each tree is then tested against this mean. That which gives the lowest correlation is taken out and a new mean is made of the remainder. The test process is run again, removing again the measurement which gives the lowest correlation. This cycle is continued until a robust mean is built, where all tree-ring measurements give a high correlation with the mean, thus indicating a homogenous group. Ronald Visser very kindly made it possible to try this procedure with the data in this study. One of the disadvantages of this procedure is that it cannot be used without controlling the data for varying overlap. A single measurement providing a link between two temporally quite separate datasets might cause the whole material to be grouped together. Two datasets could end up linked, even though they are not only temporally separate, but also geographically from separate areas. Therefore it is necessary to check how the data is distributed temporally, in other words, how well replicated the group of measurements being analysed are, and how spread over time they lie, before carrying out the procedure. Comparing the resulting grouping that this procedure indicated for the site of Haderslev (Eriksen 1996) with the results of the analysis adopted in this study, the conclusion reached was that adopting this procedure would not save any time. The Haderslev site consists of material from two distinct periods, which have to be dealt with separately in Visser's program. When the early (12^{th} - early 13^{th} century) group is run through Visser's analysis, at the level of agreement for series that might be included in a site chronology set at $r \geq 0.5$, only two trees were grouped together from the group tested. When one changes the level of the cluster though, from $r \geq 0.5$ to $r \geq 0.4$, a larger group is suggested. The table (fig. 9) shows the matrix of *t*-values for the Haderslev site as generated in the procedure used in this study (described above). The matrix depicts the internal correlation between all series, from both periods (12^{th} and 15^{th} centuries). The tree-ring series which Visser's method groups together at $r \geq 0.4$ are highlighted in blue. Clearly the grouping that is used to make the early Haderslev site chronology, includes more trees than the Visser group, although the Visser group is clearly made *within* my group. The advantage of the method used in this study is that a visual illustration of the correlation groups can be produced, in the form of the site's internal matrix, so that the decision making process is transparent for review. The matrix of correlation for each site is available for inspection, to clearly show the samples included in the site chronology. The matrix though is not the only indication

	CD51J019	CD51J059	CD51J039	CD51J2Y9	CD51J2V9	CD51J319	CD51J2X9	CD51J359	CD51J439	CD51J3L9	CD51J2U9	CD51J3H9	CD51J3F9	CD51J3N9	CD51J3Z9	CD51J3Y9	CD51J4G9	CD51J389	CD51J3C9	CD51J4M9	CD51J3P9	CD51J4F9	CD51J4H9	CD51J4Q9	CD51J509
CD51J019	*	8,29	5,09	-	-	-	-	-	-	-	-	-	-	-	-	\	\	\	\	\	\	\	\	\	\
CD51J059	8,29	*	4,23	-	3,85	\	3,73	3,74	3,69	-	3,96	3,35	-	-	-	\	\	\	\	\	\	\	\	\	\
CD51J039	5,09	4,23	*	\	3,02	\	-	3,49	-	3,77	-	-	-	-	-	\	\	\	\	\	\	\	\	\	\
CD51J2Y9	-	-	\	*	-	\	4,45	4,65	4,38	3,12	-	4,5	-	-	-	\	\	\	\	\	\	\	\	\	\
CD51J2V9	-	3.85	3.02	-	*	\	-	4.53	3.1	4.88	3.24	-	-	4.83	-	\	\	\	\	\	\	\	\	\	\
CD51J319	-	\	\	\	\	*	\	\	\	-	\	5.38	3.27	3.16	-	\	\	\	\	\	\	\	\	\	\
CD51J2X9	-	3.73	-	4.45	-	\	*	6.79	4.1	3.95	3.38	4.36	4.57	3.25	-	\	\	\	\	\	\	\	\	\	\
CD51J359	-	3.74	3.49	4.65	4.53	\	6.79	*	7.18	7.07	4.34	6.3	4.49	-	-	\	\	\	\	\	\	\	\	\	\
CD51J439	-	3.69	-	4.38	3.1	\	4.1	7.18	*	4.64	4.73	6.19	-	-	3.84	\	\	\	\	\	\	\	\	\	\
CD51J3L9	-	-	3.77	3.12	4.88	-	3.95	7.07	4.64	*	-	3.5	4.47	-	-	\	\	\	\	\	\	\	\	\	\
CD51J2U9	-	3.96	-	-	3.24	\	3.38	4.34	4.73	-	*	7.32	-	3.85	-	\	\	\	\	\	\	\	\	\	\
CD51J3H9	-	3.35	-	4.5	-	5.38	4.36	6.3	6.19	3.5	7.32	*	4.55	4.34	4.39	\	\	\	\	\	\	\	\	\	\
CD51J3F9	-	-	-	-	-	3.27	4.57	4.49	-	4.47	-	4.55	*	11.5	3.12	\	\	\	\	\	\	\	\	\	\
CD51J3N9	-	-	-	-	4.83	3.16	3.25	-	-	-	3.85	4.34	11.5	*	4.1	\	\	\	\	\	\	\	\	\	\
CD51J3Z9	-	-	-	-	-	-	-	-	3.84	-	-	4.39	3.12	4.1	*	\	\	\	\	\	\	\	\	\	\
CD51J3Y9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	*	3,94	\	\	\	\	\	\	\	-
CD51J4G9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	3,94	*	\	-	\	\	-	3,25	-	-
CD51J389	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	*	4,79	4,94	3,25	3,54	\	\	\
CD51J3C9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	-	4,79	*	6,19	5,98	-	-	\	\
CD51J4M9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	4,94	6,19	*	3,57	\	\	\	\
CD51J3P9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	3,25	5,98	3,57	*	\	\	\	\
CD51J4F9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	-	3,54	-	\	\	*	3,75	\	\
CD51J4H9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	3,25	\	-	\	\	3,75	*	\	\
CD51J4Q9	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	-	\	\	\	\	\	\	*	-
CD51J509	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	-	-	\	\	\	\	\	\	-	*

Fig. 9. Table showing the matrix of t-values for the Haderslev site as generated in the procedure used in this study. The matrix depicts the internal correlation between all series from the Haderslev site, from both periods (12th and 15th centuries). The tree-ring series which Visser's method groups together at r ≥ 0.4 are highlighted in blue.

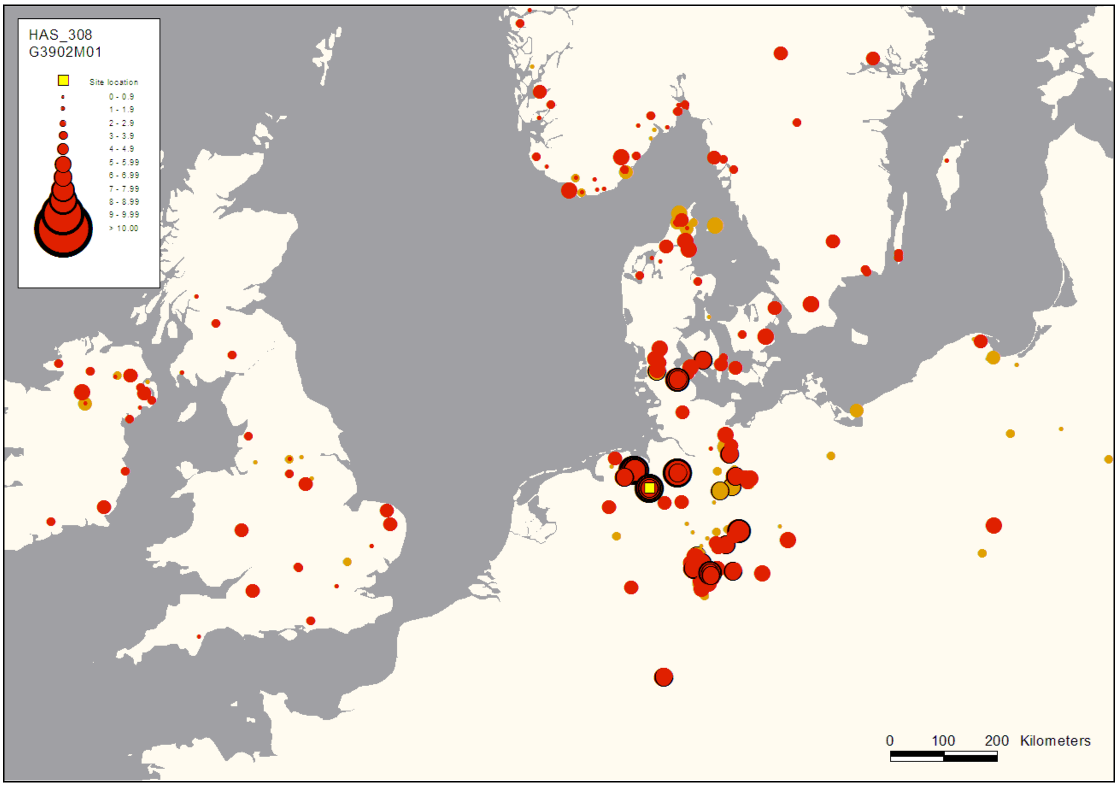


Fig. 10. Map illustrating the result where the overlap of greater than 100 (red dots), or greater than 30 (orange dots) is chosen in the comparison of the Hasbruch living tree site chronology with the single tree data.

used in the analysis for each site. As most sites have samples with varying overlap, it is necessary to check the tree-ring curves visually. This is to avoid things like jumps in the site chronology, where one sample of, for example very narrow rings, extends further back in time than the remaining samples of average ring-width.

3.7 *Choice of overlap*

In calculating the *t*-value, account is taken of the length of the series being compared. In dendrochronology this is then the overlap between two tree-ring series. If the overlap is large, say greater than 100 rings, the *t*-value will be higher than with shorter overlap. This reflects the statistical representativity, where correlation over longer series is less likely to be due to coincidence. When plotting the *t*-value results of the comparison of a site chronology with the chronology data or single tree data, ideally only series of equal overlap can be directly compared with each other.

One of the methods to get around this problem has for instance been used by Bartholin and Berglund (1975) when comparing correlation values between sites. He takes the shortest tree-ring curve to fix the length of all others for the internal correlation test. This could be done for example when making the site matrix. The approach taken in this study in making a site matrix has been to use the actual tree-ring curves at their variable lengths, and make a judgement from case to case, also observing the data length visually, when for example it is seen that the site matrix is weak. This is necessary as the curves need to be looked at visually to check for extremes in measurements and the like, as explained above.

The map shown in fig. 10 illustrates the result where the overlap of greater than 100 (red dots), or greater than 30 (orange dots) is chosen in the comparison of the Hasbruch living tree site chronology with the single tree data. Where comparison is made with data not fully overlapping with the site chronology in question, the resulting lower *t*-values do not ultimately affect the provenance result achieved. The lower values achieved where there is shorter overlap do not change the distribution, because, for provenance determination, it is the high values which are significant, not the lower. If, theoretically, the forest which the timber comes from is not overlapping sufficiently with the site in question, a lower *t*-value will be the result. The provenance conclusion therefore will be on the basis of correlation with adjacent forests. This will, depending on the proximity of the nearby forestry, still allow either a local area of origin determination, or a less precise regional determination. It is, in fact the same problem when the forest is not represented in the data at all: the methodology is only as strong as the data which is contained in it, and can be subject to improvement by filling in the 'gaps'.

What if, on the other hand, a significantly higher correlation value appeared with a series with less overlap? We expect that where the overlap is shorter, a lower *t*-value is produced. If, in a provenance test, we find correlation with shorter overlap giving very high results, how do we interpret that, in relation to the other correlations, where the overlap is longer? Could it be that the high value with shorter overlap takes on an even greater significance because of its shorter overlap? Could we perhaps find a way of weighting the results to account for shorter overlap, as very high *t*-values with shorter overlap have perhaps a greater significance than equal *t*-values at longer overlap? If we test with consistent overlap, the *t*-values should be directly comparable to each other. Although still they are not fully comparable as often account must also be taken for varying replication.

If we consistently only test at the same overlap as the site chronology being tested, and the forest, from which the site being tested comes, coincidentally does not cover the same time period as the site, then the correlation with that forest will be excluded. The correlation between the site being tested and that forest might still turn out to be the highest, even with a shorter overlap than the other forests.

Discussion of the number of years overlap is an important one when we are trying to date a tree-ring sequence, as short sequences might achieve relatively high correlation at several positions. But once the date is found, and the question is the provenance, does short overlap have a significant role? The table (fig. 11) shows a test of the length of overlap, on a site chronology of a modern forest in Denmark (Brahetrolleborg also discussed below). In this test, the site chronology for Brahetrolleborg (CD41CZ01) is divided into small sections, first 50 year long

			230 years	50 years in length				30 years in length						
Filenames	-	-	z01	50 1	50 2	50 3	50 4	30 1	30 2	30 3	30 4	30 5	30 6	
-	start	dates	AD1740	AD1921	AD1871	AD1821	AD1771	AD1941	AD1911	AD1881	AD1851	AD1820	AD1791	
-	dates	end	AD1970	AD1970	AD1920	AD1870	AD1820	AD1970	AD1940	AD1910	AD1880	AD1849	AD1820	
CD41CZ01	AD1740	AD1970	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	9999,99	A5542 Brahetb, 8
CD51DZ01	AD1788	AD1967	9,06	6,70	8,08	5,92	-	\	3,01	4,27	5,07	4,77	-	A5577 Als Nørreskov 7
H11C5M01	AD1818	AD1994	8,40	3,05	5,17	5,38	\	-	-	6,20	4,64	4,06	\	Fa Flensb, Glöcksb, 3
CD51CZ01	AD1822	AD1966	7,50	-	5,60	3,71	\	\	-	3,46	-	\	\	A5584 Mandbjerg Skov 2
CD209Z01	AD1841	AD1949	7,00	\	8,05	-	\	\	-	5,41	-	\	\	A6095 Vallø 41
H13CDM01	AD1824	AD1994	6,83	-	3,66	4,52	\	-	-	-	-	\	\	Elsdorf Fa Rendsb, 4
CD209Z02	AD1840	AD1949	6,81	\	7,69	-	\	\	-	5,39	-	\	\	A6095 Vallø 33
CD229Z01	AD1848	AD1973	6,40	5,10	4,73	\	\	4,38	3,72	-	-	\	\	A6064 Egemosen 7
CD819Z01	AD1827	AD1987	6,13	7,64	-	-	\	6,44	-	-	-	\	\	A6916 Egenseskloster 8
H11C6M01	AD1818	AD1994	6,09	-	4,46	3,94	\	-	-	4,70	-	3,13	\	Fa Flensb, Glücksb, 2
CN011Z01	AD1810	AD1988	6,04	4,00	-	3,75	\	4,88	-	-	3,27	-	\	A6900w Nakkestad 9
CD61OZ01	AD1815	AD1968	6,03	3,31	5,06	4,05	\	\	-	3,11	3,42	3,31	\	A5538 Eldrup Skov 2
CD806Z01	AD1779	AD1987	5,73	6,44	4,13	-	-	5,12	4,98	4,54	-	-	-	A6845 Ørnholt 4
CD805z01	AD1884	AD1984	5,64	3,91	3,90	\	\	3,98	-	\	\	\	\	A6761 Bangsbo 3
CD51GZ01	AD1808	AD1968	5,47	3,80	3,89	3,39	\	\	-	-	-	4,60	\	A5624 Madeskov 7
CN00XZ01	AD1842	AD1988	5,47	4,47	3,23	\	\	3,24	4,10	-	-	\	\	A6900r Mossige 6
CD809Z01	AD1800	AD1984	5,41	5,48	3,08	3,16	\	4,40	3,92	-	-	4,57	\	A6744a Gettrupgård 2
H11C9M01	AD1780	AD1994	5,34	-	3,58	5,05	-	-	-	-	-	4,58	-	Fa Sl, Tiergarten 2
CD505Z01	AD1668	AD1971	5,30	3,90	6,24	3,32	-	-	-	5,53	-	4,71	-	A5537 Draved 5
CD51BZ01	AD1712	AD1970	5,22	3,63	4,75	5,92	-	6,00	-	3,29	3,02	**7,12**	-	A5578 Lindet Skov 15
CD80JZ01	AD1749	AD1987	5,09	6,18	4,31	-	-	4,43	4,57	3,49	-	3,07	-	A6765 Oxholm 10
CN00JZ01	AD1811	AD1988	5,06	3,33	-	-	\	3,48	-	-	-	-	\	A6900m Skiftenes 9
CD804Z01	AD1920	AD1984	5,02	5,20	\	\	\	6,28	\	\	\	\	\	A6804 Uggerby 8
S2111M0A	AD1560	AD1973	4,97	3,47	-	4,69	-	3,12	-	-	-	4,97	-	From Bkurv17 3
CN012Z01	AD1882	AD1989	4,89	-	4,07	\	\	3,39	-	\	\	\	\	A6900 Utåker 8
CN00WZ01	AD1829	AD1989	4,79	-	-	4,37	\	3,14	-	-	-	\	\	A6900ab Torvund 7
CD51FZ01	AD1618	AD1970	4,73	-	5,57	4,36	-	3,06	-	4,62	-	3,02	-	A5609 Gråsten Skovdi 2
CD80AZ01	AD1753	AD1984	4,73	6,84	3,64	-	-	**8,67**	3,38	3,92	-	3,60	-	A6763 Langholt Skov 9
CN017Z01	AD1805	AD1987	4,66	-	-	-	\	-	-	-	-	-	\	A6900' Holum Savv'rk 3
CS004Z01	AD1779	AD1991	4,60	4,00	-	3,26	-	-	-	-	-	-	-	A7325b Gullmarsberg 7
CD807Z01	AD1809	AD1985	4,47	4,11	-	-	\	4,47	-	-	-	-	\	A6734 Skovbo 6
CN004z01	AD1763	AD1987	4,33	3,93	-	-	-	3,46	-	-	-	-	-	A6900a Telemarkslund 4
CD30MZ01	AD1727	AD1969	4,30	4,10	-	3,03	-	\	-	-	-	-	-	A5613 Kristianelund 2
CD81AZ01	AD1858	AD1987	4,02	4,58	-	\	\	3,74	3,25	-	\	\	\	A7071 Hvanstrup 3
CN010Z01	AD1860	AD1988	3,82	**6,31**	-	\	\	6,77	-	-	\	\	\	A6900v Havnehagen 10
CD808Z01	AD1883	AD1987	3,81	4,41	-	\	\	6,13	-	\	\	\	\	A6931 Ormholtgård 7
S1111M0C	AD1760	AD1973	3,75	4,48	4,10	4,09	-	-	4,57	-	-	3,67	-	From Bkurv17 7
CD802Z01	AD1884	AD1987	3,59	5,85	-	\	\	4,81	-	\	\	\	\	A6716 Bagterp Plantage 10
CD30LZ01	AD1708	AD1969	3,56	3,94	5,11	3,73	-	\	-	3,86	-	-	-	A5550 Pederstrup
CD80BZ01	AD1843	AD1984	3,38	5,30	-	\	\	4,95	-	-	-	\	\	A6704 Dronninglund 8
S2111M0B	AD1729	AD1973	3,22	-	5,72	3,23	-	-	-	3,79	-	4,71	-	From Bkurv17 4
CN003Z01	AD1782	AD1987	-	4,22	-	-	-	3,44	-	-	-	-	-	A6900a Søsters Hvile 2
CN00YZ01	AD1877	AD1988	-	-	4,41	\	\	-	-	5,32	\	\	\	A6900s Eikehaugen 10

Fig. 11. Table showing a test of the length of overlap, on a site chronology of the modern forest of Brahetrolleborg in Denmark. In this test, the site chronology for Brahetrolleborg (CD41CZ01) is divided into small sections, first 50 year long sections, then 30 year long sections. The series used in this test are all from the EU-project dataset.

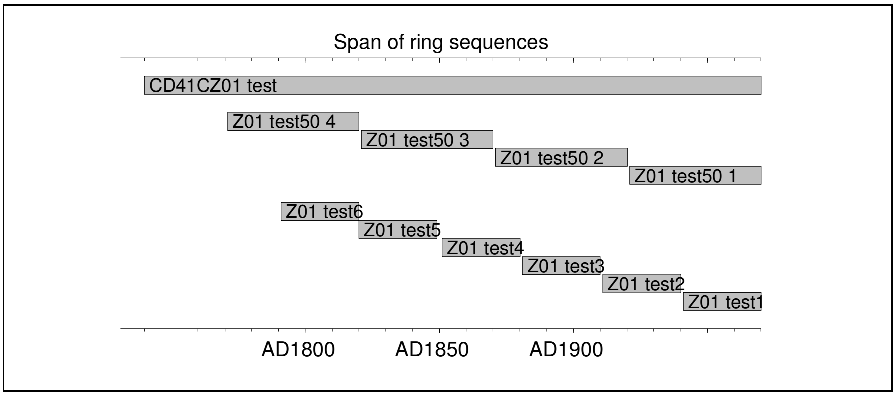


Fig. 12. Bars indicating the different lengths of the smaller sections of Brahetrolleborg for the overlap test above

sections, then 30 year long sections (fig. 12). All these are tested against the site chronologies in the Northern European dataset to see what correlations appear. It seems that, at the short 30 year length, one section of the mean curve gives a higher *t*-value with a forest in Northern Jutland, somewhat outside the region of Brahetrolleborg, and this value is highlighted by yellow text. So it is most advisable not to include overlaps as low as 30 years. Rather, for the examples used in the *t*-value mapping in this study, an overlap of 50 years is used throughout. Having said that it might be stressed that in fact in the provenance determination exercise it is the very high *t*-values that are significant in interpreting the correlation results. When these high values occur we always look at the sites with which the high correlations appear. As will be seen in the case studies below, account is taken of overlap, and replication of the site average being tested and the sites with which high values are achieved.

Let us take another example, this time working with much longer, but varying, overlaps. In the analysis of a shipwreck, Lynæs 1 (Daly 1998d; 1999b), found at Lynæs, at the mouth of Roskilde Fjord, Denmark, excavated in 1975 (Crumlin-Pedersen 1979), a map of the correlation of the tree-ring curve for the ship with the available master chronologies for Northern Europe was produced. One *t*-value on the map (Fig. 13), between the ship's mean curve and the master

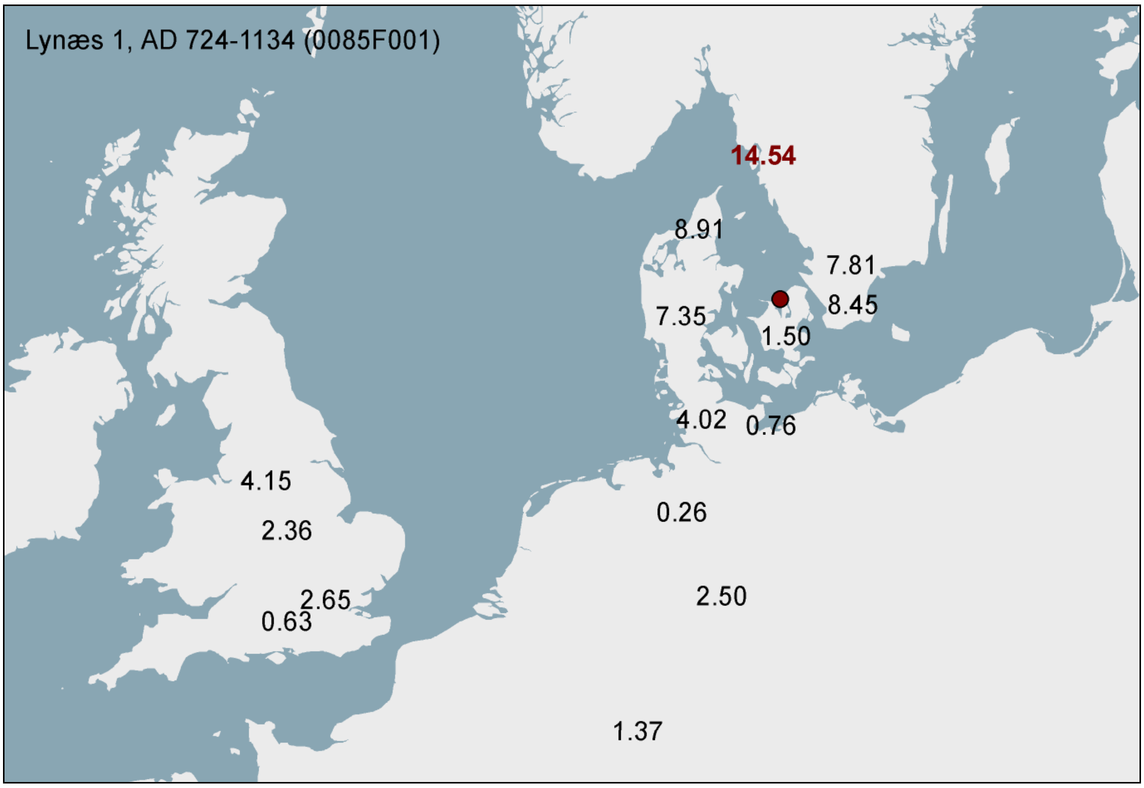
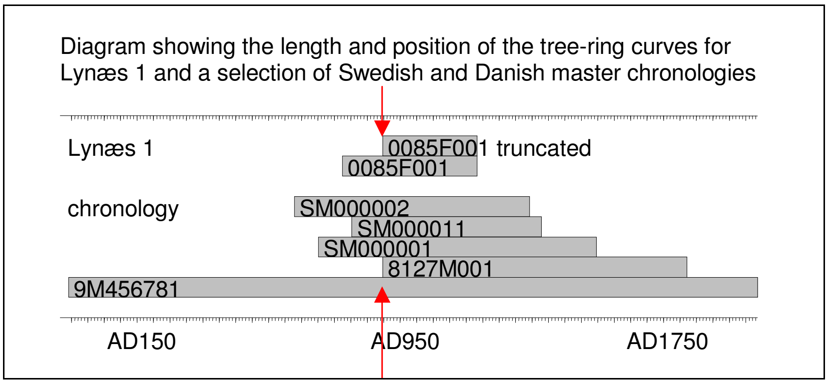


Fig 13. Map of the correlation of the tree-ring curve for the ship Lynæs 1 with a selection of master chronologies for Northern Europe.

A



Filenames	-		0085F001 truncated	0085F001
-	dates		AD 846-1134	AD 724-1134
SM000011	AD 753-1329	West Sweden (Bråthen 1982)	16,48	14,54
8127M001	AD 846-1771	Aalborg (Daly 2000a; 2001b)	8,91	8,91
SM000002	AD 578-1293	Lund Skåne Blekinge (LU)	7,69	7,81
SM000001	AD 651-1496	Southwest Skåne (LU)	7,65	8,45
9M456781	109 BC-AD 1986	Jutland Funen (NM)	5,81	7,35

B

Fig. 14. Diagram (A) showing the chronological position of the ship average for Lynæs 1 and showing the positions of the master chronologies from Denmark and Sweden, which match best with the ship. The red arrows mark the position at which the Lynæs 1 average needs to be shortened (also shown, labelled "0085F001 truncated") so that when tested against the chronologies the same overlap length will apply. The table in this diagram (B) shows the resulting correlation between the truncated and the original Lynæs 1 average and these key master chronologies. The t-values for the truncated version show that the highest match with the west Sweden chronology is confirmed.

chronology from West Sweden (14.54), is calculated where the overlap is 382 years, whereas the ship's mean curve is 411 years long. The very high value achieved might be interpreted as all the more significant because the overlap is shorter. If the ship's tree-ring curve had resolutely not been compared with any master, which did not cover the full length of the ship's curve, this very high value would be missing, resulting possibly in an erroneous provenance interpretation. Ultimately, if we only use masters, site means or single tree data which have the same overlap as the site being tested, we get blank spaces on the maps. If we include all data, even down to just 50 years overlap, we get probably small dots in those locations. Another approach is to adjust the length of the ship's average so that it corresponds to the position of the masters it is being tested against. In fig. 14 the chronological position of the ship average for Lynæs 1 is shown, as are the positions of the master chronologies from Denmark and Sweden which match best with the ship. The red arrows mark the position at which the Lynæs 1 average needs to be shortened (also shown, labelled "0085F001 truncated") so that when tested against the chronologies the same overlap length will apply. In this way, instead of trying to devise a way of weighting the correlation at shorter overlaps, we adjust the test so that we only calculate with the exact same overlap. The table in this diagram shows the resulting correlation between the truncated and the original Lynæs 1 average and these key master chronologies. The *t*-values for the truncated version show that the highest match with the west Sweden chronology is confirmed.

Where this procedure also has applicability is in the example where we compare the local provenance of three ships (Daly 2007; appendix 2, this volume), which were built within a single decade and whose tree-ring curves cover almost the same time period. The three three ships are the Karschau ship of Nordic type dating to c. 1145 (Daly 2007), the Kollerup cog made of oak felled in the 1150s (Daly 2000b; this volume) and the Eltang ship dating also to the 1140s (Eriksen 1999). Here, to directly compare the provenance maps of the three ships, the shortest sequence might set the length to be tested for the other two. In the diagram (fig. 15) the chronological position of the three ship averages are shown. The red arrows

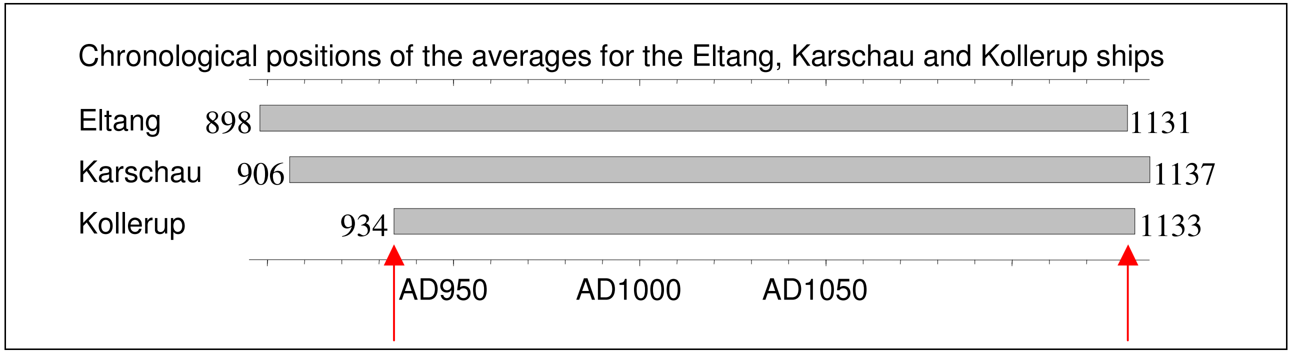


Fig. 15. The Karschau, Kollerup and Eltang ships. Bar diagram showing chronological position of the three ship averages. The red arrows mark the period of time that all three ships' tree-ring curves cover, that is 198 years, or from AD 934 to 1131.

Filenames	-		Karschau _aveF3	0013M001 Kollerup	0200m001 Eltang	Karschau _aveF3 truncated	0013M001 kollerup reduced	0200m001 eltang reduced
-	Dates		AD 906-1137	AD 934-1133	AD 898-1131	AD 934-1131	AD 934-1131	AD 934-1131
30079M01	AD 998-1374	Stegeborg (Daly 2001d)	-	3,97	6,03	-	4,16	6,03
4013M001	AD 964-1164	Odense Sortebrødre Kl. (NNU j.no. A5921)	10,43	3,91	4,71	10,12	3,74	4,71
5069M001	AD 944-1163	Løgumgårde (Daly 1999a)	5,59	6,15	3,96	5,39	6,03	3,96
5081M002	AD 1008-1199	Roager kirke (Eriksen 2001a)	5,94	9,13	7,99	5,67	8,96	7,99
CD51JZ01	AD 929-1234	Møllestrømmen (EU-project)	8,49	14,56	8,63	8,52	14,46	9,39
F001M001	AD 973-1088	Birkely bro (Daly unpubl.)	4,83	7,20	5,36	4,83	7,21	5,36
6075M001	AD 914-1082	Viborg Søndersø (Daly 2005c)	-	6,80	6,13	3,23	6,80	6,00
CD61AZ02	AD 975-1083	Tamdrup Kirke (EU-project)	7,04	6,18	6,32	7,04	6,18	6,32
CD61HZ01	AD 1001-1090	Moeskjærgård V (EU-project)	3,31	6,02	5,57	3,31	6,02	5,57
70314M04	AD 953-1198	Skjern Bro (Daly 2001c)	4,94	7,96	9,06	4,94	8,03	9,06
RIBEZ001	AD 907-1206	Ribe Daly unpubl.)	6,08	9,99	8,95	6,42	9,83	9,45
CD701Z03	AD 931-1076	Vorbasse (EU-project)	3,39	6,46	7,53	3,37	6,46	7,91
8127M001	AD 846-1771	Ålborg (Daly 2000a; 2001b)	4,60	8,53	8,43	4,91	8,34	8,69

Fig. 16. Karschau, Kollerup and Eltang. Table of correlation between the ship averages and site chronologies in Denmark. The example shows the full length of each ship average, and a shortened version where all three ship averages cover the same years.

mark the period of time that all three ships' tree-ring curves cover, that is 198 years, or from AD 934 to 1131. To directly compare the results of the provenance determination between the three ships, we can reduce the three averages, so that they all cover the same period. These results are illustrated in table form (fig. 16). The three original ship averages are shown and their correlation with Danish site chronologies. Furthermore the three shortened averages, all three covering exactly the same years are shown with their correlation results. The highest *t*-value for each average is highlighted with yellow text. As can be seen, the regional differences between the Karschau and Kollerup ship is maintained when tested with identical overlap. The reduced Eltang ship average does however not give so confidant a result. This is due to the weaker result also in the ship's full-length average. A southern Jutland origin for the Eltang ship's timbers is probable, but a more precise determination as we see in the case of Kollerup and Karschau might be forthcoming if a site more similar to the timber from the Eltang ship is analysed from this region.

At a conference in September 2005 it was asked if a test of the correlation results of a shipwreck, at any other position than the dated position, had been tried. This is in fact an interesting exercise. What do the correlation results look like at a wrong position? Ultimately, if the position for the tree-ring curve is wrong, when run against, say, all single trees in the dataset, we would expect the correlation test results to be a random distribution, where the correlation results might be distributed about what is called in statistics 'the normal curve'. Using the *t*-value for example, the normal curve would be distributed around $t = 0.00$ (no correlation, neither positive nor negative) with most values appearing around zero, and falling gradually away to either side of zero. The diagram (fig. 17) shows the distribution of the *t*-values for the Kolding Cog mean curve with the single tree data. The results at the dated position (AD 959-1188) are in blue while a wrong position (here 1759-1988 was chosen) is in orange. Clearly for the orange series, the wrong position, the correlation test shows the normal curve, centred on $t = 0.00$. The *t*-values for the correct dated position also displays a normal curve, but this is centred well into positive correlation values. Generally, the lower values represent the long distance

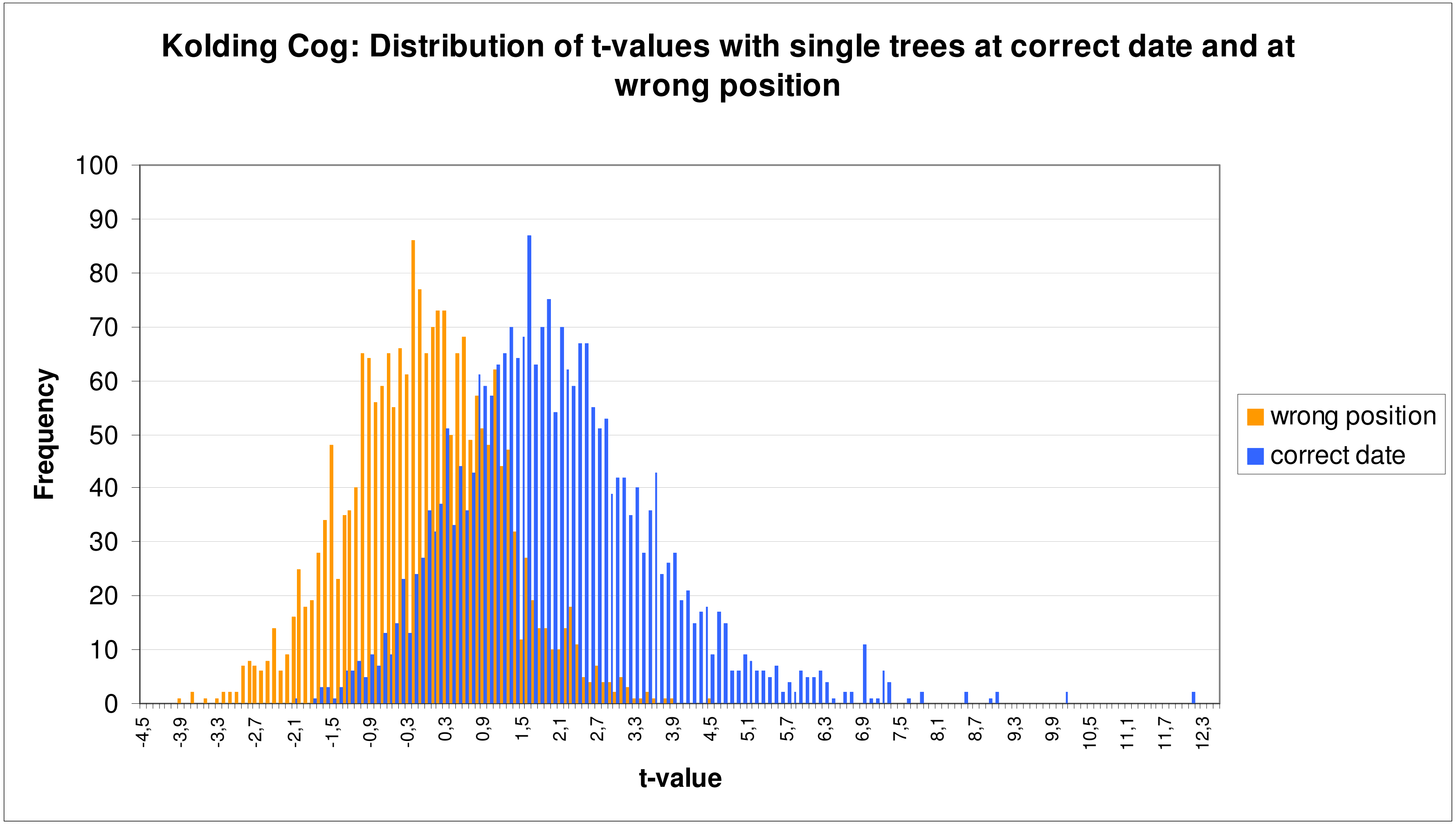


Fig. 17. Diagram showing the distribution of the t-values for the Kolding Cog mean curve with the northern European single tree data. The results at the dated position (AD 959-1188) are in blue while a wrong position (here AD 1759-1988 was chosen) is in orange. Clearly for the orange series, the wrong position, the correlation test shows the normal curve, centred on t = 0.00. The t-values for the correct dated position also displays a normal curve, but this is centred well into positive correlation values.

trees, while higher values are geographically closer trees. It is perhaps a lesson in basic dendrochronological methods. Wrong positions are just a set of random numbers, the dated position shows a clear positive correlation. Note also the extreme outliers in the correct date values, where very high correlations appear with certain tree-ring curves. These fall outside the normal curve distribution, and as is very obvious here, there are not many. It is actually these few that provide the good provenance result, and this diagram illustrates very clearly, how little needs to be missing in the dataset such that a satisfactory provenance result, to the local level, will not be forthcoming.

3.8 *Geographically floating chronologies*

The picture from the historical sources of increasing timber transport with time, is important in the development of the methodology of this study. If the single-tree dataset is heavily contaminated with imported oak from the 17th century onwards, then the most contaminated set of data would be the 18th and 19th century data that should link with the living tree data. It could be argued that the weakest link in the construction of small continuous regional chronologies is in the link between the living trees and the potentially most contaminated portion of the dataset, where timber transport of oak is most prevalent. This stresses the fact that, to avoid a serious possible error in the provenance determination tool, the data should be kept at the site level. Apart from avoiding circular argument in the provenance determination exercise, doing this will mean that in the future it will be possible to reassess individual sites with a view to documenting trade of construction timber in the historical dataset. A serious flaw in the construction of large chronologies for certain regions is introduced when historical data from outside that region, through dendrochronology is seen to fit best with a certain region, then is included in the region’s chronology. It is problematic because later data collection could potentially show that the data in fact fits even better with another region, and thus is erroneously included in the first chronology. A classic case of circular argument would arise using such a chronology for provenance determination. To guard against this it could be decided to only include data which matches extremely well with the confirmed data from the region for which the chronology is being built. For instance in including the German Sengwarden site data which seems to be of Norwegian origin and the Scottish Norwegian data in a Southern Norway chronology currently being built (Baittinger and Bonde 2006, building on previous work by Christensen and Havemann (1998)), it could be recommended that only very strong correlating data might be included. There is the possibility then though, that the resulting chronology will represent a very restricted area, not a large regional chronology. A better option in such a case would be to group for example the timbers from Scottish sites, which seem to be of Norwegian origin, in clusters, but refrain from grouping them with the Norwegian sites. These chronologies could then be used, in a similar way to the way that the Southern Baltic or Southeastern Baltic 'panel painting' chronologies are used, in the dating and provenance determination process. These chronologies could be made use of, without introducing circular argumentation into geographically more well-founded master chronologies. In keeping with a dendrochronological term where an undated chronology is called a 'floating chronology', we could refer to the dated but transported chronologies of the panel painting data and the Norwegian timber abroad data as 'geographically floating'.

In dendrochronological methodology, just as *t*-values of greater than 3.5 are interesting when looking for the *date* of an object, *t*-values greater than *c*. 9.00 are interesting when looking for the *provenance* of the object. Additionally, as in dendrochronological methodology, where a *date* for a tree-ring curve is also checked visually before a position is accepted, the distribution of the correlations and the overlap and replication of the well matching sites is examined before a *provenance* is suggested.

To sum up, we now have a method by which we approach the determination of the provenance of oak structures in the archaeological record. The screening of data and the building of chronologies is complete for the Danish, Swedish, Norwegian and German tree-ring data, while other site chronologies are utilised from Poland, built by Ważny (Haneca et.al. 2005; Ważny, pers. comm.). We work on three levels of correlation testing, going from the regional to the local scale. We use Student's *t*-test in the correlation calculation, and we work with an overlap of a minimum of 50 rings. One of the most important developments is the mapping of the correlation results so that a clear visual illustration of the results is produced. However before we launch into the case studies, where the provenance of archaeological structures is testes, let us take a good look at how the provenance test works, where we know the geographical parameters. Let us, in chapter 4, take a look at the living tree dataset.

4 Chapter 4: Results

4.1 *Cockchafer*

All the data then was checked for cyclical signals, which could indicate that the tree had been affected by the cockchafer beetle. The cockchafer lives most of its life cycle in the roots of trees. During a small part of its life cycle though, it flies and consumes the leaves of trees. In Northern Europe the cockchafer does this every three, four or five years, having a shorter cycle to the south, and longer further north. A batch of cockchafers will fly every year but some batches are particularly numerous and the year these fly, the tree suffers (Christensen 1987). This affects the growth of the tree-rings and is seen in the tree-ring sequences as a very narrow ring at regular three, four or five year intervals. The tree-ring measurements affected by the cockchafer can be identified, by running three artificial series, with a narrow number every third, fourth and fifth "width" against every tree-ring curve. The artificial cockchafer-checking series are 40 'years' in length and are illustrated in fig. 18. Tree-ring sequences, which achieve high correlation values (greater than t = 3.5) at more than three positions with these artificial sequences are those which might have been affected by the cockchafer. (The choice of a t-value of 3.5 or above is taken, as this value has often been quoted as the minimum t-value a dendrochronologist looks for when looking for a date for a tree-ring curve. In other words it indicates a positive correlation between two sets of numbers. A method to give an indication of how severely the individual tree-ring curves are actually showing these cycles, is also devised below.) Unusually, some of the oak data from Norway displayed agreement with the three-year artificial sequence. This might be due to a possible six-year cockchafer cycle this far north. A quite low level of sensitivity has been taken in this data filtering, that is, measurements which give even quite low agreement with one or other of the artificial sequences was removed from the usable dataset. This is to err on the side of caution. If just small sections of the tree-growth was affected the whole measurement sequence gets removed. It

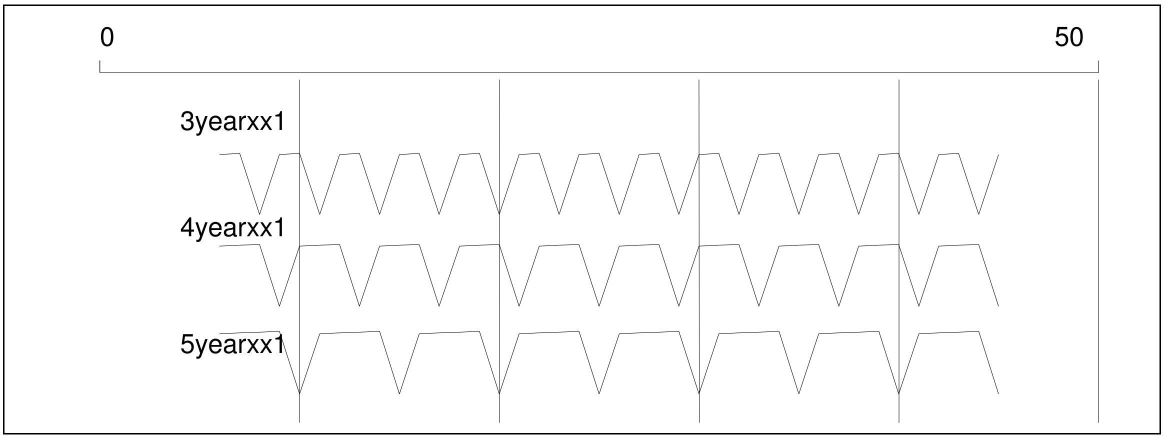


Fig. 18. Diagram showing the three artificial cockchafer-checking series. The series are 40 ‘years’ in length. Tree-ring sequences, which achieve high correlation values (greater than t = 3.5) at more than three positions, with these artificial sequences, are those that might have been affected by the cockchafer.

```
Using C:\GOTTPROG\H___EURO\Hamburg4\H11ED\H11ED08B.D Dated AD1671 to AD1769
to date C:\DENDRO\4or5yrtest\3yearxx1.d of length 40 years

Using C:\GOTTPROG\H___EURO\Hamburg4\H11ED\H11ED08B.D Dated AD1671 to AD1769
to date C:\DENDRO\4or5yrtest\4yearxx1.d of length 40 years

At position AD1654 to AD1693 t = 3.95 r = 0.69 overlap = 23 years TTT
At position AD1658 to AD1697 t = 4.81 r = 0.72 overlap = 27 years TTTT
At position AD1662 to AD1701 t = 4.97 r = 0.71 overlap = 31 years TTTT
At position AD1666 to AD1705 t = 5.57 r = 0.72 overlap = 35 years TTTTT
At position AD1670 to AD1709 t = 5.58 r = 0.70 overlap = 39 years TTTTT
At position AD1674 to AD1713 t = 5.85 r = 0.71 overlap = 40 years TTTTT
At position AD1678 to AD1717 t = 5.38 r = 0.68 overlap = 40 years TTTTT
At position AD1682 to AD1721 t = 4.35 r = 0.60 overlap = 40 years TTTT
At position AD1686 to AD1725 t = 4.10 r = 0.57 overlap = 40 years TTTT
At position AD1690 to AD1729 t = 3.98 r = 0.56 overlap = 40 years TTT
At position AD1694 to AD1733 t = 3.93 r = 0.56 overlap = 40 years TTT
At position AD1698 to AD1737 t = 4.37 r = 0.60 overlap = 40 years TTTT
At position AD1702 to AD1741 t = 4.53 r = 0.61 overlap = 40 years TTTT
At position AD1706 to AD1745 t = 4.84 r = 0.64 overlap = 40 years TTTT
At position AD1710 to AD1749 t = 4.96 r = 0.65 overlap = 40 years TTTT
At position AD1714 to AD1753 t = 4.11 r = 0.58 overlap = 40 years TTTT
At position AD1718 to AD1757 t = 4.58 r = 0.62 overlap = 40 years TTTT
At position AD1722 to AD1761 t = 3.74 r = 0.54 overlap = 40 years TTT
At position AD1726 to AD1765 t = 3.77 r = 0.54 overlap = 40 years TTT

Using C:\GOTTPROG\H___EURO\Hamburg4\H11ED\H11ED08B.D Dated AD1671 to AD1769
to date C:\DENDRO\4or5yrtest\5yearxx1.d of length 40 years

Using C:\GOTTPROG\H___EURO\Hamburg4\H11ED\H11ED0C0.D Dated AD1717 to AD1768
to date C:\DENDRO\4or5yrtest\3yearxx1.d of length 40 years

Using C:\GOTTPROGH___EURO\Hamburg4\H11ED\H11ED0C0.D Dated AD1717 to AD1768
to date C:\DENDRO\4or5yrtest\4yearxx1.d of length 40 years

At position AD1702 to AD1741 t = 4.18 r = 0.69 overlap = 25 years TTTT
At position AD1706 to AD1745 t = 5.04 r = 0.72 overlap = 29 years TTTTT
At position AD1710 to AD1749 t = 5.59 r = 0.73 overlap = 33 years TTTTT
At position AD1714 to AD1753 t = 5.63 r = 0.71 overlap = 37 years TTTTT
At position AD1718 to AD1757 t = 4.31 r = 0.59 overlap = 40 years TTTT

Using C:\GOTTPROG\H___EURO\Hamburg4\H11ED\H11ED0C0.D Dated AD1717 to AD1768
to date C:\DENDRO\4or5yrtest\5yearxx1.d of length 40 years
```

Fig. 19. Text file showing the kind of information produced when the artificial sequences for the three, four and five year cycles are run against individual tree-ring series. The example shown is from ‘Kniphagen, Wassermue’, a site analysed at the University of Hamburg’s Dendrochronology Laboratory. As can be seen, the tree-ring series H11ED08B displays a strong four-year cyclical pattern, as the high *t*-values at numerous positions emerge when it is tested against the four-year artificial curve 4yearxx1.

would have required a lot of time to identify sections for removal, keeping the rest, for so many tree-ring curves.

As this large amount of information on the cyclical patterns in oaks over Northern Europe had not been gathered before it seemed obvious that this information should be summarised somehow. The text file (fig. 19) shows the kind of information produced when the artificial sequences for the three, four and five year cycles are run against individual tree-ring series. In the example shown it is a site, "Kniphagen, Wassermue" from the Hamburg Laboratory. As can be seen, the tree-ring series H11ED08B displays a strong four-year cyclical pattern, as the high *t*-values at numerous positions emerge when it is tested against the four-year artificial curve 4yearxx1. It was necessary to summarise this kind of information so that a map could be produced showing the European distribution of the affected trees, but at the same time distinguishing between trees severely affected and trees only somewhat affected by these different cycles. The process was to convert this text output information into three simple tables, one for the three-year, one for four-year and one for five-year cycles, with the "sitecode", which is the link into the GIS system of coordinates, and some simple summary of the many *t*-values. As can be seen by the example here, the output consists of a position for each *t*-value greater than 3.5. At the end of each of these positions the *t*-value calculated is summarised by the letter "T" Three Ts for a *t*-value of 3.00 to 3.99, four Ts for *t*-values between 4.00 and 4.99 and so forth. To attain a summary of all these an index, that can be called a Cockchafer Cycle Index (CCI), was made, which in simple terms is a count of the number of Ts for each tree-ring series, such that where no correlation was found, the CCI is zero. In the case of the four-year example here the CCI for H11ED08B is 75, and for the second example, H11ED0C0, it is 23. This index accounts thus for the number of positions the cyclical patterns give, and for the degree of agreement, as measured by the *t*-value.

The resulting map then (fig. 20) represents the degree to which cyclical patterns were encountered in the Northern European oak tree-ring dataset. The size of the circle is determined by the Cockchafer Cycle Index. Clearly the four-year

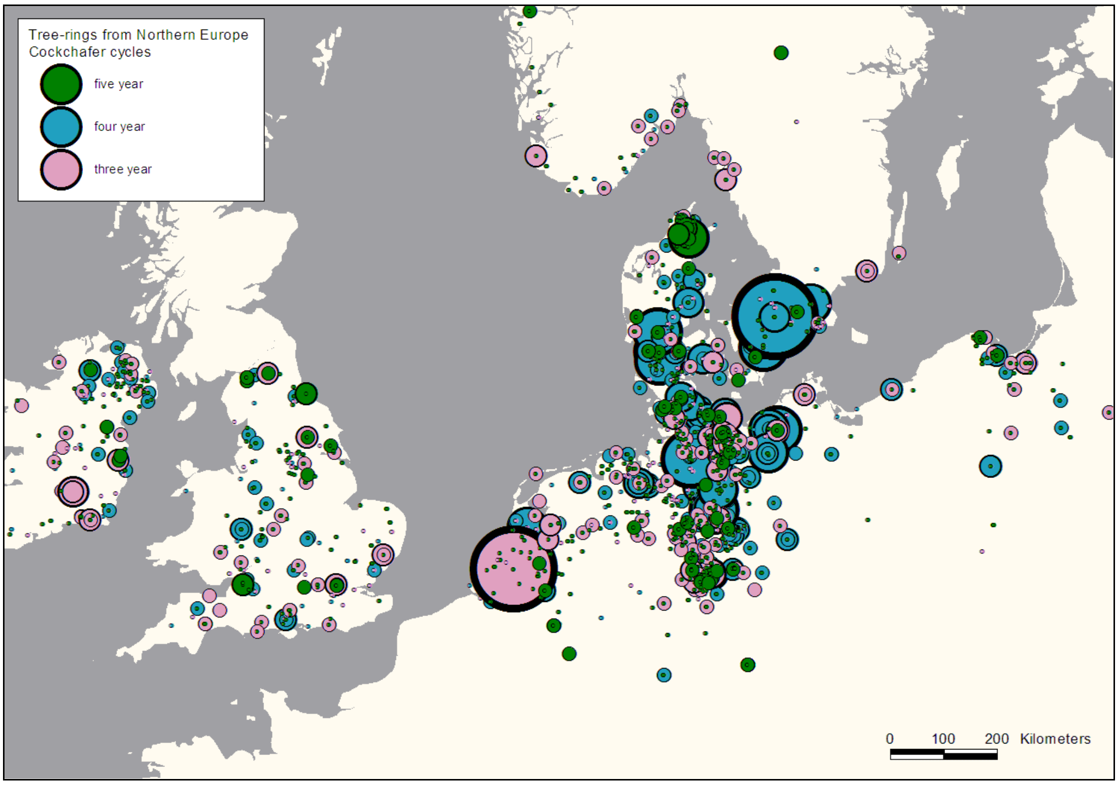


Fig. 20. Map showing the degree to which cyclical patterns were encountered in the Northern European oak tree-ring dataset. Each circle represents a single tree-ring measurement. The size of the circle is determined by the 'Cockchafer Cycle Index'.

cycle is the dominant, with many badly affected series in the dataset, as indicated by the blue circles. The high values in the index do indeed seem to confirm the expected distribution of the cyclical pattern, with three-year to the south and five-year to the north of the Northern European region, but the moderately affected series seem to be very widespread over the whole region, north to south although perhaps with the exception of the Irish data. Here, interestingly, the three-year cycle has a more southerly distribution, and the four and five year cycles a more northerly.

It might be stressed here though that this map represents the samples affected by possible cockchafer cycles but that are dated nonetheless. When working with oak, even at the measuring phase of an analysis, samples with marked cyclical ring width minima can be observed. Invariably, these samples cannot be dated. As this study deals with tree-ring data that is dated, a distribution map of tree-ring data which displays severe cyclical patterning, so severe that it could not be dated, is not produced.

As mentioned above, the tree-ring series represented on this map are those that were taken out of the main dataset, to remove the possibility that provenance determination was influenced by the cockchafer phenomenon.

At an early stage in the process of the analysis, some site chronologies were made before filtering the data for cockchafer. In testing the provenance methodology using the living forest data using earlier versions of site chronologies sometimes high t-values were achieved with adjacent living tree sites. It was subsequently found that some trees which gave the strong correlation had been removed from the tree-ring dataset as they displayed some possible cockchafer influence in their tree-ring curves. Sometimes the cyclical pattern is not strong though, giving only three positions with $t > 3.5$. If the parameters for filtering for cockchafer-influenced cycles was adjusted to allow more tree-ring series through the filter, or by identifying the actual affected portions of the individual tree-ring curves and removing just the cyclical parts, it is possible that more tree-ring data could be included in the useable dataset. Time did not allow a full check of the degree of cyclical patterns for every site, but in many instances it was only very few positions giving t-values over 3.5 when compared with the three, four and five year cyclical patterns that caused their removal from the useable dataset. The necessity of their removal could be discussed.

4.2 *Living tree examples*

So having screened the dataset for all these pitfalls we are ready to test the method on the living tree dataset. This is of course based on trees, sampled in living forests, which can be used as a control, as all the geographical parameters are known. The living tree section of the tree-ring dataset is made up of the measurements from standing trees throughout Northern Europe. These data have been collected over the years and consist of measurements covering the last 200 years or so. As we are dealing here with trees whose location is known, we can use them to test the methodology when we move into the historical data, where an unknown history of the building timber can affect the results. Having now established a network of site chronologies for the regions Denmark, Sweden, Norway, Northern Germany and Central Germany, we are now presented with the possibility of testing the methodology on the living tree data. Each example shows the kind of result that can emerge in testing the tree-ring data for provenance determination, and certain points are brought up for each example, showing the kinds of obstacles that can occur.

4.2.1 Langholt forest

Let us take an example from the Danish dataset. Measurements from eight trees are included in the mean for Langholt forest in Northern Jutland. The correlation between this mean and site chronologies from Northern Europe is tested, which is called the second level test, and the same mean is again tested against all single trees in the dataset, called the third level test. The second level test is mapped in fig. 21 and shows a neat cluster of high *t*-values with other forests in the area. The test at the third level similarly shows a clear cluster of high *t*-values (fig. 22). With this living tree example we see a very good demonstration of what we might expect of a provenance determination using the three level correlation mapping, developed in this study.

4.2.2 Brahetrolleborg

Brahetrolleborg is a forest on the island of Funen in Denmark. Eleven measurements from oaks in the forest were included in the dataset, but three of these were filtered out due to possible cockchafer influence. A very strong internal correlation matrix of the remaining eight tree-ring series meant that all eight are included in the mean for this forest.

When the Brahetrolleborg site mean is compared with the European regional master chronologies clearly the highest values appear with the southern Jutland region. This is to be expected, as the measurements from this site are most

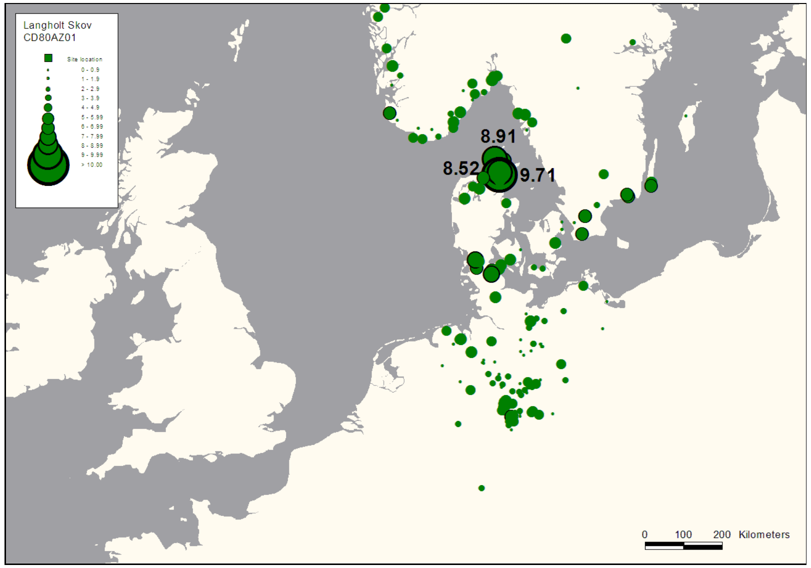


Fig. 21. Langholt forest, Northern Jutland. Map showing the distribution of correlation values achieved between the mean for Langholt forest and site chronologies from Northern Europe (the second level test).

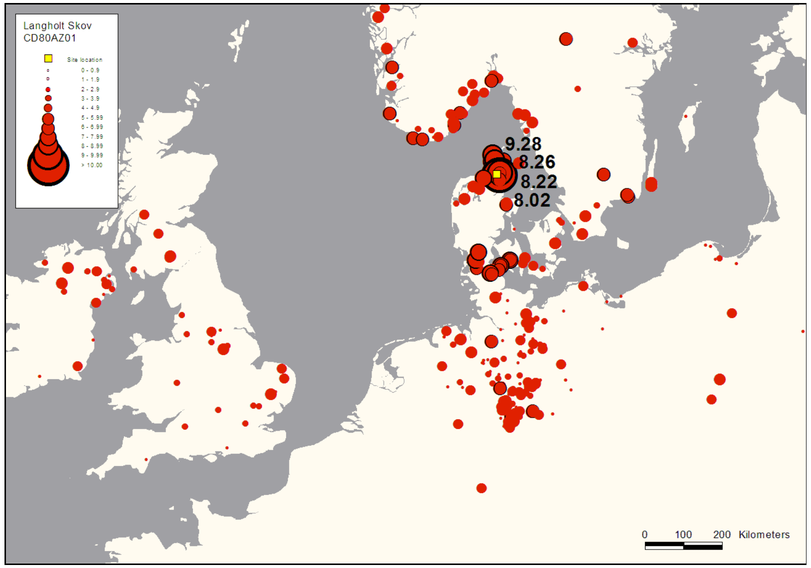


Fig. 22. Langholt forest Northern Jutland. Map showing the distribution of correlation values achieved between the mean for Langholt forest and single tree-ring measurements from Northern Europe (the third level test).

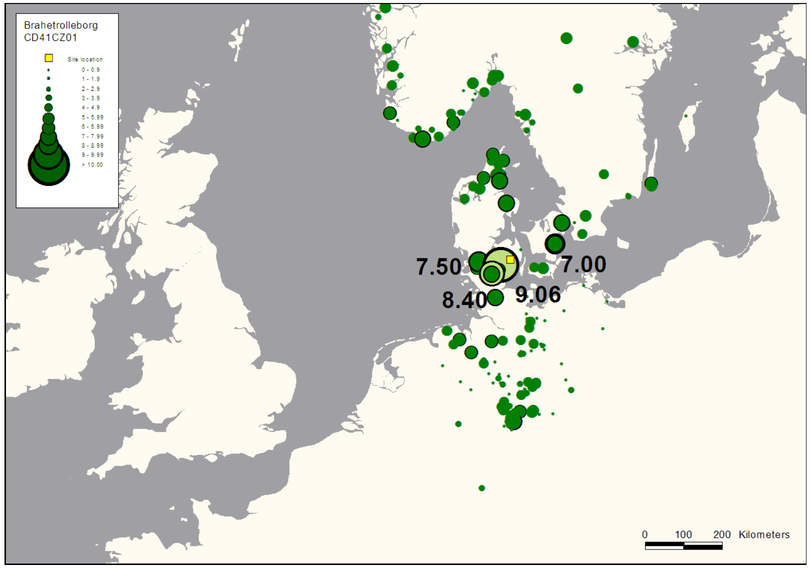


Fig. 23. Brahetrolleborg forest, Funen. Map showing the distribution of correlation values achieved between the mean for Brahetrolleborg forest and site chronologies from Northern Europe (the second level test).

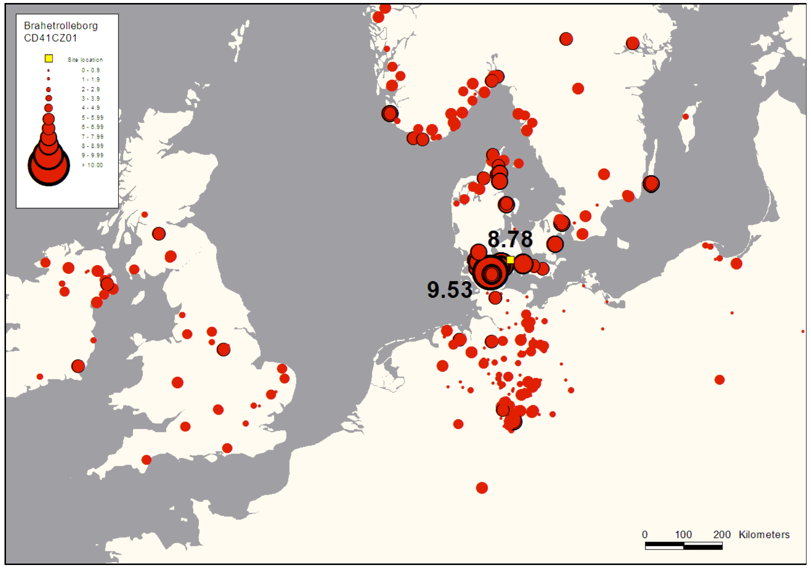


Fig. 24. Brahetrolleborg forest, Funen. Map showing the distribution of correlation values achieved between the mean for Brahetrolleborg forest and single tree-ring measurements from Northern Europe (the third level test).

likely included in the West Danish regional chronologies. This underlines an aspect that must be taken into account when revising old data. The problem emerges in the case of a ship from The Netherlands reassessed in section II in this study, where the ship's tree-ring curves are included in a master chronology (see below).

When this site mean is tested with the other Northern European site means (the second level test) the distribution of correlation, shown in fig. 23, is the result. The highest *t*-value appears with the site mean from Als Nørreskov ($t = 9.94$) circa 27 kilometres southwest of Brahetrolleborg, while the next highest is with the site mean for a Forest south of the Danish border at Flensburg ($t = 8.40$) at circa 60 kilometres distance.

When the Brahetrolleborg site chronology is tested at the third level, with single trees, a distribution of the highest correlation values again with trees from nearby forests emerges (fig. 24). Highest values are with a tree from Keldstrup Fredskov, *c.* 60 km away ($t = 9.53$), and with Als Nørreskov. *T*-values from 7.00 to 8.00 appear also only in the same region. Clearly the higher correlations are achieved with trees in adjacent areas, and there is decay with distance to less high correlation values.

When we take a look at the length of the samples that are included in the site mean for Brahetrolleborg though (fig. 25) we can see that one sample (CD41C029) is from a quite older tree than the rest. This tree-ring curve also gives slightly lower *t*-values when compared with the rest, as can be seen in the correlation matrix (fig. 26). If we make a site mean which does not include the longer lived tree, and test the provenance method on this site mean, what kind of result emerges? This is shown at the second level test (correlation between the shorter Brahetrolleborg mean (CD41CZ02), which is 164 years in length) with the available site means for Northern Europe) in fig. 27. Here it can be seen that we get high *t*-values with sites in the region of the forest being tested, but we also get a similar value with a forest in Southwest Sweden (LS111), *c.* 200 km away. The removal of just one tree from the mean, which results in the removal of the first 67

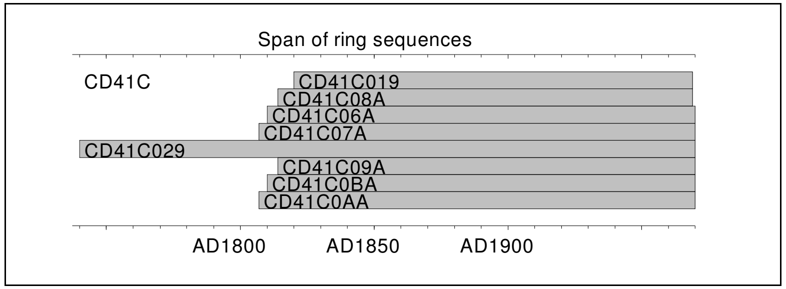


Fig. 25. Brahetrolleborg forest, Funen. Diagram showing the chronological position of the tree-ring series from the forest. One sample is from a tree that is older than the rest.

	CD41C029	CD41C019	CD41C0AA	CD41C09A	CD41C0BA	CD41C06A	CD41C07A	CD41C08A
CD41C029	*	-	5,15	5,86	5,15	3,61	4,98	3,95
CD41C019	-	*	8,39	8,68	7,97	7,52	4,91	4,68
CD41C0AA	5,15	8,39	*	14,22	11,87	11,07	8,97	8,71
CD41C09A	5,86	8,68	14,22	*	10,84	10,8	9,17	8,14
CD41C0BA	5,15	7,97	11,87	10,84	*	10,68	9,16	9,63
CD41C06A	3,61	7,52	11,07	10,8	10,68	*	10,54	10,32
CD41C07A	4,98	4,91	8,97	9,17	9,16	10,54	*	9,58
CD41C08A	3,95	4,68	8,71	8,14	9,63	10,32	9,58	*

Fig. 26. Brahetrolleborg forest, Funen. Matrix of internal correlation.

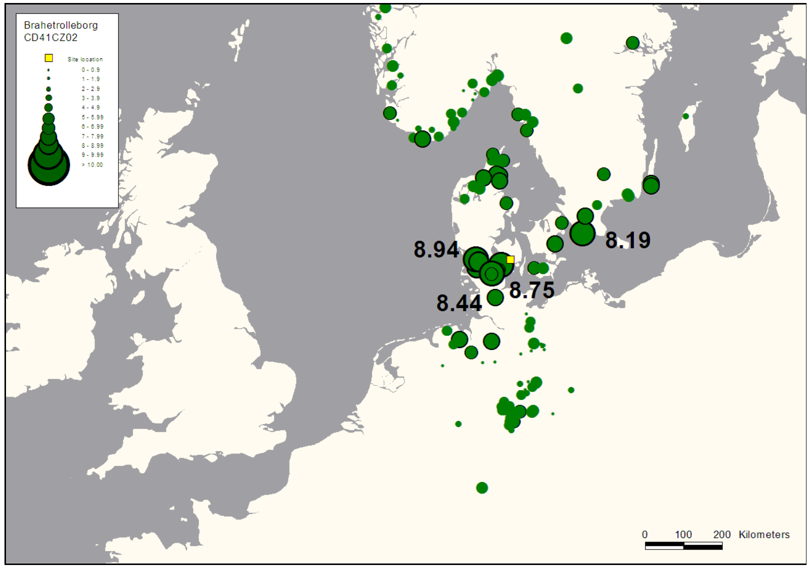


Fig. 27. Brahetrolleborg forest, Funen. Map showing the distribution of correlation values achieved between the shorter mean for Brahetrolleborg forest (CD41CZ02) and site chronologies from Northern Europe (the second level test).

tree-rings in the first mean, produces a quite high *t*-value at some distance from the forest being tested here. Now let us discuss the Southern Swedish forest.

One important message emerging from the Brahetrolleborg test case is to do with the *t*-value level acceptable for provenance determination. Account must be taken in this case of the fact that living tree data for the island of Funen is not well represented in the database. Just two other living tree sites from the island are included, each though consisting of a single tree only. It can be that for this test case higher correlation would be achieved with other Funen forests, thus lessening the significance of the high Skåne correlation. Actually this is the kind of conclusion which is reached by Haneca et al (2005) when discussing provenance determination, although they are using large regional chronologies:

> "While the regional chronologies now cover a larger area, it becomes more likely that individual series show high similarities with more than one regional chronology. When trying to interpret the provenance of an oak specimen it is necessary that the *t*H-value should be significantly higher compared to the other values calculated with the remaining chronologies. There should be only one *t*H-value that clearly points towards one region." (Haneca et al 2005, 266.)

4.2.3 LS111

In a test of the correlation of this site, from southwest Sweden, high matches were appearing with some Southern Jutland sites, especially with the Brahetrolleborg forest discussed above. The only information that came with the LS111 data was the title "from bkurv17", and it was not accompanied by map coordinates. It is possible to confirm that the data is from the Skåne area (Southwest Sweden), simply by comparing it with the master chronologies for the northern European region. Several versions of site means had been made for this site, as are indicated in the correlation matrix, and a high correlation between Brahetrolleborg and the average of all

				ls111020	ls111050	ls111010	ls1110i0	ls1110f0	ls1110e0	ls1110h0	ls111060	ls111070	ls111080	ls1110a0	ls1110c0	ls1110b0	ls1110d0	ls1110q0	ls1110o0	ls1110r0	ls1110p0	ls1110s0
LS111M01	LS111M02	LS111M0A S2	ls111020	*	5,99	7,14	4,93	4,94	4,28	2,92	3,88	3,09	-	2,47	2,74	4,39	4,67	3,06	3,31	2,36	2,68	4,06
			ls111050	5,99	*	7,16	5	5,08	4,5	3,21	4,83	6,25	2,91	3,87	2,65	3,88	4,5	3,96	5,05	4,3	4,09	3,81
			ls111010	7,14	7,16	*	4,94	7,31	5,21	4,35	4,48	4,12	4,43	3,34	3,83	2,96	3,9	2,01	2,32	2,35	2,86	4,14
		LS111M0B S2	ls1110i0	4,93	5	4,94	*	7,28	7,84	7,47	3,46	5,22	3,49	3,69	2,75	3,62	2,77	-	-	2,96	-	-
			ls1110f0	4,94	5,08	7,31	7,28	*	10,89	8,33	4,72	4,31	4,47	5,06	5,06	5,29	3,83	3,97	4	4,89	2,85	-
			ls1110e0	4,28	4,5	5,21	7,84	10,89	*	9,63	3,82	4,52	4,71	4,05	4,65	5,43	4,24	2,31	2,34	4,37	2,86	2,61
			ls1110h0	2,92	3,21	4,35	7,47	8,33	9,63	*	2,16	3,56	4,13	4,44	4,55	4,41	2,74	-	4,04	5,67	3,26	2,54
		LS111M0C S1	ls111060	3,88	4,83	4,48	3,46	4,72	3,82	2,16	*	11,17	8,85	6,75	2,91	3,37	3,91	2,86	2,03	3,42	3,06	-
			ls111070	3,09	6,25	4,12	5,22	4,31	4,52	3,56	11,17	*	8,87	6,21	3,74	3,87	6,07	-	-	3,19	3,72	2,66
			ls111080	-	2,91	4,43	3,49	4,47	4,71	4,13	8,85	8,87	*	6,41	4,33	5,63	2,29	-	2,07	3,88	3	2,39
			ls1110a0	2,47	3,87	3,34	3,69	5,06	4,05	4,44	6,75	6,21	6,41	*	6,61	3,86	3,99	4,2	3,26	4,5	2,55	2,38
			ls1110c0	2,74	2,65	3,83	2,75	5,06	4,65	4,55	2,91	3,74	4,33	6,61	*	8,27	5,4	4,47	3,84	4,32	2,08	2,18
			ls1110b0	4,39	3,88	2,96	3,62	5,29	5,43	4,41	3,37	3,87	5,63	3,86	8,27	*	5,75	3,64	2,96	4,3	2,87	2,2
			ls1110d0	4,67	4,5	3,9	2,77	3,83	4,24	2,74	3,91	6,07	2,29	3,99	5,4	5,75	*	2,17	-	2,87	-	-
	LS111M03	LS111M0D S3	ls1110q0	3,06	3,96	2,01	-	3,97	2,31	-	2,86	-	-	4,2	4,47	3,64	2,17	*	5,58	7,32	5,45	4,68
			ls1110o0	3,31	5,05	2,32	-	4	2,34	4,04	2,03	-	2,07	3,26	3,84	2,96	-	5,58	*	8,58	8,07	4,13
			ls1110r0	2,36	4,3	2,35	2,96	4,89	4,37	5,67	3,42	3,19	3,88	4,5	4,32	4,3	2,87	7,32	8,58	*	6,32	5,85
			ls1110p0	2,68	4,09	2,86	-	2,85	2,86	3,26	3,06	3,72	3	2,55	2,08	2,87	-	5,45	8,07	6,32	*	5,92
			ls1110s0	4,06	3,81	4,14	-	-	2,61	2,54	-	2,66	2,39	2,38	2,18	2,2	-	4,68	4,13	5,85	5,92	*

Fig. 28. LS111 'from bkurv17'. Matrix of internal correlation. The matrix shows that the tree-ring curves from LS111 might be divided into two groups.

samples from this Skåne site was puzzling. It seemed necessary to examine what was going on here.

There is the possibility that the trees in this series are not from a single site, and that the site average should be seen more as a master chronology rather than a site mean, resulting in a higher *t*-value. The internal correlation matrix (fig. 28) shows that actually the tree-ring curves from LS111 might be divided into two groups. When means of these two groups are made, the shorter Brahetrolleborg mean still gives a very high *t*-value (t = 9.38) with the first group, so still the high correlation appears with this forest, some 200 kilometres away.

This is actually a very difficult discovery in terms of the methodology being developed here. If the high correlation at his distance is due to a large geographical spread of the data from the Skåne site, but which is not necessarily distinguishable through the correlation matrix, then this is quite problematic. Ultimately, this kind of phenomenon can occur in the historical data, with no way of identifying the homogeneity of the data but by a correlation matrix. In the making of site chronologies from the archaeological and historical sites, we have only the correlation of the tree-ring curves (a form of cluster analysis) to allow the choice of what curves should be included. Some site chronologies from historical sites with many trees might be less homogeneous than others, in other words might represent larger regions, while others represent very small areas, affecting the provenance result.

But lets take a look at the correlation matrix for LS111 again. The larger group that is identified (LS111M02) can be further divided into three groups, as indicated. The resulting four groups for the site are also shown in fig. 29. It is interesting in this context that when the four groups are defined, we find that the groups follow the alphabetical and numerical numbering of the individual files, leading to the idea that indeed there was some grouping of this data when the files were numbered. Can this mean that the tree-ring series indeed come from quite separate sites?

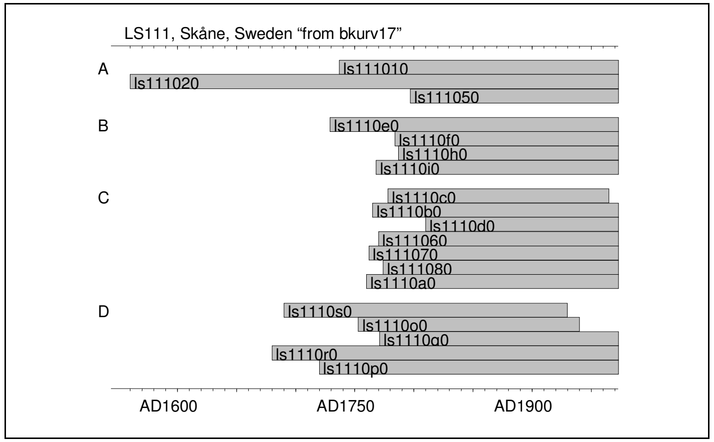


Fig. 29. LS111 ‘from bkurv17’. Diagram showing the chronological position of the tree-ring series from the site. The data can be divided into four groups, as indicated.

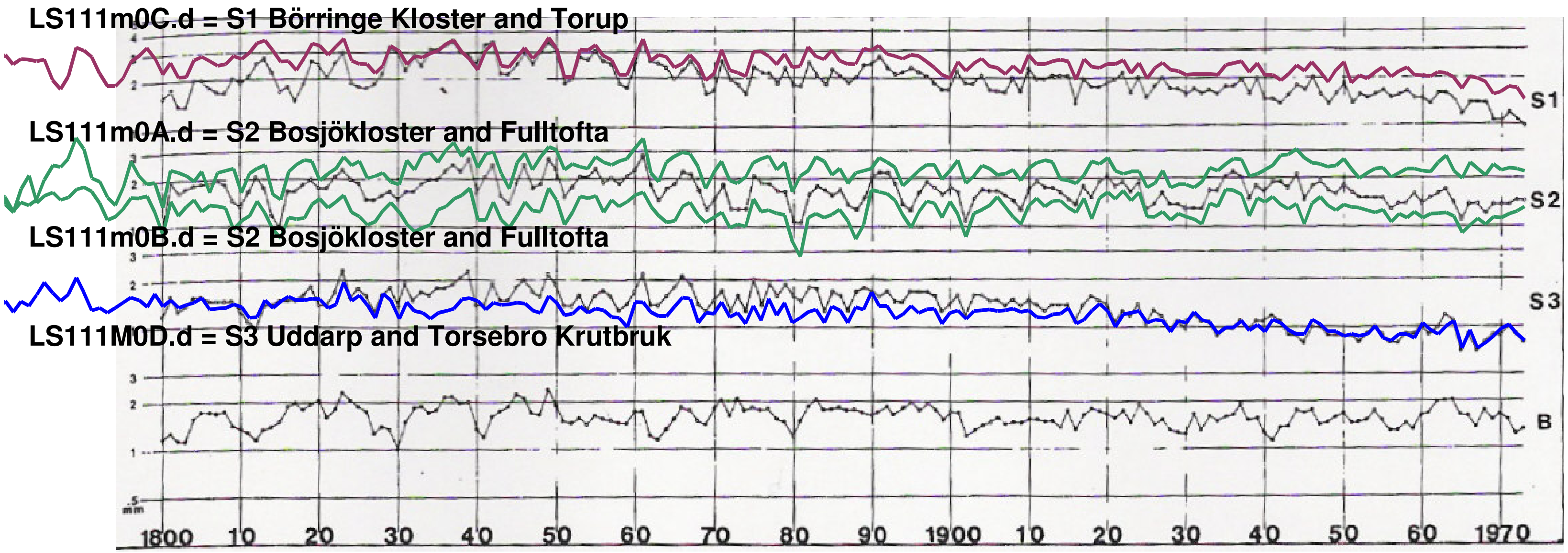


Fig. 30. Diagram showing Bartholin’s Skåne chronologies (reproduced from Bartholin and Berglund 1975, 205), compared with the four LS111 curves, confirming the location of the LS111 sites.

Bartholin and Berglund (1975) describe the beginnings of dendrochronology of oak in Southwest Sweden. Several living tree sites were sampled, three in the Skåne region and one in Blekinge. For this study it was important to identify to what site the material LS111 belonged. In the paper a segment of the tree-ring curves for the four sites are illustrated. The diagram from Bartholin and Berglund (1975, 205) is reproduced in fig. 30 along with the four tree-ring curves constructed here for LS111. Comparison of Bartholin and Berglund's and these four tree-ring curves confirms that LS111 includes trees from the three Skåne living tree sites (the very slight differences in the curves will be due to the fact that in this study, series which showed possible cockchafer influence have not been included). The high correlation then with Brahetrolleborg is due to the fact that grouping all of LS111 trees together results in a wider regional chronology, not an individual site chronology. When it is now clear that we are here dealing with several forest sites, one in Southwest Skåne (S1), one in middle Skåne (S2) and the third in Northeast Skåne (S3).

One last piece of information, which emerges from Bartholin and Berglund's paper, is concerning the sampling at the various sites.

> "At each place at least 10 trees were selected. The distance between the trees could be as much as *c.* 10 km."
> (Bartholin and Berglund 1975, 204)

Clearly the strategy was one of widespread sampling. The resulting tree-ring curves will be of a more regional nature, ideal for the early development of dendrochronology for dating purposes, rather than producing local site chronologies useful in provenance determination to the local level.

All of these problems encountered with the methodology test for the results for the Brahetrolleborg and LS111 sites serve also to show the value of the third level provenance test, that is the test using the single-tree data. In the test for Brahetrolleborg, the singe trees from Skåne LS111 do not produce as high *t*-values as the trees near the Funen forest site (fig. 25).

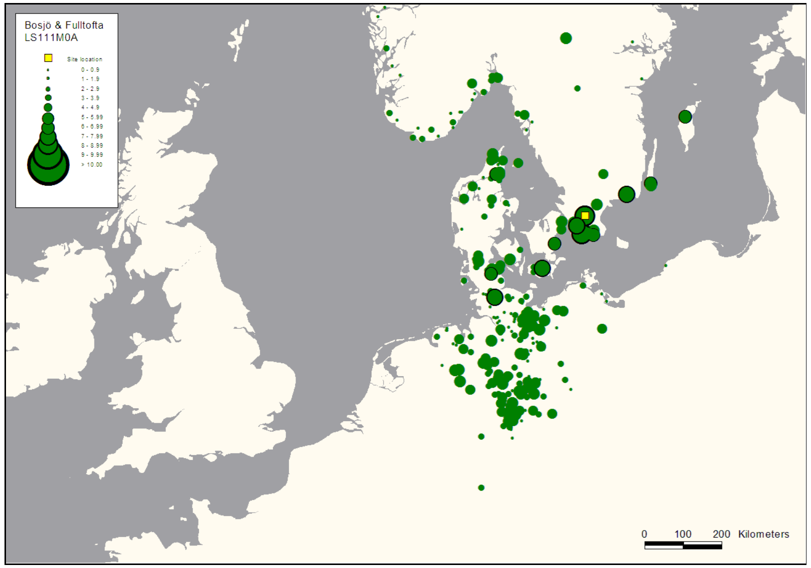


Fig. 31. LS111M0A, Bosjökloster and Fulltofta, Skåne. Map showing the distribution of correlation values achieved between the mean LS111M0A for Bosjökloster and Fulltofta and site chronologies from Northern Europe (the second level test).

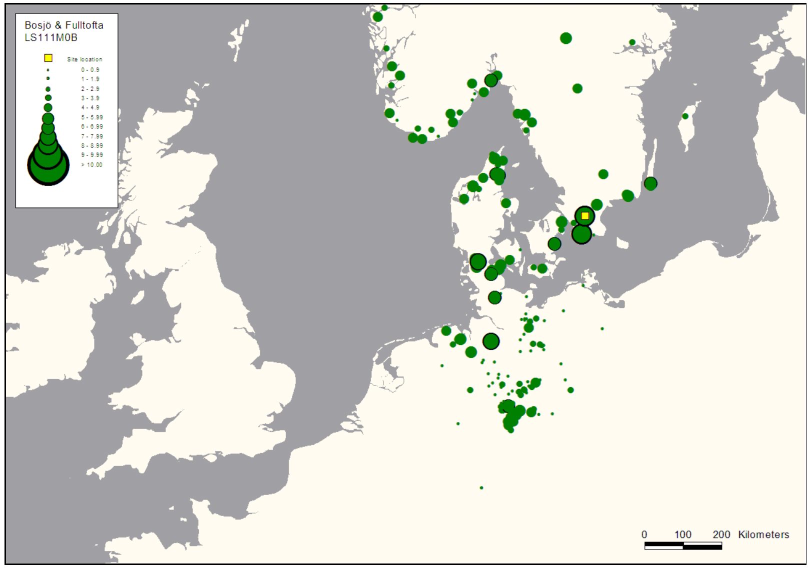


Fig. 32. LS111M0B, Bosjökloster and Fulltofta, Skåne. Map showing the distribution of correlation values achieved between the mean LS111M0B for Bosjökloster and Fulltofta and site chronologies from Northern Europe (the second level test).

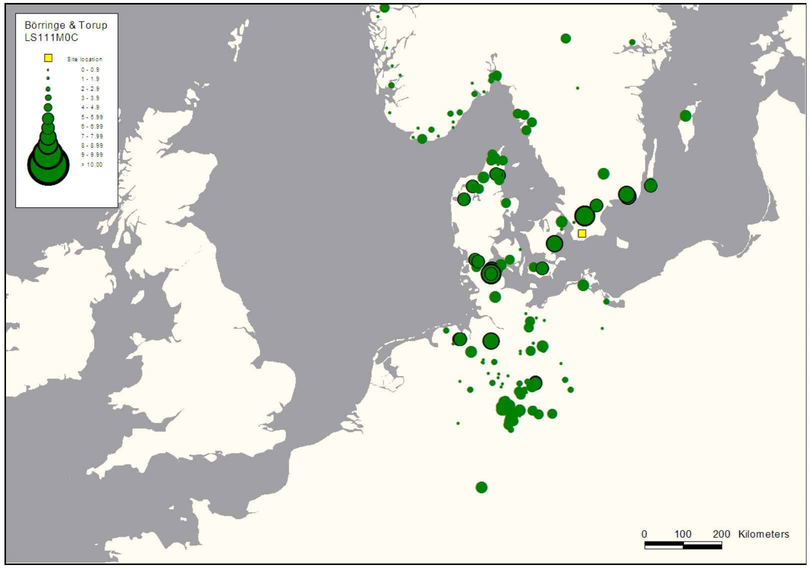


Fig. 33. LS111M0C, Börringe Kloster and Torup, Skåne. Map showing the distribution of correlation values achieved between the mean LS111M0C for Börringe Kloster and Torup and site chronologies from Northern Europe (the second level test).

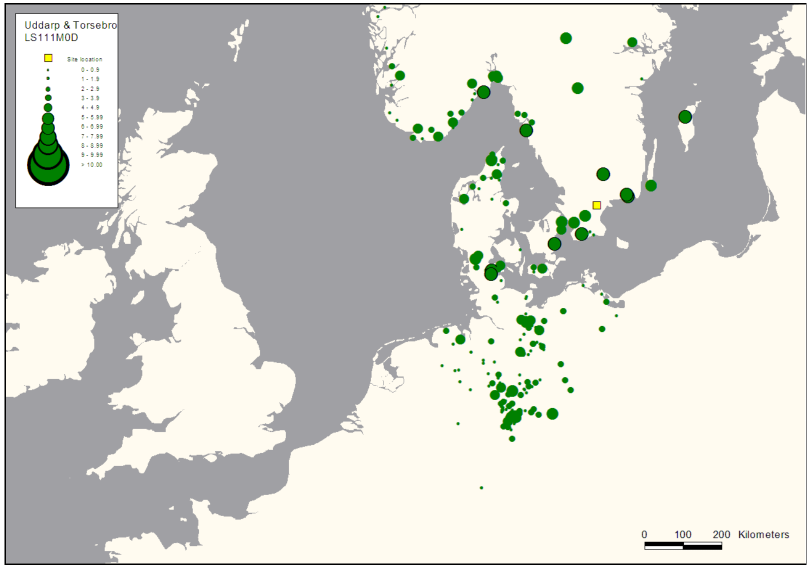


Fig. 34. LS111M0D, Uddarp and Torsebro Krutbruk, Skåne. Map showing the distribution of correlation values achieved between the mean LS111M0D for Uddarp and Torsebro Krutbruk and site chronologies from Northern Europe (the second level test).

The discovery of the high match between Brahetrolleborg and the site at Skåne, Sweden leads into a discussion then of the Swedish site. As mentioned above, it is now confirmed that the site is not a single location, but a grouping of three sites with circa 80 km between the easternmost and westernmost sites. *T*-value distributions for each of the four means are produced, with the site means from the European dataset (second level provenance determination), to examine the results geographically for the LS111 sites. These are shown in Figs. 31, 32, 33 and 34).

Further very high *t*-values from other Swedish sites do not appear, but looking at the map of the living tree data available in this study (fig. 35) it is quickly obvious that there is not a high density of living tree sites in that region.

4.2.4 Flensburg

This site was analysed in the Dendrochronology Laboratory at Hamburg University and lies just south of the Danish border, in Sleswig-Holstein, Germany. Of five samples, just four are included in the site mean (one is removed from the analysis as it had some cyclical patterning in its tree-ring curve). A map of the correlation at the second level, using the site chronologies made after the cockchafer-affected trees had been removed (as described above) is shown in fig. 36. Here, while the highest value achieved is not as high as might be desired (t = 8.62), it is nevertheless with a quite local forest. The fine strong cluster of high values near the site as we have seen in other examples though is not apparent here.

Does the single tree test produce similar results? This is mapped in fig. 37. One single tree from a Danish forest (Keldstrup Fredskov) gives a higher correlation (t = 9.46) than in the case of the site mean test above. We can see with this example that *t*-values lower than 9.00 can occur at some distance from the site being tested, and when we do not see a clear cluster of high values within a small area, a provenance determination to the local level is not reliable.

4.2.5 Ratzeburg (H11FA)

Again we take a living forest as a test case. The trees in this forest were analysed by the Dendrochronology Laboratory in Hamburg University. There are seven measurements from the site, but two are taken out of the analysis as they have a certain degree of cyclical growth which might be due to cockchafer. One tree does not match very well with the others, as seen by the correlation matrix for the site, so just four trees are represented in the site chronology, which covers a period of 142 years, from 1845 to 1986. As in the previous examples, the site chronology is compared to all other site chronologies from the Danish and North German data (fig. 38). As can be seen from this map, the highest values achieved are with adjacent forests, but the values are not as high as in other examples. It is not a part of this study to go into a detailed ecology of the forests being tested here, as in the historical data such analysis would be impossible, so even though the distribution of t-values is not problematic as such in this test case, we need to search for an explanation for the *relatively* low values that appear here. There are no extreme ring-widths in the site chronology which could reduce the correlation result, but the correlation matrix shows that the internal correlation is not exceptionally high, contrasting to other living tree examples above. A combination though of the fact that this site only contains four trees, and that the two forests, which give the highest results, consist of two trees and eight trees respectively, might contribute to the relatively low correlation. Again it should be stressed that t-values of t = 7.08 or 7.54 are not low correlation values in a statistical sense, but for provenance determination, these tests are showing that higher values improve the result. This map though illustrates the argument that it is not necessarily the actual correlation values achieved that should be the deciding factor in the interpretation of the provenance analysis. The distribution of t-values in this map, though relatively low, shows that the highest values are with adjacent forests. One could say there is a clustering of the highest correlation, not a spread of correlation like that seen for example in the Hasbruch example below. If we say that because the highest correlation values are geographically grouped together, that the provenance

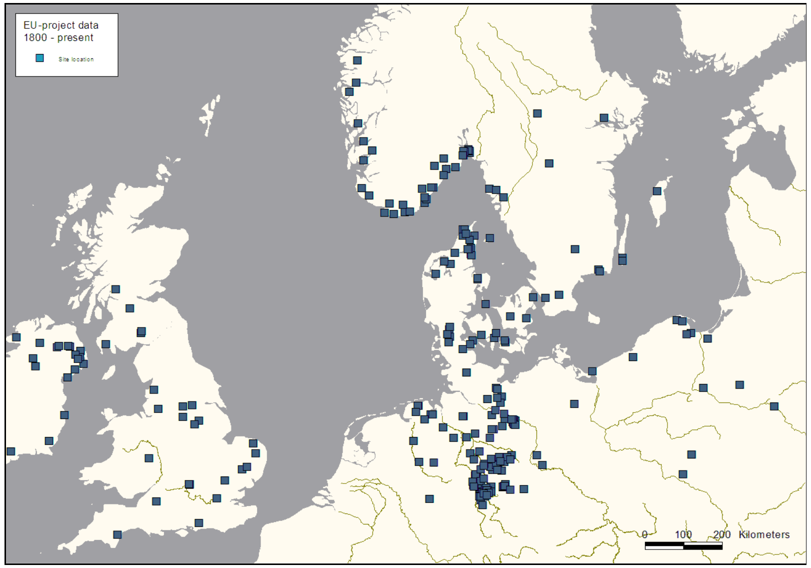


Fig. 35. Map of Northern Europe showing the distribution of sites for which tree-ring measurements from living trees (1800 to 2000) are available for this study.

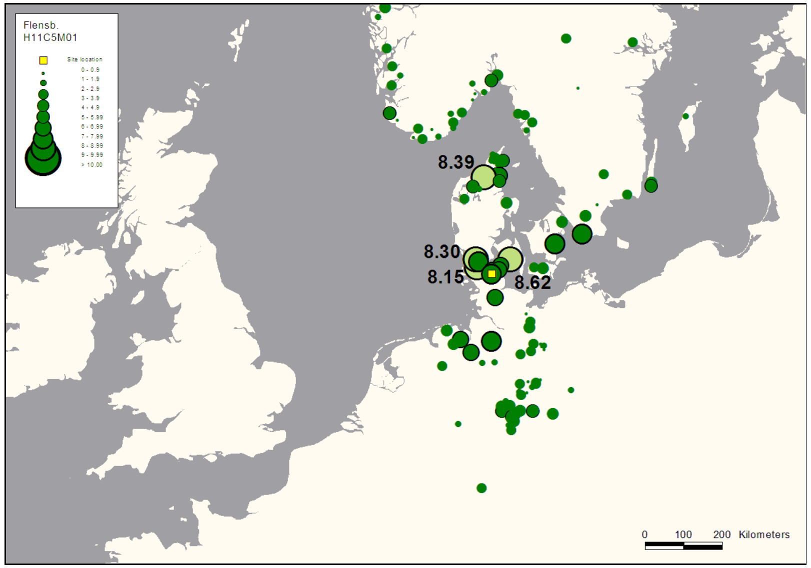


Fig. 36. Flensburg forest, Schleswig-Holstein. Map showing the distribution of correlation values achieved between the mean for Flensburg forest and site chronologies from Northern Europe (the second level test).

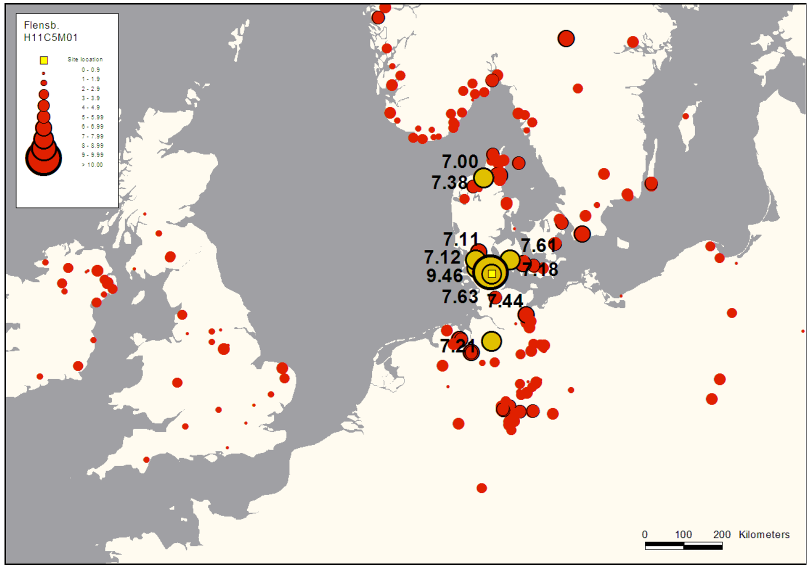


Fig. 37. Flensburg forest, Schleswig-Holstein. Map showing the distribution of correlation values achieved between the mean for Flensburg forest and single tree-ring measurements from Northern Europe (the third level test).

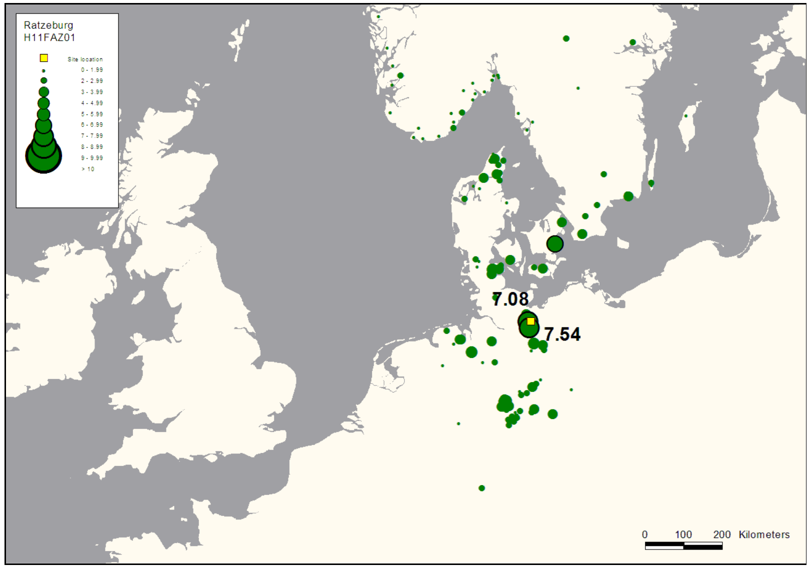


Fig. 38. Ratzeburg forest, Schleswig-Holstein. Map showing the distribution of correlation values achieved between the mean for Ratzeburg forest and site chronologies from Northern Europe (the second level test).

determination is confidant, we meet though the problem that in the historical material, we can't know if a higher value again is missing, due to the random nature of the representativity of the historical data, and that a higher value might be some distance from the lower values as appear here.

To increase the probability of getting a good provenance result a good many samples should be analysed. It might be that few samples can give satisfactory provenance, as with the Knobben example with only 5 trees giving a site chronology of 149 years, but other living tree sites with few trees show a less reliable result.

4.2.6 Hasbruch (G3902)

For this site, analysed by the Dendrochronology Laboratory in Göttingen University, the correlation on the second and third level have been tested, using the site chronologies, and the single tree data. The site chronology for Hasbruch is made from 10 trees and is 182 years long, covering the period 1810 to 1991. The second level test map is shown in fig. 39. Here it can be seen that the highest values are with nearby forests a *t*-value of 8.84 is achieved with a site mean *c.* 60 km away, and 8,59 with an adjacent forest. It might be noted that a quite high value (t = 7.14) appears with a forest *c.* 200 km further south. This test provides us with another example of the spread of relatively high *t*-values at some distance from the site being tested. These are indeed high *t*-values from the point of view of dating a tree-ring sequence, but we can see that for provenance determination we should see values higher than t = 7. We should indeed see clusters of higher *t*-values within a relatively contained area.

When we look at the third level test for this site (fig. 40) we see that the highest values fall within a *c.* 50 km radius of the site being tested, and we do not get similarly high values further south.

4.2.7 Knobben

An inland (in the continental sense) was chosen for yet another living tree test, this time a forest in central Germany at Knobben Eiche. This forest was randomly

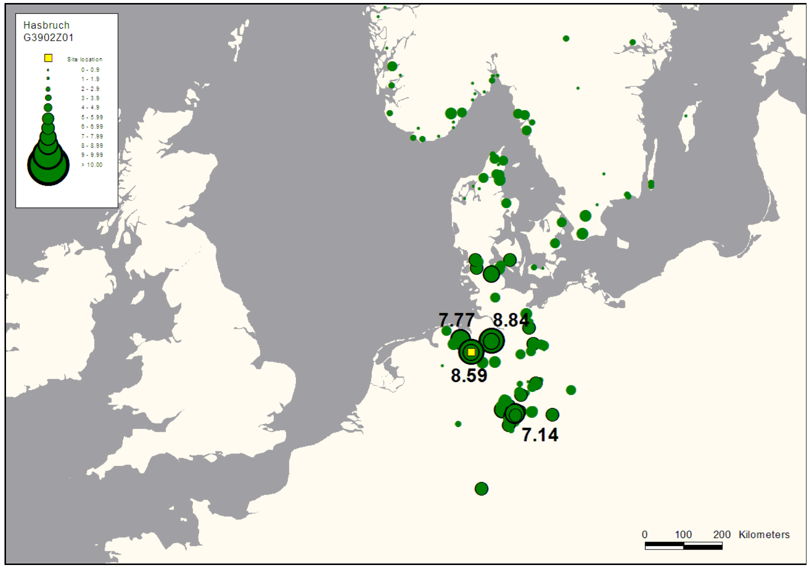


Fig. 39. Hasbruch forest, Lower Saxony. Map showing the distribution of correlation values achieved between the mean for Hasbruch forest and site chronologies from Northern Europe (the second level test).

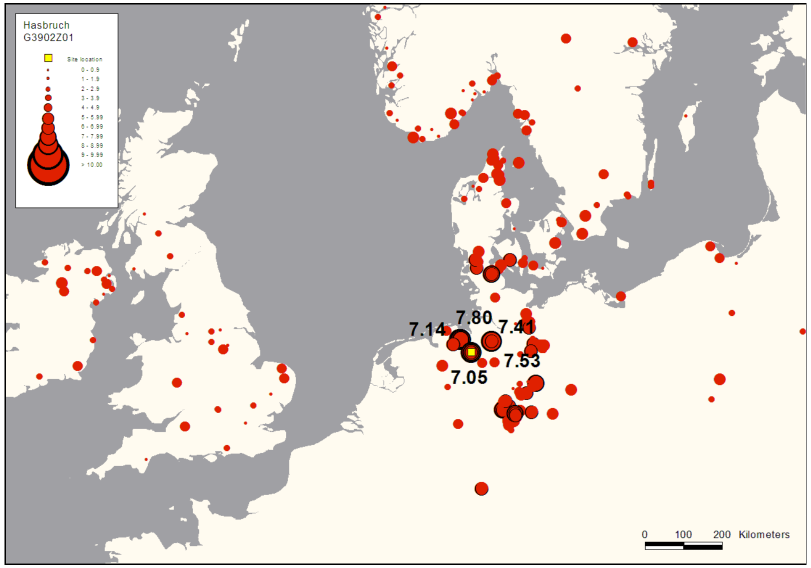


Fig. 40. Hasbruch forest, Lower Saxony. Map showing the distribution of correlation values achieved between the mean for Hasbruch forest and single tree-ring measurements from Northern Europe (the third level test).

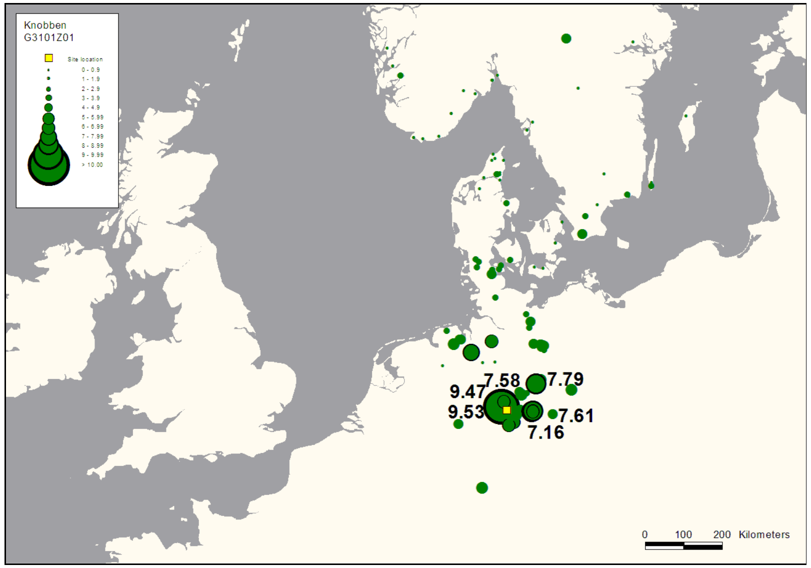


Fig. 41. Knobben Eiche forest, Lower Saxony. Map showing the distribution of correlation values achieved between the mean for Knobben forest and site chronologies from Northern Europe (the second level test).

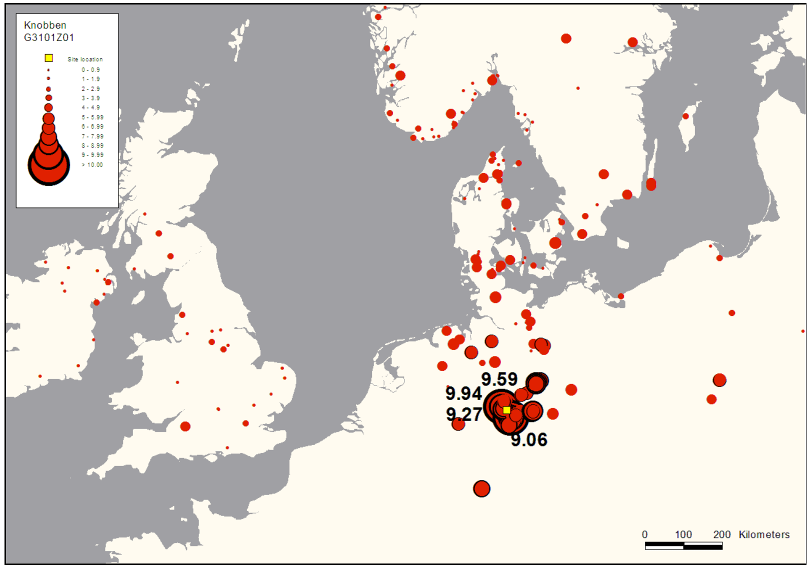


Fig. 42. Knobben Eiche forest, Lower Saxony. Map showing the distribution of correlation values achieved between the mean for Knobben forest and single tree-ring measurements from Northern Europe (the third level test).

chosen from inland Germany. The forest was analysed at Göttingen University Dendrochronology Laboratory. The site consists of five trees, none of which have cyclical patterns in their tree-ring growth, so all five are included in the analysis. The matrix for the site shows a well matching group and all five are thus included in the site chronology, which covers 149 years, from 1841 to 1989. The result of the second level test is shown in fig. 41. A clear distribution of high values appears within the region of Knobben forest, with matches of t = 9.53 and t = 9.47 the highest, both within 20 km radius of the site. A value of t = 7.79 appears some *c.* 100 km distance away. The result of the third level test for this site chronology, with single trees, is shown in fig. 42. Here again a cluster of high values emerges with trees from nearby areas. The results of the test in this case again show that the combination of the second and third level tests allows a confidant provenance determination. The distribution of high t-values near the site being tested allows us to see what kind of pattern we can expect in the correlation mapping, when we move on to evaluating historical data. A tight cluster of high values in an area gives a good indication of provenance.

4.2.8 Mossige

This site in Norway was analysed by Kjeld Christensen, who was, at the time, at the Danish National Museum's Environmental Archaeology Unit. Ten trees were analysed from the site, but the cockchafer test that has been used here showed that four trees had cyclical patterning in their tree-ring growth. A site mean was made of the remaining six trees (CN00XZ01), and the map of the result of the provenance test at the second level is shown in fig. 43, where site chronologies have been built for sites in Scandinavia and Northern Germany. Here, in contrast to other examples from the living tree dataset we have seen, we get quite a spread of quite high t-values along the Norwegian coastline, north of the Mossige forest site, and we also get a quite high correlation with a site from the northern tip of Jutland.

We are missing the site means for Scotland, which are significant in this case, as we see in the single tree test results for the Mossige mean (fig. 44). Here

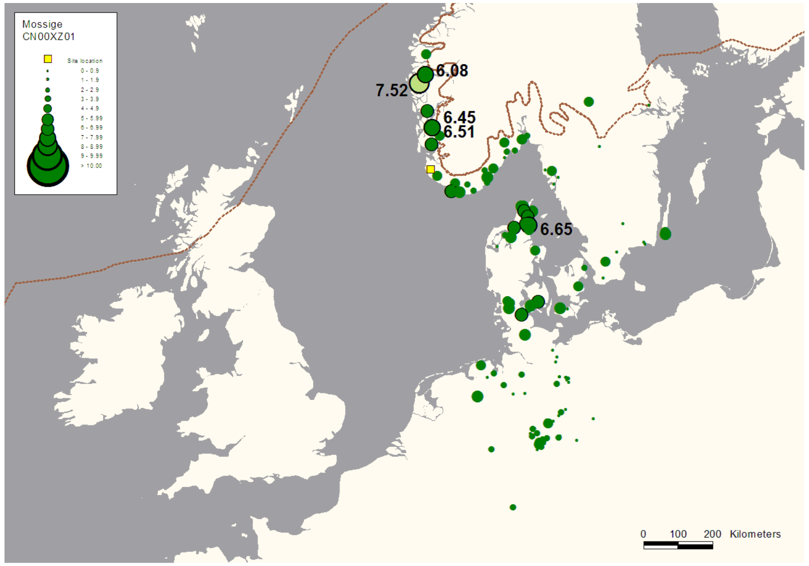


Fig. 43. Mossige, Rogaland, Norway. Map showing the distribution of correlation values achieved between the mean for Mossige and site chronologies from Northern Europe (the second level test).

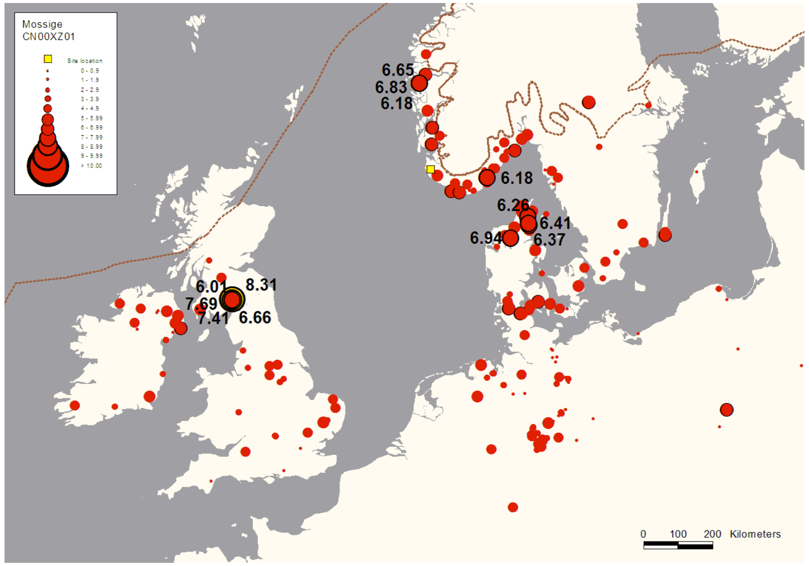


Fig. 44. Mossige, Rogaland, Norway. Map showing the distribution of correlation values achieved between the mean for Mossige and single tree-ring measurements from Northern Europe (the third level test).

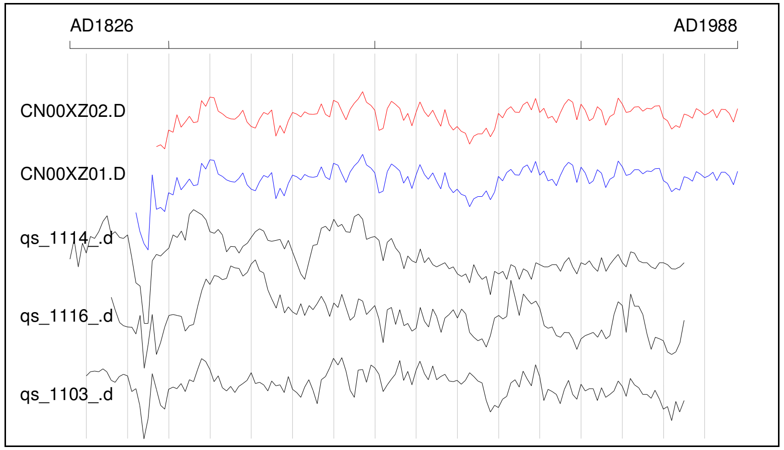


Fig. 45. The mean curve for Mossige, Rogaland, Norway (CN00XZ01 in blue) is plotted with the three single tree tree-ring curves from Raehills, Scotland (coloured black). It can be seen that at the very start of the Mossige Z01 curve is a series of narrow rings, and then abruptly a wider ring. This strong feature is echoed in the three Raehills trees.

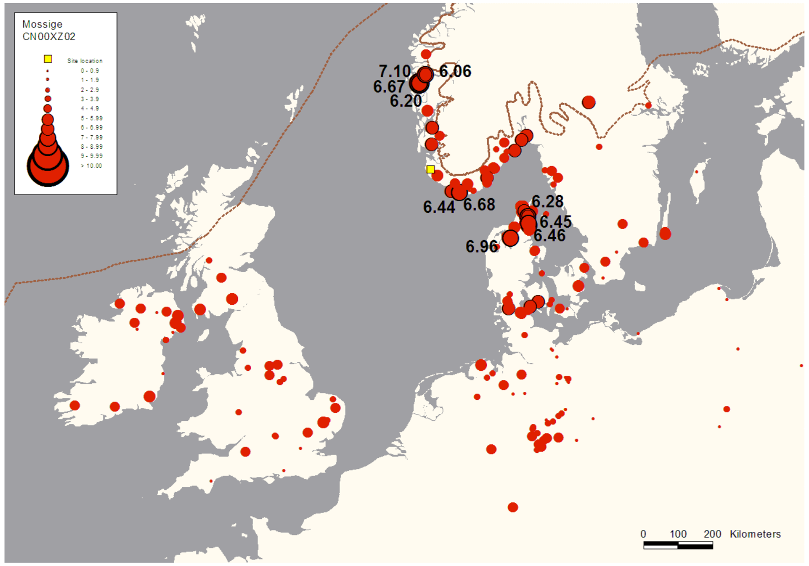


Fig. 46. Mossige, Rogaland, Norway. Map showing the distribution of correlation values achieved between the shorter mean for Mossige (CN00XZ02) and single tree-ring measurements from Northern Europe (the third level test).

the picture attained is quite different, where the highest *t*-values appear actually with single trees from Raehills, a site in Scotland. Now it is necessary to investigate why this can occur. Here a visual plot of the tree-ring curves can help in looking into why we have this surprising correlation distribution. The mean curve for Mossige (CN00XZ01 in blue) is plotted with the three single tree tree-ring curves from Raehills (coloured black) (fig. 45). It can be seen that at the very start of the Mossige Z01 curve is a series of narrow rings, and then abruptly a wider ring. This strong feature is echoed in the three Raehills trees. Now when we look again at the six samples that are included in the Mossige mean, we see that the first four years are derived from only one sample with quite narrow rings. The transition to the next year, where another sample joins the mean, causes this extreme jump. What if these early growth years, which belong to growth of the tree while very young, are causing the widespread correlation values?

So we delete the first five years from the Mossige mean Z01, making a new, Z02 (CN00XZ02, shown in red). A new series of maps can then be made using this shortened mean. The single tree third level test for the new shortened mean Z02 (fig. 46) shows the resulting correlation distribution. The shortened Mossige mean (CN00XZ02) does not produce high correlation with trees from the Scottish site (highest is 4.94). The high values that are achieved with the single trees are still quite spread though, even having removed the rings from the immature phase of the Mossige trees, as indicated on the map.

The test at the second level shows that the provenance results for Mossige are still very spread (fig. 47). Several reasons for this can be suggested. It could be for instance that the oaks in the Norwegian forests, so close to the northern limit for oaks in Europe only thrive in the protected fjords, and that each fjord has its special microclimate, thus correlating less well with trees from neighbouring fjords. The proximity to the oak tree-line in itself might be the cause of the wide spread of high values. If the limiting factor close to the tree-line is the same at both regions, for example temperature, then the trees might respond similarly to temperature

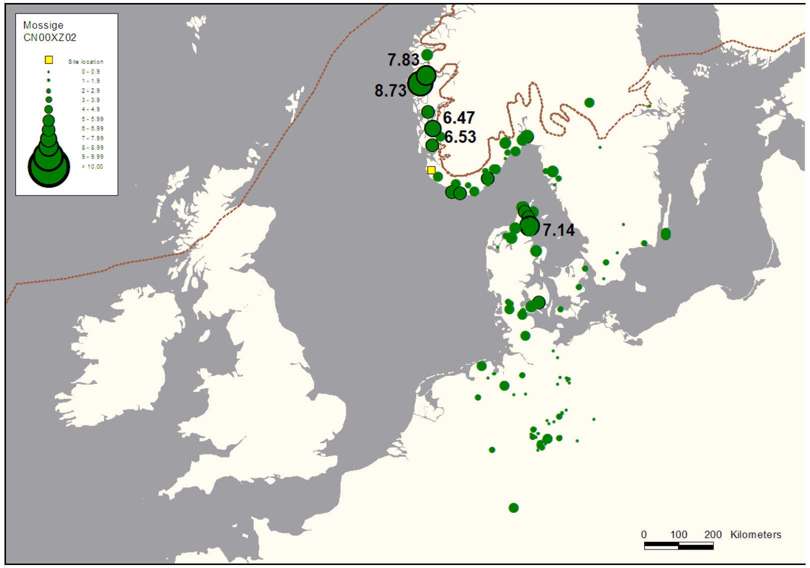


Fig. 47. Mossige, Rogaland, Norway. Map showing the distribution of correlation values achieved between the shorter mean for Mossige (CN00XZ02) and site chronologies from Northern Europe (the second level test).

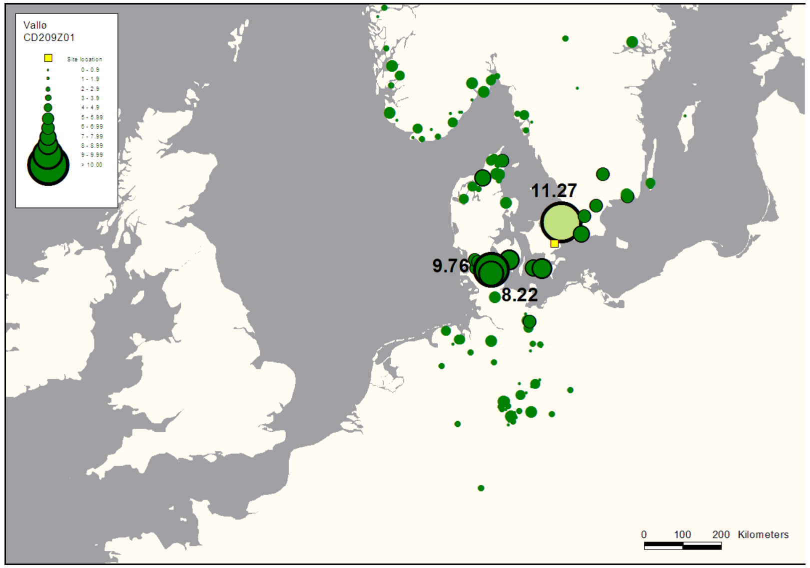


Fig. 48. Vallø forest, Zealand. Map showing the distribution of correlation values achieved between the mean for Vallø and site chronologies from Northern Europe (the second level test).

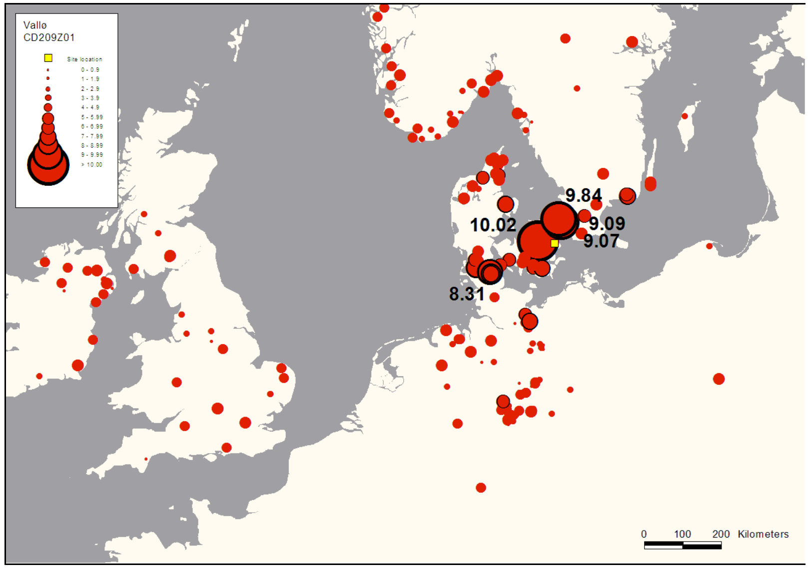


Fig. 49. Vallø forest, Zealand. Map showing the distribution of correlation values achieved between the mean for Vallø and single tree-ring measurements from Northern Europe (the third level test).

fluctuations in both regions, given the prevailing oceanic climate pattern of weather systems for both regions, coming in from the west over the Atlantic. In addition, with the more extreme landscape we are dealing with on the Norwegian coast where, in contrast to the Danish landscape, the land level rises quite steeply, directly from the coastline, the different forests sampled at the different sites can have had quite different growth conditions, depending on altitude. Another reason can have to do with the density of sites. In the Danish and German examples, many sites have been analysed and are included in the data, thus producing the very high values, useful for provenance determination. In the Norwegian material, there is some considerable distance to the next forest, a distance which is enough that the *t*-values achieved are lower than acceptable levels for provenance determination. It should be stressed here though that for dating of the tree-ring sequences the *t*-values are high, as can be seen in the map, where the highest *t*-values attained are given.

4.2.9 Vallø

Vallø forest on the island of Zealand in Denmark was sampled and analysed in the 1950s (Holmsgaard 1955). The measurements for oak amount to 57 individual series, but 15 of these have been taken out as they displayed cyclical patterns in their tree-rings, which could be due to cockchafer activity. The matrix for the remaining 41 trees shows that a site chronology of all 41 trees can be made. This site chronology then has been checked against the Northern European data, on the second level with site chronologies and on the third level with the single tree data. A clear high *t*-value is achieved with another site chronology from Zealand, Egemosen, highlighted in lighter green, with a *t*-value of 11.27 (fig. 48). The Egemosen site is *c.* 56 km north of Vallø. But note the two high values with forests on the Jutland peninsula. If we were missing the high 11.27 value, we would see a quite neat cluster of high values in Southern Jutland and determine the origin of the timber to that area.

When Vallø is tested with the single trees again the high values are with trees from Zealand forests (fig. 49). Note though that a different site, Sarauwsminde, *c.* 42 km to the west of Vallø, gives the highest correlation. Correlation with a Sarauwsminde site chronology is missing from the second level test simply because the Sarauwsminde site consists of only one tree, so no site chronology can be made. These results demonstrate the value of testing to the third single tree level. More of the dataset can be used in the analysis, even where sites consist of just single trees, as might for example often be the case in the historical material. This serves as a check on the second level test described above.

4.3 *Rules of provenance determination*

T-values must be very high. Values around $t = 6.00$ or $t = 7.00$ are not high enough. These values occur over sometimes very wide distances. When values higher than $t = 10.00$ occur, then a meaningful provenance can be suggested. And when these high values appear in a neat cluster, then provenance to a local level can be suggested. Having said that, a full analysis of the application and applicability of the different correlation statistics is needed. A comparison of the results of provenance determination using the various versions of the *t*-test and the percentage agreement test (as discussed above) would be an interesting exercise, but this is not within the remit of this study.

Provenance determination should be mapped at several levels. Up until now, the origin of archaeological objects has been determined on a wide scale, using large regional chronologies, so-called master chronologies, which is now called the first level test. This study moves away from the regional scale, assembling tree-ring data into smaller parcels. The provenance test is carried out then at what is now called the second level and third level tests, using site chronologies and individual single-tree measurements respectively. The correlation between the tree-ring curve from the site being tested and the Northern European site chronologies and individual tree-ring measurements are mapped, allowing the results to be illustrated clearly. In a provenance test at the local level, using site chronologies and even single tree data, when values of correlation of $t > 10.00$ are achieved, provenance of the timber can now be, with some certainty, identified to within a *c.* 50 kilometre radius. Ideally a good cluster of high *t*-values should appear within a small area, with several sites. Where such high values fail to appear in the second and third test levels, then the provenance determination is to a more regional level.

The pattern emerging from the test of the methodology using the living tree data is that a good provenance, to the local level, can be determined by just a few key trees, which match the chronology being tested, with very high correlation. We see this in living tree examples, and it happens also in the historical examples. When the few tree-ring curves which achieve the high *t*-values are taken out of the equation, the result is a less specific provenance identification, in other words to a wider regional level, or we get no reliable result at all. In reality, much is down to chance: do we coincidentally have data which matches well with the curve in question? Ultimately provenance determination to the local level is dependant upon a dense coverage of sites and this stresses the importance of the sharing of data between researchers so that we get closer to reaching such coverage. Ultimately, the random nature of archaeological and historical data survival and the equally random nature of dendrochronological analyses means that there is little control over whether a provenance determination analysis will work, but the more data that is generated over time, the greater the potential for successful results.

The greatest requirement for the future of dendroprovenancing is the sharing or pooling of data. Provenance determination requires that a full suite of chronologies is available over the region being studied. For determination to a more local level, more than the sharing of *large* chronologies is needed. Pooling of single tree data, with geographical coordinates, to enable small units of data to be put together, to allow the testing of timber origin to a local level, would provide the ideal conditions for the future of this sub-discipline of dendrochronology.

Section II

5 Chapter 5 Case studies

5.1 *Introduction*

A selection of archaeological objects has been chosen as specific case studies in this thesis. These consist of finds of shipwrecks and finds of barrels, chiefly from Danish finds, but some ships from other countries have also been included. The largest ship group that has been chosen is the cog. The dendroprovenance analyses of 16 of these are described in chapter 5. A selection of other ship groups has also been included. There are two vessels of Nordic type from the 12th century (Karschau (Englert et.al. 2000; Kühn et.al. 2000) and Möweninsel (Belasus 2004)). The results of the analysis of the Karschau ship are already written and submitted to the International Journal of Nautical Archaeology and is pre-published online (published March 2007). This paper is included in this volume (appendix 2). The Möweninsel ship is described in chapter 6 below. Two large cargo ships are the subjects of chapter 7. Both ships are from Norway and are dendrochronologically dated to the late 14th century. Chapter 8 describes the analysis of the provenance of the timber from two late 16th century wrecks.

In chapter 9 the barrels analyses are discussed. These are treated chronologically.

As will be apparent in the following cases studies, the material from some sites allows a straightforward provenance determination, while material from others produce problems of interpretation. The causes of these differences are varied, and these are proposed in each case.

"name"	"Felling date"	"provenance"	"group"	"reference"
Lille Kregme	ca. 1358	Baltic	cog	Rieck 1996
Vejby	winter 1372	Baltic	cog	Crumlin-Pedersen 1979; Bonde and Jensen 1995
Kuggmaren I	summer 1215	Danish	cog	Adams and Rönnby 2002
Skagen	ca. 1195	Danish	cog	Dokkedal 1996
Kollerup	ca. 1155	Danish	cog	Kohrtz Andersen 1983
Kolding	winter 1188-89	Danish	cog	Hansen 1944
Helgeandsholm 2	1330	not known	cog	Varenius 1989
Skanör	after 1382	Baltic	cog	Hörberg 1995; Nilsson 2004
Bremen	1378	Weser German	cog	Lahn 1992; Bauch 1969
Oskarshamn Bossholmen	after c. 1270	East Skåne Sweden	cog	Cederlund 1990; Dokkedal 1996
Flevol. OZ43 Nijkerk	1275-1300	not known	cog	Luns 1985
NOP M107 Marknesse	1375-1400	not known	cog	Modderman 1945
NOP Q75 Ens	1300-1325	not known	cog	Reinders 1985
Flevol. N5 Dronten	1325-1350	not known	cog	Reinders 1985
Flevol. NZ42 Spakenburg	1350-1400	not known	cog	Reinders 1985
Flevol. NZ43 Spakenburg	1402-1414	Holland/Westfalen	cog	Van de Moortel 1991
Flevol. OZ36 Nijkerk	1336	not known	cog	Luns 1985
NOP A57 Rutten	1265-75	NE Germany?	cog	Oosting 1985; 1987
Flevol. Almere	1410	not known	cog	Hocker and Vlierman 1997
Darss cog	1298-1313	Baltic	cog	Jöns 2002
Doel Belgium	1325-26	Aller/Weser German	cog	Vlierman 2006; Hanraets 2000
Dronten M61	after c. 1296	not known	cog	Vlierman 1996
CZ46 Oostvaarderplassen	after 1327	Holland	cog	Hanraets 1999
Swifterbant OG77	ca. 1305	Holland	cog	Karel Vlierman pers.comm.; Hanraets 2001

Fig. 50. Table summarising the dating and provenance determination results for the cogs examined in this study.

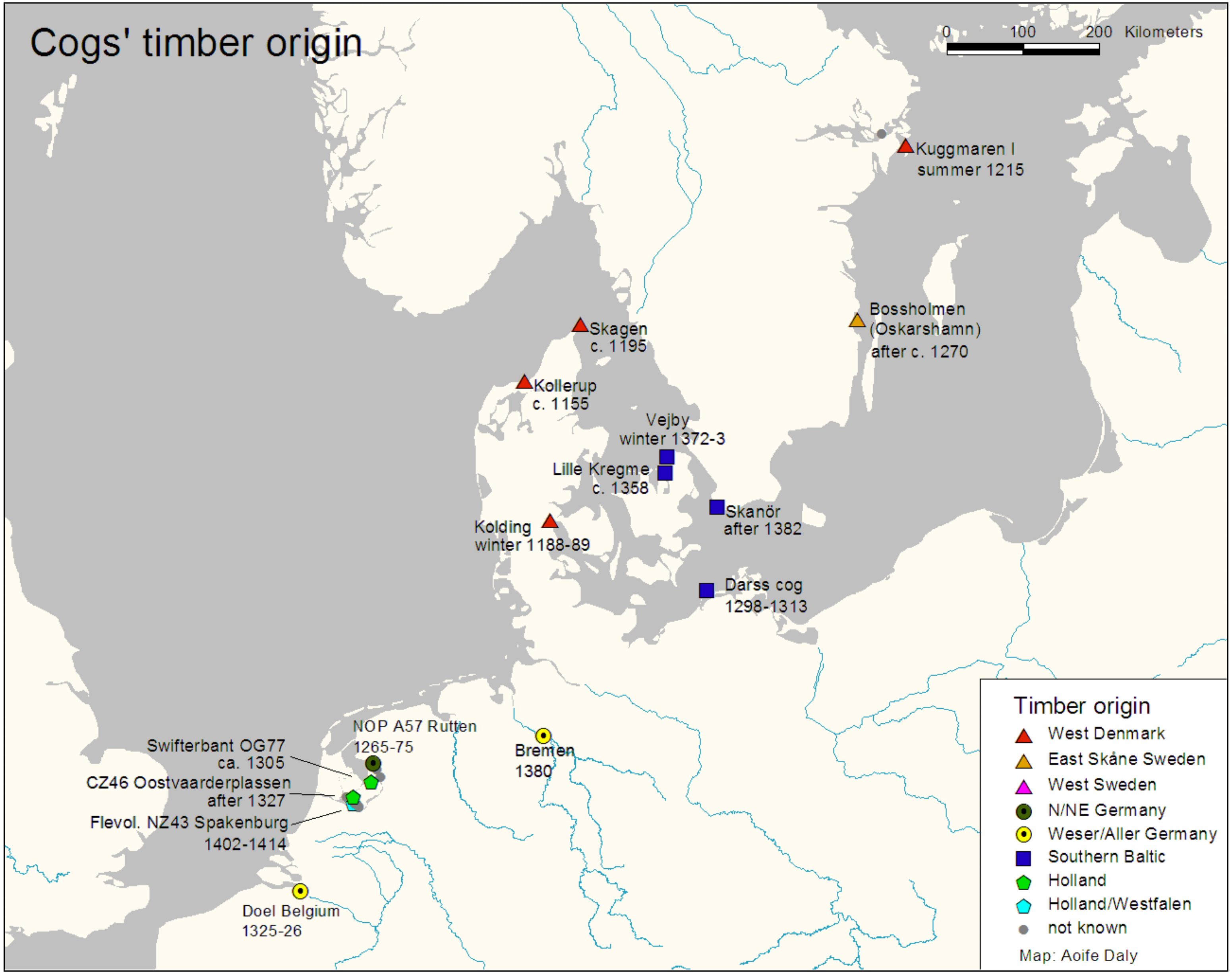


Fig. 51. Map showing the distribution of the cogs examined or mentioned in this study with name, date and provenance.

6 Chapter 6:

6.1 *The Cog*

One of the most interesting aspects that have come from this study concerns the medieval cog. The dendrochronological analysis of a great many cogs from Northern European finds allows a very detailed description of the ship type, from a precise dating and timber source point of view. When the word cog is used here incidentally, it is used as the archaeological term, when describing ship finds which have characteristics similar to the Bremen cog. The terminology and the defining characteristics are discussed in Crumlin-Pedersen (2000), where the archaeological finds of the type are also listed. The provenance of the four earliest cogs is presented in Hocker and Daly (2006) but these are discussed in more detail here, where the methodology developed is applied.

The dendrochronological dating and provenance determination of several of these ships is presented here, in chronological order. A number of other finds have emerged since Crumlin-Pedersen's paper and these are dealt with also. A table summarises the cog finds, updated and revised since Crumlin-Pedersen (2000, 237) to include dendrochronological dates for some ships and where possible, an updated suggestion of the timber origin (fig. 50).

The map (fig. 51) shows the distribution of the cog finds in Northern Europe. The map is derived initially from Crumlin-Pedersen (2000, 238) (although it might be noted that his map required the correction of a small mistake, the numbering on his map swapped nos. 5 and 6, two Dutch ships). The dating and provenance results are added in this map, in summary.

6.2 *12th century*

6.2.1 Kollerup

The earliest ship of the cog type, which has been identified archaeologically, was found at Kollerup, on the northern Jutland coast. It was excavated in 1978 and can be identified as a cog by its plank keel, its carvel joined lower strakes, its upper overlapping planking held together with double bent nails, and its angled transition from keel to stem and stern posts etc. (Kohrtz Andersen 1983; Crumlin-Pedersen 2000). Dendrochronological analysis of 17 samples was carried out in 2000 (Daly 2000b), which showed that the timbers for the ship were felled in the 1150s. This meant that the Kollerup cog was identified as the oldest cog found in the archaeological record. While this result was made available in the form of an analysis report, the full details of the dendrochronological results have not been described, and are therefore outlined here.

The internal correlation is shown in fig. 52. Here it can be seen the very high agreement between samples 1, 5 and 12, which mean that these can come from the same tree. Similarly a very high *t*-value between samples 3 and 17 indicates that these also come from one tree. Otherwise, a fairly homogeneous group of samples can be seen, outlined by a box, and the measurements from these are averaged to form the tree-ring curve which represents the ship timbers. This tree-ring curve is 200 years long, and covers the period AD 934-1133 (0013M001) and it is this curve that is analysed in the provenance determination test. There are three measurements which are not included in the ship curve. As can be seen in the matrix, one (00130079) matches only weakly with the majority of the other samples, and is therefore tested separately. Two other measurements, which are from the same plank, don't match with the other samples. While dateable, these two measurements do not give a strong agreement with the master chronologies, so are not analysed further. The tree-ring curve for these two samples matches best with Jutland (t = 4.5) but due to the irregular growth and the relatively short sequence no higher correlations are achieved.

The dating diagram (fig. 53) shows the position of the samples on a calendar timeline. The felling date for the trees, allowing for missing sapwood, can be estimated to *c.* 1150. Note that sample 00130079 stands out from the rest, in that it covers a quite earlier period. This is the same sample that stands out in the correlation matrix mentioned above. The sample has no sapwood preserved, so it is

			00130079	00130089	0013009A	00130169	0013011A	00130019	0013005A	0013012A	00130109	00130029	00130038	00130179	0013014A	0013015A	0013004A	0013013A
		00130079	*	3,72	-	-	3,21	3,46	-	3,61	-	3,58	3,25	-	\	-	\	\
0013M001		00130089	3,72	*	3,82	3,02	4,08	5,75	4,43	5,04	5,64	3,95	4,23	4,16	3,35	3,57	\	-
0013M001		0013009A	-	3,82	*	7,21	5,31	5,07	5,42	4,14	3,97	4,31	3,82	4,07	-	3,89	4,47	-
0013M001		00130169	-	3,02	7,21	*	4,1	4,29	6,72	3,49	4,13	4,24	4,58	4,58	-	-	3,39	-
0013M001		0013011A	3,21	4,08	5,31	4,1	*	7,7	7,08	4,75	4,79	4,11	4,53	3,24	\	4,06	\	\
0013M001	same tree 00131019	00130019	3,46	5,75	5,07	4,29	7,7	*	11,6	15,65	6,78	7	6	5,61	4,87	4,62	-	-
0013M001	same tree 00131019	0013005A	-	4,43	5,42	6,72	7,08	11,6	*	10,88	4,93	6,44	4,2	3,94	-	-	\	-
0013M001	same tree 00131019	0013012A	3,61	5,04	4,14	3,49	4,75	15,65	10,88	*	6,15	5,98	5,01	4,27	3,91	4,15	-	-
0013M001		00130109	-	5,64	3,97	4,13	4,79	6,78	4,93	6,15	*	8,06	4,64	5,66	5,4	4,65	-	-
0013M001		00130029	3,58	3,95	4,31	4,24	4,11	7	6,44	5,98	8,06	*	6,21	6,77	5,66	4,09	-	-
0013M001	same tree 00131029	00130038	3,25	4,23	3,82	4,58	4,53	6	4,2	5,01	4,64	6,21	*	18,44	4,98	3,28	-	-
0013M001	same tree 00131029	00130179	-	4,16	4,07	4,58	3,24	5,61	3,94	4,27	5,66	6,77	18,44	*	6,34	3,36	-	-
0013M001		0013014A	\	3,35	-	-	\	4,87	-	3,91	5,4	5,66	4,98	6,34	*	3,35	-	-
0013M001		0013015A	-	3,57	3,89	-	4,06	4,62	-	4,15	4,65	4,09	3,28	3,36	3,35	*	3,14	-
	same tree 00131039	0013004A	\	\	4,47	3,39	\	-	\	-	-	-	-	-	-	3,14	*	6,55
	same tree 00131039	0013013A	\	-	-	-	\	-	-	-	-	-	-	-	-	-	6,55	*

Fig. 52. The Kollerup cog, Jutland. Matrix of internal correlation.

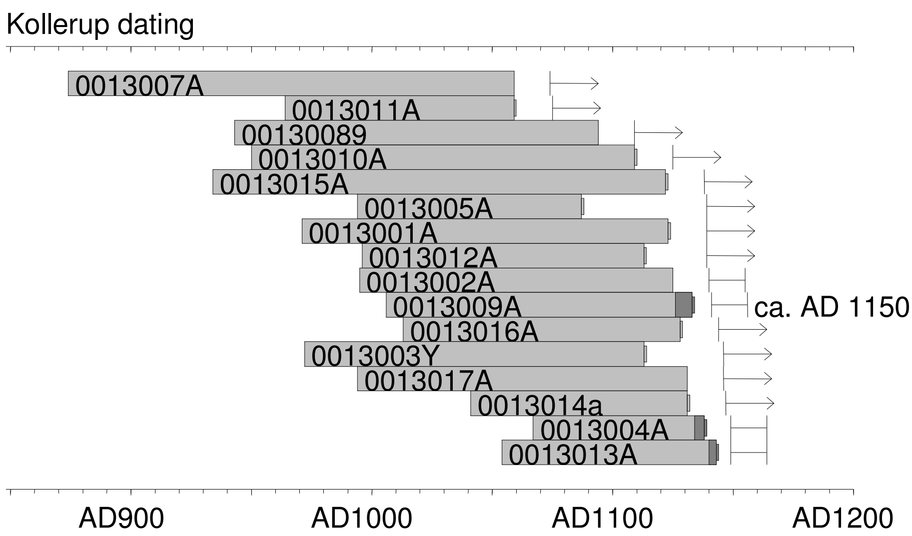


Fig. 53. The Kollerup cog, Jutland. Diagram showing the chronological position of the dated samples.

impossible to say whether it belongs to a different felling DATE but as I will show below, it is most likely to have had a different felling location.

Let's concentrate on the results from the ship average, made of ten trees, or 13 samples. In the original analysis (Daly 2000b) this dated ship average was tested against master chronologies for Northern Europe. It was clear, given the very high correlation with Jutland, (t = 15.00) that the ship was built of oak that had grown in western Denmark. The ship was however also, by coincidence, tested against some site chronologies. Another very high t-value (t = 16.21), which appeared with a site chronology from Haderslev, in Southern Jutland, already allowed the conclusion that the timber was of Southern Jutland origin. This ship was chosen therefore to be analysed using the methodology developed in this study, with the provenance test at the three levels. The map in fig. 54 shows the first level test, where the ship average is tested with the master chronology dataset. Clearly the highest correlation is achieved with the large regional master chronology from Jutland, Denmark, which was built at the National Museum of Denmark, but an even higher correlation appears with a site chronology for the town of Haderslev in Southern Jutland. What then does the test at the second level show?

The correlation between the Kollerup ship average and site chronologies is shown in fig. 55. There is a clear distribution of the highest correlations in the Southern Jutland region. The highest correlation is with the site of Haderslev. The t-value is lower though than the value achieved at the time of the initial analysis. This is because in the revision of the tree-ring dataset that has been a major part of this study, a different version of the Haderslev site chronology has been made, after the removal of the measurements that are affected by cockchafer. Although this means that a lower t-value is achieved with the Haderslev site (t = 14.56), nevertheless the ship still matches best with this site. One of the major questions to be asked of this result has to do with the problems of replication. If the Haderslev site consists of many trees, and other sites are represented for example by just two trees then should we take the simple distribution of t-values as a valid result, without allowing for differences in replication? This is why the test at the third level is important, as it

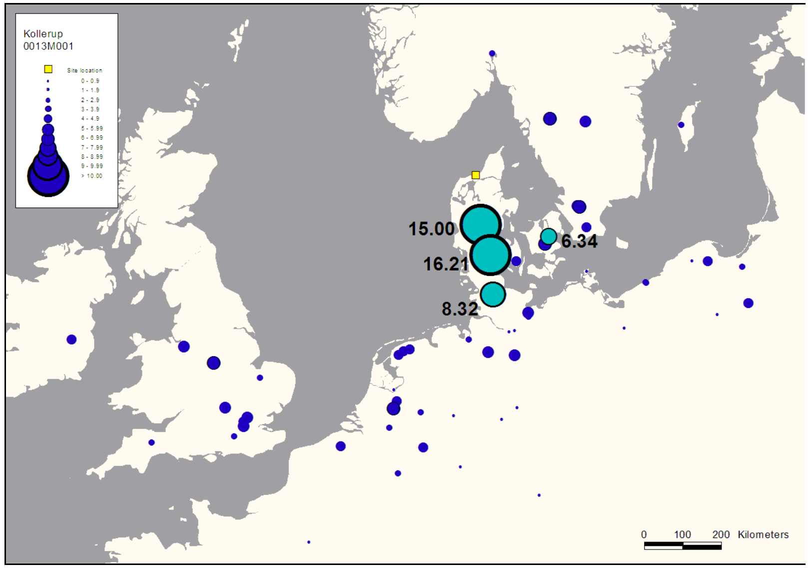


Fig. 54. The Kollerup cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kollerup and master chronologies from Northern Europe (the first level test).

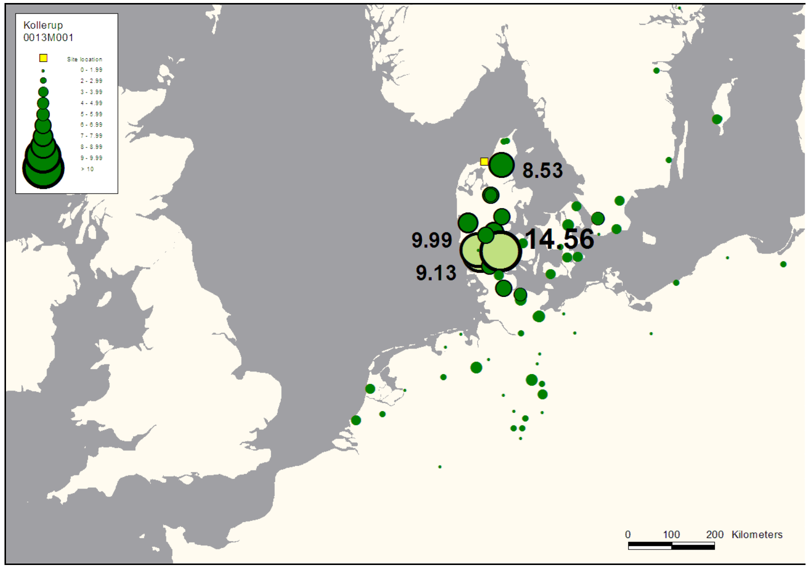


Fig. 55. The Kollerup cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kollerup and site chronologies from Northern Europe (the second level test).

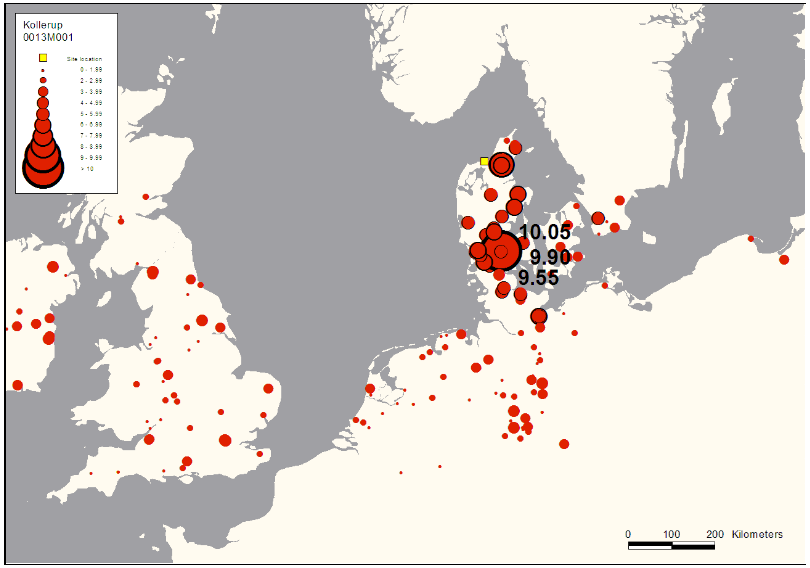


Fig. 56. The Kollerup cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kollerup and single tree-ring measurements from Northern Europe (the third level test).

reduces the material again, to the individual tree level, thus removing the replication problem.

The test at the third level then is shown in fig. 56. It can be seen that again the Haderslev site gives the strongest match. The result of the application of the methodology in this case is actually a perfect example. Some aspects should be tested for this ship though. How, for example, do the results look if each timber is tested separately? Instead of producing maps for each single timber for the trees that make up the ship average, it is considered better here to show the results in table format (fig. 57), giving the high correlation results for the ten trees. While the *t*-values are lower than in the case of the ship average, there is no single tree in this group that might lead to the suggestion of a different timber source to the rest.

Filenames		0029	0089	009A	0109	011A	014A	015A	0169	1019	1029
-		AD995	AD943	AD1006	AD950	AD964	AD1041	AD934	AD1013	AD971	AD972
-		AD1125	AD1094	AD1133	AD1109	AD1059	AD1131	AD1122	AD1128	AD1123	AD1131
DM100003	Schleswig-Holstein (HU)	4.44	4.21	3.96	6.40	5.16	-	3.89	3.06	5.78	5.18
9M456781	Jylland/Fyn (NM)	8.03	7.66	9.26	8.06	7.22	4.15	5.40	8.40	8.74	7.06
CD51JM01	Haderslev (EU-project)	8.09	7.74	8.52	7.93	8.08	3.41	6.15	7.18	8.44	7.25
RIBEM001	Ribe (Daly unpubl.)	7.06	5.17	8.12	6.76	3.73	4.67	3.16	7.64	7.82	5.09
5081M002	Roager kirke (EU-project)	4.38	4.87	7.05	5.22	3.59	3.95	-	6.91	4.92	3.51
70314M04	Skjern Bro (Daly 2001c)	4.43	4.11	5.66	6.77	5.23	3.72	5.11	3.53	4.65	4.47
8127M001	Ålborg (Daly 2000a; 2001b)	-	4.59	5.53	5.31	4.51	3.18	3.79	3.97	5.26	4.38
2X900001	Zealand (NM)	5.37	5.45	5.07	6.11	3.45	3.76	4.73	4.14	4.46	5.54

Fig. 57. The Kollerup cog, Jutland. Table showing the correlation results for all single tree-ring measurements included in the mean for the ship against master and site chronologies.

There is one timber however which is mentioned above (00130079), which matches only weakly with the main group, as shown in the correlation matrix. When tested against the ship average a *t*-value of just 3.82 is achieved. This sample covers also a longer period than the main group, as can be seen in the bar diagram. Can we see if this is due to the timber having a different origin than the rest? The table in fig. 58 shows the correlation between this timber's tree-ring sequence and chronologies from Denmark and adjacent regions. For simplicity only the highest *t*-values are illustrated. Now, the values are not as high as if we were dealing with an averaged site chronology, but it could be argued that the result might be interpreted nevertheless. It might be going too far to say that this tree had grown in Southwest Sweden or Zealand based on these low values, but it can be suggested that the timber is not part of the main group, and that this might be due to its having grown geographically separate from the rest. We have no evidence that the timber was inserted into the ship neither at an earlier nor later phase, as the plank (middle plank on the first strake on the starboard side) is an integral part of the construction. So in conclusion we might be seeing here for this ship that a usage of several sources cannot be ruled out. It is hardly surprising. If some timber were left over from one ship building job, wouldn't it be logical to use it in the next ship, here and there? By far the majority of the planks are made from a homogeneous timber source, leading to the assumption that most of the timber was collected specifically for the ship.

Filenames		-	-	0079
-		start	dates	AD874
-		dates	end	AD1059
0085M002	Lynæs 2 (Daly 1998d)	AD950	AD1118	6.39
OLUN0020	Lund (Eggertsson pers.comm.)	AD621	AD1723	5.45
SM000002	Lund Skåne Blekinge (LU)	AD578	AD1293	5.56
2x900001	Zealand (NM)	AD830	AD1997	5.02
9M456781	Jylland/Fyn (NM)	109BC	AD1986	4.65
CD51JM01	Haderslev (EU-project)	AD909	AD1234	3.35
DM100003	Schleswig-Holstein (HU)	AD436	AD1968	3.95

Fig. 58. The Kollerup cog, Jutland. Table showing the correlation between the tree-ring curve from a single timber (00130079) and master chronologies from Denmark and adjacent regions.

6.2.2 Kolding

Let's now take a look at the next cog chronologically, in the archaeological record. It is the wreck found in Kolding Fjord, in 1943 (Hansen 1944). It was the subject of investigation in 2001 (Dokkedal 2001) and dendrochronological analysis, initially of five samples (Eriksen 2000b) and subsequently supplemented with an additional 13 samples (Daly 2002), resulted in a very precise felling date for the ship's timbers. Complete sapwood to bark edge on three samples meant that a date of winter AD 1188-89 was achieved. Already in the initial analysis of the five samples the very high correlation with the Jutland chronology indicated a western Danish origin of the oak timber. When the additional analysis was complete, the correlation with the Haderslev site chronology was also remarkable, just as in the case of the Kollerup cog.

For the provenance determination of the timber from the Kolding cog there are several details that might be outlined. Of the total 16 sample examined there were 10 from frames and six from planks. From their similarity it was found that four of the planks might come from just two trees (see internal correlation matrix fig. 59). The measurements from three of the samples were found to have some cyclical patterning, probably from cockchafer, so they are not included in the further analysis. An average for the ship was made then, using 13 samples, which represents 11 trees (60873M01). The ship average is 207 years long and covers the period AD 982-1188. The provenance determination was tested on the three levels. Fig. 60 shows the map of the correlation result at the first level. The two very high values are with the large regional Jutland chronology (t = 18.95) and with the older version of the Haderslev site chronology (t = 16,36). It is a clear indication that the ship was built of timber from Western Denmark.

The test at the second level is shown in fig. 61. Here, as in the case of the Kollerup ship, the new version of the Haderslev site chronology is used, that which has had the cockchafer affected trees removed. The correlation with the new Haderslev site chronology is lower (t = 15.11) but still the highest. Other sites from Southern Jutland though, produce very high correlation also. With a chronology from Ribe, the medieval market town near the west Jutland coast, the Kolding ship matches with a t-value of 13.28. The t-value 10.68 is with a site called Løgumgårde, also in Southern Jutland, and finally a t-value of 9.42 appears with timber from Roager Church. The question that arises from this distribution of t-values is: where then can we say the oak for the ship came from? Did the trees grow in the eastern side of the Southern Jutland region, or in the western side? Admittedly, the highest t-value achieved is with the Haderslev site, but is it significantly higher than the Ribe value? The diagram (fig. 62) shows the replication of the different site chronologies that match so well with the Kolding Cog. The diagram depicts the number of trees in

Group		6087110A	60870089	6087113A	6087112A	60871089	60871039	60871049	60871059	60870019	60871069	60871019	6087109A	
60873M01	6087110A	*	-	4,91	4,87	6,86	6,21	3,6	3,51	5,03	4,71	4,54	-	5,27
60873M01	60870089	-	*	5,36	5,16	4	7,33	-	4,51	6,03	4,1	-	-	-
same tree 60872029	6087113A	4,91	5,36	*	14,79	6,32	8,11	4,45	5,74	5,26	5,72	3,75	-	4,47
same tree 60872029	6087112A	4,87	5,16	14,79	*	7,91	8,32	4,54	5,31	4,92	6,14	4,08	-	4,53
same tree 60872019	60871089	6,86	4	6,32	7,91	*	10,59	5,41	3,72	5,53	4,77	4,12	-	3,92
same tree 60872019	60871039	6,21	7,33	8,11	8,32	10,59	*	9,23	6,73	7,78	6,42	5,6	3,87	4,01
60873M01	60871049	3,6	-	4,45	4,54	5,41	9,23	*	9,59	6,72	7,41	6,8	6,07	4,56
60873M01	60871059	3,51	4,51	5,74	5,31	3,72	6,73	9,59	*	5,63	6,81	5,76	5,35	5,54
60873M01	60870019	5,03	6,03	5,26	4,92	5,53	7,78	6,72	5,63	*	7,03	6,45	5,05	-
60873M01	60871069	4,71	4,1	5,72	6,14	4,77	6,42	7,41	6,81	7,03	*	10,24	-	4,12
60873M01	60871019	4,54	-	3,75	4,08	4,12	5,6	6,8	5,76	6,45	10,24	*	3,78	5,5
60873M01	6087109A	-	-	-	-	-	3,87	6,07	5,35	5,05	-	3,78	*	-
60873M01	60870028	5,27	-	4,47	4,53	3,92	4,01	4,56	5,54	-	4,12	5,5	-	*

Fig. 59. The Kolding cog, Jutland. Matrix of internal correlation.

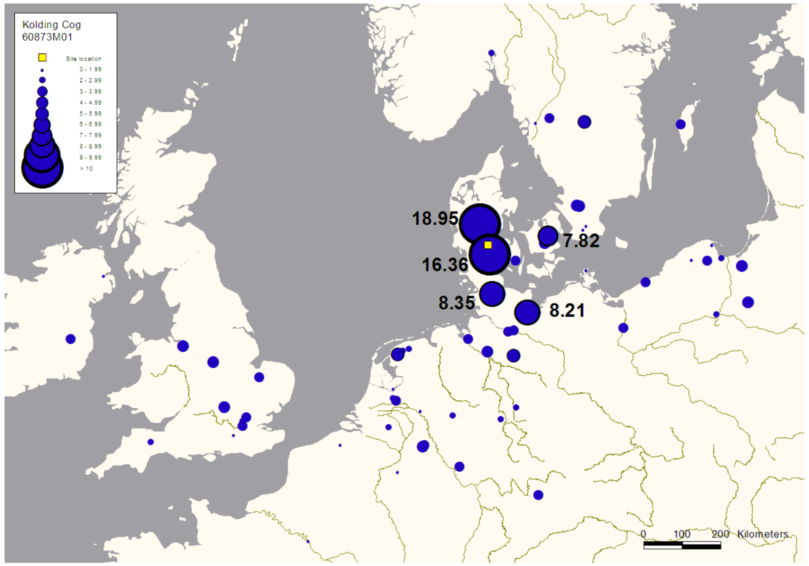


Fig. 60. The Kolding cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kolding and master chronologies from Northern Europe (the first level test).

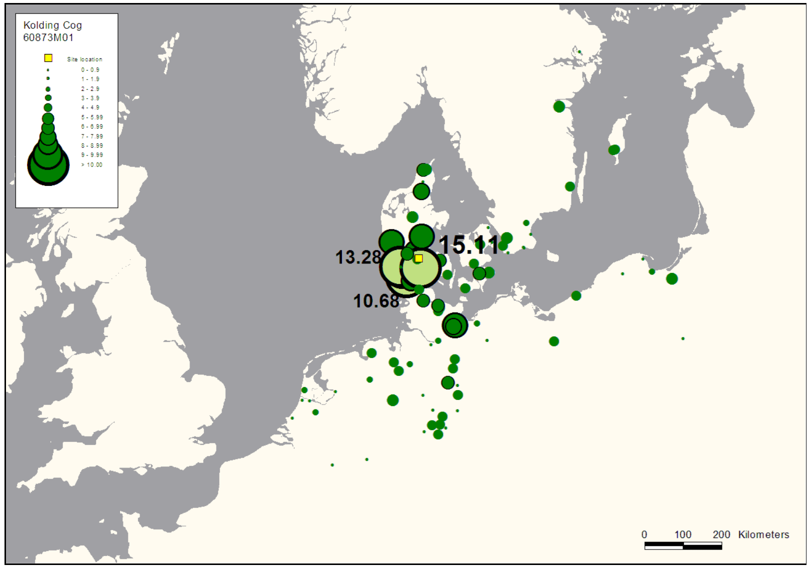


Fig. 61. The Kolding cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kolding and site chronologies from Northern Europe (the second level test).

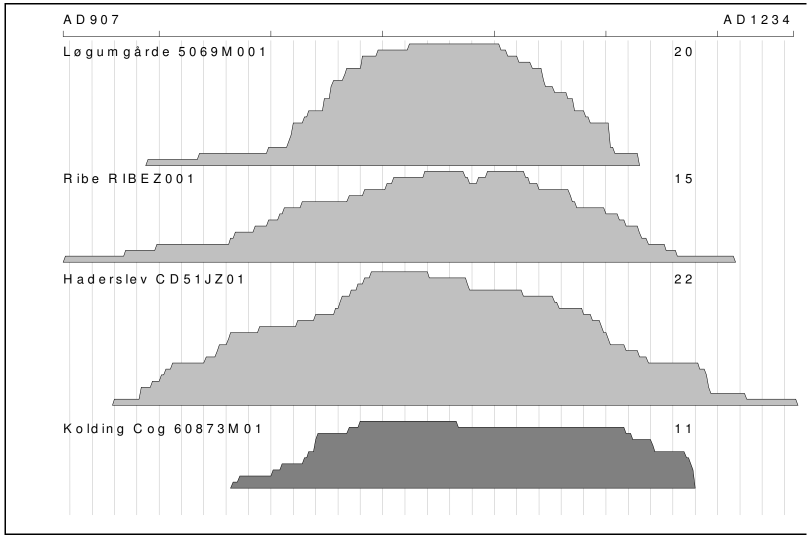


Fig. 62. The Kolding cog, Jutland. The histogram shows the replication of the different site chronologies that match so well with the Kolding Cog. The diagram depicts the number of trees, in each chronology, for each year that the chronology covers. The Kolding Cog has 11 samples at its thickest, Haderslev has 22, Ribe has 15 and Løgumgårde has 20.

each chronology for each year that the chronology covers. The Kolding Cog has 11 samples at its thickest, Haderslev has 22, Ribe has 15 and Løgumgårde has 20. The fact that the Haderslev site chronology has only 14 trees while the Ribe has 24 might mean that we should give the *t*-value between the ship and the Haderslev chronology more significance.

From this diagram it can also be seen that there are no problems of varying overlap in the case of the Ribe and Haderslev chronologies. Another aspect though has to do with the different composition of the Haderslev and Ribe chronologies. The internal matrixes for each site, shown in figs. 63 and 64, gives an indication of the homogeneity of the tree-ring data included in the site chronologies. The Ribe chronology is made from timber from several different excavations and quite a wide group has been included in the site chronology for the town. It is possible that the high agreement between the ship and the Ribe chronology is a product of the wider region the Ribe chronology represents, in contrast to the Haderslev material. What then does the test at the third level show?

Fig. 65 shows the distribution of the correlation of the Kolding Cog with single trees in the Northern European oak tree-ring dataset. Again here, problems of differences in replication are removed, and the provenance test is down to the basic individual trees' ring-width measurements. The highest *t*-values that appear in this test of the Kolding ship are with trees from the Haderslev site. Much lower *t*-values appear with trees from the other sites. This seems to underline the similarity with the Haderslev timber, and diminishes the importance of the other sites. Taking all the considerations into account, the indications are that the Haderslev timber had grown in a similar area to the timbers in the Kolding Cog, that is, in the region around Lillebælt.

	CD51J019	CD51J059	CD51J039	CD51J2V9	CD51J2W9	CD51J2Y9	CD51J319	CD51J329	CD51J2X9	CD51J2U9	CD51J3H9	CD51J359	CD51J369	CD51J3U9	CD51J3W9	CD51J439	CD51J3I9	CD51J3L9	CD51J3F9	CD51J3N9	CD51J409	CD51J449	CD51J4U9	CD51J3X9	CD51J3Z9
CD51J019	*	8,29	5,09	-	4,1	-	-	-	-	-	-	-	-	-	3,15	-	-	-	-	-	-	-	-	-	-
CD51J059	8,29	*	4,23	3,85	-	-	\	3,03	3,73	3,96	3,35	3,74	3,07	-	3,5	3,69	-	-	-	-	3,2	-	-	-	-
CD51J039	5,09	4,23	*	3,02	-	\	\	-	-	-	-	3,49	3,65	-	-	-	-	3,77	-	-	-	-	-	-	-
CD51J2V9	-	3,85	3,02	*	-	-	\	3,87	-	3,24	-	4,53	5,48	5,82	5	3,1	5,17	4,88	-	4,83	-	5,31	3,22	3,69	-
CD51J2W9	4,1	-	-	-	*	4,42	\	-	-	3,07	-	6,01	4,35	4,04	-	4,5	5,11	-	-	-	-	3,04	-	\	3,51
CD51J2Y9	-	-	\	-	4,42	*	\	-	4,45	-	4,5	4,65	4,18	5,13	4,85	4,38	6,43	3,12	-	-	-	-	\	\	-
CD51J319	-	\	\	\	\	\	*	\	\	\	5,38	\	\	\	\	\	\	-	3,27	3,16	6,57	-	-	\	-
CD51J329	-	3,03	-	3,87	-	-	\	*	4,41	4,2	5,52	3,71	3,6	4,51	4,37	-	-	-	5,34	6,63	5,02	4,03	4,62	4,76	-
CD51J2X9	-	3,73	-	-	-	4,45	\	4,41	*	3,38	4,36	6,79	5,71	3,61	4,91	4,1	-	3,95	4,57	3,25	5,02	3,29	4,23	-	-
CD51J2U9	-	3,96	-	3,24	3,07	-	\	4,2	3,38	*	7,32	4,34	3,66	4,63	3,05	4,73	3,75	-	-	3,85	3,13	-	-	-	-
CD51J3H9	-	3,35	-	-	-	4,5	5,38	5,52	4,36	7,32	*	6,3	6,31	6,02	7,35	6,19	-	3,5	4,55	4,34	4,75	-	-	-	4,39
CD51J359	-	3,74	3,49	4,53	6,01	4,65	\	3,71	6,79	4,34	6,3	*	19,56	7,19	7,73	7,18	7,08	7,07	4,49	-	5,13	5,14	5,99	-	-
CD51J369	-	3,07	3,65	5,48	4,35	4,18	\	3,6	5,71	3,66	6,31	19,56	*	5,32	7,64	7,68	5,79	6,55	4,42	-	6,78	6,28	4,71	-	3,19
CD51J3U9	-	-	-	5,82	4,04	5,13	\	4,51	3,61	4,63	6,02	7,19	5,32	*	7,89	5,71	5,91	3,08	-	-	3,42	3,66	-	\	-
CD51J3W9	3,15	3,5	-	5	-	4,85	\	4,37	4,91	3,05	7,35	7,73	7,64	7,89	*	7,74	5,85	6,86	6,45	-	5,81	3,96	3,73	4,44	-
CD51J439	-	3,69	-	3,1	4,5	4,38	\	-	4,1	4,73	6,19	7,18	7,68	5,71	7,74	*	5,76	4,64	-	-	4,56	3,21	-	-	3,84
CD51J3I9	-	-	-	5,17	5,11	6,43	\	-	-	3,75	-	7,08	5,79	5,91	5,85	5,76	*	4,88	-	-	3,63	5,7	4,1	-	-
CD51J3L9	-	-	3,77	4,88	-	3,12	-	-	3,95	-	3,5	7,07	6,55	3,08	6,86	4,64	4,88	*	4,47	-	-	4,88	3,11	-	-
CD51J3F9	-	-	-	-	-	-	3,27	5,34	4,57	-	4,55	4,49	4,42	-	6,45	-	-	4,47	*	11,56	7,65	3,9	5,02	4,28	3,12
CD51J3N9	-	-	-	4,83	-	-	3,16	6,63	3,25	3,85	4,34	-	-	-	-	-	-	-	11,56	*	5,67	4,13	4,71	3,38	4,1
CD51J409	-	3,2	-	-	-	-	6,57	5,02	5,02	3,13	4,75	5,13	6,78	3,42	5,81	4,56	3,63	-	7,65	5,67	*	5,96	4,75	-	-
CD51J449	-	-	-	5,31	3,04	-	-	4,03	3,29	-	-	5,14	6,28	3,66	3,96	3,21	5,7	4,88	3,9	4,13	5,96	*	3,63	-	4,37
CD51J4U9	-	-	-	3,22	-	\	-	4,62	4,23	-	-	5,99	4,71	-	3,73	-	4,1	3,11	5,02	4,71	4,75	3,63	*	-	-
CD51J3X9	-	-	-	3,69	\	\	\	4,76	-	-	-	-	-	\	4,44	-	-	-	4,28	3,38	-	-	-	*	3,01
CD51J3Z9	-	-	-	-	3,51	-	-	-	-	-	4,39	-	3,19	-	-	3,84	-	-	3,12	4,1	-	4,37	-	3,01	*

Fig. 63. Møllestrømmen, Haderslev, Jutland. Matrix of internal correlation.

	70220089	70220099	70220039	70220049	70220109	70220079	70220019	70220029	70220059	70340049	70340029	70340039	70070049	70070179	70070099	70050079	70070129	70070089	70070139	70070149	70080019	70070199	70080029	70090019	70070159	70070109
70220089	*	7,88	4,87	4,34	3,1	3,66	4,43	4,73	2,39	0,23	0,28	1,72	0,6	0,08	4,19	1,7	2,58	0,33	0,36	0,77	0,74	-		0,63	1,76	1,26	0,38
70220099	7,88	*	7,07	3,07	5,38	5	5,91	2,58	2,99	2,11	2,84	2,08	1,24	-	4,66	1,24	3,85	-	0,41	-	-	0,21	1,86	0,48	1,48	0,4
70220039	4,87	7,07	*	4,32	3,9	5,42	4,6	4,12	3,47	1,79	2,03	1,09	0,01	-	2,08	0,88	2,21	-	-	-	-	-	-	1,25	0,46	0,11
70220049	4,34	3,07	4,32	*	6,2	5,92	5,8	6,16	4,1	-	2,12	1,4	1,42	0,6	3,23	2,6	2,92	1,42	1,12	-	-	-	0,29	2,44	1,58	-
70220109	3,1	5,38	3,9	6,2	*	5,04	4,94	3,83	3,39	-	1,38	1,91	1,39	1,6	3,07	-	2,57	0,37	0,05	-	-	-	1,54	1,82	0,54	0,02
70220079	3,66	5	5,42	5,92	5,04	*	8,19	6,8	3,59	1,05	-	1,01	0,04	0,26	2,2	0,28	2,2	-	-	-	-	-	0,45	1,06	0,79	1,33
70220019	4,43	5,91	4,6	5,8	4,94	8,19	*	4,36	3,71	-	\	1,96	1,71	0,88	2,55	2,13	1,97	-	1,11	-	0,29	1,02	0,79	1,5	0,78	-
70220029	4,73	2,58	4,12	6,16	3,83	6,8	4,36	*	1,97	1,99	2,21	1,25	0,7	1,45	1,47	1,9	1,46	0,45	1,9	0,45	-	-	0,8	1,65	0,77	0,73
70220059	2,39	2,99	3,47	4,1	3,39	3,59	3,71	1,97	*	0,18	2,91	1,52	1,84	-	0,62	-	-	-	-	-	-	-	-	-	-	-
70340049	0,23	2,11	1,79	-	-	1,05	-	1,99	0,18	*	3,67	3,08	3,31	4,78	\	4,7	1,95	2,14	2,64	4,16	\	2,63	4,02	4,24	2,49	3,69
70340029	0,28	2,84	2,03	2,12	1,38	-	\	2,21	2,91	3,67	*	6,87	4,11	1,21	\	0,56	\	\	\	1,09	\	-	3,09	2,36	2,95	0,96
70340039	1,72	2,08	1,09	1,4	1,91	1,01	1,96	1,25	1,52	3,08	6,87	*	3,93	0,66	\	1,17	\	\	\	1,55	\	-	1,96	2,14	1,67	2,02
70070049	0,6	1,24	0,01	1,42	1,39	0,04	1,71	0,7	1,84	3,31	4,11	3,93	*	3,73	1,9	3,34	0,28	2,57	2,17	0,98	2	1,38	3,06	2,17	2,82	2,28
70070179	0,08	-	-	0,6	1,6	0,26	0,88	1,45	-	4,78	1,21	0,66	3,73	*	1,5	1,1	0,49	4,44	3,04	2,92	2,82	1,13	3,86	2,53	2,86	2,52
70070099	4,19	4,66	2,08	3,23	3,07	2,2	2,55	1,47	0,62	\	\	\	1,9	1,5	*	4,26	6,34	3,19	4,04	4,22	3,78	3,32	3,93	5,01	4,26	3,39
70050079	1,7	1,24	0,88	2,6	-	0,28	2,13	1,9	-	4,7	0,56	1,17	3,34	1,1	4,26	*	7,36	6,81	4,51	6,52	4,5	6,1	2,45	4,75	4,95	3,96
70070129	2,58	3,85	2,21	2,92	2,57	2,2	1,97	1,46	-	1,95	\	\	0,28	0,49	6,34	7,36	*	3,46	2,73	3,32	2,92	0,86	1,1	3,02	2,43	2,04
70070089	0,33	-	-	1,42	0,37	-	-	0,45	-	2,14	\	\	2,57	4,44	3,19	6,81	3,46	*	4,19	5,39	2,87	2,74	2,73	3,99	3,71	2,06
70070139	0,36	0,41	-	1,12	0,05	-	1,11	1,9	-	2,64	\	\	2,17	3,04	4,04	4,51	2,73	4,19	*	6,97	4,15	1,71	2,89	2,89	2	1,49
70070149	0,77	-	-	-	-	-	-	0,45	-	4,16	1,09	1,55	0,98	2,92	4,22	6,52	3,32	5,39	6,97	*	8,43	3,67	3,68	3,35	3,65	3,08
70080019	0,74	-	-	-	-	-	0,29	-	-	\	\	\	2	2,82	3,78	4,5	2,92	2,87	4,15	8,43	*	2,87	2,85	1,67	3,61	2,35
70070199	-	0,21	-	-	-	-	1,02	-	-	2,63	-	-	1,38	1,13	3,32	6,1	0,86	2,74	1,71	3,67	2,87	*	3,42	1,14	0,86	2,16
70080029	0,63	1,86	-	0,29	1,54	0,45	0,79	0,8	-	4,02	3,09	1,96	3,06	3,86	3,93	2,45	1,1	2,73	2,89	3,68	2,85	3,42	*	5,04	3,44	3,52
70090019	1,76	0,48	1,25	2,44	1,82	1,06	1,5	1,65	-	4,24	2,36	2,14	2,17	2,53	5,01	4,75	3,02	3,99	2,89	3,35	1,67	1,14	5,04	*	2,08	2,23
70070159	1,26	1,48	0,46	1,58	0,54	0,79	0,78	0,77	-	2,49	2,95	1,67	2,82	2,86	4,26	4,95	2,43	3,71	2	3,65	3,61	0,86	3,44	2,08	*	2,32
70070109	0,38	0,4	0,11	-	0,02	1,33	-	0,73	-	3,69	0,96	2,02	2,28	2,52	3,39	3,96	2,04	2,06	1,49	3,08	2,35	2,16	3,52	2,23	2,32	*

Fig. 64. Ribe, Jutland. Matrix of internal correlation.

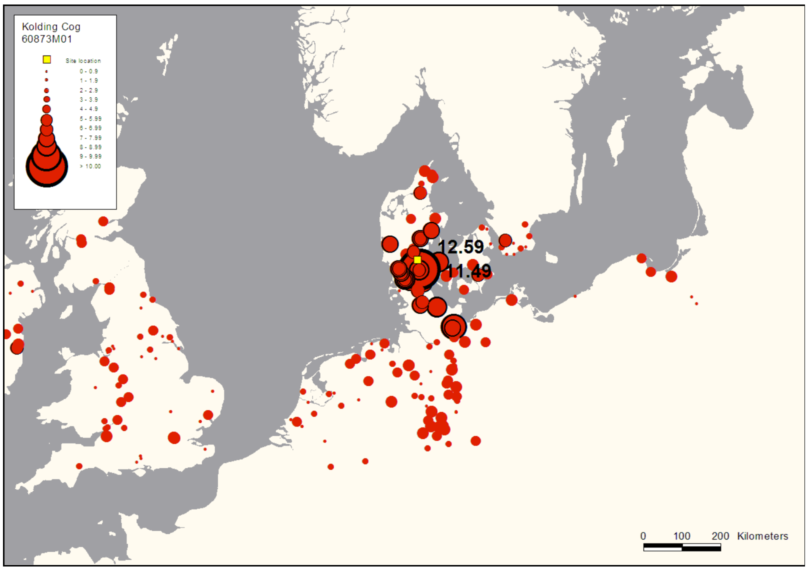


Fig. 65. The Kolding cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Kolding and single tree-ring measurements from Northern Europe (the third level test).

6.2.3 Skagen

The Skagen cog was found in 1962 on the northern point of the Jutland peninsula. A rescue excavation in 1994 allowed the identification of the vessel as a cog, similar to the Kollerup cog (Bill in press 2007). That year, dendrochronological analysis of six samples, of which five were dated, gave a date of *c.* 1193 (Eriksen 1994).

Though only few samples have been analysed from the Skagen ship it is worthwhile looking into the timber origin, in the light of the other results emerging for the early cog finds. In this reassessment of the Skagen ship's provenance the five dated tree-ring curves were first tested for cockchafer and it was found that one has cyclical patterning, and is thus not included in the ship average. The internal correlation matrix for the remaining four samples is shown in fig. 66. All four of these samples are included in the ship average (00081M01), which contains 247 years, covering the period AD 930-1176. This ship average has then been tested at the three provenance determination levels. These results are shown on the maps in figs 67, 68 and 69. From the first level test map it can be seen that the highest match is with the large Jutland chronology at t = 8.41. This t-value is not as high as those we have seen in the results for other ships and there can be several explanations for this. The Kollerup and Kolding ships have had many samples analysed and included in their ship average. The Kollerup ship average contains 11 trees, the Kolding ship average is made from 13 trees while the Skagen ship average has just four trees. It is very likely that this is a reason for the generally lower t-values for the Skagen ship. Another reason though, given the few trees which actually give the high values for the Kollerup and Kolding cogs, could be that the forest from which the Skagen cog's timbers came from is simply not represented in the tree-ring dataset. The evidence though nevertheless points towards a Danish origin for the oak from the Skagen Cog.

Does the test at the second level bring us to a closer provenance determination? As can be seen by the second level map very high t-values are not achieved between the Skagen ship and site chronologies. All those t-values greater

	00080039	00080059	00080029	
00080039	*	4,85	4,13	4,48
00080059	4,85	*	5,43	4,11
00080029	4,13	5,43	*	3,86
00080069	4,48	4,11	3,86	*

Fig. 66. The Skagen cog, Jutland. Matrix of internal correlation.

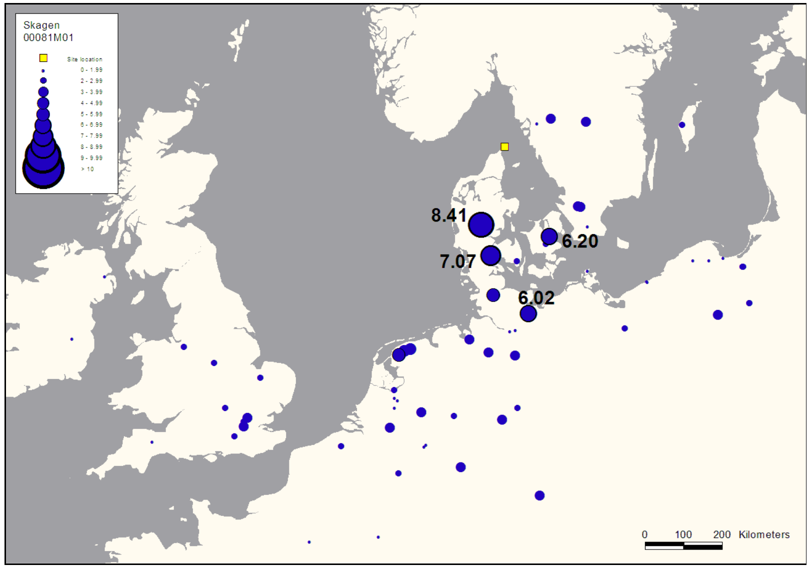


Fig. 67. The Skagen cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Skagen and master chronologies from Northern Europe (the first level test).

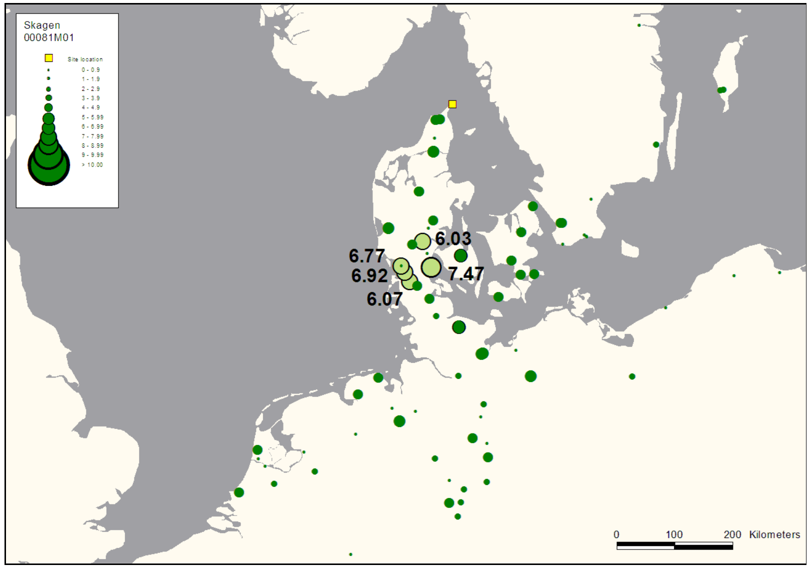


Fig. 68. The Skagen cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Skagen and site chronologies from Northern Europe (the second level test).

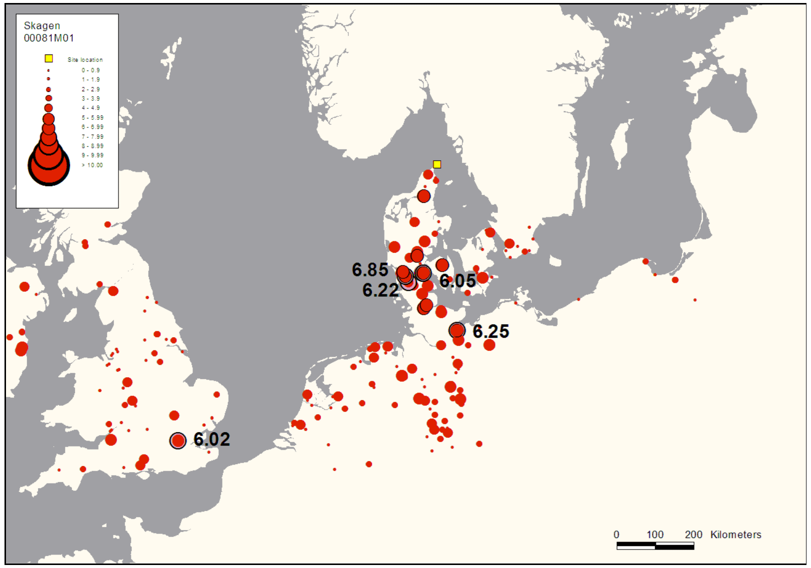


Fig. 69. The Skagen cog, Jutland. Map showing the distribution of correlation values achieved between the mean for Skagen and single tree-ring measurements from Northern Europe (the third level test).

than 6.00 are highlighted, and it can actually be seen that they are all with sites in the Southern Jutland area. Indications are that the timber for this ship might also have grown in the Southern Jutland region.

When we look at the third level test though, we do not get a clear picture of provenance. *T*-values of between six and seven appear with trees in southern Jutland but there is also one with a tree from London, and from a tree-ring measurement from Lübeck. Does this diffuse distribution of correlation values come from the dangers of doing provenance determination at the third level with so few samples from the ship though, or is it due to exported timbers in the dataset? For the single tree in London then, we can check it against all master chronologies. It matched with a London chronology with a *t*-value of 8.95 but we then needed to investigate whether the tree-ring measurements from the timber itself might be included in this London chronology. The tree didn't give significant *t*-values with other English chronologies, and it could also be seen that it matched fairly well with Scandinavian references, so could we be fully satisfied that this was indeed an English tree? Subsequently though we find that the date of measurement of the samples is stored in the header of the original EU-dataset. For this London sample it reads "`measured Helen 24/11/92`". The London chronology, it matches well with, was built by Fletcher before this date.

The provenance determination attempt for the Skagen cog, in conclusion, is hindered by the fact that so few samples have been dated from the ship. It is possible to suggest a provenance at the regional level, with the test using the regional master chronologies, but to achieve more detail we would need a good many more samples examined.

6.3 *13th century*

6.3.1 Kuggmaren 1

This ship came to the attention of archaeologists in 1998 and during inspection a sample for c14 was taken. The ship seemed to be a cog, and the c14 result showed that the ship was of medieval date. Survey of the ship was carried out in 2002 and three samples at this stage were analysed dendrochronologically by Olafur Eggertsson, who was, at the time, at Lund University (Adams and Rönnby 2002). Only heartwood on these samples meant that a precise date was still not forthcoming but an interesting result, that the timbers matched best with Danish references, prompted the sawing of an additional two samples, both with complete sapwood preserved, which were analysed by the author in 2003. A precise felling date was the result, to spring/summer 1215. The measurements, from the three original dendrochronological analyses, were kindly sent to me by Olafur Eggertsson and Hans Linderson, Lund University.

While individual samples match best with various Danish references it is very difficult to get a meaningful group from all five samples. The matrix (fig. 70) shows the internal correlation for the samples from the ship. Even with this few samples it seems that there are two groups. Between some of the samples it can be argued that this is due to the fact that the overlap is very short, as can be seen from the bar diagram illustrating the time period each sample covers (fig. 71). But the relatively long overlap (93 years) between sample 55200 (Z0012009) and Z0010029 gives a *t*-value of only 2.19, so these two separate groups might be real enough. On the basis of the groupings in the internal correlation matrix, two ship averages were made. One contains three trees and the other contains two. For purposes of experiment a third ship average was made using all five samples.

Group 1	Z0012M01	3 trees	186 rings	AD 991-1176
Group 2	Z001M001	2 trees	131 rings	AD 1084-1214
All samples	Z0012M02	5 trees	224 rings	AD 991-1214

Although we have seen that a good many samples are necessary for provenance determination, it is attempted here to see what kind of result is possible with this limited analysis. First let’s take the first ship average consisting of three trees. It is, as is now the routine, tested at the three levels. The result of the first level test is mapped in fig. 72. Although we should note that the correlation values are not as

	Z0012019	Z0012009	Z0012021	Z001001A	
Z0012019	*	3,81	-	\	-
Z0012009	3,81	*	5,15	-	-
Z0012021	-	5,15	*	\	-
Z001001A	\	-	\	*	6,03
Z0010029	-	-	-	6,03	*

Fig. 70. Kuggmaren 1, Stockholm. Matrix of internal correlation.

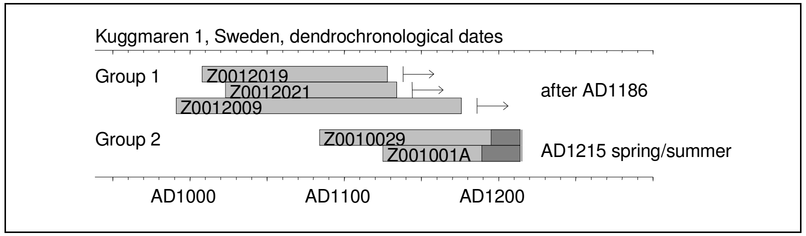


Fig. 71. Kuggmaren 1, Stockholm. Diagram showing the chronological position of the dated samples.

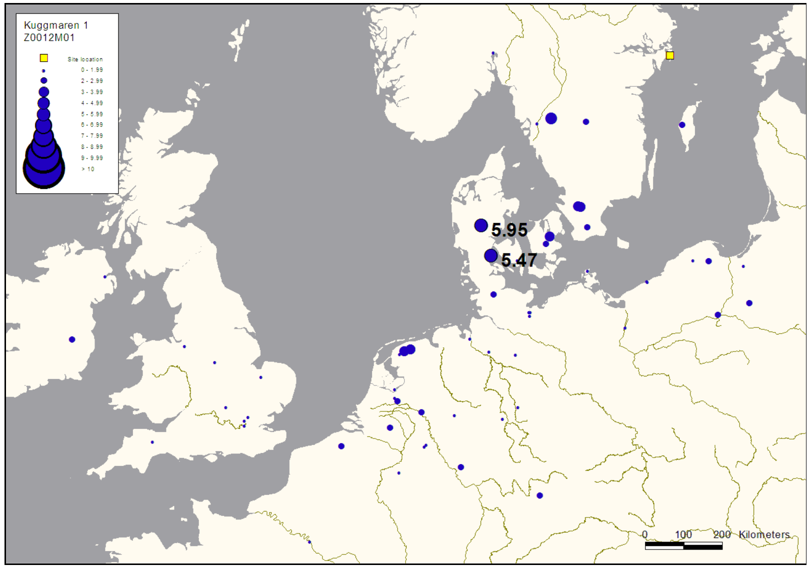


Fig. 72. Kuggmaren 1, Stockholm, group 1 (Z0012M01). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 1, and master chronologies from Northern Europe (the first level test).

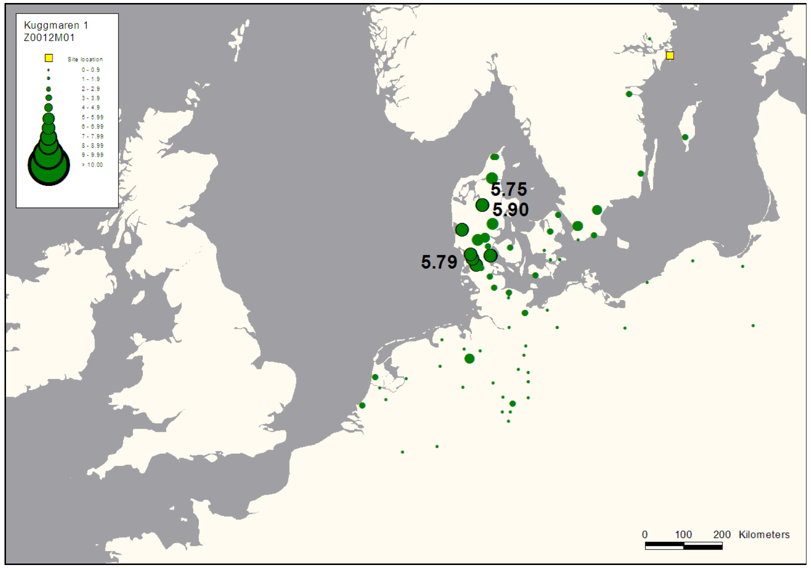


Fig. 73. Kuggmaren 1, Stockholm, group 1 (Z0012M01). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 1, and site chronologies from Northern Europe (the second level test).

high as in results from other provenance determination analyses, it is clear that the highest are with Danish master chronologies. But is this result enough that we can state that the timbers are from the Western Danish region? The argument against this conclusion might be that a higher *t*-value could appear in quite another region, a region for which we don't currently have tree-ring data. Given the decline with distance of the correlation values the further away we get from the Western Danish region, the likelihood of the real provenance being outside the periphery of our dataset might to be extremely unlikely. The relatively low values are rather due to the poor representativity of the ship average, combined perhaps with the fact that we are missing, in the dataset, trees from very close to the Kuggmaren 1 ship timbers' forest. It is the same problem we are up against in the Skagen cog case study. Obvious recommendations of course, for improving the provenance determination, include taking more samples for analysis. However, even with this few samples, what do the tests at the second and third levels show (figs. 73 and 74)? In the test with site means the highest *t*-values appear again with Danish sites. They are no higher than 5.90 but again this can be due to the low number of samples in the group 1 ship average. It might be noted here also though that the 5.90 *t*-value is with a site mean from Viborg Søndersø, a much earlier site whose chronology reaches only up to AD 1082, so the value is from an overlap of just 92 years. Caution should be applied in this case though as the Viborg site mean consists of only one sample for its last nearly 50 years, and we do also have some cyclical patterning in the tree-ring means, as apparent from the plot of the histograms and curves for group 1 from the Kuggmaren ship and the Viborg Søndersø site (fig. 75). It is of course risky to conclude too much from this limited replicated data. In the test with the single tree dataset though one higher *t*-value appears. A value of 7.05 is achieved between the group 1 ship average and a tree from Lille Torv, Århus, analysed in 1995 (Eriksen 1995). This timber in turn matches best with Jutland references so is not an import. All in all, through the three test levels, it can be concluded for the group 1 timbers from Kuggmaren that we are dealing with trees that grew in Western Denmark. We

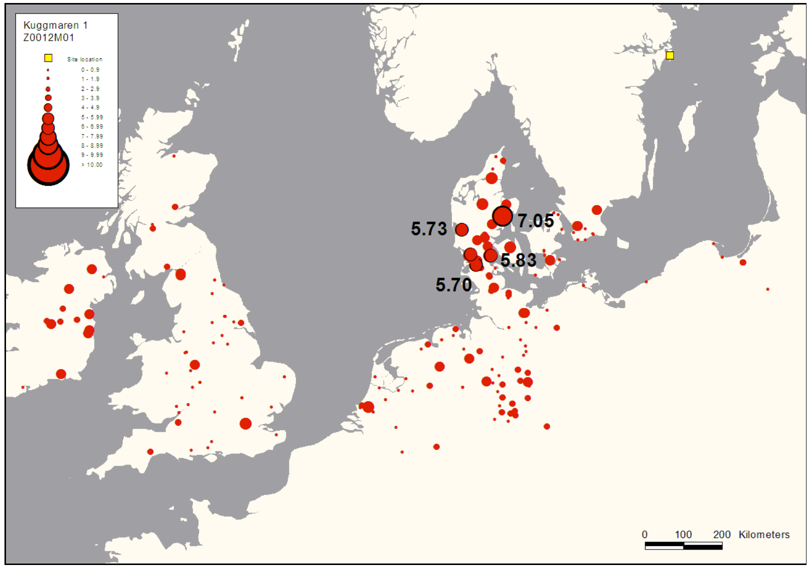


Fig. 74. Kuggmaren 1, Stockholm, group 1 (Z0012M01). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 1, and single tree-ring measurements from Northern Europe (the third level test).

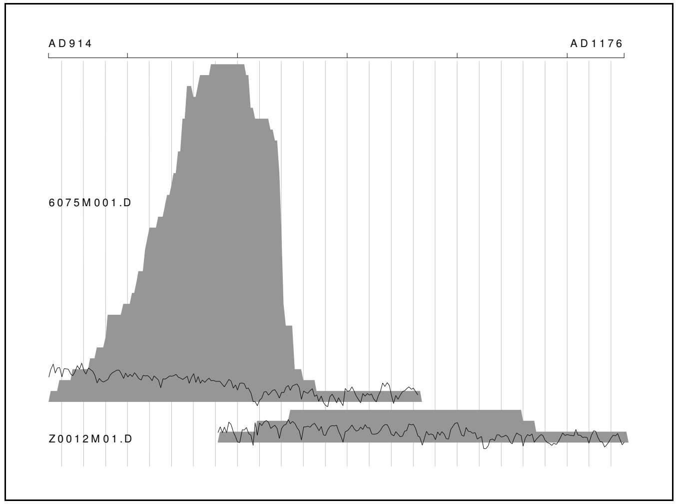


Fig. 75. Kuggmaren 1, Stockholm, group 1 (Z0012M01) and Viborg Søndersø, Jutland. Diagram showing the depth (replication) and the tree-ring indices of group 1 from the Kuggmaren 1 cog, and from the site chronology from Viborg Søndersø.

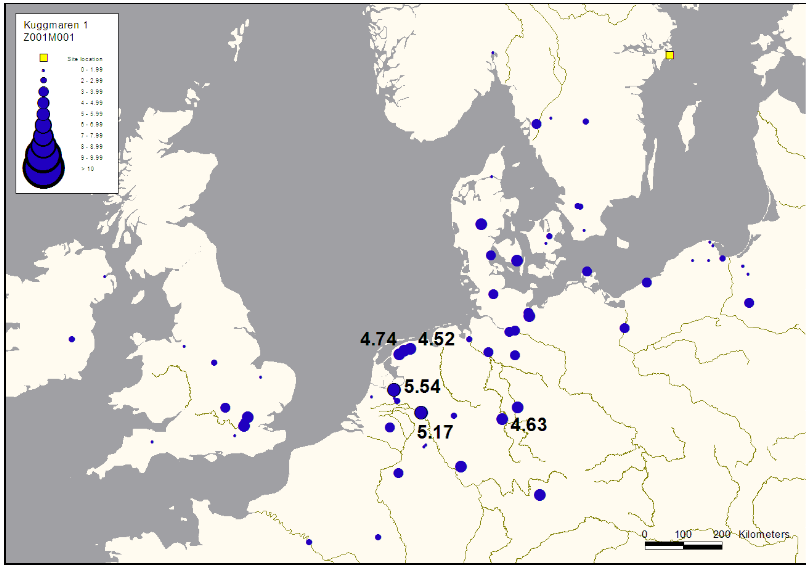


Fig. 76. Kuggmaren 1, Stockholm, group 2 (Z001M001). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 2, and master chronologies from Northern Europe (the first level test).

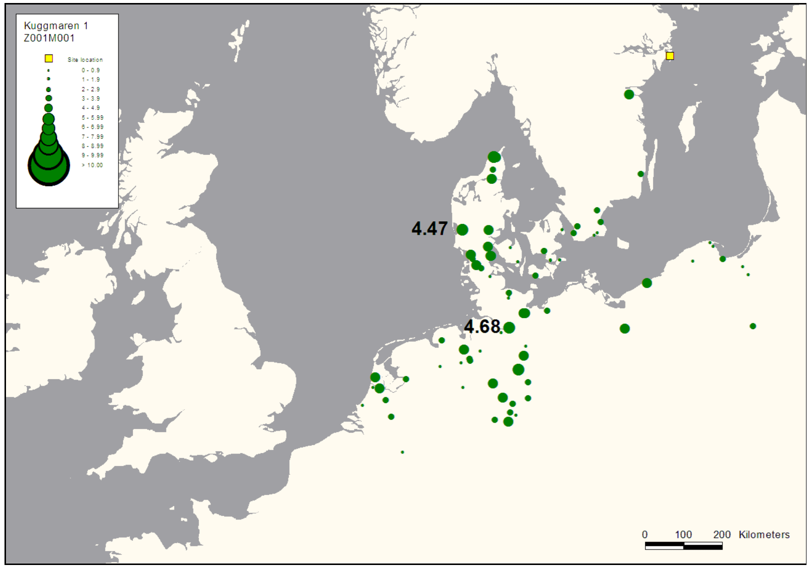


Fig. 77. Kuggmaren 1, Stockholm, group 2 (Z001M001). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 2, and site chronologies from Northern Europe (the second level test).

might even be inclined to say that they grew in the North Central Jutland region, but more samples should be analysed before this can be stated more definitively.

Group 2 from the Kuggmaren cog consists of just two samples, both taken from frames, which, with complete sapwood preserved, provided the exact felling date of spring/summer 1215. As can be seen from the correlation matrix above, the two samples match well together, with a *t*-value of 6.03, and the average of the samples covers 131 years, or the period 1084-1214. It matches with the group 1 average with a *t*-value of just 2.12 (overlap 93 years). When the group 2 average is tested at the first level (fig. 76) we find that the highest values appear actually with master chronologies from The Netherlands. The *t*-values that appear are only at t = 5.54 and t = 5.17, values that do not allow a provenance determination by any means. However given that there are indications of separate sources for the two groups of ship's timbers, such geographically separate source areas might be acceptable. But can we accept this all too weak provenance result? The second level test for group 2 is mapped in fig. 77. It is clear from the second level test that no high *t*-values emerge which might point towards a provenance within the regions that are now covered in site chronologies. The test at the third level includes the single tree data for the whole region (fig. 78). Here none of the values are very high, and the highest values are distributed widely. It is clear that a conclusion cannot be drawn as to the provenance of the group 2 timbers. This example in fact underlines the problems with attempting provenance determination with too few samples, and neither can we rule out the possibility that the group 2 timbers' origin is outside the areas covered by the dataset available here.

Because of the very few samples analysed from this ship, a ship average of all samples was made anyway, for purposes of experiment. Given the different time periods the two groups cover, joining them together gives a longer tree-ring sequence to work with. However, as the correlation between the two groups is so low, what is it that is happening when these two groups are put together anyway and can we find a justification for joining these groups, which are unrelated dendrochronologically? Well we can argue that the resulting ship average reflects a

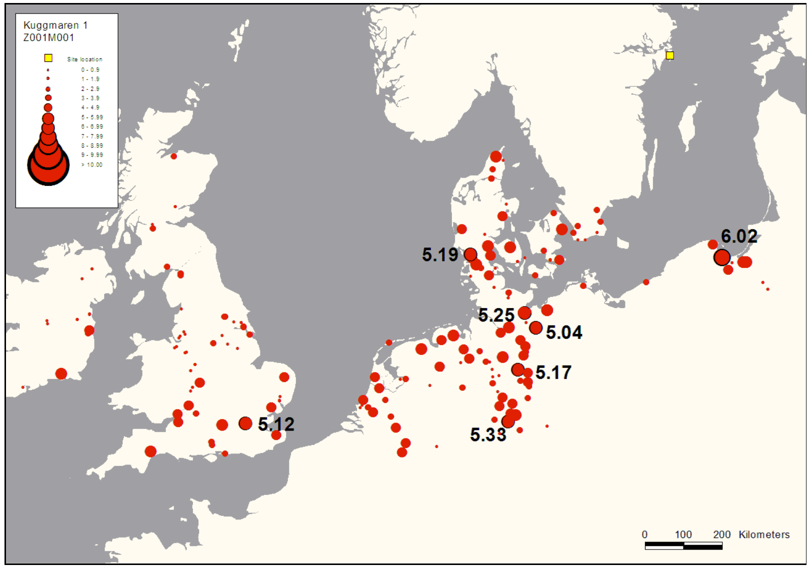


Fig. 78. Kuggmaren 1, Stockholm, group 2 (Z001M001). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 group 2, and single tree-ring measurements from Northern Europe (the third level test).

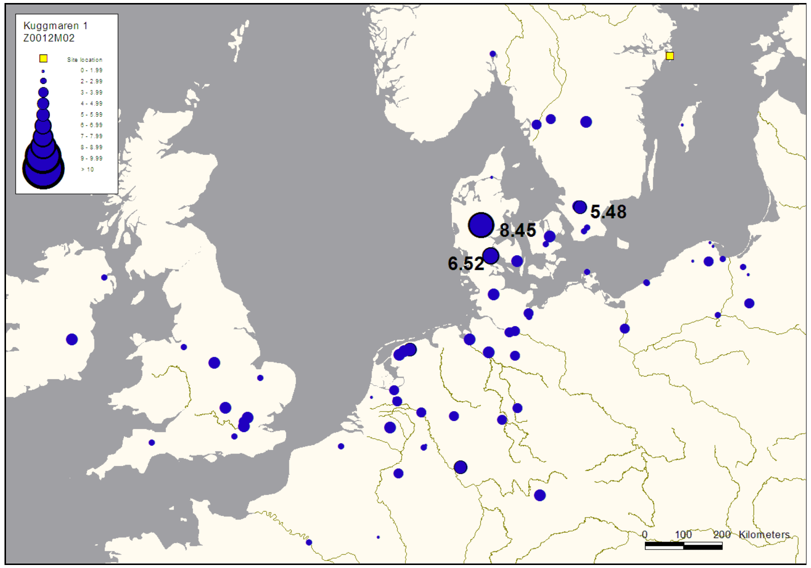


Fig. 79. Kuggmaren 1, Stockholm, all samples (Z0012M02). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 (all samples) and master chronologies from Northern Europe (the first level test).

Filenames	M001	MTST	
-	AD1084	AD1124	
-	AD1214	AD1214	
81M00003	4,07	4,65	Vendsyssel (Daly 1998b)
9M456781	4,36	6,49	Jylland/Fyn (NM)
DM100003	3,05	3,92	Schleswig-Holstein (HU)
DM100008	4,02	4,02	Lübeck (HU)
DM200001	-	5,42	Nieders, Kuestenraum (GU)
DM200003	4,42	3,27	Weserbergland (GU)
GBM00005	4,41	3,19	London (SU)
NL000001	5,54	3,29	Holland
PM000004	-	3,20	Gdansk Pomerania (Wazny)
SM000002	-	4,27	Lund Skaane Blekinge (LU)
SM000012	3,14	3,20	Sverige Vest (Bråthen 1982)
CD51JZ01	3,63	5,23	Møllestrømmen (EU-project)

Fig. 80. Kuggmaren 1, Stockholm, group 2. Table of correlation between the group 2 average (Z001M001) and the group 2 average with the first 30 years removed (Z001MTST) against master chronologies from Northern Europe.

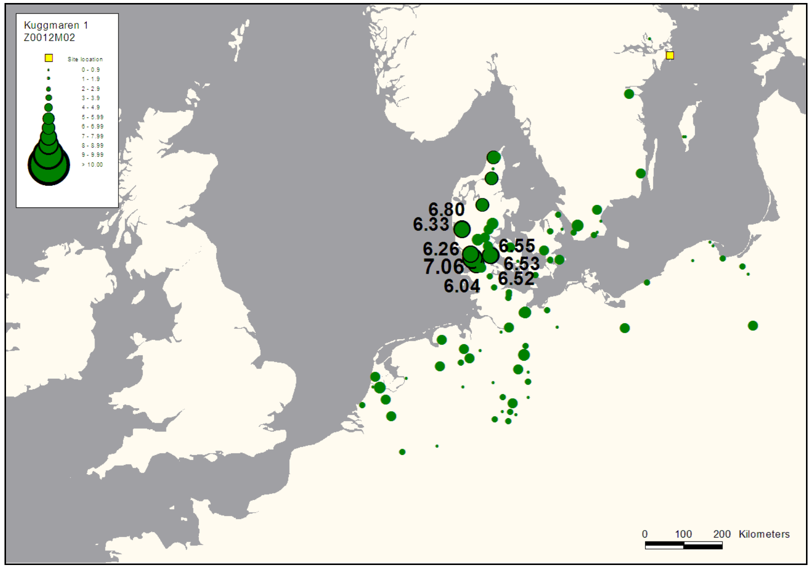


Fig. 81. Kuggmaren 1, Stockholm, all samples (Z0012M02). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 (all samples) and site chronologies from Northern Europe (the second level test).

wider regional climate signal. But if the two groups are from as far away from each other as Denmark and The Netherlands, shouldn't we get a very spread result when testing provenance? This is not the case, as we shall see. The test of the five sample ship average at the first level is shown in fig. 79. Here we can see that actually the correlations with Danish references are high, indeed higher than in the case of group 1. This instils doubt as to the Dutch origin for group 2 in fact. One of the other things that come to mind here is that the earliest portion of group 2 is measured from the pith. The extreme variability that often occurs in this early growth is not reduced by averaging only the two group 2 samples, another reason that it is important to have a larger number of samples analysed. When the group 1 and 2 samples are averaged to the single five sample average, the younger tree problem is removed. It could be that this is all that is causing the difference between the two groups.

Lets see what happens if the first 30 years of the group 2 average is removed. The table of the result of the correlation between the original group 2 average and a version where the thirty years from the pith are removed, with a selection of master chronologies from Northern Europe, is shown in fig 80. Note that it is quite a different picture that emerges, in terms of provenance, for the original (Z001M001) and the shortened (Z001MTST) versions. With the young tree growth removed, the higher *t*-value is in fact with the Danish Jutland chronology, not with the Dutch. This exercise underlines the fact that we must treat provenance determination with few samples with extreme caution. The initial suggestion of a Dutch origin for Kuggmaren's group 2, on further inspection, is not reinforced neither by the tests at the second and third level, nor by the test of the shortened group 2 average.

So looking again at the map of correlation for the five sample ship average, where the extremes of the group 2 samples' early growth is reduced, we are actually getting a good Danish correlation. It could very possibly be the region of origin for both groups of timbers. The test of this ship average at the second and third levels similarly shows a cluster of relatively high correlation with sites, and with individual trees, from middle and southern Jutland (fig. 81 and 82).

It has not been looked into, in this study, from which structural parts of the ship all the samples were taken, except that it is mentioned in Adams and Rönnby (2002, 176) that one of these is from a plank. The implications of the results therefore await further study, where the dendrochronology results are tied in with the dated timbers' actual position in the ship construction. Among other things it would be useful to check the context of the two frame dendro samples, particularly in the light of the results of this analysis, where the question arises as to whether the frame timbers represent the original construction phase or a repair. The comment in Adams and Rönnby is relevant to this issue; "Some of the floors (13-19) were systematically arranged to distribute the joints with futtocks, although this is less apparent further forward. Here the alignment of floor/futtock joints as well as additional treenails suggests that the system may have been compromised by repair." (Adams and Rönnby 2002, 173)

Due to the few samples and their low internal correlation, a less reliable provenance conclusion can be drawn for this ship. If we could summarise the result in one final conclusion, we can say that some of the oak timber for the building of the Kuggmaren 1 ship might have grown in Western Denmark.

6.3.2 Bossholmen

The Bossholmen Cog, from near Oskarshamn in southeast Sweden, was analysed dendrochronologically by Thomas Bartholin (Bartholin 1985). Twelve samples had been analysed from the ship, and Hans Lindersson, Lund University, kindly sent these measurements to me. All 12 samples are dated, and their relative position is shown in fig 83. In several publications the date of the felling of the timbers is quoted as being quite specific; "Dendrochronological analyses showed that the ship timbers had been felled *c.* AD 1250, with the exception of one plank which had been felled around 1270." (Cederlund 1990, 194) or "the Bossholmen cog from Sweden, was built in 1242 in the western Baltic" (Crumlin-Pedersen 2000, 239). Actually the conclusion in Bartholin's report is not at all so specific. He states "12 prøver indleveret hertil har givet en datering af vraget til 1272 ±5 eller senere" (Bartholin

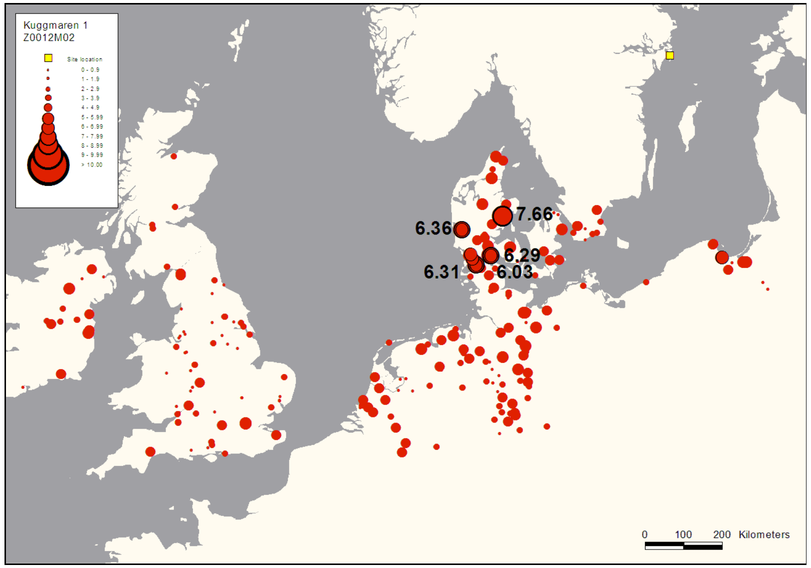


Fig. 82. Kuggmaren 1, Stockholm, all samples (Z0012M02). Map showing the distribution of correlation values achieved between the mean for Kuggmaren 1 (all samples) and single tree-ring measurements from Northern Europe (the third level test).

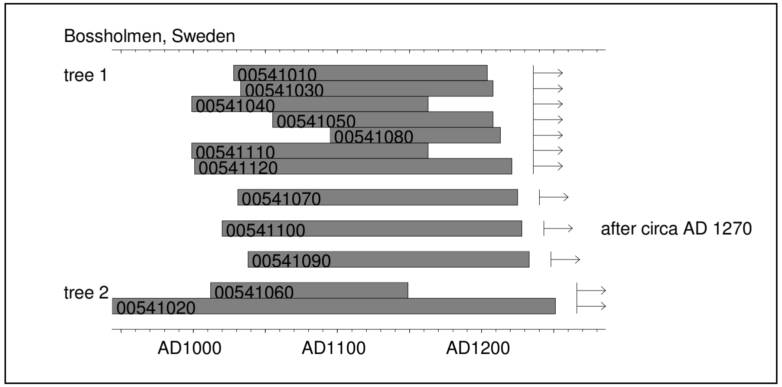


Fig. 83. The Bossholmen cog, Kalmar län. Diagram showing the chronological position of the dated samples, grouped according to Bartholin (1985).

	00541090	00541080	00541010	00541120	00541030	00541040	00541110	00541050	00541060	00541020	00541100	00541070
00541090	*	7	8,85	9,37	7,75	8,3	9	7,4	3,78	4,94	5,27	6,73
00541080	7	*	12,34	15,99	11,24	9,89	11,61	12,53	4,55	5,39	6,34	7,86
00541010	8,85	12,34	*	21,27	17,78	16,2	18,03	12,58	6,45	5,38	6,09	8,77
00541120	9,37	15,99	21,27	*	16,8	16,29	16,78	13,19	6,77	6,57	8,11	9,73
00541030	7,75	11,24	17,78	16,8	*	19,21	23,04	17,07	6,12	6,28	7,1	10,6
00541040	8,3	9,89	16,2	16,29	19,21	*	26,93	11,78	7,11	7,28	6,45	8,91
00541110	9	11,61	18,03	16,78	23,04	26,93	*	12,74	7,22	7,72	7,98	9,44
00541050	7,4	12,53	12,58	13,19	17,07	11,78	12,74	*	3,27	4,7	5,28	8,88
00541060	3,78	4,55	6,45	6,77	6,12	7,11	7,22	3,27	*	10,89	8,21	6,23
00541020	4,94	5,39	5,38	6,57	6,28	7,28	7,72	4,7	10,89	*	16,56	9,67
00541100	5,27	6,34	6,09	8,11	7,1	6,45	7,98	5,28	8,21	16,56	*	10,54
00541070	6,73	7,86	8,77	9,73	10,6	8,91	9,44	8,88	6,23	9,67	10,54	*

Fig. 84. The Bossholmen cog, Kalmar län. Matrix of internal correlation.

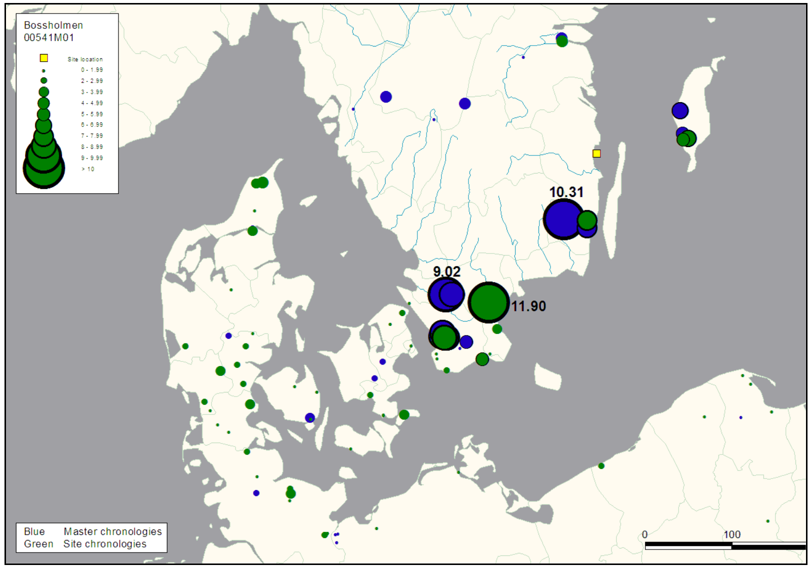


Fig. 85. The Bossholmen cog, Kalmar län. Map showing the distribution of correlation values achieved between the mean for Bossholmen and master and site chronologies from Northern Europe (the first and second level tests).

1985, 1). None of the samples had sapwood preserved so the date is only a *terminus post quem*. Bartholin does point out that just one sample gives this date, while the others could indicate an earlier date (after 1242), in other words that the later sample is a repair. To confirm this, he argues, would require additional sampling. Whether the dendro dates cited in Cederlund come from a subsequent confirmation archaeologically of the later plank, as a repair, is not explained, but nevertheless the dates are still *termini post quem* and this seems to be ignored in the archaeological publications. Given the very high correlation between the samples, the indications are that a single building phase is represented. The 12 samples in the diagram of the dates for the ship are grouped according to Bartholin's conclusions. He suggested that samples 2 and 6 might come from the one tree. It is exactly sample 2 which provides the latest preserved tree-rings in the ship, and if sample 6 comes from the same tree, we have a clear indication of the number of rings which can have been removed in the shaping of the timber for the construction. Overall the evidence from the dendrochronological analysis must conclude that a single phase is represented. We return to Thomas Bartholin's original conclusion, using the same sapwood statistic but quoting the concluding result in rounded years, we can say that the ship's timbers were felled after circa AD 1270.

The internal correlation matrix (fig. 84) shows that a very high agreement between samples is achieved. In fact so high that we can see why Bartholin grouped seven samples as just one tree. However, given the high similarity between all the samples, a ship average using all twelve tree-ring curves is made here. This is, as the routine now is established, tested at the three levels, to identify the timber origin. For this example, the first and second tests are combined in one map, blue for the master chronologies, green for the site chronologies, as it is still possible to see the results in this way (fig. 85). As can be seen, high values occur with master chronologies from Southwest Sweden. The highest (t = 10.31) is achieved with a master chronology from the provinces of Småland and Öland, in other words, from the same region in which the ship was found. This high agreement was also observed by Bartholin in his original analysis, allowing him to reach the conclusion that the timber had grown in the Southern Scandinavian region (Bartholin 1985). It can be seen from this map that the likely origin of the timber used to build this ship is the Southwest Swedish region. When compared with the site chronologies (the green circles), a very high value (t = 11.90) is achieved with timbers from a site at Östra Vram, as marked by the green circle.

In the test at the third level (fig. 86) the highest values also appear with timbers from the Östra Vram site. We are seeing a very different distribution of high t-values than with all the other cogs discussed so far. While the four earlier cogs all show a Western Danish provenance the Bossholmen ship is clearly of a Southern Swedish origin.

For the site chronology and single tree data though, we should bear in mind that we are at the edge of our dataset. While the correlation between the ship and the Östra Vram church timbers is remarkably high it cannot be ruled out that an even higher value could appear with new data from further east, which is currently only represented by the master chronology for Småland/Öland. The Småland/Öland chronology is made up of sites from the Kalmar region, and sites on Öland (Thomas Bartholin pers.comm.), but there is no information on how many sites or samples the chronology contains. It is not within the scope of this study to attempt to gather additional data for regions not included in the original EU-project dataset, and this is something that could be looked into in the future.

Given that the single tree and site chronology result is so high with the Ostra Vram church timber, and given the results of other examples, where these very high values only appear well clustered within a fairly small area, it would actually be surprising if additional building timber data changed the ship's timber origin conclusion significantly, that is, East Skåne. However the possibility that the timber from Ostra Vram church was harvested from some distance might be discussed, though here we can talk in terms of likelihood: In Southern Sweden in the medieval period where timber availability locally would not have been an issue, and where the most likely transport of timber will have been down-river (Helgeå) if anything, then the likelihood that Ostra Vram's timber came from further east must be slim. In

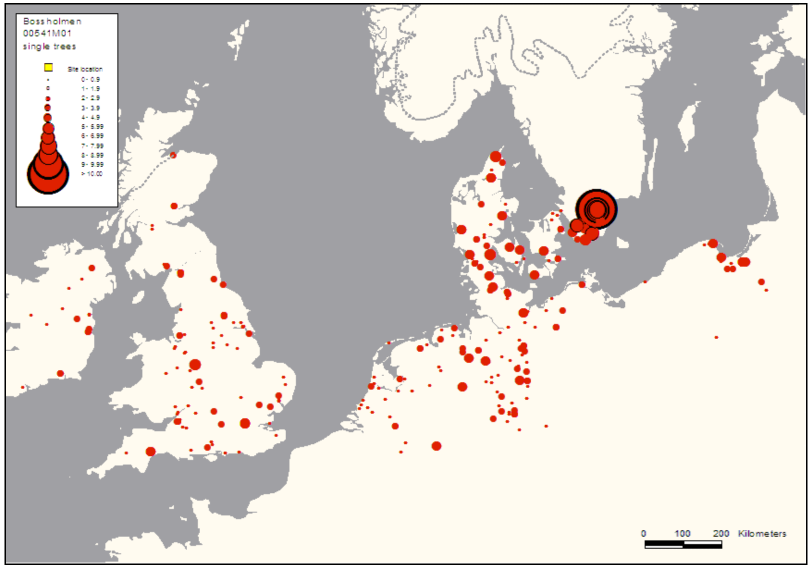


Fig. 86. The Bossholmen cog, Kalmar län. Map showing the distribution of correlation values achieved between the mean for Bossholmen and single tree-ring measurements from Northern Europe (the third level test).

	ka500061	ka500070	ka500240	ka500081
ka500061	*	10,13	-	-
ka500070	10,13	*	3,14	-
ka500240	-	3,14	*	6,74
ka500081	-	-	6,74	*

Fig. 87. The Rutten cog (A57), Flevoland (Noordoostpolder), Netherlands. Matrix of internal correlation.

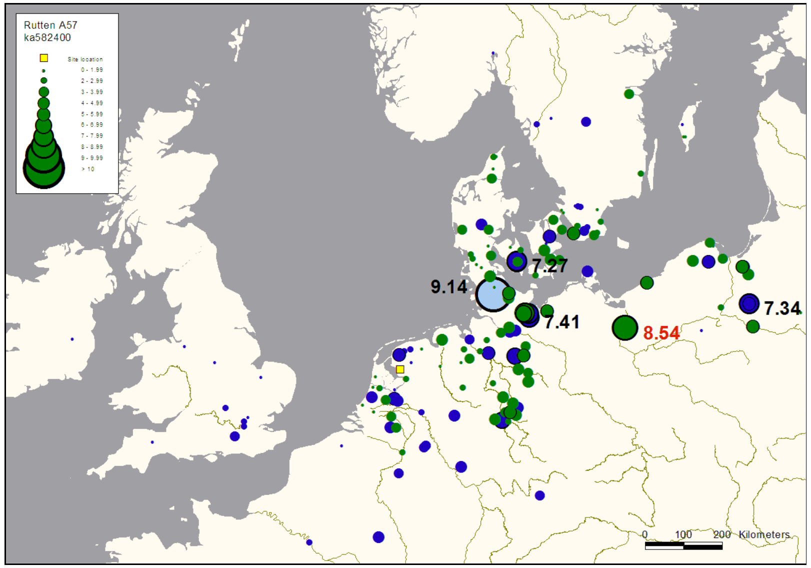


Fig. 88. The Rutten cog (A57), Flevoland (Noordoostpolder), Netherlands, group 2. Map showing the distribution of correlation values achieved between the mean for Rutten group 2 and master and site chronologies from Northern Europe (the first and second level tests).

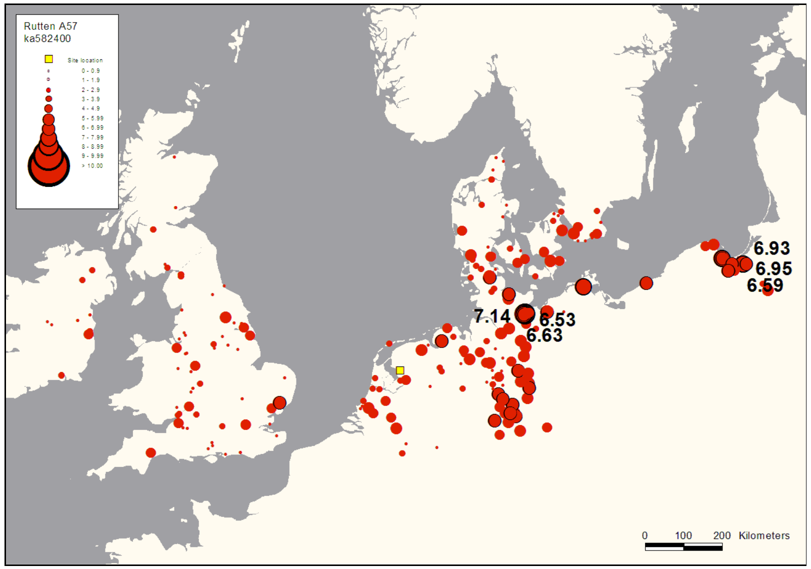


Fig. 89. The Rutten cog (A57), Flevoland (Noordoostpolder), Netherlands, group 2. Map showing the distribution of correlation values achieved between the mean for Rutten group 2 and single tree-ring measurements from Northern Europe (the third level test).

addition, the site Ostra Vram matches best with Skåne chronologies (made before Ostra Vram was analysed) so we are most probably dealing with local timber. Given also that the Småland-Öland (859-1371) chronology covers a quite wide region and that the correlation with Ostra Vram is so high, for a small site chronology, then this Ostra Vram correlation can be more significant than the correlation with the larger master chronology. So to conclude all that, we cannot rule out Skåne-Blekinge as the source of the timber. Neither can we rule out Småland. The strong match with Ostra Vram points though to the eastern Skåne area as the timber source for Bossholmen.

Chronologically, the next cogs that can be discussed in this analysis are Dutch finds. Some of these wrecks have been analysed by the dendrochronologists in The Netherlands and the results are produced as reports. Esther Jansma from ROB/NISA in Lelystad has very kindly given me the tree-ring measurements for shipwrecks on which analyses have been carried out. As can be seen from the table, there are some for which no dendro has been undertaken so these cannot be included in this discussion. For those that have been studied dendrochronologically, often only few samples have been analysed or dated, but nevertheless it is attempted, in the following, to squeeze as much information as possible out of the existing data.

6.3.3 Rutten A57

The ship was excavated in 1985 (Oosting 1985; 1987) and dendrochronological analysis of just four samples was carried out in 1994 (Hanraets and Jansma 1994b). All four samples are dated, one of which has the transition from heartwood to sapwood preserved. The date of felling of the trees used in the ship is estimated, taking account of missing sapwood, to AD 1263-1275. In their report a list is given, showing the correlation between each sample and a single chronology. Three samples are shown with a Polish chronology, the fourth with one from Lower Saxony. A ship mean of all four samples is also listed, shown to match with Poland

(t = 6.86) and Lower Saxony (t = 4.88). No specific conclusion as to the timbers' provenance is forwarded.

If we look at the correlation between the samples (fig. 87) we can clearly see that the samples can be grouped into two pairs. This was also observed in the original analysis, where two averages were made in addition to the average of all four samples, but this detail is not in the report. So even with this few samples there are indications of two timber groups. We therefore will deal with the two groups separately. For the provenance test then the two group averages are compared at the first level, with available master chronologies for Northern Europe. The values generally are not high for group 1 but a more interesting result is emerging for group 2, which is mapped in fig. 88 where the tests at the first and second levels are shown together. The highest t-values are not with Polish references but with the Master chronology for the Schleswig-Holstein region in Northern Germany (t = 9.14). Note also in the comparison with site chronologies though (green circles) a quite high correlation with Szczecin (t = 8.54). The test at the third level, with the single trees, (fig. 89) does not provide a clearer image of the timber's origin. Again we might here have the problem of geographical gaps in the dataset.

With these results with only two samples, can we draw any real conclusion from this then? Well we can revise the assumption that is evident in the original report, that this is not Southern Baltic timber as we have seen in other case studies (Avaldsnes, Vejby, etc.), where the ships clearly match best with oak chronologies from the Vistula River region. Indications are that the timber source for the Rutten is further west. Yet again we have to consider the data availability question in this case. Only two samples are represented in the ship average, and we have two high correlation values, Schleswig-Holstein (t = 9.14) and Szczecin (t = 8.54), but with no references in the region between these two. (This problem is discussed above (first section t-values) and is due to the fact that tree-ring data for North-eastern Germany is not in the EU-project dataset.) If we might allow a conclusion from what could be described as a preliminary analysis, it can be stated that the group 2 timbers from the Rutten cog might have grown in the North-east

German region. The group 1 timbers give decidedly lower correlation values with the master and site chronologies but the highest are nevertheless within the same region. Obviously this ship material needs considerably more analysis, and a solving of the dataset gap would also be necessary, to come further with a more confident and detailed provenance result.

6.4 *14th century*

6.4.1 Dronten M61

The dendrochronological analysis of Dronten M61 (Vlierman, 1996) was carried out by E. Jansma and E. Hanraets in 1996. Only two samples were analysed and they are so similar in their tree-ring pattern that they probably come from one tree. Only heartwood was preserved so the felling date is a *terminus post quem*: "De datering valt dus een onbekend aantal jaren nà 1296 AD ±6" (Jansma and Hanraets 1996).

In the comparison with master chronologies from Northern Europe, the highest *t*-values are all lower than t = 6.00. These highest appear with chronologies from Lower Saxony (t = 5.60) and Lüneburger Heide (t = 5.71) in Northern Germany but also with a chronology from Middle Sweden (t = 5.14) and even with a site chronology from western coastal Poland (Kolobrzeg, t = 5.26) so no provenance determination can be given for this single tree.

6.4.2 Swifterbant OG77

This ship is not included in Crumlin-Pedersen (2000) and is included here as it appears in the list of cogs received from E. Jansma. The dendrochronological analysis of just three samples was carried out in 2001, by E. Hanraets (2001). Sapwood on two of the samples allows a very good dating for this ship, to *c.* AD 1305. One of the samples matched very well (t = 8.5) with a chronology from The Netherlands.

The correlation between the three samples is not high, and one sample (kog00030) consists of only 69 fairly wide rings (see correlation matrix fig 90), so there is no ship average made between these three samples. There is therefore

	kog00010	kog00020	kog00030
kog00010	*	3,12	-
kog00020	3,12	*	3,6
kog00030	-	3,6	*

Fig. 90. The Swifterbant cog (OG77), Flevoland, Netherlands. Matrix of internal correlation.

				kog00020	kog00010	kog00030
	dates	end		AD1277	AD1303	AD1280
	start	dates		AD1125	AD1187	AD1212
nlnoor10	AD1041	AD1391	North Netherlands (Jansma 1995)	9,42	4,94	4,56
2121M002	AD1052	AD1596	Suså Næstved (Daly 2001a; 2001e)	7,06	3,01	-
nlwf1040	AD1040	AD1972	Nederland, Westfalen (Tisje unpubl.)	6,99	4,06	-
frlotha1	AD1016	AD1988	Northeast France (Jansma pers.comm.)	6,83	-	-
G3115M01	AD1086	AD1238	Gro (EU-project)	6,28	3,20	\
ZEALAND0	AD452	AD1770	Zealand (NM)	6,15	3,40	-
G340UM01	AD914	AD1449	Bsge (EU-project)	6,06	-	-
nlzuidmm	AD427	AD1752	S. Netherlands (Jansma 1995)	5,98	-	-
maas672m	AD672	AD1986	Oost Belgie (Jansma pers.comm.)	5,81	-	-
DM200005	AD915	AD1873	Niedersachsen Nord (GU)	5,73	3,10	-
frpardst	AD848	AD1597	Paris Basin (Jansma pers.comm.)	5,68	3,02	-
GBM00010	AD406	AD1594	Southern England (SU)	5,67	-	-
G350PM01	AD967	AD1381	Wtr (EU-project)	5,61	3,30	-
GBM00008	AD440	AD1742	Northern England/Wales (SU)	5,58	-	-
G315VM01	AD1070	AD1192	Bwgs (EU-project)	5,46	\	\
DM200006	AD914	AD1873	Lüneburger Heide (GU)	5,32	3,09	-
G315JM01	AD1033	AD1265	Agm (EU-project)	5,21	-	-
30079M01	AD998	AD1374	Stegeborg (Daly 2001d)	5,19	3,01	-
G3206M02	AD1087	AD1200	Gone (EU-project)	5,14	\	\
G3606M01	AD1046	AD1334	Bag (EU-project)	5,11	3,32	-
DM300001	AD822	AD1964	Westdeutschland (GU)	4,75	-	-
DM200003	AD1004	AD1970	Weserbergland (GU)	4,47	3,25	-
DM700001	AD631	AD1950	Suedtyskland (GU)	4,44	-	-
DM200004	30BC	AD1960	G Weser (GU)	4,36	-	-

Fig. 91. The Swifterbant cog (OG77), Flevoland, Netherlands. Table of correlation between the Swifterbant average and master chronologies from Northern Europe.

unfortunately a very weak basis on which to attempt a provenance determination for this ship. The table (fig. 91) shows the correlation results for each sample against a suite of master chronologies from Northern Europe. As can be seen, two samples, while dated, do not achieve high correlation values, although note that all three samples have their highest with the same chronology. If one might hazard a statement about the one sample, which gives quite high correlation values, indications are that we are dealing with Dutch timber.

	kka00010	kka00021	kka00040	kka00051	kka00061	kka00082	kka00171	kka00030	kka00071	kka00101	kka00141	kka00150	kka00160	kka00111
kka00010	*	18,14	-	\	4,14	\	\	-	\	-	-	\	\	\
kka00021	18,14	*	-	-	4,31	2,38	-	-	2,09	-	-	\	-	\
kka00040	-	-	*	3,98	5,73	-	4,4	-	-	2,42	-	2,84	2,08	2,55
kka00051	\	-	3,98	*	13,4	2,89	-	2,29	2,19	-	-	-	-	-
kka00061	4,14	4,31	5,73	13,4	*	5,02	2,72	2,84	4,1	2,45	-	-	-	-
kka00082	\	2,38	-	2,89	5,02	*	2,51	2,63	3,37	2,71	2,78	-	3,03	-
kka00171	\	-	4,4	-	2,72	2,51	*	-	-	-	-	-	-	2,43
kka00030	-	-	-	2,29	2,84	2,63	-	*	9,1	5,18	2,66	-	-	\
kka00071	\	2,09	-	2,19	4,1	3,37	-	9,1	*	7,51	2,84	-	-	-
kka00101	-	-	2,42	-	2,45	2,71	-	5,18	7,51	*	3,64	3,42	2,01	2,94
kka00141	-	-	-	-	-	2,78	-	2,66	2,84	3,64	*	-	-	-
kka00150	\	\	2,84	-	-	-	-	-	-	3,42	-	*	3,9	-
kka00160	\	-	2,08	-	-	3,03	-	-	-	2,01	-	3,9	*	-
kka00111	\	\	2,55	-	-	-	2,43	\	-	2,94	-	-	-	*

Fig. 92. The Doel cog, East Flanders, Belgium. Matrix of internal correlation.

6.4.3 Doel, Antwerp, Belgium

This ship was found and excavated in 2000 (Vlierman 2006). It was spectacularly well preserved, found lying inverted, with its keel uppermost. Hanraets completed dendrochronological analysis of 17 samples in December 2000. Three of the samples had very few tree-rings (less than 50) and could not date, but the remaining 14 samples are dated. Two samples with complete sapwood preserved provide a very precise date for the felling of the timber for the ship.

> “De bomen waarvan de monsters afkomstig zijn, zijn gekapt in de loop van de zomer of in de winter, maar vóór

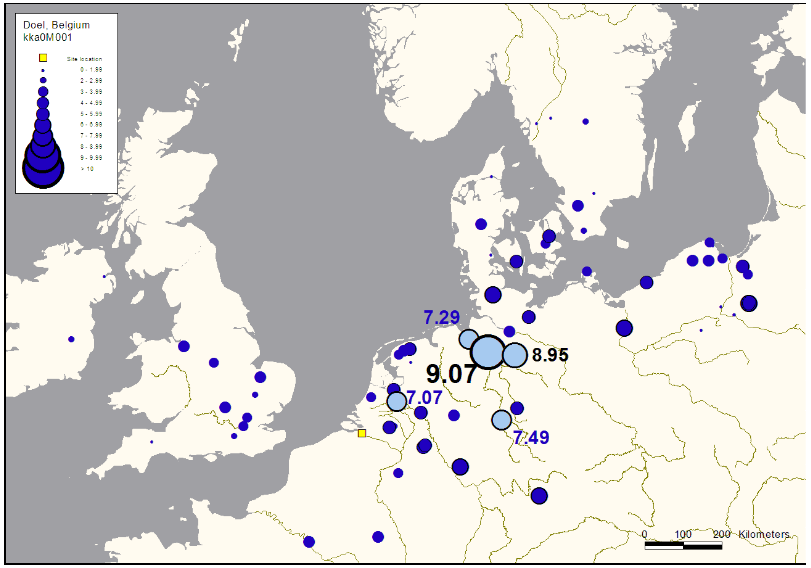


Fig. 93. The Doel cog, East Flanders, Belgium. Map showing the distribution of correlation values achieved between the mean for Doel and master chronologies from Northern Europe (the first level test).

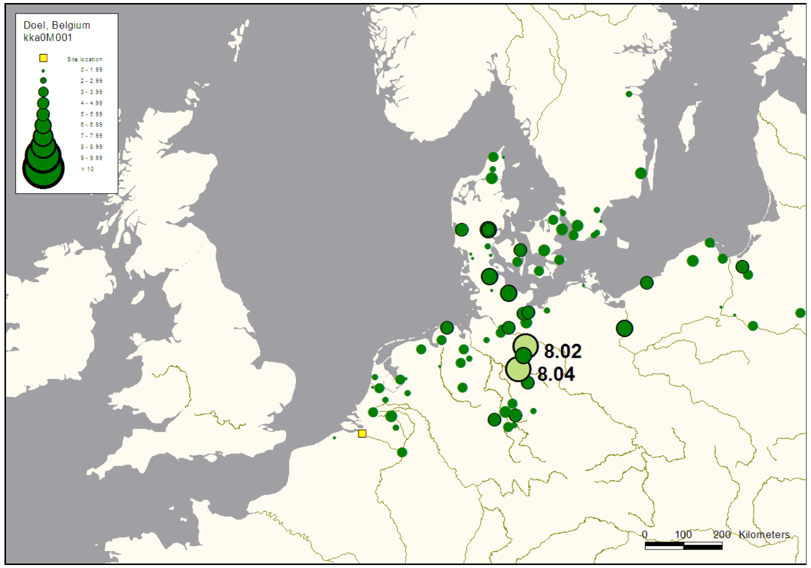


Fig. 94. The Doel cog, East Flanders, Belgium. Map showing the distribution of correlation values achieved between the mean for Doel and site chronologies from Northern Europe (the second level test).

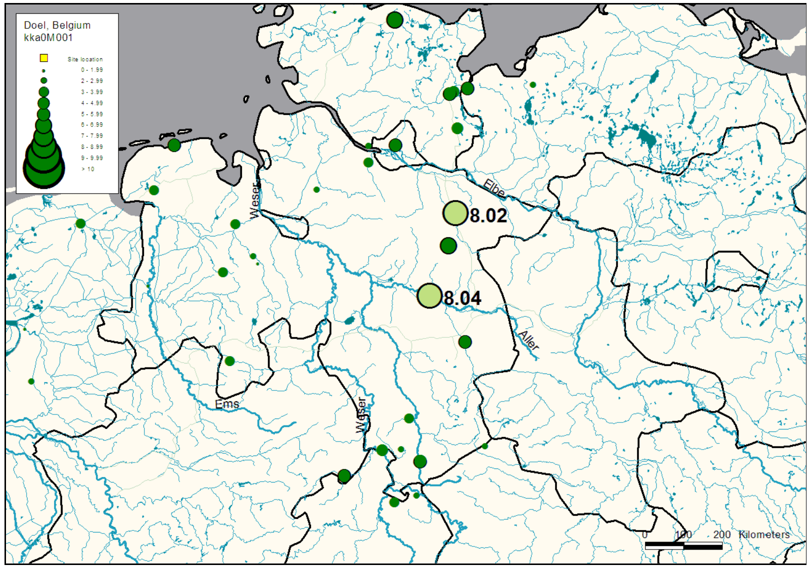


Fig. 95. The Doel cog, East Flanders, Belgium. Map showing the distribution of correlation values achieved between the mean for Doel and site chronologies from Northern Europe (the second level test) in relation to the major drainage of the region.

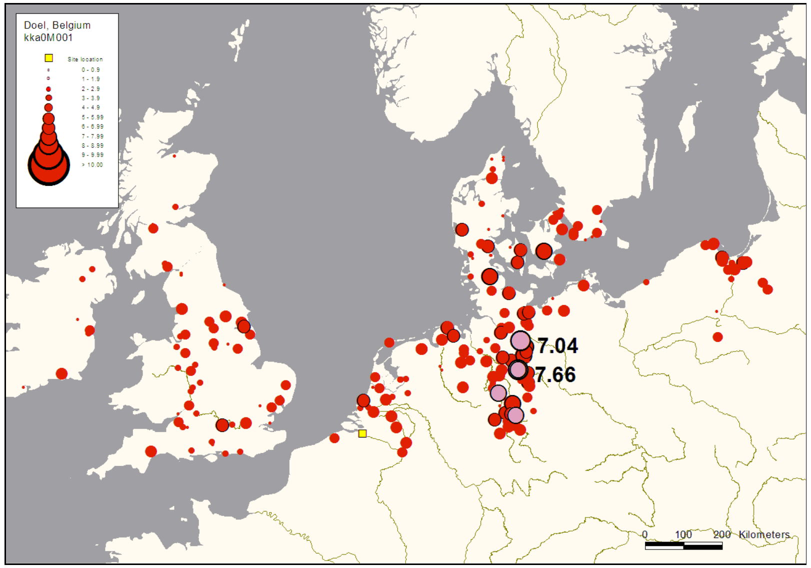


Fig. 96. The Doel cog, East Flanders, Belgium. Map showing the distribution of correlation values achieved between the mean for Doel and single tree-ring measurements from Northern Europe (the third level test).

> het opnieuw iutlopen van de bomen in het daarop volgende voorjaar, d.w.z. tussen zomer 1325 AD en voorjaar 1326 AD" (Hanraets 2000).

That is, between summer AD 1325 and spring AD 1326.

As can be seen from the matrix of correlation between all the dated samples from the Doel ship (fig. 92) it appears that we are dealing with a very spread group of timber. Three small groups appear, but otherwise there is low correlation between the samples. When each individual sample is tested against the master chronologies from Northern Europe the highest *t*-values that appear are with German chronologies especially with one from the Lower Saxony region. The *t*-values achieved for the individual trees are not high enough for confidant provenance determination, only reaching $t = 6.5$ at the most, so it has been decided to make a ship average using all dated samples, despite the relatively low internal correlation, for the provenance determination test. Hanraets in her original analysis also made an average of all samples, but the ship average used here is modified a little, deleting the first five tree-ring indices, as they had a very extreme dip in ring-width, which might be due to measurements close to the pith of the tree.

The ship average then, of all dated samples, is tested at the three provenance test levels. The test at the first level, with master chronologies (fig. 93), shows that the highest correlation ($t = 9.07$) is achieved with a regional chronology from Lower Saxony in Northern Germany. The next best ($t = 8.95$) is with a chronology from Lüneburger Heide, also in the province of Lower Saxony. Although the sizing of the circles highlights the higher *t*-value, there is not much difference between these two correlations. So the original suggestion by Hanraets can be confirmed, that the timber grew in Lower Saxony. At the test then at the second level (fig. 94) we can see whether can begin to say where, within the Lower Saxony region, we might be able to identify the timber source. Here the green circles indicate the correlation results, and the highest values are given. The two sites that give the highest correlations are both sites that have been analysed at the University of Göttingen. The site means for these sites are all longer than the ship average so there are no problems of varying overlap. The *t*-values are very similar to each other. However, the replication of the site chronologies vary. The Truhen site average is made from 35 timbers and gives a *t*-value $t = 8.04$, while the Medingen site average is from only six trees and gives a value of $t = 8.02$. All of this attention to detail is taken because we wish to look at the distribution of the highest *t*-values in relation to the topography of the region. This is so that we might be able to make a suggestion as to the shipbuilding site, or at the very least, to suggest along what major river the timber can have been transported. As can be seen from the map in fig. 95, the Truhen site is from the Aller drainage basin, which drains into the Weser. (To confirm the local nature of this site timber Truhen site chronology has also been tested with the network of site chronologies, and it matches best with another site on the same drainage system, on a tributary to the Aller River further upstream.) However the other site, which matches equally well with the Doel ship average, come from another drainage system, the Ilmenau, which is a tributary to the Elbe River. Would then the test at the third level allow the identification of the timber origin?

In the third level test (fig. 96) the correlation values greater than t= 6.00 are highlighted in pink, and the two highest are labelled. Again the highest ($t = 7.66$) is with the site on the Aller River, while the next best ($t = 7.04$) is with a tree from Lüneburg. Here we remove the problems of varying replication, but must look into the varying overlap. The second highest correlation is with an overlap of 165 years, while the highest correlation the overlap is 149 years. We might thus give the higher correlation a bit more importance than the second highest, pointing indeed to the timber origin for the Doel ship in the Aller River drainage region.

Given the non-homogeneity of the tree-ring patterns from the many samples from the Doel ship it can be suggested that the timber is from a relatively wide area, and this indicates the necessity of transport of the timber to the ship-building site. The less clear provenance determination for the timber can also be due to the non-homogeneity of the tree-ring series. When an average is made of these tree-ring series, which individually seem to come from the same general region, but which don’t match each other so well, the average might represent a wider regional climate signal, rather than a local signal. It is, you could say, in sharp contrast to the Bredfjed ship case discussed elsewhere. In its case the tree-ring series are very similar to each other indicating a very limited source area, and the resulting ship average is of a very local nature.

6.4.4 Oostvaardersplassen Almere CZ46

The dendrochronological analysis of just five samples from this ship was carried out in 1999 (Hanraets 1999) and three of these are dated. The number of tree-rings contained in each of these samples is relatively low (the maximum is 83 rings in sample 3) but they cross-match and a mean, 86 years long, is made from all three tree-ring curves. As the length of the ship’s tree-ring mean is so short, a detailed provenance determination does not appear in tests at the second level, so no further re-analysis of this ship is attempted here. As only heartwood was preserved on the samples, the original analysis concludes that the trees for the ship were felled after AD 1327. The best match achieved is with Dutch chronologies and this conclusion is incorporated into the summary of the cog ships.

6.4.5 Nijkerk Flevol. OZ36

This ship was found in 1983 and is published in Luns (1985). It was also analysed in 1993, by Jansma and Hanraets (1994) and on the basis of nine dateable samples was dated to AD 1335/1336. A good match between the dated samples indicate a homogeneous source for the timber, and an average was made using all dated samples (KKO00M01). When this was tested at the forest level, with master chronologies from Northern Europe it was found to match very well with a master from the northern Netherlands, but no other adequately high values with other masters in the region appeared. On a search of the European catalogue of chronologies (Levanic webbased database; Hillam 1997) this master was found to be listed (fig. 97). It is clear that measurements from ships and barrels are included in this chronology, and therefore this master should not be used in the re-evaluation of the provenance of the Dutch cog finds.

NL-RIN	*QUSP*	NLHist_3 / archaeological, historical / medieval, historical The Netherlands, nortern parts of the, -, -, houses, ship timber, barrels etc., Researcher:*NLEJ* TRW, Dated-Y, *AD 1346 - AD 1041 = 306 yrs.*

Fig. 97. Description of a master chronology for the northern Netherlands built by Esther Jansma, as listed in table entry in Tom Levanic's European dendrochronology catalogue (http://www.dendro.bf.uni-lj.si/first.html).

When this chronology is removed from the first level test map we see that a very weak correlation result appears for this ship, even though we have an analysis of several samples and material that had good internal correlation. The tests at the second and third levels do not serve to improve the picture.

One final attempt to try to improve the results for this ship entailed the removal of one sample from the mean, as it has extreme variation in its immature growth phase and extends further back in time than the rest. The tests of this second mean against masters still shows a weak provenance result (fig. 98).

6.4.6 Lille Kregme

We move now to the second half of the 14th century, to which a number of cogs have been dated. The earliest of these is Lille Kregme, found in 1982 in Roskilde fjord (Rieck 1996). Twelve samples from the ship were analysed dendrochronologically in 1992 and 11 were dated. Sapwood on three of the dated samples meant that a felling date could be estimated to *c.* AD 1358 (Eriksen 1992). At the time of the analysis it is noted that the tree-ring curve for the ship matched best with Pomerania, and that the oak trees grew in or close to that area.

So here we have a look again at the internal correlation of the 11 dated samples. Eriksen in his analysis found that some samples were so similar that they might come from the same tree. This was the case for three samples and again for

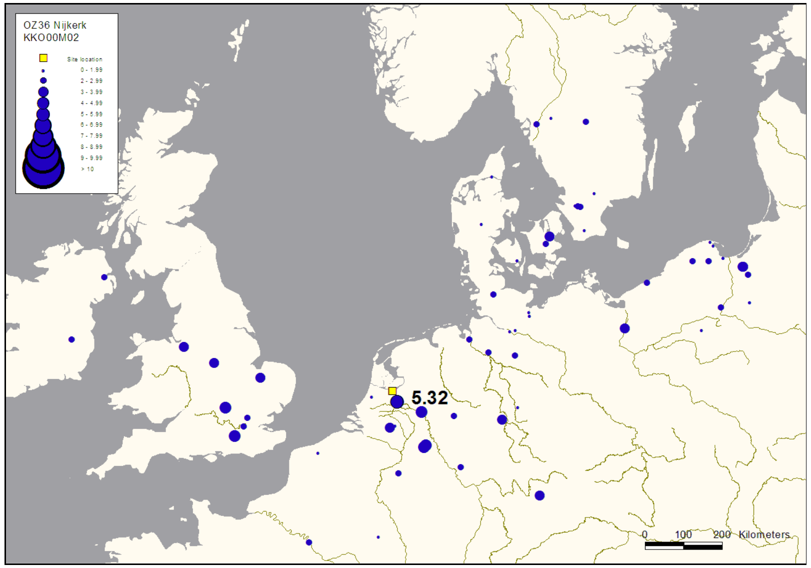


Fig. 98. The Nijkerk cog (OZ36), Flevoland, Netherlands. Map showing the distribution of correlation values achieved between a mean for Nijkerk (OZ36, KKO00M02) and master chronologies from Northern Europe (the first level test).

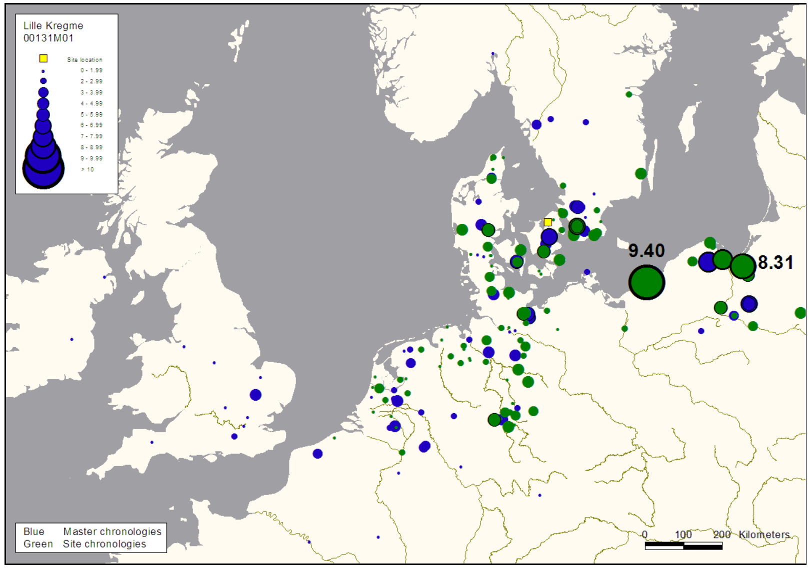


Fig. 99. The Lille Kregme cog, Zealand, Denmark. Map showing the distribution of correlation values achieved between the mean for Lille Kregme and master and site chronologies from Northern Europe (the first and second level tests).

Filenames		start	end	00121M01
-				AD1155
-				AD1353
Z005M002	Bøle ship four beams (Daly, this volume)	AD1177	AD1356	9,87
0045M002	Vejby ship (Bonde and Jensen 1995)	AD1109	AD1370	9.03
Z005M001	Bøle ship all timbers (Daly, this volume)	AD1063	AD1373	8,51
P0013009	Copper Ship (Ważny pers.comm.)	AD1200	AD1404	7,73
Z0021M01	Avaldsnes (Daly, this volume)	AD1196	AD1391	6,15
02071M01	Dokøen Wreck 2 (Eriksen 2001a)	AD1126	AD1414	5,78
Z005M003	Bøle ship four planks (Daly, this volume)	AD1063	AD1373	5,64
21214M01	Suså barrel (Daly 2001a)	AD1138	AD1321	5,60
60132M02	boringholm barrels (Daly 2000; 2005)	AD1145	AD1368	5,28
0204M001	Tårnby Amager (Daly, unpublished)	AD1187	AD1414	5,05

Fig. 100. The Lille Kregme cog, Zealand, Denmark. Table showing the correlation between the mean for Lille Kregme and other ship means.

another two. So these were averaged together, to represent the two trees. This same procedure is retained here. The correlation matrix then is therefore based on eight trees. All eight tree-ring curves are included in a ship average of 199 years (00121M01), which is then tested for provenance.

Just one map is produced here, showing the results of the first and second level tests combined (fig. 99). The highest *t*-values indeed appear with sites from the Southern Baltic region. The highest is with Kolobrzeg on the coast, with a *t*-value of 9.40. Now in the light of the fact that we have identified many ships that are made of Southern Baltic oak, as described below for several other examples, it seems appropriate to test the average for Lille Kregme with these other ships. This is illustrated in table form in fig. 100. It can be seen that high values are achieved with the ship average for the Vejby cog discussed below, but particularly with ship averages from the Bøle ship, also discussed below. Now it is interesting to note that these two ships also achieve best correlation with Kolobrzeg. And to be more specific, for the Bøle ship, the beams match best with Kolobrzeg, and it is with the Bøle beam average that Lille Kregme also matches best with. It seems we can identify a group here of timber from ships of Southern Baltic origin, but set apart from others from the same wide region, in that their timber might come from further west, not from the Vistula region as is often the case with timber identified as Southern Baltic.

6.4.7 Vejby

The Vejby cog was excavated in 1976-77 (Crumlin-Pedersen 1979) and dendrochronological analysis of 26 samples from the ship, of which five had complete sapwood, meant that the building of the ship could be dated very accurately, to AD 1372 (Bonde and Jensen 1995). In the dendrochronological analysis the question of the provenance of the timber also arose and it was found that the ship was built of timber which had grown in the region around Gdansk. The *t*-value between the ship and the Gdansk chronology was as high as t = 17.69. There is no mention in Bonde and Jensen (1995) of the internal correlation of the ship's timbers, apart from the information that some timbers are so similar that they might be from a single tree. In the light of the apparent different sources for the timber in the case of Bøle, this would be an interesting aspect to examine for the Vejby cog, particularly in relation to the planks vs. the frames.

The evidence from numismatics shed also light on the ship's origin. Coins found in the mast step can help us in the discussion of the extent of transport of shipbuilding timber in the late medieval period. In the case of the Vejby cog, a bracteate or hollow penny and a coin, both minted by the Teutonic Order in Prussia were found in the mast step. Their placing in the mast step dates to after *c.* 1360/65 (Bonde and Jensen 1995, 107-8). It seems logical to assume that if the timbers and the mast step coins are of Southern Baltic origin, then this is also the region where the ship was built

> ”within the area under the control of the Teutonic Order in Prussia” (Bonde and Jensen 1995, 114).

In this reassessment of the provenance determination we can take the mean curve for the Vejby ship made by Bonde, and test it against a more up to date suite of chronologies. The map showing the result of the tests at the first and second levels is illustrated in fig. 101. As usual, the master chronology correlations are illustrated with blue dots, the site chronologies using green. As can be seen, many very high *t*-values appear. Several are indeed greater than $t = 10.00$. Most of these high values are with chronologies from around the Gulf of Gdansk and along the Vistula River. Note the especially high value $t = 17.72$, as published in Bonde and Jensen (1995), which is between the ship and a large Gdansk-Pomerania chronology, the circle highlighted in a lighter blue. Note though that an even higher value appears further west at $t = 20.75$, with a site chronology from Kołobrzeg (Tomasz Ważny, pers. comm.) on the northern Polish coast, the light green dot indicating a site chronology to distinguish between site and master chronologies. This site chronology contains many trees, 154 to be exact (Haneca et al 2005, 265) but the *t*-value achieved is so high that the good replication of the chronology is not the only reason for the high correlation. It might be that the timber source for the Vejby cog should in fact be

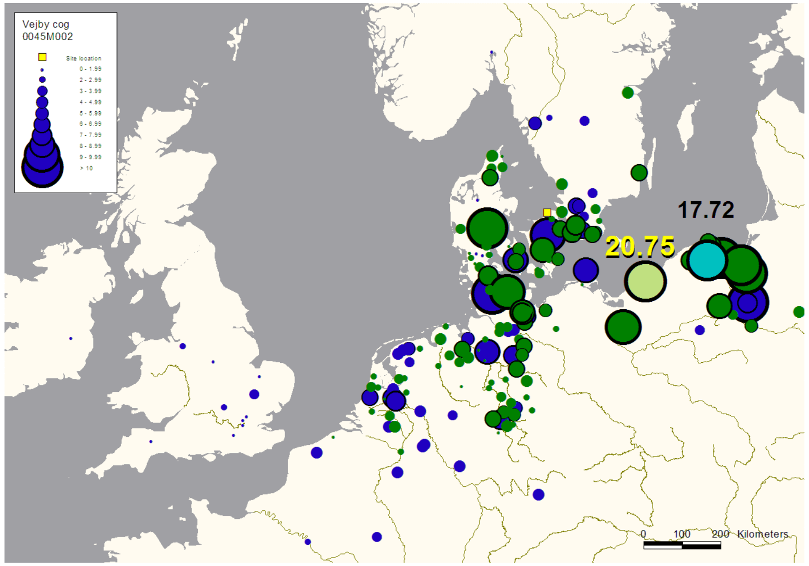


Fig. 101. The Vejby cog, Zealand, Denmark. Map showing the distribution of correlation values achieved between the mean for Vejby and master and site chronologies from Northern Europe (the first and second level tests).

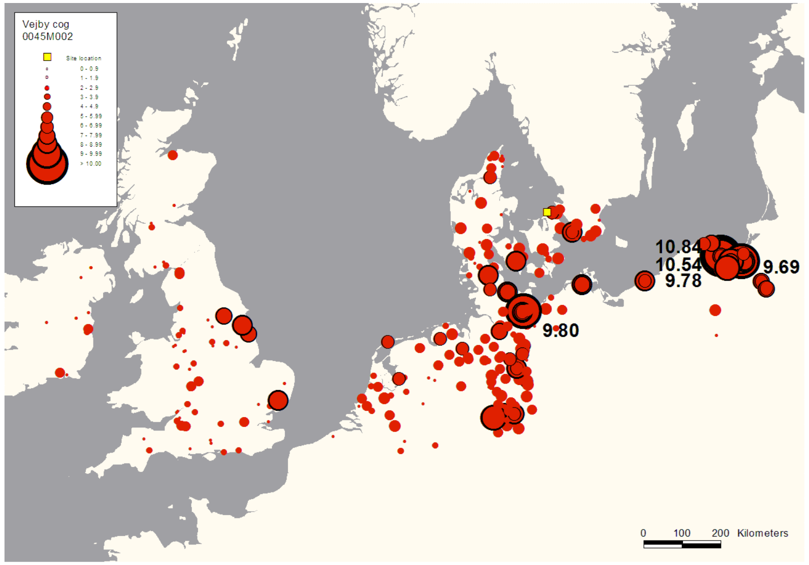


Fig. 102. The Vejby cog, Zealand, Denmark. Map showing the distribution of correlation values achieved between the mean for Vejby and single tree-ring measurements from Northern Europe (the third level test).

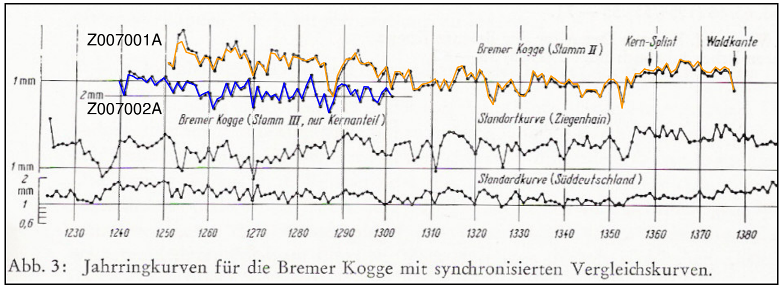


Fig. 103. The Bremen Cog, Bremen, Germany. Diagram from Bauch (1969, 125) showing the tree-ring curves from his measurements of two samples from the Bremen cog, and showing the tree-ring curves derived from this diagram, to analyse in this study.

		Z007001a	Z007002a	Z007F001	Z007M001
		AD1251	AD1240	AD1240	AD1240
		AD1378	AD1301	AD1378	AD1378
Sweden	West Sweden	4.25	-	3.80	3.70
Denmark	Zealand DK	4.37	-	5.51	5.38
Germany	Schleswig-Holstein	3.19	-	3.71	3.92
	Lübeck	4.08	-	4.54	4.61
	Nieders. Kuestenraum	3.49	-	3.17	3.43
	Lower Saxony North	4.16	3.61	4.39	4.45
	Lüneburger Heide	4.27	3.82	4.61	4.55
	Weserbergland	5.56	6.33	6.35	6.14
	G Weser	5.22	7.89	6.17	5.81
	South Germany	4.54	6.77	6.40	5.45
	West Germany	3.98	5.50	5.34	4.78
Netherlands	Holland	3.84	5.46	4.47	4.42
Poland	Gdansk Pomerania	4.39	3.13	4.78	4.32
France	Besancon East France	4.03	4.30	4.91	4.56
	North-East France	4.08	6.33	5.35	4.82
	Paris Basin	4.36	4.47	5.18	4.26
Belgium	East Belgium	3.82	4.40	4.85	5.24

Fig. 104. The Bremen Cog, Bremen, Germany. Table showing the correlation between tree-ring curves and indices from the Bremen cog and master chronologies for northern Europe. The two tree-ring curves individually and two averages (one is a filtered average while the other is a straight average) are compared.

connected with the town of Kołobrzeg. In a description of the archaeology of the town, (Rębkowski 1999) we know that the town's main production and export was salt, but grain was probably also an export commodity. In addition Rębkowski mentions that:

> ”According to some written records a shipyard was located in the vicinity of the Panmaker's Suburb there – *locus ubi naves construuntur* mentioned for the first time at the beginning of the 15th century” (Rębkowski 1999, 59).

Is it possible that we are getting nearer a more detailed provenance determination than previously, for The Vejby cog? Was the timber, used to build the late medieval urban buildings in Kołobrzeg, transported there from further east, so that no correction of the origin of Vejby be suggested, but rather that the source for the timber for Kołobrzeg is not local to the town? When we check the correlation of the Kołobrzeg site chronology with the masters and site chronologies in the northern European tree-ring dataset, there is no evidence to suggest that the Kołobrzeg material is from further east, so it is the Vejby ship that we might need to reconsider.

Again in this case as is now procedure, the ship mean is tested against the single tree dataset. The result is illustrated in fig. 102. It becomes very obvious that the very high value achieved with Kołobrzeg in the second level test is not repeated in the third level test shown here. This is very easily explained. The Kołobrzeg site chronology was constructed by Ważny (Tomasz Ważny, pers. comm.), of tree-ring data analysed after the submission of data to the EU-project dataset, so the tree-ring measurements, on which the Kołobrzeg site chronology is built, is not present in the single tree dataset.

So lets get back to the question of what these results lead us to. We have the results from the coins in the mast step, both of which were in circulation in the 1360s giving a date for their deposition to anytime after 1360/65 (Bonde and Jensen 1995). We have the date for the felling of the timber to winter 1371-72, and the conclusion that the ship was built in 1372. The possibility arises now, in this reassessment of the timber origin, that we might place the timber source further west than has been concluded up to now. Does this fit with the coin evidence? The two

Teutonic coins would have had their core circulation further east towards Gdansk, but can have been valid currency in the thriving late medieval town of Kołobrzeg. One of the coin types, the hollow penny, has been indeed found in a Danish hoard. Concerning the choice of coins for deposition under the mast step, it is also mentioned that it can have to do with the fact that the coins have the cross motif, thus providing Christian symbolism to the votive deposition.

6.4.8 Bremen

A discussion of the dendrochronological analyses of cog finds should not omit the results for the Bremen Cog, found in 1962 in the Weser River at Bremen, Germany (Abel et al 1969). The identification of the so well preserved Bremen ship as a cog, which was otherwise only known from historical references, allowed the identification of the construction features of the cog. Other medieval ship finds in the archaeological record could, on the basis of these characteristics, be then identified as cogs also. The dendrochronological analysis of the Bremen cog was initially carried out on cores from a single timber (Liese and Bauch 1965). Sapwood was not preserved on this piece, but the boundary between heartwood and sapwood was identified and dated to AD 1358. Therefore, at the time, an estimate of the felling date of the timber was made, accounting for missing sapwood. At this time dendrochronology in Europe was at its infancy, so few master chronologies existed, but the suggestion that the Bremen Cog's timber might have come from upriver, south of the town of Bremen, meant that cross-matching was successful with chronologies from regions south of Bremen. A new opportunity to sample the wreck in 1965 resulted in the analysis of two additional samples, and one of these had complete sapwood to bark edge preserved (Bauch 1969). The felling of the timber could be dated exactly, to AD 1378. To date the actual building of the ship it was considered necessary on the one hand to allow for the time it might take for the transport of the timber downriver, but on the other hand, it was suggested, given the fact that no traces of insect attack on the sapwood were present, that not too long a period of storage of the timber had taken place. It was thus concluded that the ship was built around AD 1380.

Klein mentions that even though this analysis was done so long ago still nothing changes Bauch's original conclusion as to the date of the ship: "Zu diesem Ergebnis kam Josef Bauch, Holzbiologe an der Universität Hamburg, schon 1969, und es gibt über die Entstehungszeit der Kogge von Seiten der Dendrochronologie keine darüber hinausgehenden Erkenntnisse" (Klein 2003, 157). However, given the developments in dendrochronology in Northern Europe since Bauch's analyses it seemed appropriate to reassess the results, not to test the date but to see if more could be said of the provenance of the timber.

It was possible to derive tree-ring indices from the two timbers that were examined by Bauch in 1965, as the tree-ring curves for these two are plotted in a diagram in his paper (fig. 103) (Bauch 1969, 125). The timber that supplied the bark date for the ship (stamm II) consisted of 128 rings, while the second timber had only heartwood and 62 rings. Carrying out provenance determination on just two samples is, as has been discussed above, not going to produce the kind of good results as in other ship analyses where many samples have been analysed, and the two tree-ring curves from the Bremen Cog here only match at a correlation of 4.25 and overlap for just 51 years. In other words, we do not have a good basis for dendrochronological provenance determination. The table (fig. 104) shows the correlations achieved for the Bremen timbers. The two tree-ring curves individually and two averages (one is a filtered average while the other is a straight average) are compared with Northern European master chronologies. As can be seen, the results indicate an origin for the timber in the upper Weser catchment area.

6.4.9 Skanör

The Skanör cog was found in 1992 in the waters off Skanör, on the southwest tip of Sweden (Hörberg 1995). The ship has been dendrochronologically dated to after 1382 and a Polish origin is suggested (Nilsson 2004; Ossowski et.al., 2003). An exchange of measurements was possible through the kind cooperation of the dendrochronologist Marek Krapiec of AGH University of Science and Technology, Kraków, who had analysed the Skanör cog. He had made two ship averages, one containing nine samples, the other just three. When these two ship averages are tested against the available master chronologies it is found that the best agreement appears with the art-historical chronologies (fig. 105). These are chronologies built on the basis of analyses of oak panel paintings in Germany, The Netherlands and England, where the oak itself comes from the Southern Baltic region (Baillie et al 1985; Eckstein et.al. 1986; Hillam and Tyers 1995; Ważny 2002; Klein 2003). So for this example we see that we again identify a ship whose timber grew in the Southern Baltic region, but the timber source is quite different to those of the other examples in this study. Work is underway to identify the source of the timber in these 'geographically floating' art-historical chronologies (Ważny 2002), but until then we can say that these panels and the Scanör cog have similar geographical origins.

Filenames		lskn_a1	lskn_a4
		AD1153	AD1111
		AD1372	AD1370
0M020001	Niederlande Paintings	7,70	7,15
0M020002	Nederlandene Syd Paintings	6,15	7,37
0M010004	Leiden Paintings	6,03	6,13
0628021M	Torun Joh K (Ważny, pers.comm.)	5,91	-
P734002M	Bransk (Ważny, pers.comm.)	5,33	-
0M040004	Baltic 1 Paintings (Hillam and Tyers 1995)	5,20	3,93
0M020003	Nederlandene Nord Paintings	4,97	3,40
SM100003	Ystadsomr (LU)	4,75	3,36
0628002M	Torun Joh Kir (Ważny, pers.comm.)	4,72	-
PM000004	Gdansk Pomerania (Ważny, pers.comm.)	4,70	4,24
2x900001	Zealand (NM)	4,68	-
0686003S	Przezmark (Ważny, pers.comm.)	4,46	3,33
P815001M	Bielsk Podl (Ważny, pers.comm.)	4,35	-
P719014A	Tolkmicko (Ważny, pers.comm.)	4,19	-

Fig. 105. The Skanör cog, Malmöhus län, Sweden. Table showing the correlation values achieved between a mean for Skanör and master chronologies from Northern Europe.

6.5 *15th century*

6.5.1 Ketelhaven / Spakenburg NZ43

A dendrochronological analysis of the Spakenburg or Ketelhaven ship (NZ43) was carried out on five samples in 1993 (Hanraets and Jansma 1994a). Two samples matched each other very well and a mean curve was made from these two. The remaining three samples could not be dated. Sapwood was preserved on one of the dated samples so that a date, for the felling of the trees for the ship was placed at 1402-1414. The best correlation achieved was with a chronology for the Netherlands/Westfalen. Despite a reasonable number of rings in the ship average (154) the correlation values are not terribly high, and this is perhaps due to the low replication of the mean, consisting, as it does, of only two trees. The highest *t*-value (*t* = 6.83) is with the Netherlands/Westfalen chronology as found in the original analysis. *T*-values of 4.89 and 4.52 appear with other Dutch chronologies, while similar values (4.60) appears with some art-historical chronologies (see fig. 106). There are only very few *t*-values greater than 3.00 with site chronologies in the available dataset so the test at the second level is not pursued further. In conclusion, a very slim basis for provenance determination is apparent for this ship.

Filenames	-	-		kn42x000
-	start	dates		AD1246
-	dates	end		AD1399
nlwf1040	AD1040	AD1972	Netherlands, Westfalen (Tisje unpubl.)	6,83
nlnoordm	AD1041	AD1346	North Netherlands (Jansma 1995)	4,89
0M020001	AD1115	AD1643	Niederlande paintings	4,64
0M010004	AD1146	AD1491	Leiden paintings	4,60
nlmidden	AD1023	AD1666	Mid Netherlands (Jansma 1995)	4,52
0M010006	AD1000	AD1655	Koeln Wouwermann paintings	3,21
0M040004	AD1156	AD1597	Baltic 1 (Hillam and Tyers 1995)	3,14
0M020003	AD1199	AD1635	Nederlandene Nord paintings	3,10

Fig. 106. The Ketelhaven / Spakenburg cog (NZ43), Flevoland, Netherlands. Table showing the correlation values achieved between a mean for Ketelhaven and master chronologies from Northern Europe.

7 Chapter 7: Two 12th century Nordic ships

7.1.1 Karschau

The Karschau ship can be included in this group, but as a paper dealing with the analysis of this ship is now published (Daly 2007) it is not discussed here. The paper is included, instead, in the appendix to this volume.

7.1.2 Möweninsel Ship

The ship from Möven Island in the Schlei fjord at Schleswig, was analysed dendrochronologically at the University of Hamburg, and dated to after 1169. The ship is the subject of a master's thesis carried out by Mike Belasus (Belasus 2004). Five planks and the keel from the ship have been analysed (Sigrid Wrobel, pers comm.). Three planks might come from one tree, while the other two planks might be from a second tree, so all in all only three trees are represented in the averaged tree-ring curve. Two average curves were made from the data, one a straight average of the five planks and the keel, a second an average of the three trees that are represented in the analysed samples. As can be seen in the table (fig. 107), the analysis indicated a Scandinavian origin for the timber, but geographically a very wide distribution of correlation values, and none higher than t = 5.62, emerged. This meant that it was not possible to identify the origin of the ship's timber. Sigrid Wrobel at the University of Hamburg very kindly sent the averaged tree-ring curves, so that a re-analysis could be carried out, with a view to attempting to refine the provenance determination result.

Only the second average curve for the ship is dealt with here. When the tree-ring curve is tested against master chronologies for Northern Europe the highest t-value appears with a chronology from the island of Zealand in Denmark (t = 7.47). Values between 6.00 and 7.00 appear with a chronology from Jutland (National Museum of Denmark) and with Aalborg (Daly 2000a; 2001b) in Denmark, and with a chronology from West Sweden (Lund University).

		1S	2S
Germany	Schleswig excavation	3,54	3,96
Sweden	Lund	5,13	4,77
	Sweden West Chr 5	5,42	5,20
	Sweden Scania	4,62	4,26
Denmark	Sydjylland	5,52	5,62
	Danmark Vest+Slesvig	5,22	5,26

Fig. 107. The Möweninsel ship, Schleswig-Holstein, Germany. Table of the correlation values achieved in the initial analysis of just two samples from the Möweninsel ship (Sigrid Wrobel, pers.comm.).

The single tree level test does not produce any values higher than t = 5.43, and these highest values occur with single trees from very diverse locations that we cannot use this level in the case of the Möweninsel ship.

However, when the Möweninsel ship is tested against the tree-ring curves of other ships from the period, a high value (t = 8.47) is achieved with the Swedish ship find Galtabäck 1 (Enqvist 1929), dating to AD 1195 or shortly after (Daly 1998e). The table (fig. 108) shows the correlation between the Möweninsel ship's tree-ring curve and chronologies from Northern Europe. Several other ship averages are tested and shown in this table, as a connection can be seen between these ships dendrochronologically, in that they seem also to have a western Swedish provenance.

At the top of the table the correlation between these four 12th century medieval ship finds are listed. We see here that the Möweninsel ship and Galtabäck 1 might, dendrochronologically, be taken as a pair, and that Lynæs 1 (Englert 2000) from *c.* 1140 (Daly 1999b) and Roskilde 2 (Bill et.al. 1998; 2000; Gøthche 2006) from *c.* 1185 (Bonde 1998) can be taken as another pair. Analysis archaeologically of the building tradition used in these ships is interesting in the light of the provenance of the timber. Möweninsel has treenails of pine, which is not unlikely for a ship built in Sweden (Jan Bill, pers.comm.). One treenail from Lynæs 1 is also of pine (Bill, forthcoming). Bill, in addition, mentions that Möweninsel and Galtabäck 1 have a number of characteristics in common. Bill also suggests that

Galtabäck 1 and Roskilde 2 have a common feature in that the floor timbers are nailed to the keel. Although Lynæs 1 is from slightly earlier (c. 1140) the other three of these four ships are made from oaks felled within probably no more than 25 years of each other (Möweninsel, after 1169; Roskilde 2, *c.* 1185; Galtabäck, 1195 or shortly after).

ship				Möweninsel	Galtabäck	Lynæs 1	Roskilde 2
Filenames	-	-		1683002S	0094M001	0085F001	ROSVRAG2
-	start	dates		AD967	AD960	AD724	AD770
-	dates	end		AD1146	AD1174	AD1134	AD1173
1683002S	AD967	AD1146	Möweninsel (Wrobel pers comm.)	9999,99	8,47	5,09	3,13
0094M001	AD960	AD1174	Galtabäck 1 (Daly 1998e)	8,47	9999,99	5,63	-
0085F001	AD724	AD1134	Lynæs 1 (Daly 1999b)	5,09	5,63	9999,99	10,86
ROSVRAG2	AD770	AD1173	Roskilde 2 (Bonde 1998)	3,13	-	10,86	9999,99
Ships							
00694M01	AD931	AD1118	Roskilde 5 (Bonde 1997)	7,44	10,13	9,03	4,55
00698M01	AD881	AD1167	Roskilde 9 (Bonde and Daly 1998)	7,01	8,52	8,29	5,82
00696M01	AD959	AD1269	Roskilde 7 (Bonde and Daly 1998)	6,36	9,14	3,86	3,65
0076M001	AD967	AD1258	Korsholm Vrag 1 (Eriksen 1997)	6,29	8,98	6,95	5,43
00541M01	AD944	AD1251	Bossholmen (Bartholin 1985)	5,93	3,54	4,11	3,58
0013M001	AD934	AD1133	Kollerup Kog (Daly 2000b)	5,04	7,24	5,02	5,33
60873M01	AD982	AD1188	Kolding Cog (Daly 2002)	4,46	4,47	4,40	5,37
0200M001	AD898	AD1131	Eltang (Eriksen 1999)	3,99	5,81	7,37	5,93
0006M001	AD922	AD1149	Ellingåskibet (Bonde et.al 1991)	3,71	4,68	7,98	7,11
N055M002	AD1005	AD1317	Sørenga Båd 3 (Eriksen 1994b)	-	-	4,32	7,89
00692M01	AD869	AD1048	Roskilde 3 (Daly 1999d)	-	-	-	3,20
00695M01	AD674	AD997	Roskilde 6 (Bonde 1997)	\	\	10,30	6,60
N0552M01	AD1020	AD1352	Sørenga Båd 2 (Eriksen 1994b)	3,45	3,58	-	4,61
Chronologies							
SM000011	AD753	AD1329	Vestsverige (Bråthen 1982)	6,03	8,71	14,54	9,61
2X900001	AD830	AD1997	Zealand (NM)	7,47	7,73	4,97	5,08
SM600001	AD855	AD1385	Mellansverige (LU)	4,79	7,36	3,22	4,79
9M456781	109BC	AD1986	Jylland/Fyn (NM)	6,16	6,54	7,35	8,27
DM100002	AD436	AD1460	Schleswig-Holstein (HU)	5,81	5,61	4,03	4,90
SM600002	AD859	AD1371	Smaaland-Oeland (LU)	5,63	4,69	3,82	4,86
O0121019	AD895	AD1127	Sproge church (Eggertsson pers.comm.)	4,97	3,80	3,63	3,77
SM400001	AD833	AD1138	Gotland (LU)	4,38	4,37	-	3,38
SM000002	AD578	AD1293	Lund Skaane Blekinge (LU)	4,33	6,50	7,81	6,15
SM000001	AD651	AD1496	Sydvestskaane (LU)	3,91	6,38	8,45	7,38
OLUN0020	AD621	AD1723	Lund(Eggertsson pers.comm.)	3,91	6,04	7,18	6,70
O0640039	AD978	AD1291	Småland Voxtorp (Eggertsson pers.comm.)	3,83	3,95	-	3,26
81M00003	AD1009	AD1466	Kirker i Vendsyssel (Daly 1998c)	3,76	3,08	-	3,93
O0020019	AD931	AD1334	Söderköping (Eggertsson pers.comm.)	3,64	4,64	-	3,21
NM000002	AD537	AD891	Oslo Fjord (NM)	\	\	5,78	4,19
SM100002	AD988	AD1131	Ystadsomr (LU)	-	-	-	3,71
00000087	AD959	AD1213	Oslo Glbyen (Eggertsson pers.comm.)	-	-	3,63	3,24
OKSIGTUN	AD774	AD1097	Sigtuna (Eggertsson pers.comm.)	-	3,80	4,11	4,81

Fig. 108. Four 12th century ships. Table showing the correlation values between the means for four ships and master and site chronologies and ship means from Northern Europe.

It might be noted here that the ship average for Lynæs 1, though achieving a very high correlation with western Sweden (*t* = 14.54) also attains a high value with the ship average for Roskilde 6 (*t* = 10.30) Now it should be noted that as long as perhaps a whole century passed between the building of these ships. The timber for Roskilde 6 was felled after *c.* 1025 (Bonde 1997) while the oaks for Lynæs 1 were felled in *c.* 1140, that is possibly over a hundred years later. Chance has it that the tree-ring curve for Lynæs 1 extends as far back as AD724, allowing a substantial overlap with Roskilde 6 (273 years). The tree-ring curve from the dendrochronological analysis of samples from Roskilde 6, it has been found, matches with Norwegian references, particularly with oak from parts of a stave built church, found re-used in Austad church in Lyngdal, in southern Norway (Stylegar 2006). This leaves us wondering, despite the high value with west Sweden (*t* = 14.54), whether or not the provenance determination for Lynæs 1 should move further eastwards, if chronologies for further north and east were available for the period.

The general shortage of oak chronologies for a large part of the Norwegian and indeed the western Swedish regions means that a final provenance determination of many of these ships mentioned here is not yet possible. Links though between these ships of Swedish or Norwegian provenance can be found however, and where analysis of the building techniques and traditions are compared to links in the dendrochronological analyses we can begin to identify regional groups.

So the dendrochronological analysis of the Möweninsel ship opens up a whole series of links to other ships that have been analysed, all showing a possible timber provenance in western Sweden. Although the correlation of the Möweninsel ship tree-ring curve in itself does not achieve exceedingly high correlation with the available master or site chronologies, it nevertheless can be placed within the group of these West Swedish ships, due to its correlation with Galtabäck 1. The preliminary archaeological analyses that are still in progress, link these two ships technologically (Jan Bill, pers.comm.).

8 Chapter 8: Two large cargo ships from Norway

8.1.1 Avaldsnes

The Avaldsnes ship was examined and surveyed in 2003 and subsequently, in 2004, four timbers were sampled for dendrochronological analysis (Alopaeus and Elvestad in press). The ship is a cargo vessel, built in the Nordic tradition, but with some characteristics, which have been described as cog-like. Particularly the keelson, which is found to be very alike the keelson from the Skanör cog, from a similar date, found in Southwest Sweden. It has a curved keel to stem, but an angled keel to sternpost.

Only four samples were extracted from the ship, and these were analysed in 2004. All four samples were taken from floor-timbers. Sapwood on one of the samples meant that a felling date for the trees used in the ship could be placed at *c.* AD 1395.

As can be seen from the internal matrix, three of the tree-ring curves match fairly well together, while the fourth (sample 003A) matches less well with the others. From the table fig. 109, where the correlation between the individual samples and chronologies from Northern Europe are listed, tree-ring curve 003A again has a slightly different result than the other three curves. Taking a look at the diagram showing the time span covered by the individual samples (fig. 110) the same sample, 003A, stands out as being different from the others: All samples are measured from the pith of the tree, so from the diagram it can be seen that sample 003A, although felled probably around the same time as the others, is from a much longer lived tree. This can be because the three younger trees are from a similar forest with some common history of regeneration, while the 003A tree is from an older forest stand. With all these observations taken into account, it might be concluded, even with this small number of samples, that we might, similar to the case of the Bøle wreck discussed below, be seeing more than one timber source for the frames from the Avaldsnes ship. Obviously again the very few samples analysed

Country	name	-	-	Z002001	Z002002	Z002003	Z002004	**Z002M001**
-	start	start	dates	AD 1196	AD 1205	AD 1117	AD 1206	AD 1117
-	end	dates	end	AD 1363	AD 1391	AD 1369	AD 1355	AD 1391
SWEDEN	Sydvestskaane	AD 651	AD 1496	3.10	-	3.58	-	-
	Mellansverige	AD 855	AD 1385	-	-	3.28	-	3.53
DENMAR	Jutland	AD 846	AD 1793	3.87	-	3.72	-	4.67
	Zealand	AD 452	AD 1770	4.61	-	5.77	-	6.18
GERMAN	Schleswig-holstein	AD 436	AD 1968	3.20	-	3.04	3.26	4.68
	Weserbergland	AD 1004	AD 1970	3.23	-	-	-	3.37
	Niedersachsen	AD 915	AD 1873	4.27	-	3.16	-	3.84
	Luneburger Heide	AD 914	AD 1873	3.99	-	3.18	-	3.73
	Westdeutschland	AD 822	AD 1964	3.21	-	-	-	-
	Suedtyskland	AD 631	AD 1950	-	-	3.10	-	-
U.K.	Northern England/Wales	AD 440	AD 1742	-	-	-	-	3.28
POLAND	Kolobrzeg	AD 1067	AD 1393	6.54	5.23	5.73	5.13	6.73
	Przezmark	AD 1140	AD 1390	7.37	6.39	3.25	3.20	6.22
	Tolkmicko	AD 1309	AD 1469	5.10	5.82	5.62	3.14	7.49
	Elblag	AD 980	AD 1347	8.36	4.60	5.51	5.38	7.79
	Gdansk Pomerania	AD 996	AD 1985	9.92	6.83	6.06	5.46	8.66
	Gdansk-st.nikolaus	AD 1121	AD 1398	5.99	4.56	7.12	5.58	8.07
	Starzyno	AD 1147	AD 1374	6.56	5.59	4.86	4.10	6.55
	Puck Kirche	AD 1111	AD 1407	4.90	3.98	3.58	3.80	4.63
	Pruszcz Gdanski	AD 1151	AD 1431	4.44	5.78	-	-	4.63
	Dabrowno	AD 1079	AD 1349	4.97	3.73	3.08	3.01	4.94
	Pultusk	AD 1192	AD 1452	3.94	3.26	-	-	3.29

Fig. 109. The Avaldsnes ship, Rogaland, Norway. Table of correlation between the individual tree-ring measurements from the Avaldsnes ship and master chronologies for Northern Europe.

from Avaldsnes means that only speculative conclusions can be put forward at this stage.

Let us have a look then at what we can say with a case study that, in terms of dendroprovenance, we realistically might consider very preliminary. The tree-ring curves from just three frame timbers are averaged to form a ship average of 196 years, covering the period AD 1196-1391. The correlation between the ship

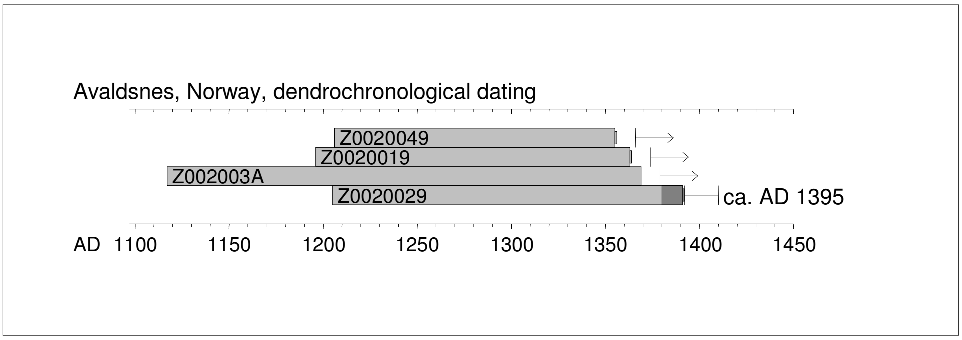


Fig. 110. The Avaldsnes ship, Rogaland, Norway. Bar diagram showing the chronological position of the four samples from Avaldsnes.

average and masters is shown in table form in fig. 111. As can be seen the highest *t*-value achieved at the dated position is with a large Gdansk-Pomerania master chronology (Ważny 1990). Clearly we are dealing here with a ship built of southern Baltic oak.

So, even with the very few samples analysed from this ship what does the provenance test at the second and third levels show? Fig. 112 shows the distribution of correlation of the ship average with site chronologies in the Northern European tree-ring dataset. As can be seen, the highest values appear with Southern Baltic sites, but the values are not strikingly high, that a more precise provenance might be suggested. The reasons for this can easily be a combination of the fact that so few samples are analysed, and that given the relatively sparse network of sites in the large Polish region, the Avaldsnes ship's local timber source might simply not be represented in the site chronology network. We will see this in other case studies discussed in this volume.

The provenance test at the third level is also applied for the Avaldsnes ship average, and is illustrated in fig. 113. The result is very similar to the second level test above. Highest values are with Southern Baltic trees but none high enough to allow a strong provenance determination. Clearly for this ship, we need to await a combination of additional analysis of the ship, and a denser network of tree-ring data for the Southern Baltic region.

Filenames	-	-	Z0021M01	
-	start	dates	AD1196	
-	dates	end	AD1391	
PM000004	AD996	AD1985	10,02	PL-GDANSK POMERANIA
PM000007	AD980	AD1347	8,30	ELBLAG
0686003S	AD1140	AD1390	7,94	PL-PRZEZMARK
P676001M	AD1067	AD1393	7,26	KOLOBRZEG
0684004S	AD1147	AD1374	7,05	PL-STARZYNO
P719014A	AD1309	AD1469	6,28	TOLKMICKO
GD98010A	AD1250	AD1338	6,16	GDANSK WYSPA SPICHRZOW
0693005S	AD1151	AD1431	6,10	PL-PRUSZCZ GDANSKI
0680001S	AD1121	AD1398	6,06	GDANSK-ST,NIKOLAUS
0681005S	AD1111	AD1407	5,31	PL-PUCK KIRCHE
O0640039	AD978	AD1291	4,94	SMÅLAND SE V0XTORP
P738001M	AD1079	AD1349	4,86	DABROWNO
0M040004	AD1156	AD1597	4,61	Baltic 1 Paintings
2x900001	AD830	AD1997	4,32	Zealand
0M040005	AD1257	AD1615	4,27	Baltic 2 Paintings
0M020001	AD1115	AD1643	4,22	NIEDERLANDE Paintings
P734001M	AD1246	AD1412	4,13	BRANSK
OLUN0020	AD621	AD1723	4,10	LUND
O0706509	AD1188	AD1444	4,05	MK L,FISKAREGT,+BANT
SM600002	AD859	AD1371	4,03	SMAALAND-OELAND
DM100003	AD436	AD1968	3,86	SCHLESWIG-HOLSTEIN

Fig. 111. The Avaldsnes ship, Rogaland, Norway. Table showing the correlation values between the mean of the tree-ring curves from three framing timbers from Avaldsnes and master chronologies from Northern Europe.

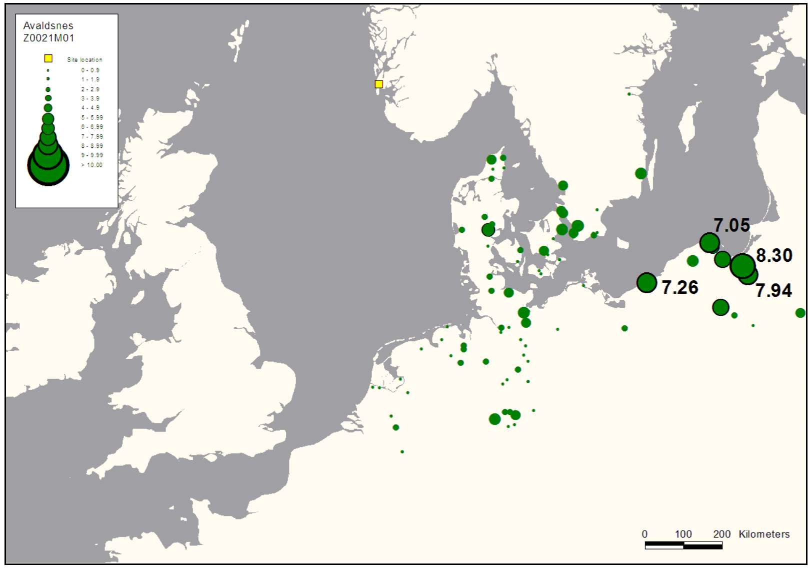


Fig. 112. The Avaldsnes ship, Rogaland, Norway. Map showing the distribution of correlation values achieved between the mean for Avaldsnes and site chronologies from Northern Europe (the second level test).

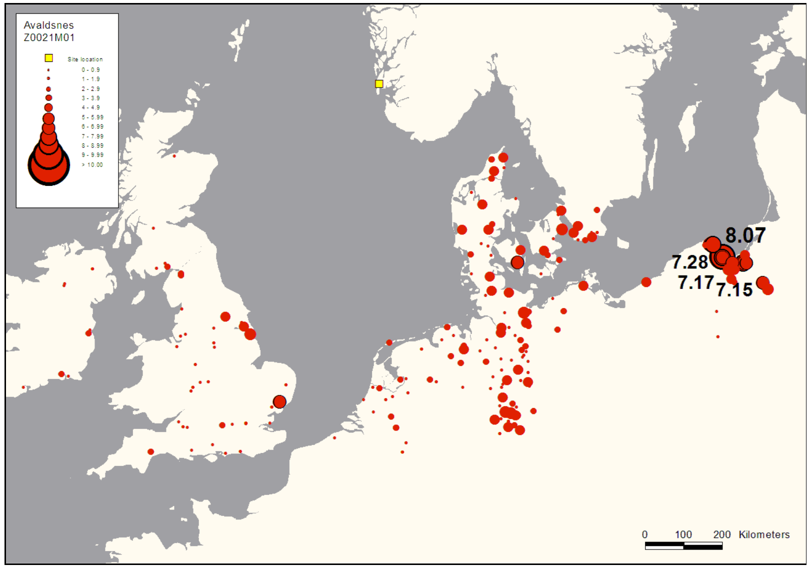


Fig. 113. The Avaldsnes ship, Rogaland, Norway. Map showing the distribution of correlation values achieved between the mean for Avaldsnes and single tree-ring measurements from Northern Europe (the third level test).

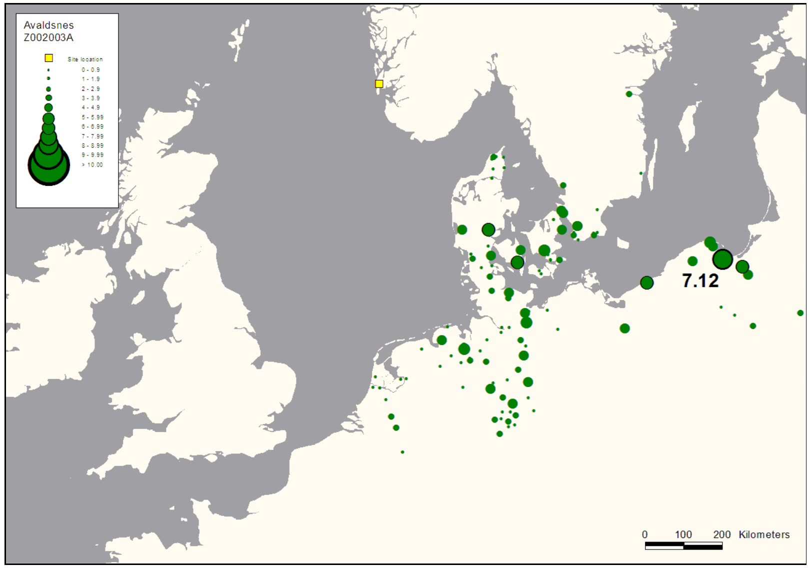


Fig. 114. The Avaldsnes ship, Rogaland, Norway, (sample Z002003A). Map showing the distribution of correlation values achieved between sample Z002003A from Avaldsnes and site chronologies from Northern Europe (the second level test).

As mentioned above, the fourth sample from Avaldsnes is dendrochronologically different from the other three and can be treated separately. A map of the second level test for this sample, against site means, is shown in fig. 114. Again a Southern Baltic provenance is picked out, where the highest value (t = 7.12) is with a site from Gdansk. As sites in Gdansk dominate the data from Poland we cannot conclude a local timber provenance for this single sample.

For the Avaldsnes ship then we can see that even having only analysed four samples we can begin to suggest that there might be more than one source of the timber for the ship, but both timber groups identified are of Southern Baltic origin.

8.1.2 The Bøle ship, Skien, Norway.

Bølevraget was originally discovered in 1959 during dredging of Skien fjord in South Norway (Nævestad 1999; Nymoen 2005). Norsk Sjøfartsmuseum under leadership of Svein Molaug recorded and salvaged what they could of the timbers that had been brought up onto land.

The ship's timbers were very well preserved, and were brought to Norsk Sjøfartsmuseum for storage. Some of the cargo of the ship was also salvaged, consisting in the main of hone stones, whose source can be traced to further inland along the waterway, at Eidsborg.

A new study of this ship was initiated in 2005, again by Norsk Sjøfartsmuseum, this time by Pål Nymoen (Nymoen 2005). Salvage of the remainder of the ship timbers and cargo has been completed in December 2005, and an in depth recording of the ship's construction and the context of the ship's cargo will be undertaken in the coming years (Pål Nymoen, pers. comm.).

The ship is clinker built, with a curved stem, in the Nordic tradition, but with an angled stern, to accommodate a stern rudder. The ship, in other words, belongs in the category of medieval cargo ships, which combine cog-like characteristics with the Nordic tradition. Other ships of this tradition include another

Norwegian find, Avaldsnes, (Alopaeus and Elvestad in press) which is also dealt with in this thesis.

Considering the picture emerging in this study of the provenance of many later medieval ships, and the similarity this ship had archaeologically with the Avaldsnes ship, it was decided to include the Bøle wreck in this thesis. Timbers from the original dredging in 1959 were still stored at Norsk Sjøfartsmuseum, and it was decided that these could be examined with a view to choosing suitable timbers for an initial, exploratory dendrochronological analysis. When sampling took place on the 19th of April 2006, with archaeologist Pål Nymoen, conservator Pål Thome, both from Norsk Sjøfartsmuseum and myself, it was found that a great many suitable timbers were available, including many ship's planks and a big pile of ship frames (fig. 115). Despite these timbers having been salvaged from the fjord nearly half a century ago, their condition of preservation was quite remarkable. Only superficial treatment of the timbers' surface had been carried out, but the pieces were solid, dry and in a stable condition. Two timbers from the recent (2005) salvage were also examined. From the large pile of timbers it was not easy to extract many timbers, and it was preferred that timbers which were already incomplete (broken in the dredging operation presumably) should be sampled, while more complete timbers should not be sawn, out of concern for a future museum display of the ship. It was therefore difficult to find timbers with sapwood preserved, but of course the samples were sawn at the place where the outermost rings were preserved. In the end ten samples were sawn, four planks, and six beams/frames, providing a potentially good basis for this initial analysis. On one of the planks, sapwood was preserved. The dendrochronology sample from this plank is shown in fig. 116, where the sapwood rings are clearly visible on the prepared section.

All ten samples were measured and nine are dated. All the timbers were from very slow grown trees, that is, the tree-rings were very narrow. The plank timbers had a quite regular growth though, in contrast to the timbers used for the frames/beams. Two of the frame/beam timbers showed periods where the tree had formed extremely narrow rings, in one case so narrow that it was impossible to

Fig. 115. The Bøle ship, Telemark, Norway. The pile of Bøle ship timbers, found in the 1959, in storage at the Norwegian Maritime Museum.

Fig. 116. The Bøle ship, Telemark, Norway. Of the samples analysed, just one had sapwood preserved. The sapwood is clearly visible in this photograph of the outermost portion of plank Z005007 (x3).

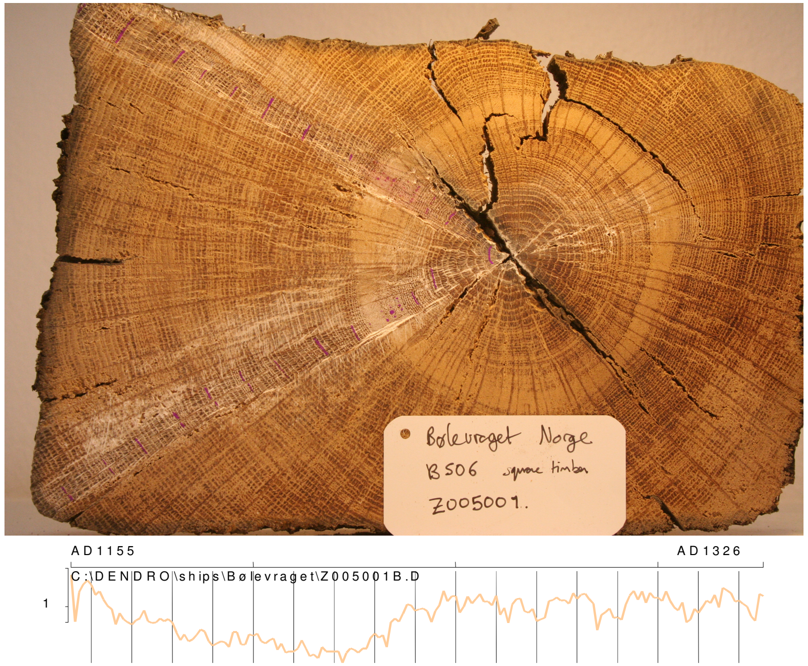


Fig. 117. The Bøle ship, Telemark, Norway. Photo of the tree-rings for sample Z005001 (B506) and the tree-ring curve produced from the measurements. Note the period of very narrow growth. Only the outer 92 rings of this sample were used in the dating and provenance determination analysis.

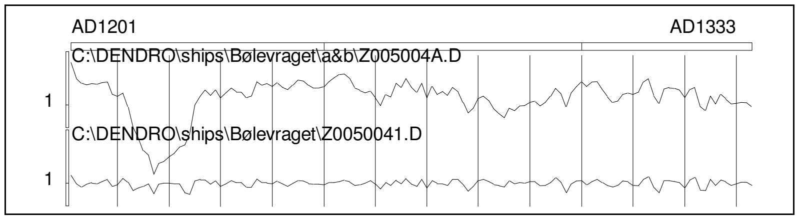


Fig. 118. The Bøle ship, Telemark, Norway. The tree-ring measurements from the second beam, Z005004 (X1), with an extremely narrow band of rings, was filtered with a five year running mean to reduce the extreme jump in the tree-ring curve as illustrated.

achieve a reliable measurement of the rings across that phase (fig. 117). For this sample, only the outermost 92 rings were included in the analysis. The tree-ring measurements from the second beam, Z005004 (X1), with an extremely narrow band of rings, was filtered with a five year running mean to reduce the extreme jump in the tree-ring curve as illustrated in fig. 118.

The diagram (fig. 119) shows the chronological position of the nine dated timbers. The sapwood preserved on sample Z005007A (X3) is indicated in darker grey. Allowing for missing sapwood, using a sapwood statistic for Polish timber of *c.* 15 rings (-5+15) (Ważny 1990, 184-187), the felling date for the tree from which this plank was made, is calculated to lie in the range AD 1376-1396. The ship was most probably built in this period.
Of course, a more specific date for the felling of the timber for the ship requires that samples, with complete sapwood to bark edge preserved, be analysed. This would be one of the aspects, which can be addressed, in an eventual future dendrochronological study of the ship.

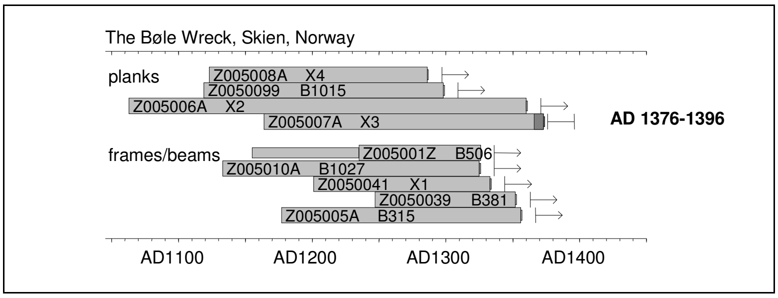


Fig. 119. The Bøle ship, Telemark, Norway. Bar diagram showing the chronological position of the nine dated samples from the Bøle ship. The oaks were felled within the period AD 1376-1396.

The internal correlation matrix (fig. 120) gives an indication of the internal correlation between the dated timbers. The planks have a relatively high internal correlation, but these match not so high with the frames/beams. Four of the frames/beams similarly match well together, while a fifth only matches well with one other. The correlation of the tree-ring curves from the ship can indicate several sources for the timber, where the planking is made from oaks from one source, while two sources for the frame/beam timbers might be represented.

Two means have been made of the tree-ring data from the ship. One (Z005M003) is the mean of the measurements from the four planks, while the second (Z005M002) is a mean from the four beams/frames that match best together (Z005001Z, Z0050039, Z0050041 and Z005005A). Using these two means, and the remaining single sample measurement (Z005010A), three maps can be produced at the first level provenance test, the ship's three possible source groups against the large regional master chronologies.

		Z0050041	Z005001Z	Z0050039	Z005005A	Z005010A	Z005006A	Z005007A	Z005008A	Z0050099
BEAMS	Z0050041	*	3,23	4,02	4,52	-	3,82	4,64	4,17	-
	Z005001Z	3,23	*	10,63	-	-	-	-	-	3,10
	Z0050039	4,02	10,63	*	5,12	-	-	3,84	-	-
	Z005005A	4,52	-	5,12	*	5,34	-	5,19	3,84	-
	Z005010A	-	-	-	5,34	*	-	3,34	-	4,13
PLANKS	Z005006A	3,82	-	-	-	-	*	7,39	4,75	3,41
	Z005007A	4,64	-	3,84	5,19	3,34	7,39	*	6,92	-
	Z005008A	4,17	-	-	3,84	-	4,75	6,92	*	5,00
	Z0050099	-	3,10	-	-	4,13	3,41	-	5,00	*

Fig. 120. The Bøle ship, Telemark, Norway. Matrix of internal correlation.

Frames/beams

First we will take a look at the results for the ship frames/beams. The correlation result for the four frames/beams averaged together (Z005M002) against master and site chronologies for Northern Europe, is shown in fig. 121. In this map, two levels are included in the provenance test. The test with master chronologies is shown in blue, while the second level test with site chronologies is in green, as described above. The highest values are labelled and are achieved with several sites from along the Southern Baltic coast. By far the highest value, t = 12.07, is with a chronology from Kołobrzeg on the western Polish coast. Note also the high values from other Polish sites around the Gulf of Gdansk. Two quite high values appear further west, on in Northern Germany, which will be discussed below, and another in Denmark. The Danish material that the Bøle beams match so well with (t = 9.25) is actually a barrel, from a late 14th century fortified site at Boringholm in Jutland (Daly 2005a). The barrel is made from Southern Baltic oak.

It might be noted here that the site chronologies for the Scandinavian and German sites are built from the EU-project data described above, while the site chronologies used in this and the following maps for the Polish region have been built by Ważny (Haneca et.al. 2005). Another aspect, which should be noted, is that the EU-project data represents data that has accumulated in the different dendrochronology laboratories up until 1996. The last ten years of dendrochronological data production is missing from the single-tree dataset. This is significant here, as some of the Polish chronologies used in this and subsequent maps have been built by Ważny since the EU-project data gathering (Tomasz Ważny, pers. comm.).

The test of the provenance of the beams from Bøle, at the third level, with single trees, illustrates what this means (fig. 122). In this, where the beam average is tested against single trees, the highest value is with a tree-ring sequence from Gdansk, but note that the next highest is with a timber from Kiel. Several aspects need to be explained in this result. Firstly, why do no high values appear with single trees from Kołobrzeg, when the Kołobrzeg chronology gave the highest

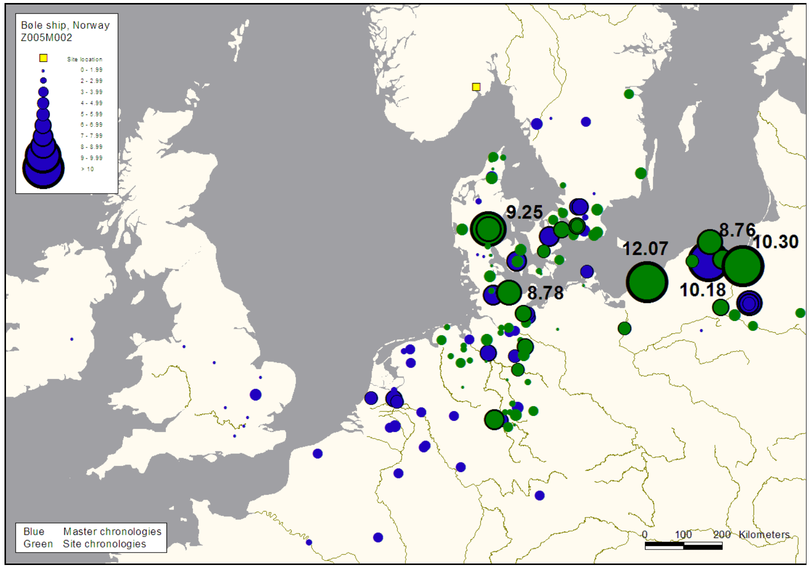


Fig. 121. The Bøle ship, Telemark, Norway, the beams. Map showing the distribution of correlation values achieved between the mean from four beams from the Bøle ship (Z005M002) and master and site chronologies from Northern Europe (the first and second level tests).

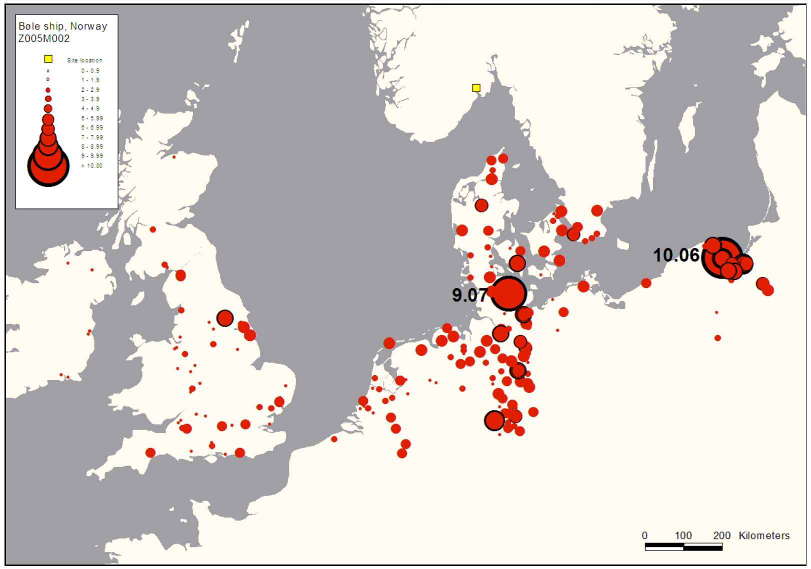


Fig. 122. The Bøle ship, Telemark, Norway, the beams. Map showing the distribution of correlation values achieved between the mean from four beams from the Bøle ship (Z005M002) and single tree-ring measurements from Northern Europe (the third level test).

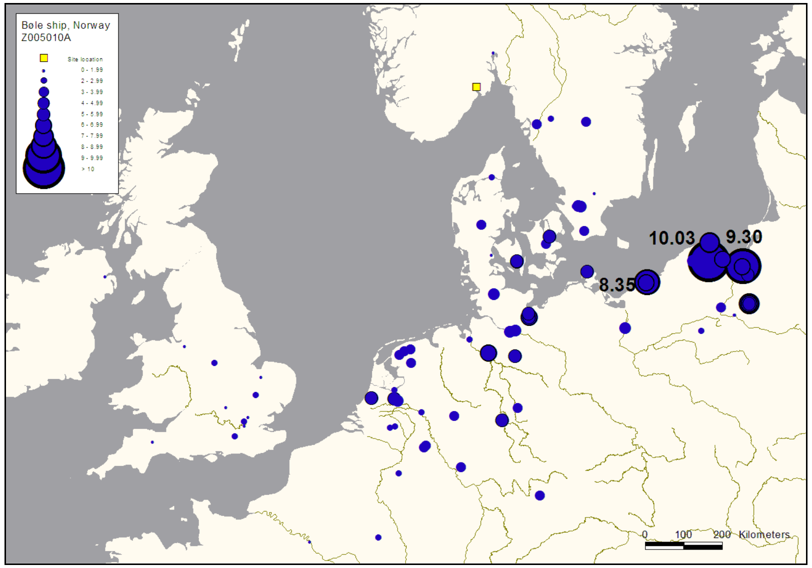


Fig. 123. The Bøle ship, Telemark, Norway, beam Z005010A. Map showing the distribution of correlation values achieved between the tree-ring curve for beam Z005010A and master chronologies from Northern Europe (the first level test).

	M004	0041	005A	
	AD1235	AD1201	AD1177	
	AD1352	AD1333	AD1356	
Denmark	-	3.20	5.46	Jutland Funen (NM)
Germany	-	3.09	4.78	Lübeck (HU)
	-	4.36	7.41	Schleswig-Holstein (HU)
	-	5.36	6.34	Lower Saxony (GU)
Poland	-	3.14	4.04	Vistula (Tomasz Ważny pers comm)
	5.19	5.35	6.07	Gdansk St.Nikolaus (Tomasz Ważny pers comm)
	4.64	4.99	9.90	Gdansk Pomerania (Ważny 1990)
	3.66	4.70	11.14	Elblag (Tomasz Ważny pers comm)
	7.28	6.39	9.51	Kolobrzeg (Tomasz Ważny pers comm)
Ships of Polish provenance	6.80	7.84	9.62	Vejby ship, Denmark (Bonde and Jensen 1995)
	6.96	4.52	8.90	Lille Kregme ship, Denmark (Eriksen 1992)
	5.46	4.70	8.74	Avaldsnes ship Norway (Daly, this volume)
Barrel	5.15	5.94	7.13	Boringholm barrels 2 lids & 3 staves (Daly 2005)

Fig. 124. The Bøle ship, Telemark, Norway, the beams. Table showing the correlation between tree-ring curves from the beams from the Bøle ship and a selection of master, ship and barrel chronologies.

correlation in the provenance test against the master chronologies? This is quite simply because the tree-ring data used in Ważny's Kołobrzeg chronology are not included in the EU-dataset.

What then explains the very high value with the site "Alte Feuerwache" in Kiel? Well when the sample and site mean from the Kiel site are tested against the Northern European master chronology network, it becomes clear that the timber from this site was imported from the southern Baltic region. The Bøle ship is actually allowing the identification of Southern Baltic timber in Western European historical sites.

The two provenance tests for the frames/beams from the Bøle ship allow the conclusion that indeed the source of the timber for the ship frames is in the coastal southern Baltic region. The test though also clearly illustrates some of the problems that can be encountered when dealing with a dataset that is only partly complete, and in a period where problems of exported/imported building timber in the provenance determination tool are emerging. The gap in the single tree data for the northeastern German region is also obvious in this case. Future collaboration should rectify this problem, and in the future, detailed provenance determination for many of the Southern Baltic timber finds in the European archaeological record might be improved.

The remaining beam, Z005010A (B1027), is dealt with separately as the correlation between it and the other analysed samples from the ship is not strong. The map illustrated in fig. 123 shows the correlation for this beam with master chronologies, the first level provenance test. Even though we are here dealing with just a single sample, a very clear correlation distribution indicates that this tree grew in the coastal region around the mouth of the Vistula river, matching best with a large chronology for Gdansk-Pomerania (t = 10.03).

Why is this t-value distribution much clearer than the distribution for the four beams that have been dealt with as a homogeneous group? For the single beam Z005010A a neat cluster of high values appears. For the four beams group though, the very high values are quite widely spread geographically, which leads to the possibility that the four frames/beams in fact should not be grouped together after all. Looking at the correlation matrix again it might be argued that in fact these four frames are not so homogeneous, and that only two, Z005001Z and Z0050039 should be averaged together. In other words, the source of the timber represents a wider geographical region. What then happens if we subject the tree-ring data from the frames individually to the provenance determination test? Well, the match between Z005001Z and Z0050039 is very strong, so we can at least treat these two timbers as one unit. Correlation then between the three tree-ring curves and a selection of chronologies is illustrated in the table fig. 124. Clearly the highest values appear in all three tree-ring curves with Polish references. There is though a difference as to which of the chronologies each curve matches best with. The average values for each tree-ring curve are different, with generally higher values for 005A, which is most likely due to the fact that its tree-ring sequence is longer than the other two (005A contains 180 rings, while M004 and 0041 contain 118 and 133 respectively). Note then, that 005A achieves the highest *t*-value with a chronology from Elblag, near the Gulf of Gdansk, while the highest values for the other two curves appear with the chronology from Kołobrzeg, further west along the Polish coast. (In fact, the three samples, which seem to match best with the northwest Polish chronology, are the two which have bands of extremely narrow rings (Z005001Z and Z0050041) and the one which fits very well with Z005001Z (Z0050039). Its centre was decayed away so it cannot be determined as to whether it also had a band of extremely narrow rings, but the decayed portion is at the same chronological position as the other samples' narrow ring phases.)

We might be seeing here evidence for several sources for the oak used for the frames. Analysis of a larger number of frame timbers might allow a better grouping of the oak internally in the ship, allowing a clearer picture of the timber groups, and perhaps allowing a clearer provenance conclusion.

Planks

As explained above, the planks are dealt with separately from the beams/frames. Four planks were analysed and dated and the tree-ring curves from these four have been averaged to a mean curve (Z005M003), which is 311 years in length. This mean curve is tested against available Northern European master and site chronologies, and the results are plotted in fig. 125. High values appear with master chronologies from Elblag, on the Gulf of Gdansk.

For the test of the tree-ring mean from the ship planks with the Northern European single tree dataset, the map in fig. 126 shows the resulting distribution. Again the problems of the appearance of Polish timber in Western Europe, for this period, become obvious. The tree that the ship planks match best with was used in a construction in England (New Baxtergate, Grimsby). The timber was identified as imported from the Eastern Baltic region at the time it was analysed (Groves 1992). In fact, the timbers were found as part of a waterfront, and those of Eastern Baltic origin were in fact from the remains of a clinker built boat, reused in the revetment (Cathy Groves (now Tyers) pers. comm.). When the site mean for the timbers from the New Baxtergate site is tested against European master chronologies, we find that this timber is clearly imported from the Southern Baltic region.

Another high value appears with a second English site, York Minster in York. Again here we have oak timber imported into England from the Southern Baltic region. The tree-ring measurements come from doors and cupboards from the cathedral (Fletcher and Morgan 1981), in other words panelling; the typical timber product exported out of the Southern Baltic region in the late medieval period. A third high *t*-value appears with a timber from Kiel in Northern Germany. The site is mentioned above in the description of the beams, and is named “Kiel, Alte Feuerwache” (Kiel, Old Fire Station) which is a location in the city of Kiel. It would be interesting to know what kind of ancient timbers were analysed from here. There are five timbers from the Alte Feuerwache site, and they match well together and have been grouped into a site mean. The outermost tree-ring for each of these timbers is dated to 1300. When the site chronology from this Kiel site is tested

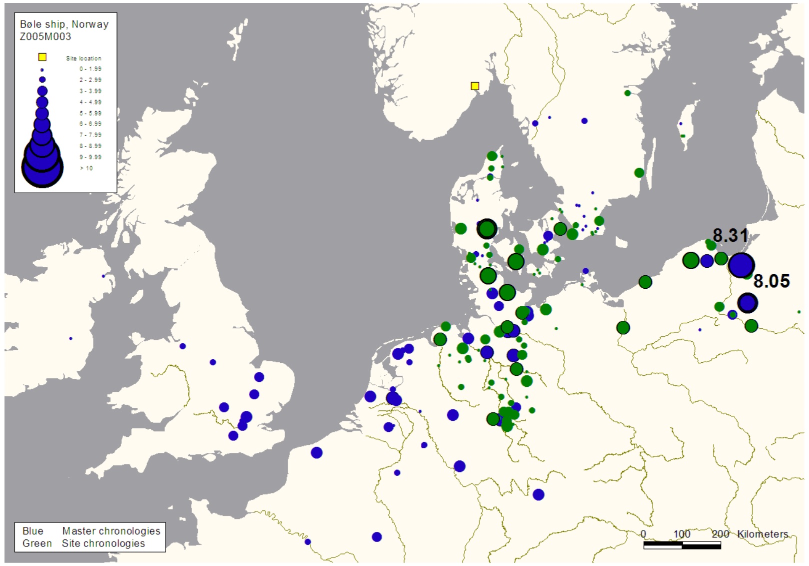


Fig. 125. The Bøle ship, Telemark, Norway, the planks. Map showing the distribution of correlation values achieved between the mean from the four planks from the Bøle ship (Z005M003) and master and site chronologies from Northern Europe (the first and second level tests).

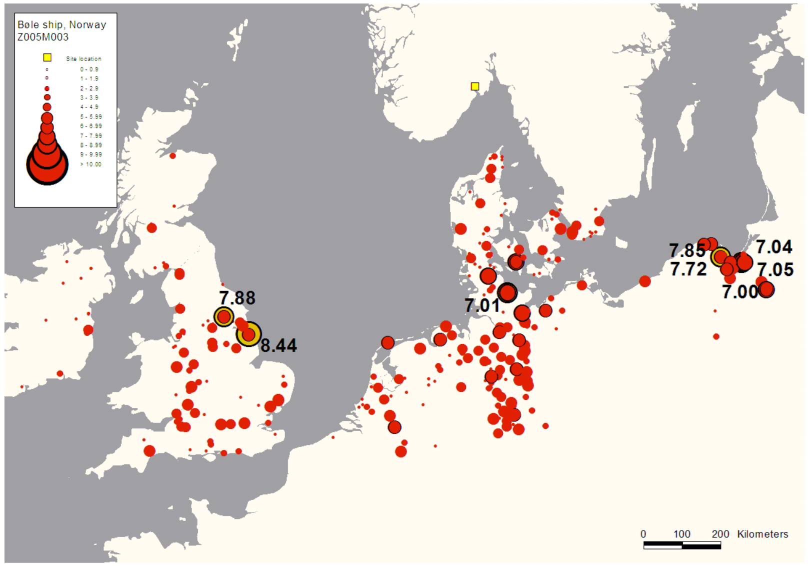


Fig. 126. The Bøle ship, Telemark, Norway, the planks. Map showing the distribution of correlation values achieved between the mean from the four planks from the Bøle ship (Z005M003) and single tree-ring measurements from Northern Europe (the third level test).

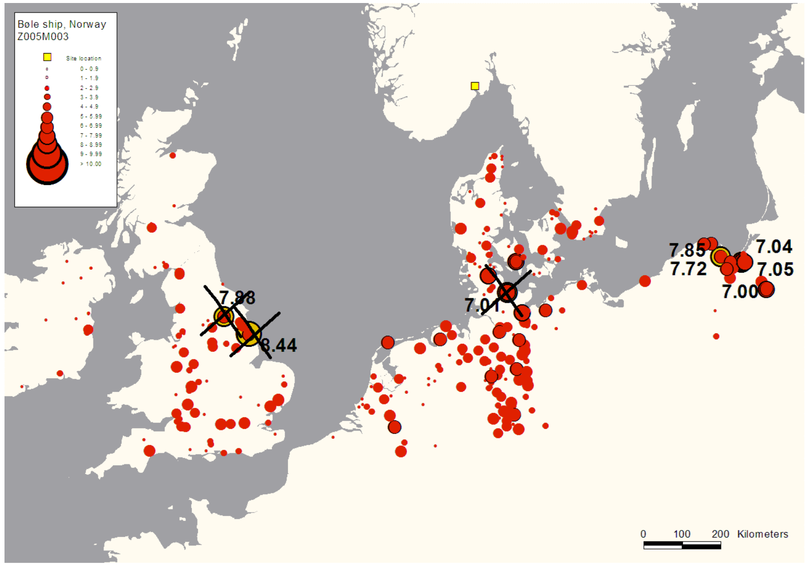


Fig. 127. The Bøle ship, Telemark, Norway, the planks. Map showing the same distribution of correlation values achieved between the mean from the four planks from the Bøle ship (Z005M003) and single tree-ring measurements from Northern Europe (the third level test), but with the English and Kiel import sites crossed out!

Filenames	010A	M002	M003	M004	
timbers	beam	frames	planks	2frames	
-	AD1133	AD1177	AD1063	AD1235	
-	AD1325	AD1356	AD1373	AD1352	
0207M002	-	3.54	3.21	-	Dokøen Wreck 3 (Bonde and Eriksen 2002)
00751M01	3.69	3.81	3.59	4.29	Vejdyb ship (Daly 1997c)
lskn_a1	-	4.42	-	3.39	Skanör cog (Marek Krąpiec pers. comm.)
P0013009	5.84	5.10	3.66	-	Copper Ship (Tomasz Ważny pers. comm.)
0204M001	5.03	6.32	4.50	3.50	Tårnby ship (Daly unpubl.)
02071M01	4.19	6.73	8.20	3.78	Dokøen Wreck 2 (Eriksen 2001a)
P0011009	4.69	7.36	5.39	3.49	Copper Ship Wainscots (Ważny pers. comm.)
Z002M001	3.45	9.17	5.39	5.46	Avaldsnes (Daly this volume)
00121M01	4.42	9.87	5.64	6.96	Lille Kregme cog (Eriksen 1992)
0045M002	8.32	12.28	4.63	6.80	Vejby cog (Bonde and Jensen 1995)

Fig. 128. The Bøle ship, Telemark, Norway. Table showing the correlation between the Bøle ship's tree-ring curves and other ships built from oak of Southern Baltic origin.

against the masters, it agrees best with the Southern Baltic chronologies and, of those, the best match is with Elblag. So the next map (fig. 127) shows the same distribution as the previous, but with the three problematic high values in Western Europe crossed out, to underline the point. Then a more meaningful distribution of the high *t*-values is the result.

Discussion

If we look at the result of the two third level tests (single trees) for the Bøle ship, we can see that for the beams and planks, the site at Kiel shows up strongly for both types of structural elements in the ship, while the two English sites only in the case of the planks. What this shows is that we can begin now to not only date the Bøle ship, and identify the region of origin for the ship, we can also find other connections to increase our picture of the connections between different sites, in terms of the timber supply reaching those regions, and in terms of finding connections between ship finds in the archaeological record over long distances. A new discovery in the provenance determination analysis, which has emerged in this case, is that a clinker-built ship re-used in revetments in New Baxtergate, England, is similar, in terms of the tree-ring pattern in the timber, to the Bøle ship planks. This discovery should lead to an archaeological assessment of the ship building tradition to which the New Baxtergate ship belongs, to see if similarities can also be seen in the construction of the two ships.

The implications though of the increasing number of ship remains from western Europe which are of Southern Baltic origin presents us with new possibilities in terms of analysing aspects of medieval timber trade. This is particularly because when we, through dendrochronology, can determine the origin of the timber used in a ship, the question still remains; where then was the ship built? Medieval ships were built with green wood, not seasoned wood, but if timber can be transported before the wood is seasoned, theoretically the ship can have been built anywhere! We can see that the transport of oak panels, a specialised timber product, from the Southern Baltic region took place in the late medieval period.

How widespread was the transport of specialised ship timbers and how early did export/import of shipbuilding timbers take place? A comparison of the shipbuilding tradition/technology evident in the archaeological finds of ships from England, Norway, Denmark and so forth, which are manufactured with Southern Baltic oak, will help to shed light on this question. If the Southern Baltic timber ships in England from the late medieval period are built in a local tradition, then we are dealing with the transport of the timber as a commodity. If on the other hand all or many of the ships of Southern Baltic timber belong to a Southern Baltic shipbuilding tradition, then we have a clear sign that the ships were built close to the timber source.

One final aspect in the analysis of the Bøle ship timbers involves the comparison of the tree-ring curves with other ships of the period. Particularly as the original reason for the interest in this ship dendrochronologically was in the light of the findings for a similar ship found at Avaldsnes, in Southwest Norway. This ship was surveyed by Endre Elvestad of Stavanger Sjøfartsmuseum (Alopaeus and Elvestad in press) and one of the features, it was found to include, was the smooth curved stem and the angled stern. Samples from four of the ship's frames were retrieved in 2004 for dendrochronological analysis. One of the samples had sapwood preserved which meant that the date for the felling of the timber for the ship could be estimated to the period AD 1392-1410. The analysis showed also that the timbers had grown in the Southern Baltic region (Daly this volume).

Having made the analysis of the Bøle ship and assembled the data into the different groups, the Bøle tree-ring curves have been tested against average tree-ring curves from a selection of medieval ships from Scandinavia. The table in fig. 128 shows the results of this exercise. Only ships where a high *t*-value appears are listed. Taking the single beam 010A, it can be seen that the ship it matches best with is the Vejby cog, found in Denmark but which was built of Southern Baltic timber (Bonde and Jensen 1995). The mean curve from the other frames/beams in the Bøle ship, M002, match also best with the Vejby cog, but note also the high values with Lille Kregme cog and with the Norwegian Avaldsnes ship. It here might be pointed out that the comparisons can't be taken at face value: in the Vejby cog dendrochronological analysis, 26 samples were examined, for Lille Kregme 11 samples were analysed, while only four were analysed from the Avaldsnes ship. In fact, when we look at the *t*-values that the tree-ring mean from the four frames from the Avaldsnes ship achieve, when compared with chronologies and other ships from the period, the highest is with the mean of the frames from the Bøle ship. Given the similarity of the two late 14th century cargo ships from Norway in their construction, a more detailed and extensive dendrochronological analysis of the Avaldsnes ship would clearly be an interesting exercise. Even though the highest correlation between the Bøle ship and the selected ships here is with the Vejby cog, given the large number of samples analysed from Vejby, and the very low number from Avaldsnes, a full conclusion as to the similarity, dendrochronologically, of the two Norwegian ships cannot as yet be reached.

The mean curve for the Bøle planks achieve the highest *t*-value with Dokøen wreck 2, one of the ships found in the harbour of Copenhagen at Dokøen, in 2001 (Gøthche and Høst Madsen 2001). Again in this comparison, the Bøle planks give a different result than the frames/beams, indicating again the possibility of quite different sources for the two timber types.

Summary

To conclude, let us summarise the research history and the result from the dendrochronological analysis of the Bøle ship, Norway. Ten samples, one of which had sapwood preserved, were analysed and nine of these are dated. Estimating for missing sapwood rings, the felling of the timber dates to the period AD 1376-1396, or put another way, for simplicity, the timber was felled around the 1380s. The tree-ring patterns of the timber achieve the highest correlation with chronologies from coastal Poland, chiefly around the Gulf of Gdansk, but some frame timbers might come from further west along the Polish coast.

9 Chapter 9: Two late 16th century ships

9.1.1 B&W1

In 1996 and 1997, during excavations at a large property in Copenhagen harbour (Schiellerup 1999), no fewer than eight ships were found (Lemée 2006). The site had been used by the Burmeister & Wain company for building ship engines, so the site became known as the B&W site. Before this, the site had been a harbour (Grønnegård Havn), with associated piers and boatbuilding installations, and the shipwrecks had been incorporated in the pier constructions at various periods. The ships range in date from the late 16th to the early 18th centuries, and all but one were dated dendrochronologically (Daly 1997b; 1997e; 2000d).

While emphasis in this study is on medieval ships, it is interesting to describe the dendrochronological results for later, Renaissance ships, to demonstrate both the technique of provenance determination and the different picture which emerges in terms of timber transport, in this later period. B&W1 was selected due to the large number of samples that were dated from this ship.

B&W1 was dendrochronologically dated to ca. AD 1584. Sixteen samples were dated from this phase, of which two had sapwood. This ship had later been lengthened, by cutting the ship in two and inserting a new hull section midships (Lemée 2002; 2006). Timbers from this phase were also analysed, three of which had sapwood. The felling date for the trees for this phase can be placed at ca. AD 1608. The dating of the samples is summarised in fig. 129.

As the tree-ring series from the building phase and the lengthening phase couldn't be separated from each other in terms of their correlation, the two phases were grouped together when the ship averages were made. Three averages were made, according to the groups that appear when all samples are compared with all others (fig. 130). The main group consists of timbers from both the building and the lengthening phases. Some timbers are grouped together as they are so similar that they might come from one tree. This is the case for 12 measurements, which

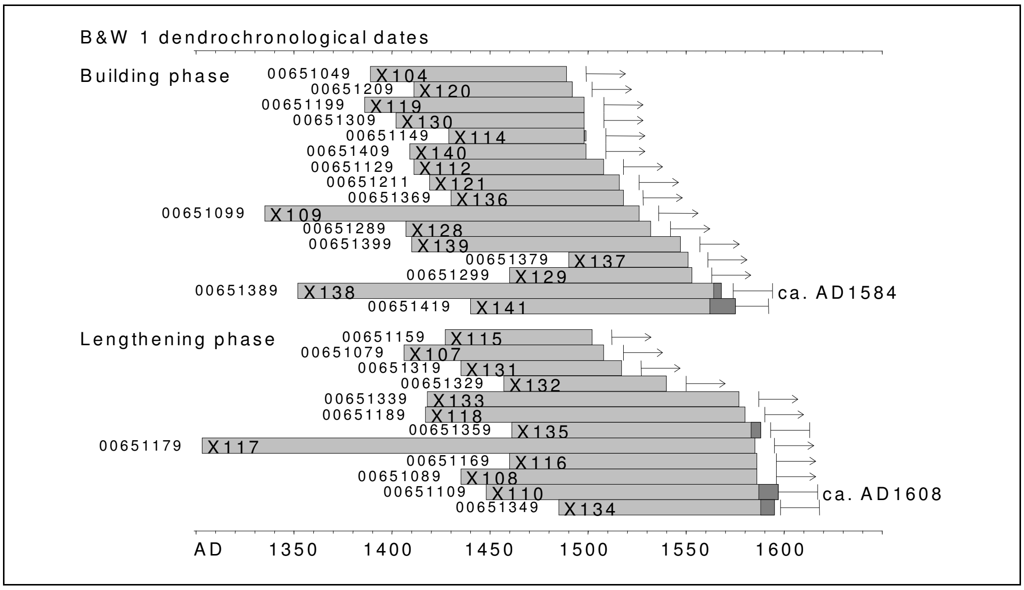


Fig. 129. B&W1, Copenhagen, Denmark. Bar diagram showing the chronological position of the dated samples from B&W1.

			00651049	00651149	00651129	00651211	00651209	00651309	00651409	00651399	00651419	00651379	00651349	00651369	00651319	00651079	00651339	00651159	00651329	00651359	00651189	00651109	00651199	00651089	00651169	00651179	00651099	00651289	00651299	00651389
		00651049					3,54								4,35	3,31		3,11												
		00651149			4,41	3,6								3,22									3,01	3,07						
00651M04	Same tree 1519	00651129		4,41		8,23	7,87							3,6	4,59					3,27	4,79									
		00651211		3,6	8,23		4,61			3,94				3,46	3,84	3,18	4,12				3,09		3,11	3,32						
		00651209	3,54		7,87	4,61								3,76	4,35	4,08					4,47									
	Same tree 1509	00651309							13,03		4,38			3,78			4,25							3,33						
		00651409						13,03			4,98			4,62		3,57	3,88		3,57		4,09			3,56						
		00651399				3,94					6,26				4,27		3,14	3,54												
		00651419						4,38	4,98	6,26				3,48	3,07		3,82				5,31	4,88		4,24						
		00651379											6,27				3,62		3,19	5,25	3,83									
		00651349										6,27					5,93			4,05	4,47	4,27		3,11	4					
		00651369		3,22	3,6	3,46	3,76	3,78	4,62		3,48				5,3	6,09	5,18	4,33	3,17	4,02	3,73									
	Same tree 1529	00651319	4,35		4,59	3,84	4,35			4,27	3,07			5,3		4,31	5,56	5,01			3,26									
		00651079	3,31			3,18	4,08		3,57					6,09	4,31		7,01	7,69	4,45	3,49	4,21									
		00651339				4,12		4,25	3,88	3,14	3,82	3,62	5,93	5,18	5,56	7,01		11,12	4,69	5,26	4,24									
		00651159	3,11							3,54				4,33	5,01	7,69	11,12		4,82											
		00651329							3,57			3,19		3,17		4,45	4,69	4,82		3,52										
		00651359			3,27							5,25	4,05	4,02		3,49	5,26		3,52		6,14	4,97								
	Same tree 1559	00651189			4,79	3,09	4,47		4,09		5,31	3,83	4,47	3,73	3,26	4,21	4,24			6,14		15,84	4,1	5,07	4,06					
		00651109									4,88		4,27							4,97	15,84		3,53	5,21	4,18					
		00651199		3,01		3,11															4,1	3,53		5,88	3,87					
	Same tree 1569	00651089		3,07		3,32		3,33	3,56		4,24		3,11								5,07	5,21	5,88		18,03					
		00651169											4								4,06	4,18	3,87	18,03						
0065 1M03		00651179																									11,98			
		00651099																								11,98				
00651M02		00651289																											3,38	5,43
		00651299																										3,38		6,84
		00651389																										5,43	6,84	

Fig. 130. B&W1, Copenhagen, Denmark. Matrix of internal correlation.

represent just five trees. So the largest group average (00651M04), covering the period AD 1386 to AD 1597, is made up of 15 trees. As can be seen from the matrix, the group is somewhat diffuse. Indeed smaller groups could be isolated to some extent. But let us see what results this group gives in the provenance test. The test with master chronologies shows that the group achieves high correlation with chronologies from Lower Saxony (t = 10.31) and with Lüneburger Heide (t = 10.41), but high values also appear with Dutch chronologies, specifically one from Westfalen (t = 10.40) (fig. 131). Now the problem with attempting provenance determination on material from this period (felled in the late 16th century but tree-rings covering the 15th and 16th centuries) is that we can assume that the master chronologies are less likely to be of a local nature. The increase in bulk trade and the decreasing availability of local wood resources will mean that the master chronologies in this period are made from wood from a wider region. Indeed dendrochronologists in The Netherlands have commented that from the High Middle Ages all wood is imported from further away (Esther Jansma, pers. comm.). The possibility cannot be ruled out that the high match between B&W1 and the Westfalen chronology can be due to the fact that the Westfalen chronology is not made of local wood, but of wood imported from the more forested regions of inland Germany. Could then the test at the second level help to solve some of these problems? The test at the second level (fig. 132) shows high correlation values for Lower Saxony, but high values with sites in The Netherlands also appear. What it shows actually is that the distribution of these high correlations is wide. The pattern emerging is not as clear in terms of provenance determination, as we have seen in the examples of ships from earlier periods, nor indeed from the test on living trees. It seems that the building timber data for this period, which should be the known geographical fix-points for the determination tool, consists of timbers which have been moved greater distances than in other periods. This is why we get this spread of high correlation. It can also be suggested that the high correlation values are spread along the main river systems in the region. If we look at the same correlation distribution, but this time moving in on the Netherlands and Lower Saxony region,

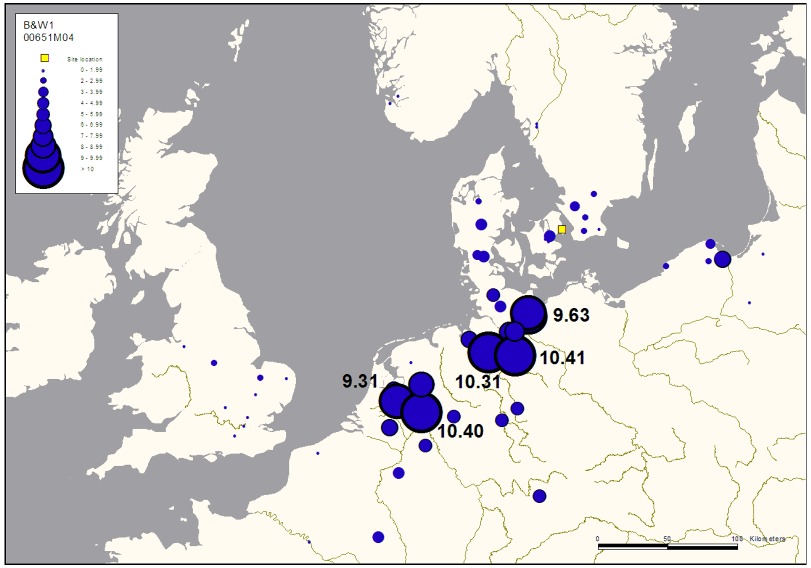


Fig. 131. B&W1, Copenhagen, Denmark. Map showing the distribution of correlation values achieved between the 15 tree mean for B&W1 (00651M04) and master chronologies from Northern Europe (the first level test).

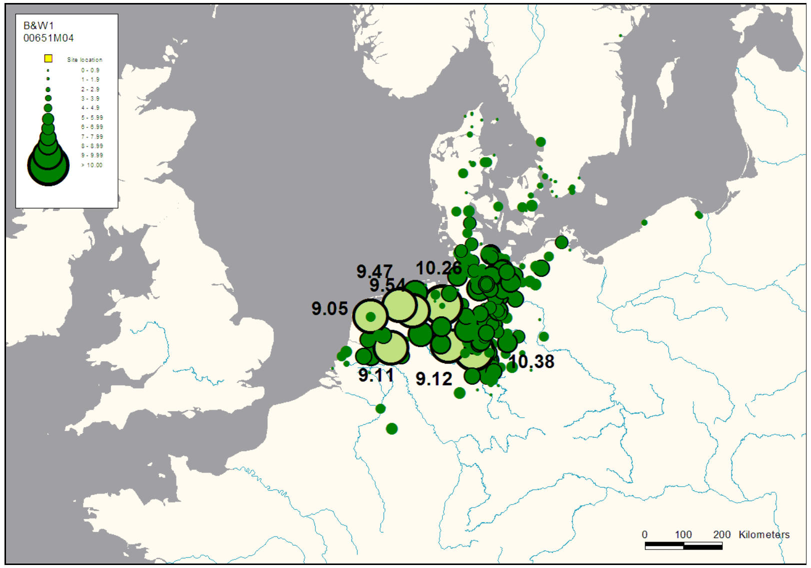


Fig. 132. B&W1, Copenhagen, Denmark. Map showing the distribution of correlation values achieved between the 15 tree mean for B&W1 (00651M04) and site chronologies from Northern Europe (the second level test).

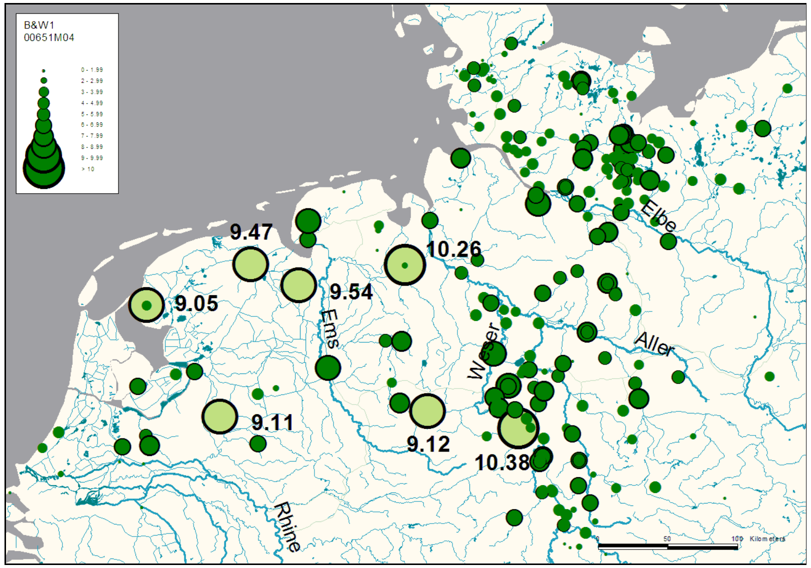


Fig. 133. B&W1, Copenhagen, Denmark. Map showing the distribution of correlation values achieved between the 15 tree mean for B&W1 (00651M04) and site chronologies from Northern Europe (the second level test), focussing on the Lower Saxony region.

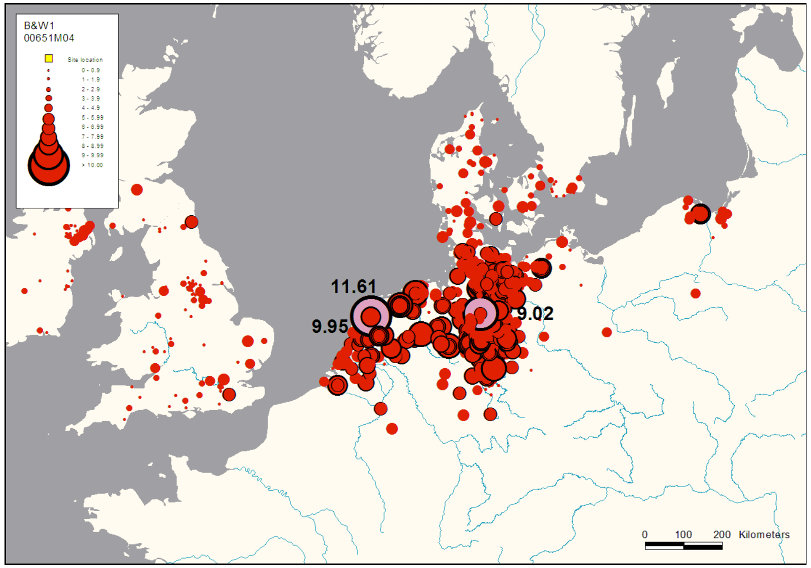


Fig. 134. B&W1, Copenhagen, Denmark. Map showing the distribution of correlation values achieved between the 15 tree mean for B&W1 (00651M04) and single tree-ring measurements from Northern Europe (the third level test).

with major drainage indicated, we see that the high correlation values are with sites on the Weser or Ems river systems, and with a couple of Dutch sites (fig. 133). It is not difficult to imagine the timber sources along these rivers being exploited, by rafting down-river to be used in buildings, and this transported timber data ending up in the Dutch tree-ring dataset as Dutch timber becomes less and less available. As can be seen in the test at the third level, with the single trees (fig. 134), a very widespread distribution of correlation values is the result, with high values appearing with single samples in The Netherlands and in Lower Saxony. It is to be noted that the Lower Saxony site which gives the high single tree correlation (t = 9.02) is not a site which gave an exceedingly high site chronology t-value (t = 6.95). With the large confusion of quite high correlations it seemed appropriate in this example to produce a map showing the correlation values greater than t = 8.00, to attain a clearer view of the results (fig. 135). The spread of values over the region is also clear in this t-value range. So all in all a very diffuse picture emerges in this case. In comparison with other cases in this study and with the results of the modern tree correlation distributions it is clear that something quite different is happening here. To suggest a provenance for this group of timber from B&W1 we can really only conclude to the wide regional level.

As mentioned above however, the non-homogeneity of the group can influence the diffuseness of this result. Focussing on the timbers from the lengthening of the ship in the correlation matrix, couldn't we define this as a single group? Well when we run all individual trees from this group against master chronologies, we see that most match best with Lower Saxony but two actually match better with a Lübeck chronology, sample 00651199 and tree 00651569 which is made from two very similar samples (00651089 and 00651169). So we should in fact define two groups, as indicated in the correlation matrix. A whole new range of correlation distribution maps can be made for each of these groups, at the three provenance test levels. First we will look at the largest group (00651M08), the individuals of which agree best with the Lower Saxony and Dutch regions. The test at the first level (fig. 136) shows that a higher match is now achieved with the Dutch

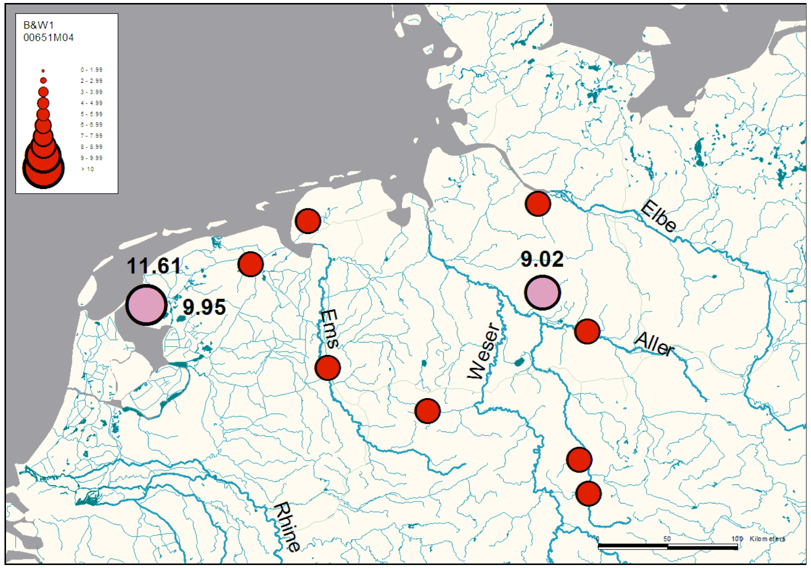


Fig. 135. B&W1, Copenhagen, Denmark. Map showing the distribution of correlation values achieved between the 15 tree mean for B&W1 (00651M04) and single tree-ring measurements from Northern Europe (the third level test), showing only where t ≥ 8.00.

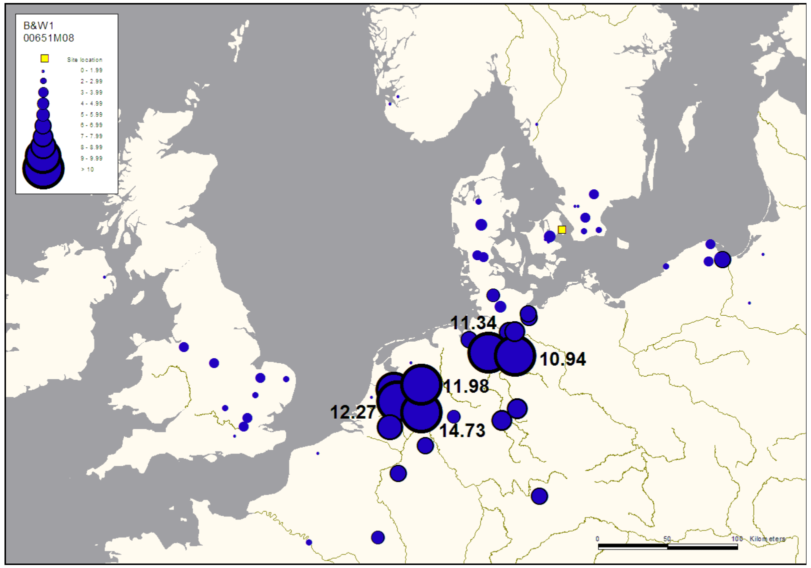


Fig. 136. B&W1, Copenhagen, Denmark, the Lower Saxony group (00651M08). Map showing the distribution of correlation values achieved between the Lower Saxony group mean (00651M08) for B&W1 and master chronologies from Northern Europe (the first level test).

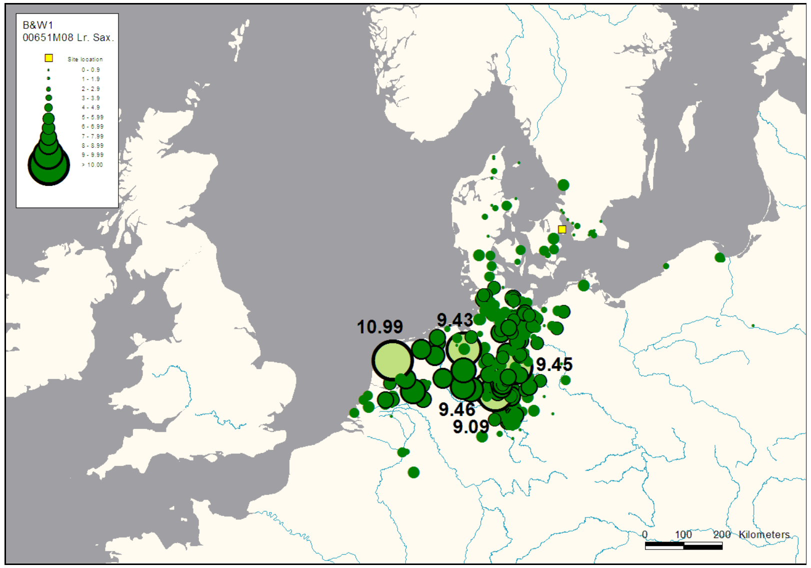


Fig. 137. B&W1, Copenhagen, Denmark, the Lower Saxony group (00651M08). Map showing the distribution of correlation values achieved between the Lower Saxony group mean (00651M08) for B&W1 and site chronologies from Northern Europe (the second level test).

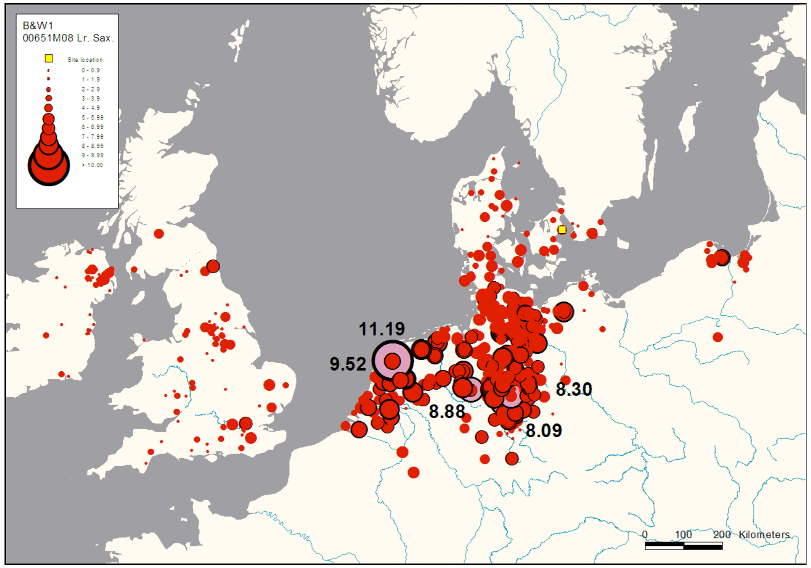


Fig. 138. B&W1, Copenhagen, Denmark, the Lower Saxony group (00651M08). Map showing the distribution of correlation values achieved between the Lower Saxony group mean (00651M08) for B&W1 and single tree-ring measurements from Northern Europe (the third level test).

references, than that achieved for the larger group. Having removed the three samples which should not be in this group though, quite a widely spread distribution of correlation is the result. We have very high correlation with master chronologies from Lower Saxony and from the Netherlands. The test at the second level (fig. 137) shows a similarly diffuse correlation distribution. High correlation with sites in the Lower Saxony region appear, but a higher correlation is with a Dutch site (t = 10.99). The highest correlation with sites otherwise is with Lower Saxony locations as illustrated. In the map, circles higher than t = 9.00 are coloured lighter green to highlight them, and these values are also labelled. It can be seen that the high values are with sites around the Weser and Ems River region. The third level test (fig. 138) shows very high correlation with single trees from a site in The Netherlands (t = 11.19 and t = 9.52) but quite high values appear also further east (t = 8.88, t = 8.30). All in all for this timber group we are still affected by the possibility of transported timber in the structural oak tree-ring dataset, as discussed above. To demonstrate this a test of the site in The Netherlands, which gives the highest correlation with the main B&W1 timber group, was carried out. Unfortunately the name of the site is not included in the database so we will refer to it by its site code, which is NLV15. There are seven trees from the site and the correlation matrix shows that we have a very homogeneous group of timber (fig. 139), that is, the timber is from a relatively confined area, perhaps even from a single forest. A site mean was made for NLV15, consisting of all seven samples. The resulting site mean, which is 147 years long spanning the period AD 1393 to 1539, is tested against single trees in the Northern European dataset to try to identify whether or not the timber from this Dutch site was imported (fig. 140). We cannot test at the first level, with the master chronologies, because we don't know if this material is included in one of the Dutch chronologies, which would lead to circular argument. Let us look at the third level, single tree test to see what it tells us about the Dutch timber from NLV15? Well as can be seen from the map, we get a correlation of 8.63 with a tree from a nearby site, along the northern coast, but another (t = 9.09) from a more inland site. The

	nlv15020	nlv15010	nlv15040	nlv15030	nlv15050	nlv15060	nlv15070
nlv15020	*	5,32	6,36	4,76	6,07	5,17	3,14
nlv15010	5,32	*	10,49	6,35	6,73	6,22	2,65
nlv15040	6,36	10,49	*	11,26	7,19	6,51	3,77
nlv15030	4,76	6,35	11,26	*	6,19	6,71	3,06
nlv15050	6,07	6,73	7,19	6,19	*	18,08	6,19
nlv15060	5,17	6,22	6,51	6,71	18,08	*	7,64
nlv15070	3,14	2,65	3,77	3,06	6,19	7,64	*

Fig. 139. NLV15, a Dutch site. Matrix of internal correlation.

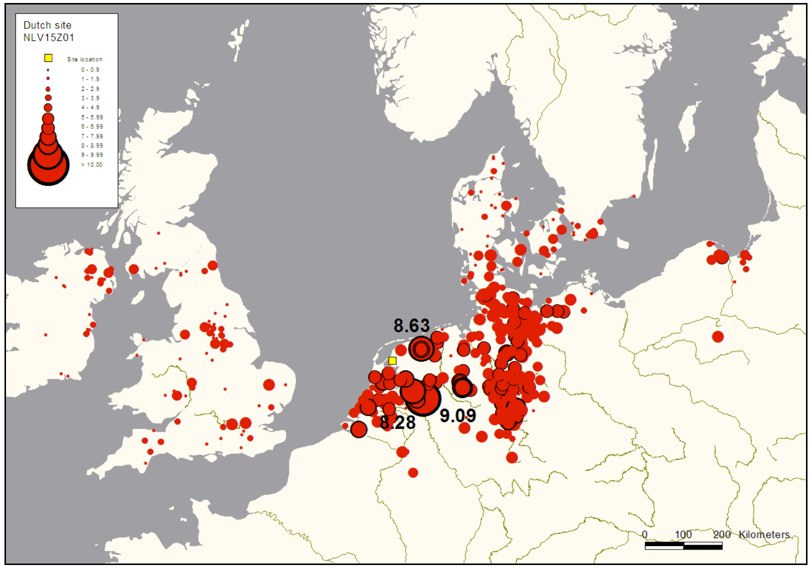


Fig. 140. NLV15, a Dutch site. Map showing the distribution of correlation values achieved between the mean for NLV15 (NLV15Z02) and single tree-ring measurements from Northern Europe (the third level test).

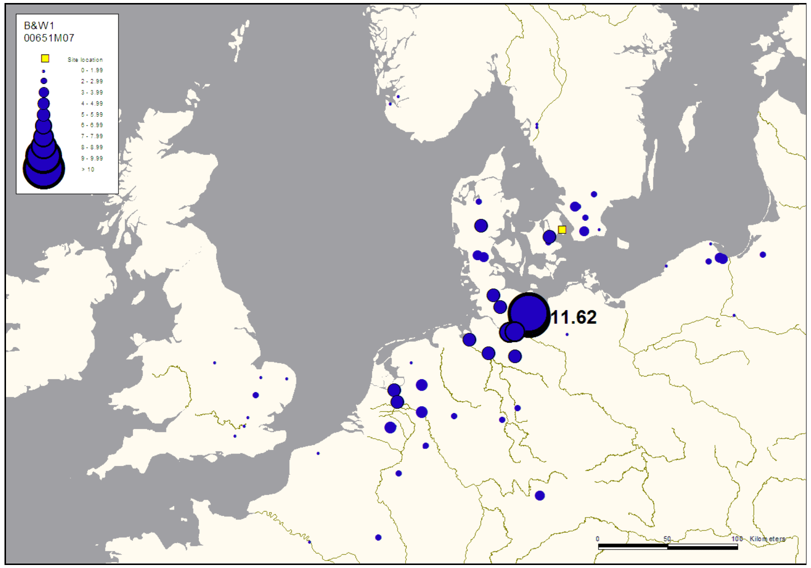


Fig. 141. B&W1, Copenhagen, Denmark, the Lübeck group (00651M07). Map showing the distribution of correlation values achieved between the Lübeck group mean (00651M07) for B&W1 and master chronologies from Northern Europe (the first level test).

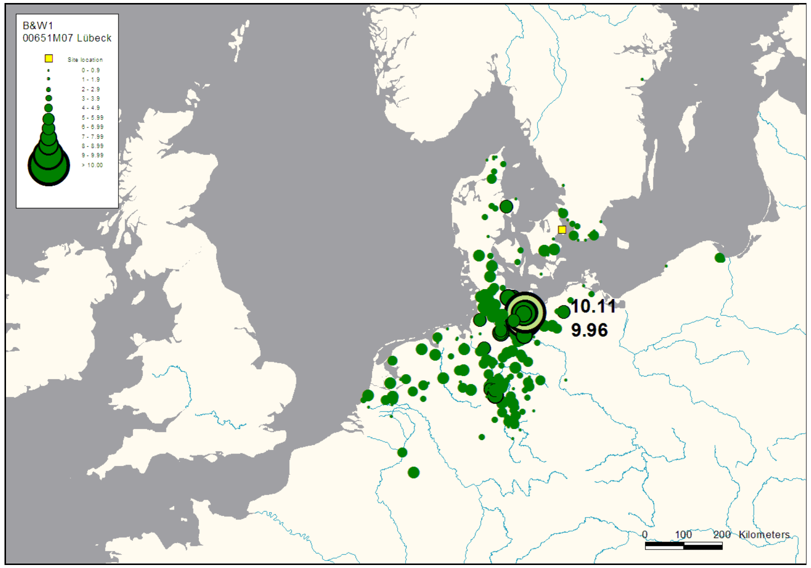


Fig. 142. B&W1, Copenhagen, Denmark, the Lübeck group (00651M07). Map showing the distribution of correlation values achieved between the Lübeck group mean (00651M07) for B&W1 and site chronologies from Northern Europe (the second level test).

homogeneity of the timbers point to a single, not a mixed source, and the provenance test might indicate a Dutch source.

All in all, if we are to conclude the result of the provenance determination of the larger timber group from B&W1, taking all the considerations into account, we can identify the origin to the wide regional level. The timbers grew in the Netherlands or in the neighbouring German states. We get a more promising result than with the larger more diffuse group, but still we do not achieve as clear a picture of provenance as we do with so many other examples. A considerable degree of interpretation is necessary to arrive at the provenance conclusion. The diffuse distribution of correlation for this group can be attributed to the increased transport of timber in this period, particularly to the Netherlands. Oak in the Dutch historical dendrochronological dataset might originate from imported timber, thus giving problems in the provenance determination test.

Let us take now the second group of just three samples, representing two trees, from the lengthening phase of the ship, as indicated in the correlation matrix. Again three maps are produced. The test at the first level (fig. 141) shows a clear high correlation with the large master chronology from Lübeck in Schleswig-Holstein, Northern Germany. We are certainly getting a much clearer picture for this small group. The test at the second level is just as convincing (fig. 142). A cluster of high correlation with Lübeck sites is the result, with the highest at t = 10.11. The test at the third level serves to confirm the clear provenance determination of these few timbers from B&W1 (fig. 143). Timber from Lübeck matches best with this group from the ship.

The contrast between the conclusions of the provenance determination for these two groups brings us back to the problems of timber availability in different regions in different periods. While it seems, judging by the clear distribution of correlation for this group, that relatively local timber is still used in buildings in Lübeck in the end of the 16th century, timber for construction in The Netherlands is not so available, and the oak tree-ring pool is ‘contaminated’ by timber that has been transported some distance, thereby a diffuse correlation distribution for the larger timber group is the result.

There are a number of additional timber groups from B&W1. These are shown in the correlation matrix above. One group consists of just two trees (00651M03), while the other is of three trees (00651M02). These two groups do not match so well together (t = 2.30) and given their low replication only the test at the first level is presented here. The M03 group correlation distribution with regional master chronologies (fig. 144) shows that the two timbers are of Scandinavian origin. The best match is with a master from Göteborg in western Sweden (t = 7.70). Similarly, the M02 group might show a Scandinavian origin for the three trees (fig. 145), although the match is not as strong as for the M03 group. A somewhat more southerly Scandinavian origin might tentatively be suggested, but the low density of sites for this large Swedish and Norwegian region hinders a more confidant provenance identification, as does the low replication for these two groups.

So if we should summarise the findings of the dendrochronological analysis and provenance identification for B&W1 we can see that the ship is made from oak from a wide variety of sources. The majority of the timber is Dutch or from the German region that borders The Netherlands, but timber from further east in the Lübeck region and from further North in Scandinavia have also been utilised. As Lemée puts it "This situation represents a change from a mobility of personnel (the shipbuilders) to a mobility of the raw materials (the wood supplies)" Lemée 2006, 256. However it is stated that "the dendrochronological analyses have indicated that the timbers used for the building and the lengthening did not have the same origin" (Lemée 2006, 261) and this is not the case. It is not stated in the original report (Daly 1997b) nor is it possible to say this in this reassessment. It is indeed possible to distinguish between timbers of different origin, as explained in detail above, but the timber origins do not coincide with information about the original and lengthening portions of the ship. In Lemée's summary of the dendrochronologically dated timbers the phase to which the timber belongs is listed (building or lengthening) (Lemée 2006, 255). For the two Lübeck timbers one is

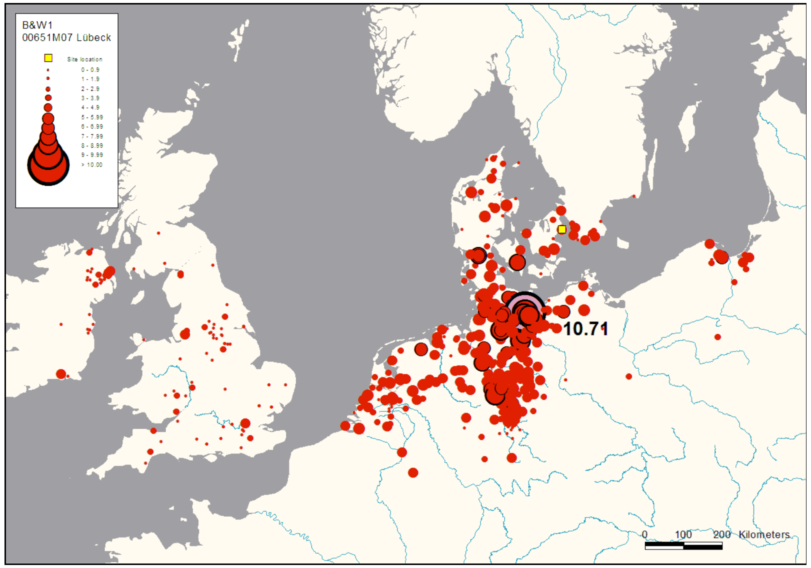


Fig. 143. B&W1, Copenhagen, Denmark, the Lübeck group (00651M07). Map showing the distribution of correlation values achieved between the Lübeck group mean (00651M07) for B&W1 and single tree-ring measurements from Northern Europe (the third level test).

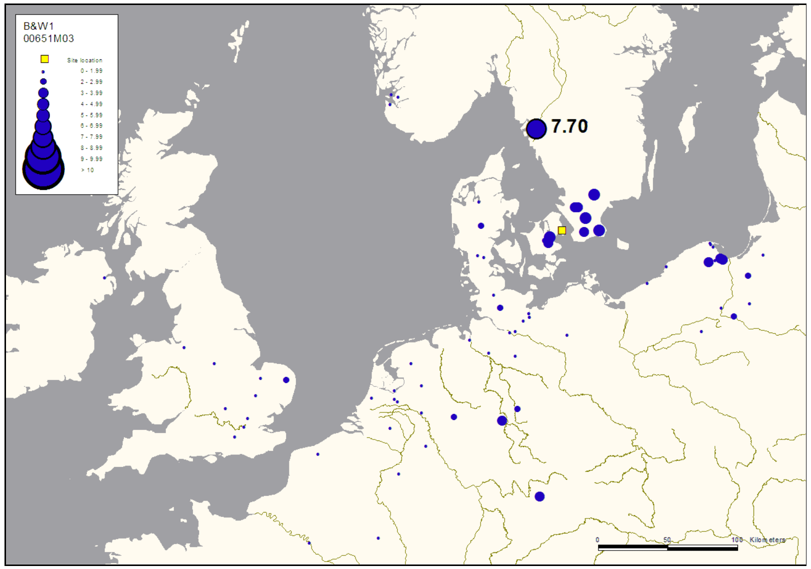


Fig. 144. B&W1, Copenhagen, Denmark, the M03 group (00651M03). Map showing the distribution of correlation values achieved between the M03 group mean (00651M03) for B&W1 and master chronologies from Northern Europe (the first level test).

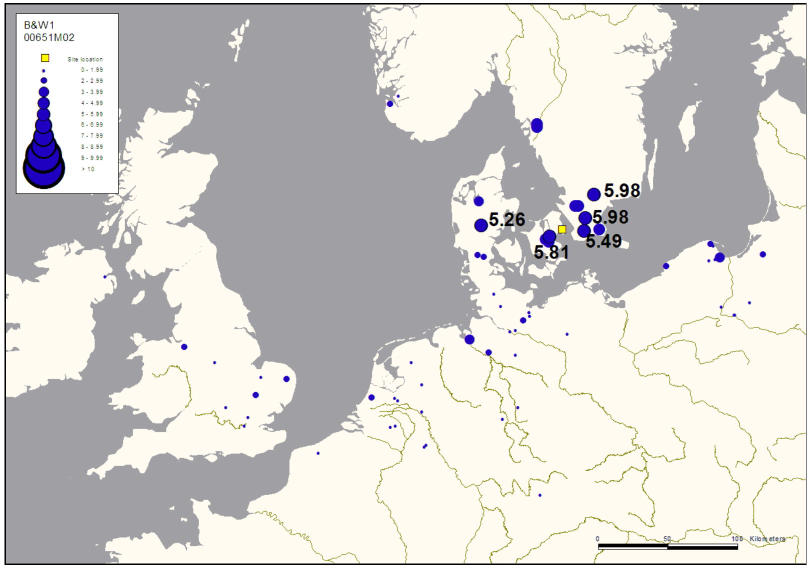


Fig. 145. B&W1, Copenhagen, Denmark, the M02 group (00651M02). Map showing the distribution of correlation values achieved between the M02 group mean (00651M02) for B&W1 and master chronologies from Northern Europe (the first level test).

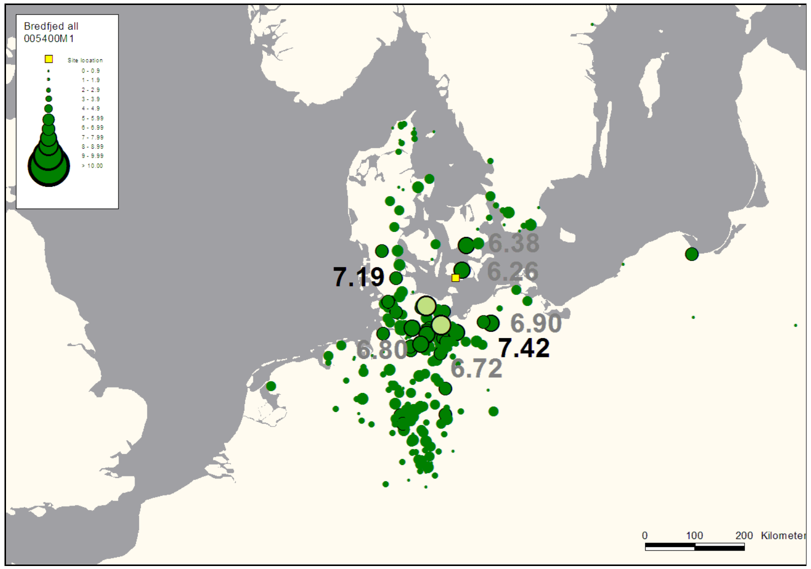


Fig. 146. The Bredfjed ship, Lolland, Denmark. Map showing the distribution of correlation values achieved between the mean for Bredfjed and site chronologies from Northern Europe (the second level test).

from the building phase and one is from the lengthening phase. For the two Scandinavian groups the Southern Scandinavian M02 is from the building phase while the Western Swedish group (M03) is from two lengthening timbers. The remaining and the majority of the timbers from both the building and lengthening phases are from The Netherlands or adjacent German region. So the suggestion that the original ship was built in Northern Holland and lengthened also in this region is actually made more probable given the dendrochronological results.

Incidentally a ship from the Netherlands, from c. 1655, shows a very similar pattern in terms of timber origin. Out of 12 samples from the Scheurrak (T-24) five matched best with the west German chronology, four with Schleswig-Holstein or Hamburg and three had another source again (van Holk 1987).

9.1.2 Bredfjed case study

The Bredfjed ship was initially discovered in 1967 and excavated by Ole Crumlin-Pedersen. At the time, the dating of the wreck was placed at 1200-1600. The ship was subsequently chosen for full excavation, for the reason that the ship has features which were similar to another ship from the area, the Gedesby ship. Full excavation of the Bredfjed ship would allow more detail to be gathered on this ship type. Features, which were comparable, included a heavy stempost with large hole, and the use of sawn planks. This excavation was carried out by Jan Bill in 1993 (Bill forthcoming). Thomas Bartholin carried out a very extensive dendrochronological analysis of nearly all the timbers from the wreck. In total 73 oak samples were examined, 15 from the timber framing and 58 from the planks (Bartholin 1997). Two samples with sapwood preserved, but no bark-ring, allowed the date of the felling of the trees for the ship to be placed at *c.* 1600.

Despite the many samples analysed, the ship averages made from the planks contain fewer trees than might be expected. This is because in many instances, the correlation between tree-ring curves from planks was so high, that the timbers were taken to come from very few individual trees. In the tree-ring average for the planks though, all of 17 trees are represented, so this can be taken to be a fairly well replicated ship average. For the other construction parts, 11 dated samples are included in the frame construction average. Even though the planks and other timber are treated separately in the analysis, the conclusion reached was that the growth of the trees is similar enough that the two timber groups can have grown in the same forest. Another conclusion, given the very uniform timber source evident, was that the ship had been built at a small shipyard, where the local timber resource was sufficient to meet all the oak requirements. The similarity of the two timber categories in terms of their tree-rings means that an average of all dated samples was also made. In Bartholin's report, a table was produced, showing the correlation between the ship averages and master chronologies from Northwest Europe. The highest correlation appeared with masters from Lübeck, Schleswig-Holstein and Southern Jutland, leading to the conclusion that the trees had grown in the Southern Danish or Northwest German Baltic region. At the time of the analysis, extensive tree-ring data for Eastern Denmark did not exist and therefore a re-evaluation of the provenance of the Bredfjed Ship is attempted here, not least to try to attain a more local provenance result.

As can be seen from the test of the ship average at the second level, with the oak site chronologies, (fig. 146) the highest *t*-values that appear are all with northern German sites. Note though that these values are not as high as in other examples of provenance determination, and that the values are quite widespread geographically. Why is it that this ship with its very well replicated tree-ring curve does not produce a clear local provenance result? A combination of several factors might account for this. The first, that the ship, with features that indicate that it was a locally built ferry, which sailed the waters between Gedesby and Rødby harbours and Northern Germany or Southern Jutland, was probably built in this region. The homogeneous nature of the tree-ring curves from the ship indicates a very limited source area for the oak timber, resulting probably in a very local tree-ring signal. It could be that we unfortunately don't have timber from the same local area as the ship and therefore circle round the area with the results of the correlation, but still unable to get closer to a provenance result. As has been shown in the methodology chapter above, a strong provenance determination is dependent upon the density of references/sites being compared with the ship. If we are missing just few key sites, which correlate highly well with the ship, then the provenance signal is much more diffuse, and pinpointing a local area for the ship less successful. If the timber for the ship grew in the region where the ship sailed, to identify the timber source we would need references from that region covering the same period as the ship's tree-ring curve. Unfortunately we don't. The map here seems to indicate that the source could be in Northern Germany rather than on the island of Lolland, where the ship was found. The question remains though, is this due solely to the high density of sites in Germany, in contrast to the low density in the Zealand, Lolland, Falster region of Eastern Denmark?

As can be seen on the map, one site on Lolland gives a relatively high correlation with the ship (t = 6.26). On first glance the correlation is obviously not higher than that of the two German sites that give t-values greater than 7.00, and indeed there are several sites in Northern Germany which also give t-values between 6.00 and 7.00. The Lolland site is of timber from Hunseby kirke (analysed by Orla Hylleberg Eriksen, the National Museum of Denmark, in 1993). The site mean, which has been made, consists of just two trees and is also quite short, consisting of just 78 rings. Could it be that if sites with shorter overlap than the ship average being tested were to be increased in significance (if the correlation results for example were weighted where shorter overlap occurred), would we be able to refine the interpretation of the ship timber's provenance? Even if this were attempted in this case, it probably would not significantly change the interpretation, as the two German sites, which give the highest correlation, are also site chronologies that do not cover the full length of the Bredfjed ship average. The years these key sites cover is shown in fig. 147. With weighting of the correlation results, these two sites would also increase, resulting still in a similar provenance conclusion.

The one site chronology, which might have the potential of being the key to suggesting a timber origin local to the find site, is built from timber from an excavation in the town of Næstved, on Southern Zealand, *c.* 70km from the Bredfjed

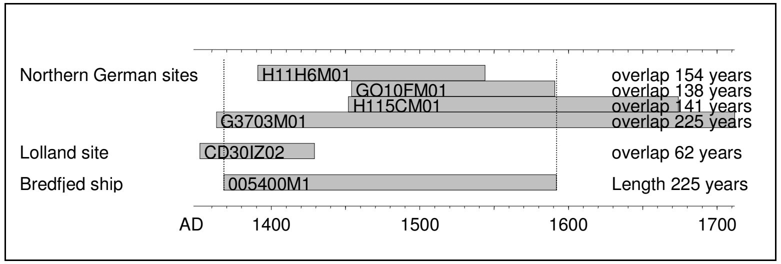


Fig. 147. The Bredfjed ship, Lolland, Denmark. Bar diagram showing the chronological position of the Bredfjed ship mean and other key site means, showing the varying overlap between the ship and the different sites.

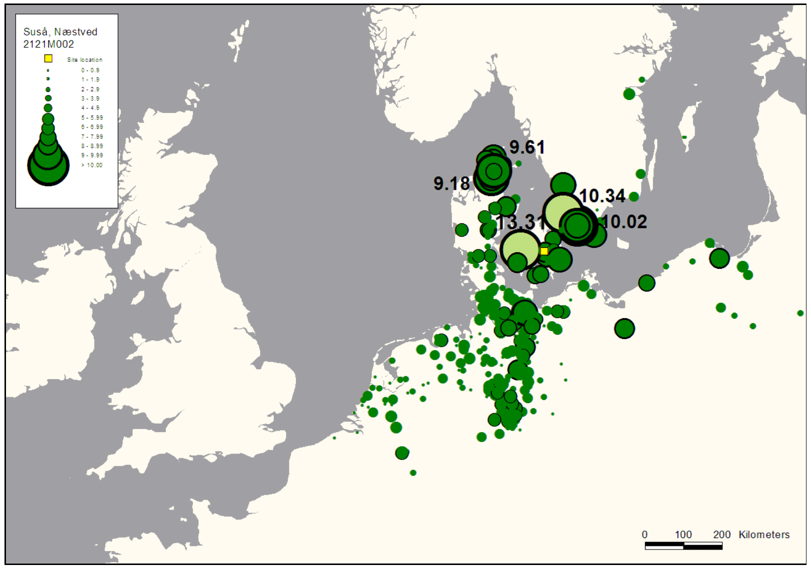


Fig. 148. Suså, Næstved, Denmark. Map showing the distribution of correlation values achieved between the mean for Suså, Næstved and site chronologies from Northern Europe (the second level test).

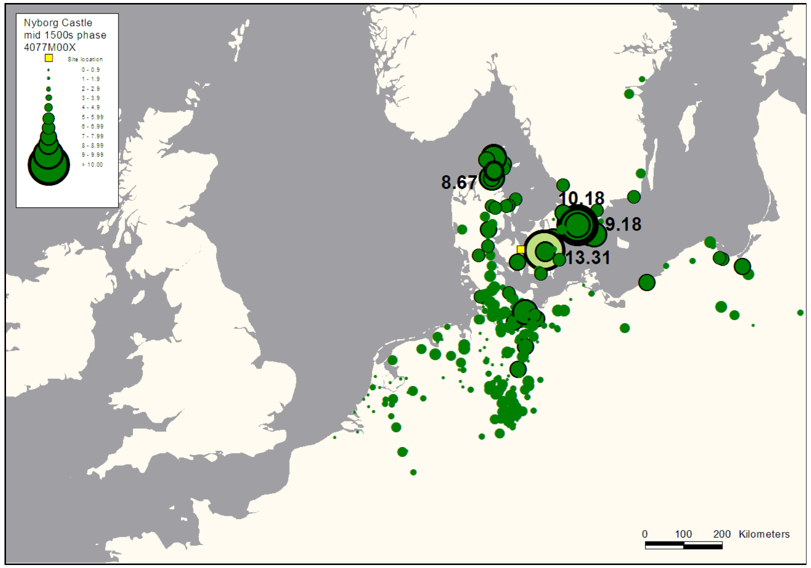


Fig. 149. Nyborg Castle, Funen, Denmark, Renaissance phase. Map showing the distribution of correlation values achieved between the mean for Nyborg Castle's Renaissance phase and site chronologies from Northern Europe (the second level test).

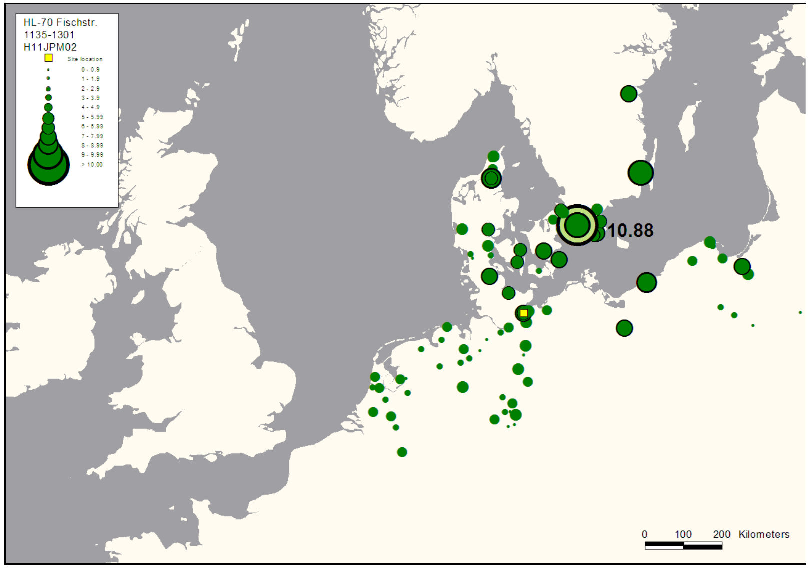


Fig. 150. Fischstrasse, Hamburg, Germany. Map showing the distribution of correlation values achieved between the mean for Fischstrasse and site chronologies from Northern Europe (the second level test).

site as the crow flies. This site chronology is based on oak timber from waterfronts in the medieval market town, and covers the period 1052-1596, while the Bredfjed ship average covers 1368-1592 (Daly 2001a; 2001e). The Næstved site chronology is also well replicated for the period the ship average covers, with at least 20 trees represented for most of the period. If the timber for the Bredfjed ship grew in the Southeastern Danish area, we would expect the correlation with the Næstved site to be higher than the *t*-values we achieve with the North German sites. So even though a more local provenance determination is not obvious, the evidence presented here, in the re-evaluation, points towards a timber source on the Puttgarten side of the ferry route.

One aspect that arises out of this case concerns the geographical uncertainty of some of the site chronology data. To confirm that the Næstved site's oak can be argued to be local, the chronology was run against all other site chronologies. This results in the map (fig. 148), where it can be seen that the Næstved site matches equally well with sites from Lund and Helsingborg in Southwest Sweden, and with western Danish and Schleswig-Holstein sites. It matches in fact best with the mid 16th century phase of timbers from Nyborg Castle in the eastern coast of the island of Funen. What if though, this timber was imported from afar, for the Nyborg Castle building? These kind of possibilities can have you running around in circles testing the one construction timber site chronology after the other to rule out the possibility of basing the provenance determination on a false foundation, particularly when dealing with a ship from this later period. So if we produce a test, this time of the Nyborg site chronology based on the oak felled in the mid 16th century (fig. 149). It matches best with the Næstved site, so we might be seeing here a climatic reaction, which is shared by the southern Zealand site and the Funen site. We could ask though what if both sites come from the Southern part of Sweden, given the good agreement with timbers from Lund. If, though, we refer back to the test of the living trees in the methodological test using living tree data in the first section of this study, similarity of trees in Southwest Sweden and some Danish forest sites also occurred.

Actually, when the oak chronology from Lund is checked against the data it is striking how many Danish sites it achieves very high agreement with. A Lund chronology spanning the period AD 801-1496 made by Olafur Eggertsson (pers.comm.) gives a very high agreement for example with a chronology from Zealand. We are inclined to presume that transport of timber between moder day Denmark and modern day Sweden went only one way, from the very forested Skåne/Halland/Blekinge to the increasingly de-forested Zealand for example. Given that the Skåne region was a part of the Danish kingdom until 1658, it is not inconceivable that timber was brought to Lund from Zealand. We know that timber from Scottish buildings was purchased from the Danish region, as dendrochronology and historical sources are showing (Crone 2000; 2002; Crone et.al. 2004; Crone and Fawcett 1998), so there was enough oak timber in the region for export. In fact, in the building timber dataset used in this study, instances of transported timber can be identified. Ideally actually, every tree or site in the historical data could be tested for geographical provenance. This could be done systematically, and sites, which are not local, could then be taken out. However this was considered a far too time-consuming task. In the provenance test though many of these sites become apparent in the *t*-value mapping, as they stand out. When the Lund chronology was tested for instance, a *t*-value of 10.88 appeared with tree-ring data from a site in Fischstrasse, Hamburg. This was too striking to be ignored so it was necessary to test the Fischstrasse site chronology at the second level, with all other sites. The map in fig. 150 depicts the result. While the period which the Fischstrasse timber covers is not relevant for the Bredfjed ship, the exercise reveals the care that should be taken in the provenance determination process. Always to be source-critical! As shown on the map, the Fischstrasse timber covers the period 1135-1301, and matches best with southern Scandinavian sites, agreeing best with Lund. Clearly here we have evidence for transport of construction timber in the 14^{th} century.

name	type	Dendro no.	Date		Provenance	samples	data length	Museum no.	Report status
Dommerkontorets Have, Ribe	Barrel	7005	after c.	705	Rhine Mainz	4	231	NNU A5820	(Christensen 1989)
Giørtzvej	Barrel	W466	after	715	Rhine Mainz	4	263	ASR 990	(Carsten Sønderby, pers.comm.)
Giørtzvej	Barrel	7035	after *c.*	712	Rhine	3	179	ASR 1357	(Daly 2000)
Seminarievej Ribe	Barrel	W425	after	750	S. Germany	5	120	ASR 863	(Carsten Sønderby, pers.comm.)
Viborg Søndersø	Barrel	F008	after	998	Northern England?	1	119		(Daly 2005; this volume)
Horsens A130	Barrel	W438	last ring	1125	Danish local Tamdrup K.	3	138	HOM 505	(Carsten Sønderby, pers.comm.)
Dagmarsgården	Barrel	W575	*c.*	1160	West Germany Rhine	3x3	258	ASR 1015	(Carsten Sønderby, pers.comm.)
Præstegade 13 Ribe	Barrel	7022	after	1160	France	9	185	NNU A7577	(Eriksen 1994) (Crone et al. 2004)
Ribelund	Barrel	W426	after *c.*	1163	coastal Lower Saxony	14	117	ASR 926	(Carsten Sønderby, pers.comm.)
Nygade 10, Ribe	barrel	G001		1210-30	western continental Europe	1	59	ASR 11	(Daly, this volume)
Skjern Bro	Barrel	7031203A	after	1238	?	1	108		(Daly 2001)
Skt Pederstræde Viborg middelalder	Barrel	F0040	*c.*	1270	Sleswig-holstein / Lübeck	11	132	VSM990C	(Daly, this volume)
Slotsgade 3-7 Ribe	Barrel	W570	*c.*	1273	West Germany Rhine	6	142	ASR 1200	(Carsten Sønderby, pers.comm.)
Saltgade 4 Ribe Brønd A	Barrel	W80	after	1272	France/London	14	112	ASR 2M80D	(Carsten Sønderby, pers.comm.)
Stege	Barrel	3032	*c.*	1280	Sleswig-holstein / Lübeck	7	178	SMV 7737	(Bonde 2003)
Horsens A116	Barrel	W439	last ring	1299	Lübeck / Szczecin	3	143	HOM 505	(Carsten Sønderby, pers.comm.)
Gl. Åby Kirkegård, Århus	Barrel	WM2029	after	1320	Southern Baltic	1	100	FHM 4407	(Carsten Sønderby, pers.comm.)
Kathedralskole Ribe	Barrel	W20718/2005	*c.*	1325	Southern Baltic	4	120	ASR 1445	(Carsten Sønderby, pers.comm.)
Suså Næstved	Barrel	21214	after	1337	Southern Baltic	3	184	98:113	(Daly 2001)
Aberdeen	Barrel	0056		1350's	Southern Baltic	?	162		(Anne Crone, pers.comm.)
Boringholm	Barrel	60132	*c.*	1372	Southern Baltic	6	224	NNU A5885	(Daly 2005)
Svendborg	Barrel	4079	after *c.*	1400	Southern Baltic (weak)	3	148	NNU A6382	(Bonde 1982)
Niels Hemmingsensgade Copenhagen	Barrel	2129	after *c.*	1413	Southern Baltic	3	276	KBH2138	(Daly, this volume)
Kompagnistræde, Næstved polish	Barrel	B0111	*c.*	1425	Southern Baltic	3	214	NÆM2004:200	(Daly, this volume)
Brolæggerstræde København	Barrel	B004	after AD	1466	France	10	100	KBM 2801	(Daly, this volume)
Pilestræde 8 København fridge	Barrel	B0090	after	1585	West Germany Rhine	3	168	KBM 2897	(Daly, this volume)
Skt Pederstræde Viborg renæssance	Barrel	F0041	winter?	1652-3?	Lower Saxony Weser	3	220	VSM990C	(Daly, this volume)

Fig. 151. Table summarising the dating and provenance determination of the barrels included in this study.

10 Chapter 10: Barrels

Twenty-seven barrel finds from Danish excavations are included in this study, and these are listed in fig. 151, sorted chronologically. A full provenance determination test at three levels is not presented here for each barrel, but the provenance results are documented in most cases in the form of tables of correlation of the tree-ring curves from each barrel and master chronologies for Northern Europe. The majority of the barrel finds are from the town of Ribe, where 11 dated barrels are listed. A large number of these were analysed by Carsten Sønderby from the dendrochronology laboratory "Wormianum" and he very kindly sent me his measurements so that the provenance of these finds could be reassessed. The following section examines the provenance determinations for the thirty Danish barrel finds, in chronological order.

10.1.1 Four barrels from the earliest Ribe

Giortzvej, Ribe (ASR 990), Giortzvej, Ribe (ASR 1357), Seminarievej, Ribe (ASR 863), Dommerkontorets Have.

These four finds, all from excavations in Ribe, are treated as a group, due to the similarity in age of the dates achieved for the oak, and the similarity of their provenance. Two of the barrels, Giortzvej ASR990 and Seminarievej were analysed by Carsten Sønderby, whose results are archived at the Antikvariske Samling in Ribe. The other Giortzvej site (ASR 1357) was analysed in 2000 (Daly 2000e). The barrel parts from Dommerkontorets Have were examined in the 1970s at the Natural Science Unit at the National Museum of Denmark, but it was not until 1989, when the tree-ring data was looked into again by Kjeld Christensen, that the barrel was dated (NNU archive journal no. A5820).

The barrel staves from Dommerkontorets Have were dated to after *c.* AD 705 using German chronologies (NNU archive A5820 report by Kjeld Christensen dated 18th May 1989). As early as 1979 before the barrel staves were dated, an analysis of the substance adhering to the barrel was analysed, and identified as a tar,

	7005M00x dommerk	7035M001 giortzvej ASR1357	w466M01 giortzvej ASR990	w425x1 seminarievej
7005M00x dommerk	*	9,22	7,38	-
7035M001 giortzvej ASR1357	9,22	*	9,29	4,77
w466M01 giortzvej ASR990	7,38	9,29	*	4,71
w425x1 seminarievej	-	4,77	4,71	*

Fig. 152. Dommerkontorets Have, Seminarievej and the two Giortzvej barrels. Matrix showing the correlation between the means of these four barrels.

Filenames		Ribe 700s M1	7005M00x	7035M001	w466M01	w425x1
-		AD438	AD449	AD516	AD438	AD621
-		AD700	AD679	AD694	AD700	AD740
WD400std	W. Germany Hollstein 1980	15,24	10,12	9,98	12,69	4,55
nlzuidmm	S. Netherlands Jansma 1995	14,40	9,65	11,81	10,09	6,02
zdlmidde	S. Germany	10,38	8,80	6,65	8,44	3,61
BOG00000	GOETT	7,12	4,58	5,10	5,33	-
DM200004	G WESER	7,07	4,64	5,04	5,27	-
DM700001	SUEDTYSKLAND	6,60	5,78	3,82	5,62	3,14
vlaanzn2	Flanders	6,08	4,17	5,58	5,51	3,18
GBM00007	London	5,80	3,19	-	6,43	-
ofrmidde	O,Friesl,	5,28	4,66	4,21	3,89	-
DMML003A	Ost-NDS Leuschner	4,96	4,23	4,21	3,70	-
9M456781	Jylland/Fyn	-	3,05	-	-	-

Fig. 153. The four barrels from Early Ribe, Denmark. Table showing the correlation between the means from the four barrels and a mean of three of the barrels combined (Ribe700sM1) and master chronologies from Northern Europe.

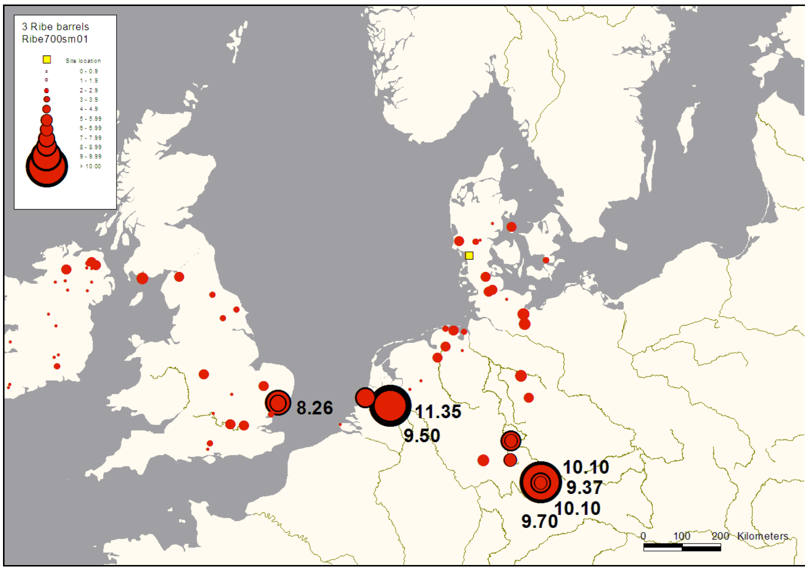


Fig. 154. Three 8th century barrels from Ribe (Ribe700sM1). Map showing the distribution of correlation values achieved between the mean for the three barrels and single tree-ring measurements from Northern Europe (the third level test).

from spruce, pine or larch. This, in combination with the narrow tree-rings of the barrel staves, led to the suggestion that the barrel and the tar might come from a mountainous region in Central Europe (NNU archive A5820 letter from Mogens Bencard to Poul Sigsgaard dated 2nd November 1979).

Carsten Sønderby's original conclusion for the analysis of four barrel staves from well A7 at Giortzvej ASR 990 was that the outermost tree-ring was formed in the year AD 700, and that the oak came from the Rhine River in the region of Mainz (letter from Carsten Sønderby dated 1st December 1997 in ASR 990). No sapwood was preserved on the barrel staves so if we add 15 rings to account for missing sapwood the felling date for the tree that supplied the timber can be placed at after AD 715.

Three staves, two from a complete barrel and one additional stave from Well A159 were analysed from Giortzvej (ASR 1357). The tree-ring curves from the two staves were so similar that they might be from a single tree. The third stave, the strayfind, matched quite well with the staves from the complete barrel. Sapwood on one of the staves meant that a date for the felling of the oak for the complete barrel could be placed at *c.* AD 712 (Daly 2000e). An interesting observation in the analysis was that the barrel matched quite well with Germans chronologies utilised at the time, and with just one site in Denmark, again data from Ribe, at Dommerkontorets Have. The barrel matched with just four samples from Dommerkontorets Have, and this was at the time puzzling, but wasn't pursued further.

With the receipt of the other barrel from Giortzvej from Carsten Sønderby a link between these three sets of data emerge. The two barrels, analysed in different dendrochronological laboratories, but from adjacent archaeological excavations, match well to each other, and to the four measurements from barrel staves from Dommerkontorets Have. The correlation matrix in fig. 152 shows how well these three barrels match, and an average of the three barrels has been made. It can also be seen in the matrix that the fourth Late Germanic Iron Age barrel from Seminarievej does not match as well with the other three.

The average tree-ring curves for the four barrels, and the average of the three well matching barrels from Giortzvej and Dommerkontorets Have are compared with master chronologies for northern Europe, shown in fig. 153. Very clearly there is quite a spread, geographically, of high values, noticeable for all barrels. High values occur with Southern German chronologies, but also with a chronology for the Southern Netherlands. Now this might not be a problem when we remember that the Rhine River flows out of central Europe exactly in the Southern Netherlands, so the suggestion of a Rhine provenance for these barrels is not impossible. It is, in this light though considered important to carry out a third level test using the average of the three similar barrels, and this is shown in fig. 154. The individual sites that the three barrels match with are spread out from Upper Rhine, a site in the Southern Netherlands and even a site in Southeast England. Clearly this is not a problem of the technique of provenance determination but a product of the inclusion in the European dataset of exotic oak data in different regions. When the tree-ring measurements of the English and Dutch examples that match very well with the three Ribe barrels are run against masters, they also match best with the Upper Rhine region. It is very probable that a search in the archives for these sites will show that the measurements are from barrels. So the map reflects the transport of barrels transported from the upper Rhine region down river to the Rhine Mouth, and shipped to Southern England and to Ribe.

10.1.2 Viborg Søndersø

Excavations in 2001, carried out in the town of Viborg, in Jutland, Denmark have uncovered remains of a building, used as a smithy (Iversen et.al. 2005). The water-logged conditions at the site, on the shore of the inland lake, Søndersø, meant that wooden walling and other timber constructions were preserved. The dendrochronological dates for the building and associated latrine and other structures show that the area was in use beginning in winter AD 1018-19 with additional building in summer AD 1020 and in spring AD 1025 (Daly 2005c). In the floor of the smithy building an oak stave from a fairly large bucket or tub was found.

As is usual for a dendrochronological analysis, the object was sawn to enable the tree-rings to be measured. The oak stave contained 119 rings and the outermost ring was formed in AD 987. The stave was made of the heartwood of the tree; that is the sapwood had been removed in the manufacture of the stave. The felling date thus can be estimated to after circa AD 1010. In contrast to the building timber from the site, which was dated using tree-ring data from other Danish sites, the tree-ring curve from the stave dated against master chronologies from England. The table in fig. 155 shows the results of the calculation of the correlation of the tree-ring curve from the stave, with master chronologies from England and smaller site chronologies from the county of Yorkshire. It is with the Yorkshire site chronologies that the highest *t*-values are achieved.

Filenames			**F008001F**	
	start	date	AD869	
	date	end	AD987	
IRE_DUB1	AD855	AD1306	3.54	Ireland Dublin
ENME0364	AD947	AD1974	3.74	England East Midlands
ENSW1146	AD770	AD2001	4.08	England South West
EM_NEW	AD882	AD1981	4.26	East Midlands
ENSE0841	AD435	AD1811	4.33	England South East
ENNW0741	AD892	AD1753	4.34	England North West
ENAN1378	AD406	AD2001	4.98	England East Anglia
ENLO1659	AD413	AD1994	5.39	England London
ENMW0984	AD860	AD1790	5.82	England West Midlands
ENYO0928	AD440	AD2003	**6.71**	England Yorkshire
BEV_BDP	AD967	AD1092	3.82	Humberside-EYorkshire Beverley Dominican Priory
YORK_QH1	AD769	AD1036	4.27	NYorkshire-York Queens Hotel
BEV_EG	AD858	AD1310	4.89	Humberside-EYorkshire Beverley Eastgate
BEV_DL	AD903	AD1183	5.57	Humberside-EYorkshire Beverley Dyer Lane
YORKCPG3	AD460	AD1011	**6.12**	NYorkshire-York Coppergate Viking
BARTCOFF	AD785	AD1134	**6.31**	Humberside-NLincolnshire Barton Coffins
YORKSWGT	AD749	AD986	**6.59**	NYorkshire-York Swinegate 1990 7 coffins
BEVMCOFF	AD848	AD992	**6.65**	Humberside-EYorkshire Beverley Minster coffin

Fig. 155. Viborg Søndersø, Jutland Denmark, the bucket stave. Table showing the correlation between the tree-ring curve for the bucket stave from Viborg Søndersø and English chronologies and site means. Calculated by Ian Tyers, University of Sheffield.

When carrying out the analysis of wood from such archaeological finds with a view to determining the origin of the timber, it is more reliable to analyse several samples from a single structure. Fifteen samples might be cited as a minimum for successful provenance identification. This is so that the tree-ring curves for each tree in a structure can be compared with each other initially, and averaged then to form a single curve, representing the whole structure. Variations in the single trees' tree-rings, which might be due to non-climatic causes (insect attack, local soil or slope conditions, changes in the vegetation on the forest floor etc), are thus reduced and a climate signal for the area, in which the forest grew, is accentuated. However the random nature of archaeological preservation means that finds of such amounts of timber are not always available. In this case, only one stave of a wooden tub was found. Can it be a coincidence that the single stave matches best with Yorkshire? The dendrochronologists in the University of Sheffield (Ian Tyers and Cathy Tyers, pers.comm.) have grouped their material in large regional chronologies, but have also built smaller site chronologies; that is, based on the timbers from single sites. When the tree-rings from the Viborg tub stave are compared with the larger regional chronologies, the highest *t*-value is with Yorkshire. When tried against their land-wide network of smaller site chronologies, the *t*-values achieved are again highest with Yorkshire sites and are consistently lower with sites from other counties. We have here tangible evidence that the stave is from Northern England, and was brought to Denmark, probably as part of the container for which it was manufactured. The stave has a large square hole at its upper end, which is possibly for attaching a handle. The bucket can have stood in the hold or on the deck of a Viking ship, sailing across the North Sea, containing perhaps food for the journey, or some product to be traded. It can have finally been used to carry charcoal to the furnace at Viborg, or water from the adjacent lake to cool the hot metal in the manufacturing process. This otherwise mundane find, through provenance analysis, takes on a greater significance. Though as with all archaeological finds we don't know how it ended up at Viborg, how many owners it had throughout its usage, how many times it was used, reused, exchanged or traded, but it tells us that objects from far away came to this inland site, and raises perhaps the 'status' of Viborg, at this early date, from a local settlement to the beginnings of the trading town it became.

10.1.3 Horsens (A130)

This barrel was found lining a well, during an excavation in Horsens in Jutland, and three samples were analysed by Carsten Sønderby and he kindly sent me his measurements. Measurements from two of the barrel staves match extremely well together indeed so well that they might come from a single tree, while the third matches less well with the other two. All samples are dated. Felling of the trees for the barrel took place in the mid 12th century. As the table in fig. 156 shows, the highest agreement between the mean curve for two samples, and the third curve, against master and site chronologies, are with Danish references. Even with the very few number of samples analysed here we can see a difference, within the country, in

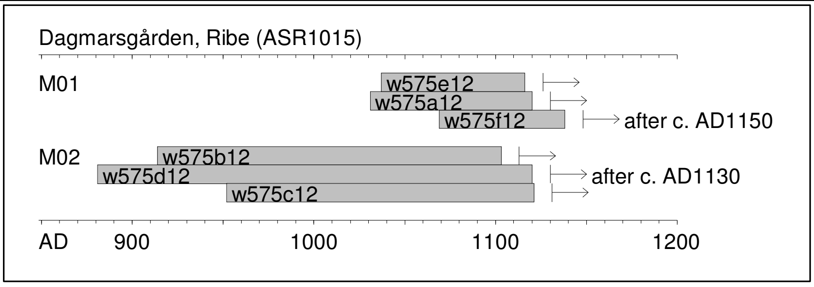
Filenames		w438c12	w438M01
-		AD999	AD988
-		AD1148	AD1125
9M456781	Jylland/Fyn (NM)	6,11	7,51
CD61AZ02	Tamdrup Kirke (EU-project)	-	11,00
0013M001	Kollerup Kog (Daly 2000b)	4,79	6,23
CD51JZ01	Møllestrømmen (EU-project)	4,75	6,73
6084M001	Sejs Snævringen (Daly unpubl.)	7,95	-
70314M04	Skjern Bro (Daly 2001c)	6,24	3,04
0200m001	Eltang ship (Eriksen 1999)	5,93	5,47
CD50LZ01	Rabsted Kirke (EU-project)	5,75	-
RIBEZ001	Ribe (Daly unpubl.)	5,64	5,57
60871M01	Koldingkoggen (Daly 2002)	5,63	5,54
60730029	Erritsø Skib (Daly unpubl.)	5,35	3,46
00696m01	Roskilde 7 (Bonde and Daly 1998)	5,26	3,01
81M00003	Kirker I Vendsyssel (Daly 1998c)	5,02	-
60730019	Erritsø Skib (Daly unpubl.)	-	5,54
6075F001	Viborg (Daly 2005c)	-	5,33
0006M001	Ellingåskibet (Bonde et.al 1991)	4,69	3,13
2x900001	Zealand (NM)	4,66	4,57
P671001M	Elblag (Ważny pers.comm.)	4,63	-
0085M002	Lynæs B (Daly 1998d)	4,51	5,40
8127M001	Ålborg (Daly 2000a; 2001b)	4,32	5,31
5081M002	Roager Kirke (Eriksen 2001a)	3,57	5,11
0085M00A	Lynæs A (Daly 1999b)	4,23	3,16
8102M001	Bindslev K, Hjørring (Daly 1998b)	4,13	-
CD701Z03	Vorbasse (EU-project)	4,11	3,22
0076M001	Korsholm 1 (Eriksen 1997)	4,06	3,52
4013M001	Odense Sortebrødre Kl. (NNU j.no. A5921)	-	4,68
F001M001	Birkely (Daly unpubl.)	-	4,12
5069M001	Løgumgårde (Daly 1999a)	3,58	4,81
DM300001	Westdeutschland (GU)	4,60	-
nlzuidmm	S. Netherlands (Jansma 1995)	4,09	-
nlwf1040	Nederland, Westfalen (Tisje unpubl.)	-	4,38

Fig. 156. Horsens barrel, Jutland, Denmark (A130). Table showing the correlation between the mean for the barrel and master and site chronologies from Northern Europe.

the probable origin of the timbers. The mean curve W438M01 matches best with timber from Tamdrup church near Haderslev, and with timbers from Haderslev itself and the Kollerup Cog which has been found to also agree best with Haderslev. The other barrel stave measurement matches best with sites from mid Jutland, with a site called Sejs Svævringen in Skanderborg Amt (Daly unpubl.), and with tree-ring data from the bridge at Skjern in western Jutland (Daly 2006).

10.1.4 Dagmarsgården, Ribe (ASR 1015)

A barrel from the excavations carried out in 1993 at Dagmarsgården in Ribe was analysed by Carsten Sønderby and dated to *c.* 1159 +/- 9 years (letter and report from Carsten Sønderby to Lis Andersen dated 29th December 1993 in ASR 1015). As the barrel is dated using western German chronologies he suggests that the barrel is from the central Rhine region. Six samples have been analysed and Carsten Sønderby kindly sent his measurements. In fig. 157 the bar diagram is shown of the position of the six samples at their dated position, alongside the matrix of correlation between the samples. Clearly two groups are evident, each consisting of three samples, both in relation to the correlation between samples and the length of the tree-ring curves. A study of the full find circumstances for this barrel is not a part of this thesis, but if a single barrel was found archaeologically then we here might have evidence for the assembly of a single barrel with wood from diverse sources. Two mean curves have been made representing each group, and the correlation between these two and chronologies for Northern Europe is shown in fig. 158. Sønderby's conclusion that the barrel came from the Middle Rhine region is supported by the values in this table.



		w575f12	w575a12	w575e12	w575d12	w575c12	w575b12
W575M01	w575f12	*	13,08	9,05	4,08	-	-
	w575a12	13,08	*	13,14	4,66	4,25	-
	w575e12	9,05	13,14	*	4,38	4,66	-
W575M02	w575d12	4,08	4,66	4,38	*	9,23	7,85
	w575c12	-	4,25	4,66	9,23	*	9,89
	w575b12	-	-	-	7,85	9,89	*

Fig. 157. Dagmarsgården, Ribe, Denmark (ASR 1015). Bar diagram showing the chronological position of the dated samples the Dagmarsgården barrel, alongside the matrix of internal correlation.

Filenames	-	-	w575M01	w575M02	
-	start	dates	AD1031	AD881	
-	dates	end	AD1138	AD1121	
DM200004	30BC	AD1960	6,46	-	G Weser (GU)
frpardst	AD848	AD1597	7,45	-	Paris Basin (Jansma pers.comm.)
WD400std	AD400	AD1975	8,25	8,47	West Germany (Hollstein 1980)
nlzuidmm	AD427	AD1752	9,70	7,22	Netherlands S. (Jansma 1995)
DM300001	AD822	AD1964	5,65	7,81	West Germany (GU)
DM700001	AD631	AD1950	5,76	6,72	Suedtyskland (GU)
maas672m	AD672	AD1986	6,58	5,94	Oost Belgie (Jansma pers.comm.)
nlnoordm	AD1041	AD1346	5,77	4,14	N. Netherlands (Jansma 1995)
freastst	AD582	AD1991	6,07	4,22	East France (Jansma pers.comm.)
DM200003	AD1004	AD1970	5,31	3,65	Weserbergland (GU)
frlotha1	AD1016	AD1988	4,34	4,35	North-East France (Jansma pers.comm.)
DM200005	AD915	AD1873	5,63	3,71	Niedersachsen Nord (GU)
ofrmidde	AD300	AD1200	5,01	3,32	O,Friesl, (Jansma pers.comm.)
GBM00005	AD413	AD1654	5,56	-	London (SU)
GBM00004	AD882	AD1981	3,33	3,86	East Midland (SU)
DM200006	AD914	AD1873	5,17	-	Lüneburger Heide (GU)

Fig. 158. Dagmarsgården, Ribe, Denmark (ASR 1015). Table showing the correlation between the mean for the barrel from Dagmarsgården and master chronologies from Northern Europe.

10.1.5 Præstegade 13, Ribe

Two barrels were found in Ribe, in Western Jutland, Denmark, during excavations by Mogens Bencard in 1963 (Antikvarisk Samling i Ribe, archive ASR33/63). They had been re-used, one on top of the other, to line a well. Nine samples from one of these barrels were analysed in 1994 and at the time were dated to the second half of the 12th century (Eriksen 1995a; 1995b). At the time of the analysis, it was found that the tree-ring curve matched best with English chronologies, and thus the barrel was coined 'the English barrel'. When compared with data from England and Scotland however, it was found that the tree-ring sequence from the Ribe barrel showed a great similarity to that of two other barrels, one found in London, the other in Perth in Scotland (Crone et.al. 2004). The curves from these three barrels combined, achieved the highest correlation, not with English chronologies, but with French. The table in fig. 159 shows the *t*-values achieved for the tree-ring curve from this barrel, where clearly a French origin can be suggested. It is highly probable that these barrels represent the transport of wine from France in the second half of the 12th century, for use in the churches or monasteries at Mass or for 'festive' consumption. Whatever goods these barrels contained, the dendrochronological provenance results point to the Champagne/Burgundy region of

		7022M00X	G0010012
		AD963	AD1146
		AD1147	AD1204
freastst	East France (Jansma pers.comm.)	9,97	-
GBM00007	London (SU)	7,24	-
WD400std	Germany (Hollstein 1980)	6,50	4,69
nlzuidmm	S. Netherlands (Jansma 1995)	5,76	4,47
GBM00010	Southern England (SU)	5,74	-
DM300001	Westdeutschland (GU)	5,49	5,22
maas672m	East Belgium (Jansma pers.comm.)	5,20	4,06
DM700001	S. Germany (GU)	4,83	4,97
nlnoordm	N. Netherlands (Jansma 1995)	4,64	-
frpardst	Paris Basin (Jansma pers.comm.)	4,63	4,84
frlotha1	North-East France (Jansma pers.comm.)	-	5,62

Fig. 159. Præstegade 13, Ribe, Denmark. Table showing the correlation between the mean for the barrel from Præstegade 13 and master chronologies from Northern Europe.

France, and it was here in the 12th and 13th centuries that the so-called Champagne Fairs were held, in towns such as Troyes and Provins in North-central France (Hunt and Murray 1999, 28-30).

10.1.6 Ribelund (ASR 926)

Carsten Sønderby, who had analysed the barrel in 1999, kindly sent the measurements. Fifteen staves were analysed and 14 were averaged together to a single mean curve. A date in the late 8th century was suggested by Sønderby, but he considered the dated position uncertain. He writes "hvis dateringen er rigtig" in his report, and in the accompanying letter "anvende det magre resultat med største forsigtighed" (Den Antikvariske Samling, Ribe archive ASR926, Carsten Sønderby in letter and report to Claus Fevejle dated 12th February 1999). In the reassessment of this date it has not been possible to identify a position for the tree-ring curve from the barrel in the 8th century. On the contrary, a quite different position emerges in this re-analysis. The *t*-values achieved between the barrel and master chronologies at the position AD 1037 to AD 1153 are shown in fig. 160. It can be seen that the barrel matches with site chronologies and master chronologies from northwest German and adjacent regions. The relatively low *t*-values for such a seemingly well-

Filenames		w426M01
-		AD1037
-		AD1153
G370OM01	Dötlingen Lower Saxony (EU-project)	6,70
DM200005	Niedersachsen Nord (GU)	6,66
DM200006	Lüneburger Heide (GU)	5,93
ofrmidde	O,Friesl, (Jansma pers.comm.)	5,01
DM200004	G Weser (GU)	4,82
nlnoordm	N. Netherlands (Jansma 1995)	4,09
WD400std	Germany (Hollstein 1980)	4,05
nlzuidmm	S. Netherlands (Jansma 1995)	3,52
4M000001	Danmark Svendborg (NM)	3,47
frpardst	Paris Basin (Jansma pers.comm.)	3,34

Fig. 160. Ribelund, Jutland, Denmark. Table showing the correlation between the mean for the barrel from Ribelund and master chronologies from Northern Europe.

replicated tree-ring mean curve is due to the probability that the staves came from just one tree. It seems that the new dating would not be in conflict with the other archaeological data. No other dateable objects (ceramics for example) were found in the well (Claus Fevejle, pers. comm.)

10.1.7 Nygade 10, Ribe (ASR 11)

Just two staves were analysed from a barrel from Nygade 10 in Ribe. The tree-ring curves from the two samples match so well together that it can be concluded that the two staves were probably made from the same tree. A mean of the two curves (G0010012) consists of just 59 rings and covers the period AD 1146-1204. Sapwood preserved on one of the samples means that the felling date for the tree could be placed at AD 1210-30. What with the low number of rings and with the fact that only one tree is represented, a provenance determination would not be reliable. The table in fig. 161 shows the *t*-values achieved for the tree-ring curve, where it can be seen that the *t*-values are not exceedingly high, but the highest appear with western Germany and Northeast France. While it is not safe to hazard a guess as to the barrel's provenance, even with this flimsy material an indication of the origin can be given, at least at the wide regional level. The barrel is made from oak which grew in Western continental Europe.

Filenames		G0010012
-		AD1146
-		AD1204
frlotha1	Northeast France (Jansma pers.comm.)	5,62
DM300001	West Germany (GU)	5,22
DM700001	South Germany (GU)	4,97
frpardst	Paris Basin (Jansma pers.comm.)	4,84
WD400std	Germany (Hollstein 1980)	4,69
nlzuidmm	South Netherlands (Jansma 1995)	4,47
maas672m	East Belgium (Jansma pers.comm.)	4,06

Fig. 161. Nygade 10, Ribe, Denmark. Table showing the correlation between the mean for the barrel from Nygade 10 and master chronologies from Northern Europe.

10.1.8 Skjern Bro barrel

This single barrel stave was found during archaeological examination of the Skjern River, prior to works to restore the river to its former meandering course. The stave was found some 100 metres downstream from a bridge and weir construction over the river (Jørgensen and Egeberg 2001; Daly 2001c; 2005). The tree-ring curve from the stave covered 108 years and is dated to the period AD 1115-1222. No sapwood on the stave means that the felling date can be placed at after *c.* 1240. While most of the high *t*-values that the tree-ring curve gets against master chronologies are with Lower Saxony and other Northwest German references, a high value also appears with a London chronology (fig. 162). It would be necessary to check the provenance determination in this case at the second and third levels, to rule out the possibility of exotic timbers in some of these master chronologies, but as this is just a single measurement, the *t*-values reached aren't high enough for detailed provenance determination.

Filenames		7031203A
-		AD1115
-		AD1222
GBM00003	London (SU)	5,40
DM200005	Niedersachsen Nord (GU)	5,12
DM200003	Weserbergland (GU)	5,02
DM200006	Lüneburger Heide (GU)	4,95
DM200004	G Weser (GU)	4,59
4M000001	Svendborg (NM)	4,26
GBM00005	London (SU)	4,25
DM100008	Lübeck (HU)	3,87
GBM00002	England (SU)	3,82
DM100003	Schleswig-Holstein (HU)	3,74
DM200001	Nieders, Kuestenraum (GU)	3,30
DM700001	Suedtyskland (GU)	3,13
GBM00004	East Midland (SU)	3,02

Fig. 162. Skjern Bro barrel stave, Jutland, Denmark. Table showing the correlation between the mean for the barrel from Skjern Bro and master chronologies from Northern Europe.

10.1.9 Stege, Møn & Skt Pederstræde, Viborg (the late medieval well)

Two barrels can be dealt with together, as they have been dated to the same decade, and the origin of the trees they were manufactured from is also very similar.

The barrel from Storegade syd in the town of Stege on the island of Møn, was excavated by Sydsjællands Museum Vordingborg. The dendrochronological analysis showed that the trees used for the barrel were felled in *c.* 1280 (Bonde 2003). The average for this barrel is made up of the tree-ring measurements from four samples and covers 178 years.

A late medieval well from Skt. Pederstræde in Viborg was excavated by Viborg Stiftsmuseum. It was lined with two barrels, one preserved to full length, the other only partially preserved (truncated). The dendrochronological analysis was carried out as part of this thesis. The fully preserved top barrel is of beech, *Fagus, sp*. One sample was measured. It contained 134 rings and is not dated. One oak wedge was used to cover a square hole in one of the beech staves. It was analysed and contained 86 tree-rings. This piece could not be dated. The partially preserved truncated barrel is of oak. All 13 staves were analysed and all are dated. Sapwood was preserved on six of the staves. The felling of the trees, which were used in making the oak barrel, took place in circa AD 1270.

As these two barrels are so similar in age, and as they both pointed towards the same region of origin, it was interesting to test them together. The *t*-value between the two barrel means is $t = 8.72$ but in addition a test of the correlation between the individual measurements from both barrels is shown in fig. 163. The file numbers for the Stege barrel are highlighted in green (beginning with 3032) while those from Skt Pederstræde are in yellow (beginning with F004). As can be seen, there is good correlation between the samples in each barrel, and between the two barrels. It would be interesting to see what kinds of results an average of the two barrels combined might give, in the provenance determination test, so an average of the measurements, boxed in the matrix, was made. The table (fig. 164) shows the resulting correlations between the combined average, and

	30321019	3032113b	30321039	30321029	30321099	30321049	F004017A	F004015A	f004013a	F004019A	F004022A	F004023A	F004024A	F004014A	F004012B	F004020A	F004016A	30321079	F004012A
30321019	*	5,22	\	\	-	-	\	\	\	\	\	\	\	\	\	\	\	-	-
3032113b	5,22	*	4,14	5,24	5,44	4,42	4,3	5,93	5,03	4,92	3,49	4,88	3,89	3,1	3,54	-	-	-	-
30321039	\	4,14	*	4,89	5,48	3,93	7,15	4,67	6,38	5,61	4,37	5,82	4,77	5,55	3,59	3,07	4,95	-	\
30321029	\	5,24	4,89	*	6,93	5,67	6,95	5,46	6,07	6	5,2	8,32	6,57	6,04	4,94	3,41	4,37	-	\
30321099	-	5,44	5,48	6,93	*	9,91	6,78	-	5,16	4,5	4,17	6,97	4,19	4,78	6,09	3,97	-	-	-
30321049	-	4,42	3,93	5,67	9,91	*	4,92	-	3,99	4,54	-	7,69	5,19	3,72	4,83	3,7	3	3,44	-
F004017A	\	4,3	7,15	6,95	6,78	4,92	*	6,24	8,34	8,21	7,59	7,22	6,00	7,5	5,29	5,74	4,53	-	\
F004015A	\	5,93	4,67	5,46	-	-	6,24	*	6,93	6,84	5,98	4,58	5,39	5,97	3,24	3,14	3,56	-	\
f004013a	\	5,03	6,38	6,07	5,16	3,99	8,34	6,93	*	11,77	10,76	7,91	5,23	4,97	5,21	-	-	-	\
F004019A	\	4,92	5,61	6	4,5	4,54	8,21	6,84	11,77	*	15,96	6,86	4,97	5,55	4,56	-	3,91	3,08	-
F004022A	\	3,49	4,37	5,2	4,17	-	7,59	5,98	10,76	15,96	*	5,09	5,09	4,26	4,58	-	3,59	-	-
F004023A	\	4,88	5,82	8,32	6,97	7,69	7,22	4,58	7,91	6,86	5,09	*	5,97	4,21	3,27	4,49	-	-	\
F004024A	\	3,89	4,77	6,57	4,19	5,19	6,00	5,39	5,23	4,97	5,09	5,97	*	8,7	6,57	3,45	4,17	3,73	\
F004014A	\	3,1	5,55	6,04	4,78	3,72	7,5	5,97	4,97	5,55	4,26	4,21	8,7	*	6,65	3,38	4,39	-	\
F004012B	\	3,54	3,59	4,94	6,09	4,83	5,29	3,24	5,21	4,56	4,58	3,27	6,57	6,65	*	3,32	-	-	\
F004020A	\	-	3,07	3,41	3,97	3,7	5,74	3,14	-	-	-	4,49	3,45	3,38	3,32	*	-	-	\
F004016A	\	-	4,95	4,37	-	3	4,53	3,56	-	3,91	3,59	-	4,17	4,39	-	-	*	4,16	\
30321079	-	-	-	-	-	3,44	-	-	-	3,08	-	-	3,73	-	-	-	4,16	*	-
F004012A	-	-	\	\	-	-	\	\	\	-	-	\	\	\	\	\	\	-	*

Fig. 163. Barrels from Stege, Møn, Denmark and Skt. Pederstræde, Viborg, Jutland, Denmark. Matrix of correlation between the individual measurements from the two barrels.

Filenames		stege and pederstræde barrels M01
-		AD1091
-		AD1268
DM100003	Schleswig-Holstein	12,55
DM100010	Lübeck	10,80
P727001M	Szczecin	10,20
P719M002	Puck	9,14
H11JBM01	Koenigstr 16 6 Timber	9,01
P671001M	Elblag	8,76
P676001M	Kolobrzeg	8,67
H11JAM01	Mengstr 40 8 Timber	7,97
nlmidden	Mid NL	7,78
PM000004	Gdansk Pomerania	7,75
D001M000	Altenkirchen	7,61
4M000001	Svendborg	6,75
P738001M	Dabrowno	6,60
DM200004	G Weser	6,42
DM200005	Niedersachsen Nord	6,28
DM200006	Lüneburger Heide	6,19
2x900001	Zealand	6,09
0680001S	Gdansk-St. Nikolaus	5,95
DM100007	Hamburg	5,88
9M456781	Jylland/Fyn	5,74
DM200003	Weserbergland	5,67
ofrmidde	O,Friesl	5,47
0686003S	Przezmark	5,30
0681005S	Puck Kirche	4,85
P720303M	Vistula	4,21
0684004S	Starzyno	4,01
nlnoor10	NL Noord	4,00

Fig. 164. Barrels from Stege, Møn, Denmark and Skt. Pederstræde, Viborg, Jutland, Denmark. Table showing the correlation between a single mean for the two barrels and master chronologies from Northern Europe.

master chronologies for northern Europe. The highest correlation appears with the Schleswig-Holstein chronology, but note that high values also appear with other coastal sites around the southern Baltic Sea. It would be interesting to check this two-barrel average with additional material from the Southern Baltic region, but this is not in the remit of this thesis. The conclusion of the provenance determination must be that the barrels indicate a Southwestern Baltic origin, and can be indicators of the trade that we know was taking place between the Hanseatic towns of the region, into Scandinavian markets at the end of the 13th century.

10.1.10 Slotsgade 3-7, Ribe

Six samples were taken for dendrochronological analysis from a barrel in a well at Slotsgade 3-7, Ribe. The analysis was carried out by Carsten Sønderby in 1998, where he found that the felling date for the trees used to make the barrel was in the AD 1270s. He wrote that the barrel dates with a western German chronology covering the central Rhine region and that the barrel is probably from that region (Den Antikvariske Samling, Ribe archive ASR1200, Carsten Sønderby in letter and report to Lis Andersen dated 4th September 1998). Carsten Sønderby kindly allowed access to his measurements. The tree-ring curves from the six barrel-staves match well together, and are averaged to form a curve of 142 years. This covers the period AD 1114-1255. As the table of correlation shows, the highest *t*-value does indeed appear with a western German chronology, and with chronologies from the Netherlands and Belgium, indeed confirming Sønderby's original conclusion.

10.1.11 Saltgade 4, Ribe

Barrels from two wells were analysed by Carsten Sønderby in 1992 and one of the barrels could be dated. As no sapwood was preserved the date is placed at after

Filenames		w80M00A
-		AD1147
-		AD1258
GBM00006	Southern England (SU)	7,39
frpardst	Paris Basin (Jansma pers.comm.)	7,35
GBM00004	East Midland (SU)	6,71
GBM00007	London (SU)	6,59
freastst	East France (Jansma pers.comm.)	6,54
GBM00005	London (SU)	6,45
WD400std	Germany (Hollstein 1980)	6,39
DM300001	Westdeutschland (GU)	6,38
DM700001	Suedtyskland (GU)	6,03
zdlmidde	S. Germany (Jansma pers.comm.)	5,89
frlotha1	North-East France (Jansma pers.comm.)	5,69
nlzuidmm	S. Netherlands (Jansma 1995)	5,63
GBM00002	England (SU)	5,31
maas672m	East Belgium (Jansma pers.comm.)	5,05
GBM00010	Southern England (SU)	5,03
0M010006	Koeln+Wouwermann paintings	4,98
0M010005	Koeln paintings	4,61
GBM00008	Northern England/Wales (SU)	4,45
nlnoor10	N. Netherlands (Hjansma 1995)	3,91
SM600001	Mellansverige (LU)	3,72
DM200006	Lüneburger Heide (GU)	3,62

Fig. 165. Saltgade 4, Ribe, Jutland, Denmark. Table showing the correlation between the mean for the barrel from Saltgade 4 and master chronologies from Northern Europe.

1272, and the dating was carried out using German chronologies (Den Antikvariske Samling, Ribe archive ASR2M80D, Carsten Sønderby in letter and report dated 11th May 1992). Carsten Sønderby sent his measurements, of which there are 14. The internal correlation between the samples is high, and therefore all 14 tree-ring curves are included in the mean curve for the barrel. The table of correlation between this tree-ring curve and master chronologies for Northern Europe are shown in fig. 165. Now while we can see high *t*-values with German chronologies, we get higher correlation with Southern England and with Northern French chronologies.

Filenames		w439M02	w439M01
-		AD1157	AD1157
-		AD1286	AD1299
P727001M	Szczecin (Ważny pers.comm.)	7,74	6,98
DM100008	Lübeck (HU)	7,68	6,62
H11HFM01	Hl Hundestr (EU-project)	7,60	7,11
DM100003	Schleswig-Holstein (HU)	7,59	6,84
0045M002	Vejby Skib (Bonde and Jensen 1995)	7,22	6,76
H11JAM01	Hl Mengstr (EU-project)	6,60	5,70
PM000007	Elblag (Ważny pers.comm.)	6,56	6,59
GO11VM01	So14 (EU-project)	6,48	5,99
H118HM02	Kiel, Alte Feuerwac (EU-project)	6,25	6,93
PM000004	Gdansk Pomerania (Ważny pers.comm.)	5,98	5,96
0676001S	Kolobrzeg (Ważny pers.comm.)	5,95	6,21
H11JBM01	Hl-Koenigstr (EU-project)	5,88	5,30
nlmidden	Mid. Netherlands (Jansma 1995)	5,62	4,87
4M000001	Svendborg (NM)	5,55	4,96
G311HM01	W26 (EU-project)	5,54	5,36
G5701M02	A/B83 (EU-project)	5,54	5,27
G315ZM01	Alki (EU-project)	5,43	5,18
60132M02	Boringholm Barrels (Daly 2005a)	5,41	5,08
DM200005	Niedersachsen Nord (GU)	5,25	4,56
G340IM02	Bsge (EU-project)	5,21	5,26
DM200006	Lüneburger Heide (GU)	5,12	4,47
DM200004	G Weser (GU)	5,11	4,84
SM100003	Ystad (Eggertsson pers.comm.)	5,08	5,60
G312CM01	Ubg (EU-project)	4,85	5,74
P738001M	Dabrowno (Ważny pers.comm.)	4,85	4,62
DM100007	Hamburg (HU)	4,78	4,56
P773101M	Elblag Gdansk Ratusz (Ważny pers.comm.)	4,61	4,64
CD40UZ03	Brogade (EU-project)	4,60	4,75
0686003S	Pl-Przezmark (Ważny pers.comm.)	4,54	4,21
OLUN0020	Lund (Eggertsson pers.comm.)	4,37	4,15
DM200003	Weserbergland (GU)	4,34	3,80
zdlmidde	S. Germany (Jansma pers.comm.)	4,29	3,63
WD400std	Germany (Hollstein 1980)	4,14	3,77
DM700001	Suedtyskland (GU)	4,07	3,55

Fig. 166. Barrel from Horsens, Jutland, Denmark (A130). Table showing the correlation between two means for the Horsens barrel and master and site chronologies from Northern Europe.

10.1.12 Horsens (A116)

Again a well lined with a stave built barrel from the town of Horsens was analysed by Carsten Sønderby who dated the felling of the trees for the barrel to the beginning of the 14th century Carsten Sønderby, pers. comm.). Just three samples were analysed and the internal agreement between the tree-ring curves was quite good, though two samples matched each other better than the third. In the re-analysis of this barrel therefore, two means have been made, one of all three samples (W439M01), and one of just the two that match best with each other (W439M02). As can be seen in the table in fig. 166 both means are compared with master and site chronologies for Northern Europe. The highest *t*-values appear with chronologies from the towns of Szczecin and Lübeck, and with a regional chronology from Schleswig-Holstein. While the *t*-values are too low to point out a specific provenance for the timber, the evidence indicates an origin in the coastal area of North-east Germany

10.1.13 The southern Baltic group

As can be seen by the table summarising the results of all barrel analyses included in this study, a considerable group of barrels dating from the 14th and early 15th centuries have been found to be of a southern Baltic origin. The evidence for this is given in a single table showing the correlation of the means for these barrels against master and site chronologies for Northern Europe (fig. 167). The results are organised chronologically.

Just one stave from G. Åby Kirkegaard, Århus was analysed by Carsten Sønderby. A date of after *c.* 1325 is found for this single stave.

Four staves from two barrels found at Kathredralskole, Ribe were analysed, also by Carsten Sønderby, two of which match well together and are from trees felled in *c.* 1320. A mean of these two is tested in the table. The tree-ring curves from the other two staves could also be dated, to *c.* 1315, although the conclusion reached by Sønderby ((Den Antikvariske Samling, Ribe archive ASR1445, Carsten Sønderby in analysis report) that the timber was of local Danish origin seems not to be the case. Highest correlations for both these series appear also with southern Baltic references.

Three staves from Suså, Næstved were analysed in 2001 (Daly 2001e). No sapwood was preserved on the staves so the date for the felling of the trees for the staves is after 1337.

A barrel found in Aberdeen in Scotland was analysed by Anne Crone (Anne Crone pers.comm.).

		G. Åby Kirkegaard Århus	Kathredralskole Ribe	Suså Næstved	Aberdeen	Boringholm	Svendborg	Niels Hemmingsensgade Copenhagen	Kompagnistræde Næstved
Filenames		WM20 29A14	WM200 5M01	2121 4M01	0056 M001	6013 2M02	4079 M001	2129 M001	B011 1M01
-		AD1211	AD1193	AD1138	AD1174	AD1145	AD1241	AD1125	AD1201
-		AD1310	AD1312	AD1321	AD1335	AD1368	AD1388	AD1399	AD1417
0M040004	Baltic 1 paintings	3,18	3,62	5,10	7,22	6,42	3,16	7,06	4,73
0M040005	Baltic 2 paintings	-	4,52	-	4,36	4,97	3,30	7,30	3,66
0M010001	Weyden paintings	3,74	3,47	4,29	4,95	6,30	-	11,40	3,55
P734002M	Bransk (Ważny pers.comm.)	-	-	-	4,24	-	-	6,24	-
0693005S	Pl-Pruszcz Gdanski (Ważny pers.comm.)	3,01	5,71	7,79	4,87	5,77	4,54	3,63	3,65
P720404M	Pultusk (Ważny pers.comm.)	-	-	-	4,35	4,70	-	8,18	3,99
P676001M	Kolobrzeg (Ważny pers.comm.)	6,80	8,31	9,63	14,76	11,06	6,10	7,59	10,49
PM000004	Gdansk Pomerania (Ważny pers.comm.)	11,19	8,11	6,76	13,29	10,93	7,61	9,44	8,88
PM000007	Elblag (Ważny pers.comm.)	9,20	7,73	6,84	11,85	10,54	5,90	7,83	7,60
0680001S	Gdansk-St,Nikolaus (Ważny pers.comm.)	7,22	5,25	5,23	10,52	10,15	5,81	5,57	7,39
0686003S	Pl-Przezmark (Ważny pers.comm.)	7,97	6,16	4,72	8,63	6,63	5,21	5,68	6,02
0684004S	Pl-Starzyno (Ważny pers.comm.)	6,36	4,11	4,26	8,56	5,36	-	6,39	7,28
0681005S	Pl-Puck Kirche (Ważny pers.comm.)	5,46	-	-	5,22	6,59	5,69	3,69	6,17
P773505S	Elblag (Ważny pers.comm.)	4,67	3,88	4,40	7,08	5,03	-	5,50	4,99
P738001M	Dabrowno (Ważny pers.comm.)	3,69	4,19	3,66	6,44	6,16	5,03	4,33	3,21
P727001M	Szczecin (Ważny pers.comm.)	-	6,59	4,28	6,29	5,72	-	3,60	-
GD98010A	Gdansk Wyspa Sp. (Ważny pers.comm.)	4,16	-	-	6,25	6,29	4,82	5,13	3,74
P670350S	Gdansk/Powroznicza (Ważny pers.comm.)	-	3,82	3,23	3,27	3,92	-	-	3,23
DM100003	Schleswig-Holstein (HU)	5,08	5,38	6,80	8,87	7,39	3,63	3,56	4,34
DM100008	Lübeck (HU)	4,66	6,31	5,56	8,66	4,38	-	3,24	-
DM200005	Niedersachsen Nord (GU)	3,54	5,08	4,60	7,32	7,14	-	5,93	3,52
DM200006	Lüneburger Heide (GU)	3,90	4,64	5,02	7,16	6,85	-	5,68	3,60
DM200004	G Weser (GU)	5,67	4,40	3,90	6,05	5,48	-	5,48	-
DM100007	Hamburg (HU)	-	4,33	-	4,26	5,13	-	4,71	-
2x900001	Zealand (NM)	4,77	3,40	5,33	10,12	6,55	-	5,28	3,55
9M456781	Jylland/Fyn (NM)	3,08	-	5,44	7,19	5,43	-	-	3,88
SM000001	Sydvestskaane (LU)	4,63	3,51	4,92	8,22	5,46	-	3,69	3,01
SM600002	Smaaland-Oeland (LU)	4,22	3,83	-	7,06	5,09	-	4,33	4,09

Fig. 167. The southern Baltic barrel group. Table showing the correlation between the measurements or means for the southern Baltic barrels and master and site chronologies from Northern Europe.

Parts of several barrels were analysed from a fortified farmstead in Jutland at Boringholm (Kock 2005). There were six pieces analysed, three staves and three lids. The tree-ring curve from one of the lids matched less well with the remaining five, and therefore this one was left out of the average for the barrel parts. Sapwood on two staves allowed the felling date for the oaks to be placed at *c.* 1372 (Daly 2005a).

Barrel parts from excavations in Skattergade, Svendborg were analysed in 1982 but no date emerged at the time (Bonde 1982). Two staves and a board have been dated subsequently but with no sapwood preserved on any of the pieces only *termini post quem* dates are possible; after circa 1355, after circa 1390 and after circa 1400.

Right in the heart of Copenhagen a large oak barrel-shaped vat was found, in 2000, during excavation in Niels Hemmingsensgade carried out by the Copenhagen City Museum. Three staves were cut and analysed and a felling date for the trees used for the barrel is estimated to after *c.* 1410 (Daly 2000c).

The final barrel in this group was found at excavations in Kompagnistræde, Næstved. It was one (K672) of several, but is dealt with alone here, as it showed a different provenance than the other pieces from the excavation. Three oak staves were analysed from this barrel, but as the internal correlation between the three tree-ring curves is not high, the felling dates for the trees used for the staves could be placed at after 1400, *c.* 1400-1425 and *c.* 1418-1440 respectively.

Well as can be seen in the table of correlation for this group, all these barrels are made from oak that grew in the southern Baltic region. Now the pattern of this period where we find so many timbers of Baltic origin is reflected in the results of the shipwrecks dating to the period, and we have seen it in the many analyses of panels in paintings, furniture etc. as is discussed below.

10.1.14 Brolæggerstræde, Copenhagen

Archaeological excavations on the corner of Brolæggerstræde and Knabrostræde again in the heart of Copenhagen, carried out by the Copenhagen City Museum, resulted in the finding of two barrels. Staves from both were to be analysed but it was found that one of the barrels was not of oak but of chestnut, *Castanea sp*,, so only one barrel was analysed. Six samples were dated, to after AD 1466.

The barrel is dated using master chronologies from England and France (fig. 168). The highest correlation though was found with another barrel, from Belgium (Ian Tyers pers.comm.). It seems that by the middle or end of the 15th

		B004M001
ENGLAND	England East Anglia 2 (Ian Tyers, pers. com.)	4.63
	England London region 86 (Ian Tyers, pers. com.)	6.02
	England South East 75 (Ian Tyers, pers. com.)	5.46
FRANCE	Beauvais (Ian Tyers, pers. com.)	3.41
	Amiens Cathedral Amiens Picardy France (Ian Tyers, pers. com.)	3.20
	France Oise9 - Normandy Picardie & Paris area Trenard (Ian Tyers, pers. com.)	4.96
	Burgundy version 31 Besancon (Ian Tyers, pers. com.)	7.04
	East France version 13 Besancon (Ian Tyers, pers. com.)	7.54
	France (Ian Tyers, pers. com.)	4.78
	La Pacaudiere (Ian Tyers, pers. com.)	5.63
	Northern France Pilcher 1987 (Ian Tyers, pers. com.)	5.11
	Paris Basin version 4 Lambert (Ian Tyers, pers. com.)	5.43
	West France version 1 Lambert (Ian Tyers, pers. com.)	7.02
BELGIUM	Heist Belgium Barrel T10B WFrance Pascale (Ian Tyers, pers. com.)	8.28
	Heist Belgium Barrel TA EFranceNeth Pascale (Ian Tyers, pers. com.)	7.02
	Heist Belgium Barrel TC WFrance Pascale (Ian Tyers, pers. com.)	7.79
NETHERLANDS	Netherlands - NL_HISTO T150 Jansma (Ian Tyers, pers. com.)	4.30
	Neth Med C7 T117 (Ian Tyers, pers. com.)	4.19
	S-hertogenbosch - Archaeological Netherland Jansma (Ian Tyers, pers. com.)	4.09

Fig. 168. The Brolæggerstræde barrel, Copenhagen, Denmark. Table showing the correlation between the mean for the barrel from Brolæggerstræde and master chronologies from Northern Europe, calculated by Ian Tyers, University of Sheffield.

century we begin to see barrels manufactured again of oak from other regions, after a century of dominance of the southern Baltic oak.

10.1.15 Late 16th to mid 17th century barrel finds

Finally let us look at the later examples of barrels from Danish finds. Three planks, which had been shaped to form a large lid for a large barrel, were found re-used in the construction of a large tub, that had been used for the dyeing of cloth, in Pilestræde 8, Copenhagen (Andersen and Moltsen, forthcoming). These three parts could be dated to after AD 1585. A barrel was also excavated at the other end of the country, in Skt. Pederstræde, Viborg (Hjermind 1998). It had been used to line a latrine, and while the staves of this barrel were not of oak, a barrel lid was found at the base of the latrine, and this was made of three rounded oak panels/planks. Sapwood was preserved on each of these planks, so that a felling date of 1652 or shortly after was identified.

			Pilestræde 8 Copenhagen	Skt. Pederstræde Viborg	
Filenames	-	-	B009M001	F0041M01	
-	start	dates	AD1407	AD1433	
-	dates	end	AD1574	AD1652	
9M456781	109BC	AD1986	-	3,71	Jylland/Fyn (NM)
DM100003	AD436	AD1968	-	5,85	Schleswig-Holstein (HU)
DM100008	AD457	AD1723	3,54	5,82	Lübeck (HU)
DM200005	AD915	AD1873	5,69	10,82	Niedersachsen Nord (GU)
DM200006	AD914	AD1873	6,17	10,15	Lüneburger Heide (GU)
DM100007	AD1080	AD1967	3,18	9,40	Hamburg (HU)
ntwe1357	AD1357	AD1724	4,36	8,99	East Netherlands (De Vries unpubl.)
DM200004	30BC	AD1960	4,98	8,77	G Weser (GU)
nlwf1040	AD1040	AD1972	4,82	8,62	Nederland/Westfalen (Tisje unpubl.)
nlmidden	AD1023	AD1666	5,12	8,18	Mid. Netherlands (Jansma 1995)
DM200003	AD1004	AD1970	4,85	8,09	Weserbergland (GU)
DM200001	AD1082	AD1972	-	6,76	Nieders, Kuestenraum (GU)
DM700001	AD631	AD1950	8,25	7,03	Suedtyskland (GU)
WD400std	AD400	AD1975	11,11	6,73	W. Germany (Hollstein 1980)
DM300001	AD822	AD1964	9,00	5,91	Westdeutschland (GU)
nlzuidmm	AD427	AD1752	8,22	6,42	S. Netherlands (Jansma 1995)
0M010006	AD1000	AD1655	8,70	5,39	Koeln Wouwermann Paintings
frlotha1	AD1016	AD1988	9,86	3,94	Noord-Oost Frankrijk (Jansma pers.comm.)
maas672m	AD672	AD1986	7,10	4,26	Oost Belgie (Jansma pers.comm.)
freastst	AD582	AD1991	5,85	-	East France (Jansma pers.comm.)
frpardst	AD848	AD1597	4,12	-	Paris Basin (Jansma pers.comm.)
PM000004	AD996	AD1985	-	4,47	Pl-Gdansk Pomerania (Ważny pers.comm.)

Fig. 169. Renæssance barrels from Pilestræde 8, Copenhagen and Viborg, Jutland. Table showing the correlation between the means for the barrels from Pilestræde 8 and Viborg and master chronologies from Northern Europe.

A table showing the correlations between the average tree-ring curves for each of these finds is shown in fig. 169. For the Pilestræde barrel lid we see high correlation with western Germany, the Netherlands and north-eastern France. We are probably dealing with timber from along the Rhine River. A high correlation also with one of the panel painting chronologies might have to do with inclusion of data from this region in what should be Southern Baltic material but this problem has not been investigated further. Testing at the second and third levels was not attempted for this barrel.

The correlation of the tree-ring curve for the Skt. Pederstræde barrel lid from Viborg show a quite different picture. Here highest correlation is with northern Lower Saxony and the Lüneburger region. Let us finally test this barrel lid at the second level, to remove the problems of contaminated master chronologies, especially here as we are dealing with a tree-ring curve which covers this later period. We produce the map shown in fig. 170. We see that the high correlation appears primarily with sites along the Weser River.

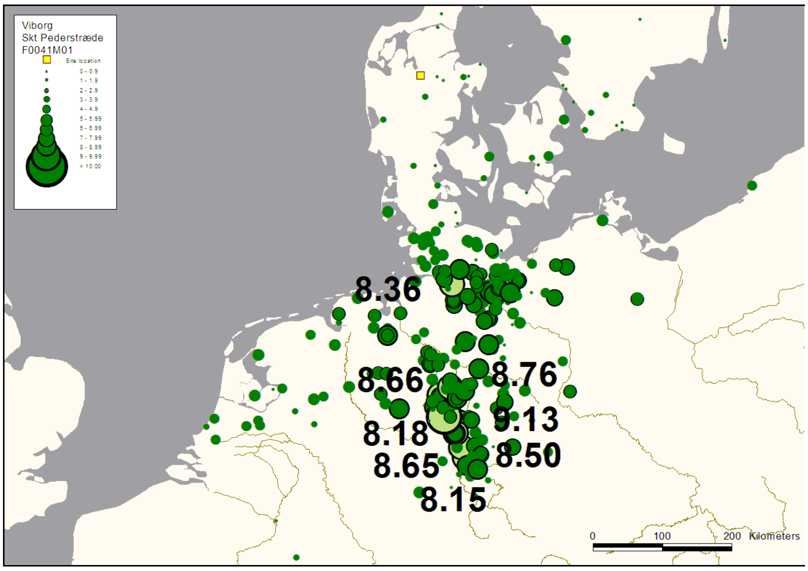


Fig. 170. The Renaissance barrel from Skt Pederstræde, Viborg, Jutland, Denmark. Map showing the distribution of correlation values achieved between the mean for the Skt Pederstræde Renaissance barrel and site chronologies from Northern Europe (the second level test).

10.2 *Summing up*

Can we make generalisations on the basis of the results of the 27 dated barrels that are looked at in this study, despite the uncertainty of the extent to which these were reused and transported to and from several markets or sites with a varying range of goods, before they were finally reused as the lining of wells and latrines? A list of the barrels presented here is ordered chronologically in fig. 153 above. Colours highlight the region of origin of the timber, as revealed in the analysis. The barrels are all Danish finds except one barrel from Aberdeen in Scotland. The list does not represent the full corpus of barrel finds in Denmark, it not being the object of this study to analyse every find, but to look at a selection of finds to demonstrate the application of the methodology. It can be seen that for a successful dating and provenance determination, generally either a good many samples must be analysed, or the few samples should contain a good many rings. Again it should be pointed out that we only have oak barrels here. Barrels of other wood, for example of beech, are not analysed. In terms of function, certain wood species might be suitable or unsuitable for certain goods. It has been suggested for example that oak barrels are not suitable for transporting salt, as the tannin will colour the salt (Jens Vellev, pers.comm.).

It can be seen that a pattern might be apparent in the barrel results. Three of the barrels in the 8th century group from the early phase of the town of Ribe, as mentioned above, can represent a single shipment of goods, as the date, correlation and origin for these three are so similar. The barrel results serve to confirm the trading status of Ribe at this early period, and the dates coincide also with the building of the causeway at Nybro (Frandsen 1999; Ravn 1999; Daly 2006) showing increased infrastructure in Ribe's hinterland in this century. Dendrochronological analysis of oak barrels found in the town of Dorestad in the Netherlands resulted in the dating of 34 barrels (Eckstein 1978). The dates range from late 7th century to mid 9th century, but by far the most were from *c*. 715 to *c*. 770. It was found that the barrels matched best with chronologies from the Mainz region of the Rhine basin.

Our Ribe barrels fit very neatly into this group of Dorestad barrels. It is explained that wine from the Rhineland was transported down the Rhine to Dorestad, and it could be from here wine was transported further to Ribe.

The single bucket stave analysed, from the late 10th or early 11th century, reminds us of the expansion of the Viking world at that time, where one piece of a bucket, made from oak from Northern England, ended its days discarded on the floor of the Smithy at Viborg Søndersø. Four barrel parts from the 12th century show that at this period a variety of sources for the oak appear in the Danish finds. We see one example of local wood, and three examples of barrels of oak from a variety of origins. It can be noted though that all three origins for these 12th century barrels are western continental Europe. One is from somewhere along the Rhine River in Germany, one from the Burgundy region of France (which also can be linked to two other barrels, one found in London, England and the other in Perth, Scotland) while the third is from coastal Lower Saxony.

Barrel parts from six sites are dated to the 13th century. While for two, from the first half of the century, a reliable provenance could not be identified, for four from the late 13th century a region of origin could be given. While we still see barrels from the western European region, now we also find barrels made of oak that seems to come from east of Denmark, in the region of Lübeck.

One barrel from the beginning of the 14th century has a similar provenance as the two Lübeck barrels from the preceding century, but after this barrel the picture changes radically. The Southern Baltic group is very clearly a chronologically well defined phenomenon, as the large block highlighted in yellow indicates. From the 1320s to the 1420s barrels built from southern Baltic oak predominate. The same phenomenon is apparent in the ship results above, and several publications also mention barrels of southern Baltic oak. Particularly, many barrels dating to the 15th century found at Raversijde in northern Holland match best with a southern Baltic chronology from Gdansk (Houbrechts and Pieters 1999). In fact all the barrels are of southern Baltic origin except one, which seems to be from the Burgundy region of France. The southern Baltic barrels are very uniform in size, while the French barrel is of different dimensions:

> "De tonnen zijn onderling zeer gelijkend, men zou haast zeggen identiek. Slechts één ton – deze die vermoedelijk uit Bourgondisch hout is vervaardigd – lijkt iets groter dan de overige" (Houbrechts and Pieters 1999, 255).

From around the middle of the 15^{th} century we again see a variety of sources of oak for barrels, reflecting the diversity of traded goods in Northern Europe.

Section III

11 Chapter 11: Timber, trade and tree-rings

Several aspects of discussion come from the process and the results of this study. One of the major and possibly most fundamental questions we can pose is tied up with the whole topic of trade in timber. If, in the past, building timber has been transported extensively over some distance from the felling site to the construction in which it was used, can we build a reliable dendroprovenance method using historical timber at all? The evidence for the extent of the trade of timber needs to be addressed from the historical point of view, as does the evidence that has emerged from the analysis in this study, which might be described as the archaeological and dendrochronological evidence for trade of timber. These questions have to be addressed, though also taking into account the different periods that are examined in this temporally very broad study. Examples from the Viking period through the Medieval period and into the Renaissance are shown in this study, and for each period different considerations emerge, many of which can be attributed to changing patterns of timber availability on the one hand, and of the transportation of specialised timber products on the other.

So the first discussion of this third and final section is derived, we might say, from the analysis of the oak tree-ring dataset for which the geographical location is theoretically ‘known’. That is the data from the numerous timbers from living trees and historical buildings (either standing or as archaeological remains) from Northern Europe.

Within this discussion, the mechanisms or the logistics of timber transport need to be considered. The investment in transport of bulky timber is ultimately an economic consideration, we might argue. Long distance transport must increase the price of timber so that by far the norm will have been to use local resources if available. Again this question has to be considered with regard to the whole period studied here, where gradual changes over the period, of increased consumption and dwindling resources in some areas, lead increasing to the necessity of buying timber from further away. Again specialised timber products should in this context also be taken into account, but considered separately from the discussion of bulk timber.

The application of the provenance determination technique is also discussed. Considerations of the archaeological context of different finds, and of the types of finds that lend themselves to a dendrochronological sourcing analysis, need to be looked into. The application of the technique, in terms of the archaeology of shipbuilding technology and traditions is clear, as the precise dating and now a very detailed identification of the timber source of ancient shipwrecks adds a new dimension to the ship development discussion. The quality of the results of the analyses of the barrel finds are also considered, in the light of the abundance or shortage of material in some cases, and in the light of the context of most of the finds, as secondary depositions in wells and latrines for the most part.

Finally, what of the future? While many results have emerged in the application of this newly developed oak timber provenance determination technique, it is still really only a beginning. The technique is limited to the dataset and its geographical and temporal distribution. Expansion of the tool requires the integration of additional data, generated by other dendrochronologists in Europe. An initiative to build a network of researchers has begun with this aim, and this is a very positive project.

The results are also limited in that many more oak structures and finds could be analysed or reassessed in the light of these new developments. We have started in the Scandinavian region, and here there are still many wrecks which have not been re-analysed here. For the cog question it is very apparent that additional analyses of many of the ship finds would be fruitful. Indeed there is huge room for expansion of the provenance determination tool to cover more regions in Europe, and there are innumerable oak structures which should be subjected to the provenance determination analysis.

11.1 *Timber trade*

The discussion of trade in timber has many aspects. Throughout the Northern European region smaller and larger extents of woodland had existed in most regions, quite deliberately, as woodlands were seen as a valuable resource on an equal footing with arable land. Woodlands were a source not only for building timber, but also for fuel, for berries, fruits and edible fungi, for animal fodder and for game. Management of the woodland resource has been shown from as early as the Neolithic period, where cyclical coppicing of hazel and other species has been carried out for the production of long regular shaped rods suitable for wattle, used extensively in construction of dwellings, fencing, fish weirs etc. From this period also, choice of specific species for specific functions has been practiced. The woodland resource has to be seen in all its variation, and this should not only be species specific. Rackham (1990) has pointed out that woodland consists of timber and underwood. The timber being the tall mature trees in the forest, the underwood is the wide variety of younger trees, bushes and smaller plants which inhabit the spaces beneath the high canopy. The underwood would for example have been harvested for firewood, while the large timber producing trees were reserved for the important constructional work.

11.2 *Wood shortage*

Given the difficulty of handling and transport of large timber it is most probable that local timber was preferred, in terms of logistics and price, over imported timber, if available. A very interesting discussion on the issue of the wood resource, pertinent to this question, deals with the fear of wood shortage between *c.* 1450 and 1850 (Warde 2006). Firstly Warde attempts to arrive at an estimate of the actual forest cover in Europe at the end of the 16th century. This is problematical in that the description of a forest could mean many things to those defining forest at the time, forestry often being a judicial definition, not an ecological one. In terms of wood supply, trees can have been found outside of these legally defined forests, which also could be harvested for fuel and timber. Interestingly Warde mentions that Flanders' lowest point in terms of forest cover was reached in the mid 13th century, and wood demand meant the specialisation and expansion of woodland, so that while wooded areas comprised only nine percent woodland in mid 13th century this had grown to 15 percent by the 18th century (Warde 2006, 34).

Warde describes the woodland management system called 'coppice with standards' by which mature trees were left dotted about the woodland while coppice management was carried out between these trees. He points out that many species of tree grow fast in their younger years, so that a coppicing rotation provided a steady supply of wood for fuel and fencing, and leaves for fodder. The standards, the trees allowed to grow to mature age grew into what is termed compass trees where their upper branches were able to spread wide, as they lacked competing neighbouring trees. These trees could then supply the large timber needed for buildings and particularly shipbuilding. Warde also suggests that coppicing encouraged oak growth as young oak trees would not thrive in dense forests. Warde then presents estimates of the kind of timber yield such coppice management produced, and these are quite high. He quite rightly suggests "to judge the case for scarcity, they must of course be ranged against demand" (Warde 2006, 37). He then goes on to estimate the requirements for fuel. He concludes that before 1750 only just over a tenth of the land area of Western Europe would have been needed for fuel. He writes: "the case for a general wood shortage by 1820 appears quite plausible, but it is hardly plausible for any period before 1750" (Warde 2006, 39). Of course, as he points out, this does not rule out the possibility that shortage might have been experienced locally. Where no waterway transport was available this was a pressing problem, because if it was necessary to transport the wood even relatively short distances, the price increased considerably. Warde attempts also to estimate the volume of demand of timber for the shipbuilding industry, which is also a difficult exercise. He proposes an estimate of twice the amount of timber in tonnage is needed for tonnes of shipping. He suggests thus that in the late 18th century the *c.* 3.5 million tonnes of ships would have required seven million tonnes or 10.3 cubic metres of oak. In other words "the real annual burden of supply for shipbuilding hovered around one percent of European domestic fuel demand at the end of the eighteenth century, and must have been a considerably lighter burden in earlier periods, as the merchant and naval marine advanced at a far more rapid rate than population across the early modern age" (Warde 2006, 40-41). Of course as he points out, the requirement of ship timber was unevenly distributed over the continent. Warde then takes a critical look at the motivation for the forest legislation that appeared for different regions throughout the European continent during the 16th century and that it was just one component in the regulation of many other resources. Justification for such regulations was often the scarcity question but, Warde argues, "the period at which legislation was initiated was not one of general scarcity, and the wide sweep of geographical contexts in which it was enacted indicates that something other than a response to local ecological pressures was taking place" (Warde 2006, 42). Rackham indeed argues that pasture in forestry was not a destructive land use. "Once the thirteenth century had passed, pasturage rarely destroyed the trees. The balance between trees and grassland often remained stable for centuries" (Rackham 1998, 2). He explains: "new generations of trees are not arising all the time. Regeneration is episodic: this is sometimes thought to be a conservation problem. A new generation of trees may arise when browsing falls below a critical limit" (Rackham 1998, 8-9).

In his description of British woodland, Rackham describes many aspects of the timber resource, particularly in regard to wood and timber availability. The felling of trees does not destroy the woodland. Just because a tree is felled does not mean that the land taken up by woodland is converted to other uses. Trees begin new growth from the tree-stump, producing many new shoots. "Although woods could be converted to other uses such as arable or wood-pasture, or vice versa, these were rare events in the life of any one wood and many woods…were hardly affected by them” (Rackham 1990, 62). Arguing for the continuity of woodland in the landscape Rackham also points out that “the economic value of woods, plus the capital cost of destroying them, tended to preserve woodland against other land uses from 1350 – 1850” (Rackham 1990, 83).

Now there are several implications, for this study, from the account of the wood resource that is described. For the different uses of different products of the forest/woodland, we have a distinct division of the renewable coppice and underwood resource which might have fully covered the requirement for fuel and small scale building construction. This means that the large, long-lived timber is reserved for the more major building requirements and therefore as a resource, in the wood scarcity question, should not be included in the figures for wood for burning. Warde points out that the requirement of timber for shipbuilding is only a small portion of the requirement for fuel, but such a direct comparison is not relevant when the two requirements demand wood from quite separate resources, the young renewable coppice/underwood vs. the mature tree resource, which takes a lot longer to grow back.

Warde’s observations fit very well with the observations in this study that the majority of the building timber in the tree-ring dataset, used in developing the provenance determination tool, is harvested and used within the local region. The shortage of timber was an intermittent and local phenomenon. Transport of timber over longer distances took place along waterways primarily, and was supplemented occasionally by timber shipped into coastal ports. Shipbuilding requirements, while estimated to be a fraction of requirements for fuel, nevertheless might have caused local shortage, as shipbuilding was concentrated in the coastal regions of Europe, and required larger longer lived timbers than for example wood for fuel. We know that timber transport increased over the period dealt with here, but forests, woodland and trees still grew and were utilised locally. It is this combination of usage of local and imported timbers for different uses that allows us to be able to map the movement of timber.

11.3 *Mechanisms of transport*

Now in terms of timber transport we need to distinguish between different methods of transport. Long distance transport of timber down rivers in the form of rafting seems to have been practiced extensively from even the Roman period, as evidenced by the dendrochronological analysis of Woerden 7, a Roman barge in the Netherlands. Here the main bulk oak timbers in the construction can be shown to have grown in middle Germany, up the Rhine River in the vicinity of the Mainz region, while other smaller constructional pieces are of local, Dutch oak (Vorst 2005). The pieces of local timber are an integral part of the construction, and cannot have been inserted at a later time (Yardeni Vorst, pers. comm). The conclusion is that the timber was floated down river and the barge was constructed in the lower Rhine region, in what is now the southern Netherlands.

So for as early as the Roman period we have evidence for the transport of timber down the Rhine. When the provenance of oak timber from a medieval ship is identified, can we with certainty suggest that the ship was also built in the same area? Indeed the transport of bulk building timber is an important aspect of the whole methodology in this study. Several aspects of this are discussed above, but here we might look into the way in which timber, and particularly oak timber can have been transport longer distances. Transport over land would be the least efficient mode of transport, while rafting on rivers, using the flow of water as the mode of propulsion, is widespread in the regions where major rivers exist. A third step in the long distance transport of timber in bulk would be again over water, but shipped, using wind as the mode of propulsion. In the following, we can consider the various forms of transport, but first we might consider the problem that, in the medieval period, oak timber was worked green, not seasoned. There is a time factor to be considered in the discussion of timber transport.

11.4 *Unseasoned timber*

It is argued that, for oak, the timber was worked green, not seasoned. Seasoned oak would have been near impossible to work, with the tools available. Indeed Rackham writes that to use timber immediately made it easier to work and reduced the problems of organization (Rackham 1990, 70). The oak, which we are dealing with in this study, is a dense hard timber, valued for its constructional qualities. When seasoned though, it would be very difficult to work with the hand tools available. So oak was shaped and used in construction while still green. Evidence for the practice of shaping timber while still green in the case of the Scandinavian oak identified in Scottish coastal buildings allow us to envisage that the timber was squared at the forest where the trees were felled. Crone observes that the Scandinavian oak in the Scottish buildings is almost consistently squared full logs, and that the surface of these squared beams have smooth toolmarks on their surface, indicating shaping while the timber was still green, i.e. presumably at the timber source (Crone 1998; 2000; 2002). Crone mentions in this context though that the joints must have been cut into seasoned wood (Crone 2000, 5). Another example of this practice is described in the context of Shapwick House in Somerset, England, where the shaping of the beams took place while the timber was still green, but that the tenons were cut into seasoned wood (Miles 1997, 54).

The question of the working of timber when still green has a bearing on the connection between the dendrochronological date for the felling of trees, and the date for the building of the construction being dated. It also has a bearing on the limitations in the material in terms of transport. If the builders need green timber to build a building or a ship, then there is a limit to the time it may take for the timbers to be transported from the felling site to the building site. This would immediately mean that the timbers were easier to handle and that they took up less space than if whole logs were transported. It also helps in understanding how a problem was solved. If the timber was worked green at source, then there wasn't a problem of it becoming seasoned in the time it took to transport or store the timber. This is why we see, in the records that document timber cargos, that timbers for specific purposes are listed. Preparation at source is necessary, and thus the decision as to what use the timber will be put to must also already be made at source. While the market for the oak panelling that we see in the 14th and 15th centuries might be reliable and regular enough that the production of this timber product could have been a standard activity, it is possible that the preparation of timber for shipbuilding was carried out to fill specific orders, and not as a routine timber product.

However it seems that oak should be still green for shipbuilding. We might divide the timber requirements for shipbuilding timber in two categories, the planking on the one hand, and the framing and other specialised parts on the other. The planking must be unseasoned wood to enable bending the planks into the hull shape. The finding of specific shapes in the trees to use for specific parts would probably have taken place by the shipbuilders before the trees were felled. This probability, combined with the awkwardness of these shapes for transport and the evidence that timbers were worked at source allows the conclusion that these parts will have been harvested near the ship building location. The shaping of pieces, which make use of the parts of the tree where the trunk branches into two, or where a large branch extends to one side, would be near impossible to achieve with seasoned oak, as the wood at these parts are extremely dense.

Having considered this, what then is the time frame, from the felling of the oak trees, within which timber can be used in shipbuilding? From experimental ship building using Viking period tools carried out at the Viking Ship Museum in Roskilde, Denmark, it has been estimated that a Viking / medieval clinker vessel of Nordic type would take approximately 10 shipbuilders, eight months to build (Jan Bill, pers.comm.). Working with that time frame, it is possible to envisage transport of pre-shaped planking to the shipbuilding site in the shipbuilding season, as we see in the case of the Dokøen examples discussed below. Again we get back to the timber availability question, and the question of transport costs. Shipping of framing timbers, the evidence suggests, was not the practice, as timber for these purposes could be found locally and was not easy to transport. Planking timber, shaped close to source specifically for shipbuilding was easier to handle, and was therefore probably shipped, and we have evidence for this in historical sources from the 14th century and from archaeological evidence for the early 15th century. This practice might though be taken as exceptional, not common, and particularly emerged from the lively exploitation and trade in Southern Baltic timber which flourished in this period.

11.5 *Rafting*

The possibility of rafting timber downriver to the site at which the timber was used is an aspect that has been aware of in work with dendrochronology especially for areas at the mouths of major European river systems. A study of the historical evidence for the phenomenon and the recognition of traces in construction timber in historic buildings is producing very interesting conclusions (Thomas Eißing, pers.comm. and Eißing 2004). The easiest way to transport heavy timber is by water, where the actual timbers are made into rafts and floated with the flow of the water to be sold to buyers downstream. The way in which the logs were tied was described by Eißing, where a hole was made in the timber to enable the fastening of the timbers together with a characteristic withy. These marks in the timber can then be recognised in the timbers in historical buildings. Eißing remarked that in the area in which he is working (Thuringia, Germany) where oak was one of the dominant naturally occurring tree species, yet 90% of church roofs from 13th to 18th century are made from softwoods, native to the higher ground of the "Thüringer Wald". So the softwoods must have been transported to the building locations. The scale of rafting would be adjusted to the means of transport available. Along smaller river courses smaller rafts might be made, while with large river courses very large rafts can be constructed.

Many of the insights into rafting are based on the modern period parallels, although the earliest trace in a timber of rafting from Eißing's work was on a timber which was dendrochronologically dated to 1155. The practise of rafting is highly significant in terms of the development of the provenance tool in this study, as rafting enables potentially the transport of timber over long distances, which would somewhat affect the distribution of the historical timber, which is used as the geographically fixed base for the provenancing tool. For the most part though the many case studies in this thesis show very clear geographical clusters of correlation, where the only exception really is in the Dutch region for the 16th century B&W1 example.

In the rafting discussion it is necessary to see a quantitative discussion of the actual evidence that has been accumulated, with a clear documentation of the dating and specifically the species of the rafted timbers. In the discussion with Eißing it emerged that oak is too heavy and dense to raft alone, it needs the softer woods to remain buoyant. So the picture that emerges from the rafting discussion seems to confirm the picture that is formed by this study, that large scale transport of bulk oak timber is the exception rather than the rule, and that the majority of that transport is of specialised timber products, particularly the explosion of southern Baltic panel wood from the 1340's on, as evidenced by the barrel analyses here, and the art-historical work of several authors (Baillie et al 1985; Crone 1998; Pousset 2004a; 2004b; Ważny 1990; 2002). Another of Eißing's remarks was concerning the way in which the distribution of the rafted timber was carried out. He suggests that the timber rafts rafted down river stopping at market towns along the way selling what they could before moving on. In this way, the distribution of timber near the source will be more frequent than timber distant from source. Again the argument that Warde suggests, that local timber resources are exploited where available, and distant transport is the exception.

11.6 *Bulk timber shipping*

Generally the picture emerging through the analysis of the extent of timber trade in the dendrochronological material over the period being studied can be compared with the picture we have of the gradual change that came about in Europe through the medieval and early modern periods. The pattern of the building of constructions using bulk timber (for both buildings on land and for shipbuilding) must be, in the late Viking and High Middle Ages, viewed in terms of the local timber resource. Only with the expansion of population after the Black Death do we see a real growth in the transport of bulk timber. Transport of conifer species dominates the trade of timber from Scandinavia, while oak timber is transported in smaller format, as boards and planking, and the trade from the Southern Baltic region dominates the hundred-year period from the mid 14th to mid 15th centuries. We can look at this picture of the timber trade emerging from the dendrochronological material in terms of Wallerstein's model of the economic world system (Wallerstein 1974), to see if we can find agreement or otherwise between the two approaches. Wallerstein's description of feudal Europe as consisting of

> "relatively small, relatively self-sufficient economic nodules based on a form of exploitation which involved the relatively direct appropriation of the small agricultural surplus produced within a manorial economy by a small class of nobility. Within Europe, there were at least two smaller world-economies, a medium-sized one based on the city-states of northern Italy and a smaller one based on the city-states of Flanders and northern Germany. Most of Europe was not directly involved in these networks." (Wallerstein 1974, 36-37).

As Wallerstein describes it:

> "From about 1150 to 1300, there was an expansion in Europe within the framework of the feudal mode of production, an expansion at once geographic, commercial, and demographic. From about 1300 to 1450, what expanded contracted, again at the three levels of geography, commerce and demography." (Wallerstein 1974, 37).

The causes of this collapse are discussed, and it is concluded that there were a combination of economic cyclical trends, that a point was reached where supply was unable to meet demand, and in combination with a climatic deterioration reducing food production making a population more susceptible to epidemic. It is Wallerstein's argument that the crisis of the 14th century was what made the enormous social change possible, to a capitalist world economy, and that this world economy was possible due to the territorial expansion of Europe. Wallerstein suggests that in feudal society long distance trade is limited, and that it is not of bulk commodities but of luxury or rare items. The principle economic activity is the production of food and handicraft, and these are traded within small economic regions (Wallerstein 1974, 27). Now really how do we define a small economic region? And we do have the occurrence of bulk timber from as early as 1286 in the example from St. Andrew's, Scotland (Baillie 1995, 132). The explosion in the appearance of Southern Baltic timber in Western Europe from the 1340s indicates that some transport of bulk commodities already began at this period, and the records for timber transport from Norway to England in the first half of the 14th century indicates that the pattern had begun before the demographic and economic collapse traditionally dated to the period of the Black Death in the mid 14th century. Wallerstein's suggestion that the crisis lasted all of 150 years from 1300 to 1450 seems not to be apparent in the northern European timber trade story.

We could also look at other theories of trade networks to see how they might enable an understanding of the mechanisms of the trade in bulk timber in the medieval period. Social exchange theory in relation to the modern world is described for example in Monge and Contractor (2003), and it endeavours to explain

> "how people create, maintain, and dissolve network linkages on the basis of resources and attributes they possess and need as well as the resources that others in their networks possess and need" (Monge and Contractor 2003, 210).

They go on to suggest that a network consists of a group of organisations along with the links that tie them together, and that a network is not necessarily organised around market or hierarchical forces, but around exchange and depencency relations. One of the limitations to the maintenance of networks is the communication capacity; "the probability of two people communicating is inversely proportional to the distance between them" (Krackhardt 1994, 213 quoted in Monge and Contractor 2003, 221).

If we try to apply this network theory to the medieval timber trade we can quickly see that the practicalities of communication are the greatest hindrance to the maintenance of exchange networks. The forester in the Southern Baltic lands is dependant on the network of transport, first by rafters downriver to the ports and subsequently onto ships to be sailed to markets in western Europe. In this light it is not surprising that those who control the communication between sellers and buyers who find themselves geographically far apart, in other words the merchants, become the centrally important structure in the development and maintenance of long distance trade that develops over the medieval period. This development also goes hand in hand with the technological development of communication in the form of ships with gradually increasing cargo capacity over the period. The trade network means that communication between two people over long distances only takes place via a complex series of links from those who control the resource to the consumer at the other end.

Records of the transport of timber have also been referred to in discussion of the timber trade. The Danish sound toll records for example, from 1497 to 1857, where the cargoes of ships passing the sound at Elsinore were recorded for taxing purposes. Timbers particularly from the Southern and Eastern Baltic region are often the subject of discussion and it is clearly seen in the archaeological record, or rather the dendrochronological record, the dominance of Southern Baltic oak from *c.* 1340s to 1440s particularly. When we see Southern Baltic oak in the dendrochronological record though, it is almost exclusively oak panelling of one form or another that is seen, as barrel staves, as wainscots used in paintings, as planking or panelling in prestigious buildings etc. The proportions of the different timber products that are seen in the sound toll records actually reflect this, where by far the dominant products are wainscots, clapboards and deals/planks. Even though the period which is dealt with in this study is predominantly earlier than these records, it is of note that unprepared structural timber is not at all prominent in the timber exports (Tossavainen 1994).

In the light of the emerging dendrochronological evidence for transport of timber for shipbuilding and other construction it is interesting to compare this with the evidence for timber transport in historical sources. Studies on the Danish sound toll records are mentioned above, but there are earlier sources in England which shed light on timber transport to England in the 14^{th} century (Childs 2002). In an analysis of these sources many comments are relevant in terms of the discussion here. In the description of the pattern of import of timber to England in the 14th century, Childs stresses that "most oak imports were in fact of relatively small timber. Sawn boards such as wainscots, righolt, and tunholt were the most usual cargoes" (Childs 2002, 204) and this is well supported by the dendrochronological findings that structural oak timber analysed from English buildings are almost exclusively of native trees, while it is the panelling which is so often of Southern Baltic oak (Tyers 2003). From Childs' description of the timber imports to England, the source at the beginning of the 14th century is primarily Norway, but that there is a shift, over the century, to the dominance of Southern Baltic boards and planking. The major ports where Scandinavian and Baltic timber was imported are also all on the East coast, as seems also likely, and we see this also in the Scottish dendrochronological material of the late 15th and 16th centuries too (Crone and Mills 2002). In discussing the volumes of timber that was imported into England Childs concludes that in some years total imports must have been well over 200,000 pieces. She mentions that "by the mid-fifteenth century the peak of imports was past, and this fits with the known decrease in exports from Danzig" (Childs 2003, 187). This ties in very well with the dendrochronological picture where the finds of Southern Baltic timber in ships, and barrels whose staves are built of Southern Baltic oak, all fall within the period *c.* 1340s to 1440s. While the Norwegian timber imports are dominated by conifer, oak timbers were among the imports also. (Childs translates *bordes de sappo* as fir, but it is considered in these early documents that the designation fir would refer to conifer species generally, and not to *Abies Alba* exclusively (Cathy Tyers, pers.comm.). Indeed dendrochronological research being carried out into conifer species found in ancient buildings in England will no doubt increase our knowledge of the extent of conifer imports into England and of the sources for conifer timber in the dendrochronological record (Groves 1997; 2000). Over the period, as a reflection of the new sources for timber, more German words enter the records for the various timber products. Of interest is the more frequent appearance of the word *deles* (deal) instead of 'planks': "Like planks these were large pieces handled in small numbers. Almost certainly most were of fir, since the word in modern English has come to mean fir or pine wood." (Childs 2003, 192 note 18). Of manufactured timbers, masts (mostly from Norway) and oars are mentioned, but these are in small numbers. Other timber types mentioned include *cogbordes* and *botumholt*, both which might indicate planking for shipbuilding.

Another very interesting pattern that emerges in the 14th century records, where "Baltic shipping also changed dramatically. Ships from western ports (Stralsund, Rostock and Lübeck) some of which in the early period had imported Norwegian goods, gave way to those of eastern ports (Danzig, Elbing and Königsberg)" (Childs 2003, 196). Indeed again the dendrochronological results of the barrel finds examined here reflect this, where barrels dated to the late 13th and early 14th centuries seem to be of oak that grew in the southwestern Baltic coastal region (Lübeck, Stralsund), while the 14th and early 15th century barrels are dominated by those of Southern Baltic timber (Gdansk, Vistula).

So a picture generally emerges that the majority of timber trade was in conifer species, but that oak was particularly prized as wainscots, boards and planking. When larger squared constructional timber is mentioned the probability is that this was conifer. This ties in well also with the picture that emerges in the logistics of rafting, where oak cannot be rafted alone, as it is too dense and will sink. Additionally, the problem of the difficulty of working oak after the wood has seasoned makes it necessary to do the main preparation of the timber into near-finished products speedily, probably in the forest where the trees are felled. This means also that immediately the heavy timber is readily transportable from source. We can begin to conclude that the transport of bulk oak has to go hand in hand with other lighter timber species. Oak worked into planks and boards etc., make them far more easy to handle and thereby possible to export on a large scale, while substantial oak timbers, transported over long distances, are a relative rarity.

11.7 *Forest management*

Details of the ownership and management of woodlands is described by Bo Fritzbøger (Fritzbøger 2004). In his introduction, a summary of woodland management and wood consumption is presented. Fritzbøger writes that the population crisis in the 14th century with its corresponding reduction in land usage, and increase in forestry is visible in the pollen records, but that after a time the demographic recovery meant renewed exploitation of the woodland resource. He writes,

> "By 1500 woods were scattered in the Danish landscape in a manner which in broad terms was comparable with the one reflected in maps three hundred years younger. Eastern Jutland and the archipelagos of Funen and Zealand all had large areas dominated by woodland, where manufacturing of timber products augmented a peasant economy based mainly upon animal farming. Only northern Skåne, Halland and Blekinge, however, had wastelands totally marked by forest. And these areas were, consequently, major suppliers of timber and firewood to the rest of the country." (Fritzbøger 2004, 110)

The picture described is of a dwindling resource over the period, but it can also be stressed that there was still a wood resource in the region. If we for example rephrase the text above stressing the availability of timber, as opposed to shortage it might sound: by 1500 there were woods dotted about the Danish landscape in broad terms reflecting that which we see in maps three hundred years later. Timber products augmented an animal farming economy in the large areas dominated by woodland, in Eastern Jutland, Funen and Zealand archipelagos. Northern Skåne, Halland and Blekinge were dominated by forest.

Fritzbøger goes on to write that overall wooded land decreased until the middle of the 17th century, due to over-usage, conversion to arable or thirdly, due to grazing animals impeding tree regeneration. Therefore increasingly more wood products were imported from abroad. "By 1600 all timber in the naval dock-yard in Copenhagen, for example, originated from Norway or provinces east of the Sound." This is an important piece of information to bear in mind in terms of this study, and indeed is apparent in the archaeological record in the broadest terms, with the increased appearance of pine timber in buildings (Fritzbøger 1994, 200). But oak was very likely transported too, with time, and the extent of the appearance, in the dendrochronological record, for example of Norwegian oak in countries on the North Sea (Scotland, Netherlands etc) is currently being established, where one site on the German North Sea coast (Wh-Sengwarden) whose felling date is in the first half of the 17th century, is mentioned (Baittinger and Bonde 2006). Details of this ongoing work are not yet published but other research has shown evidence for Norwegian timber for example in Scottish buildings (Fenton Tower, East Lothian, of timber felled in spring/summer 1572 (Crone 2002) and The Great Hall, Edinburgh Castle, built around 1510 (Crone 2000)). For these examples it might be again stressed that the timbers are from the 16th century. Timber in buildings and from excavations in Scotland, from before 1400, are of native oak, but from 1400 "the frequency of imported and re-used timber increases" (Crone and Mills 2002, 792).

Fritzbøger summarises his four woodland property forms for medieval and early modern Denmark, from commonage ('alminding') to 'woodlots' where each farm has access to the resources of a specific allotment of the forest. All four forms, he writes, are known during the medieval period but with an evolutionary trend from the first form to the last (Fritzbøger 2004, 57). This administration and organisation of the forest resource locally shows that indeed the resource was present. This should be borne in mind in the discussion of the dendrochronological dataset and the timber transport issue.

In Part II Fritzbøger introduces the medieval origins of forest ownership and administration from 1150-1350. In conclusion of this discussion he summarises that palynological evidence cannot give us a picture of the relative distribution of mature (pollen producing) trees and immature underwood. He mentions, though, analysis of coffin planks from Lund, which suggest that stands of straight oak trees are replaced by more open woodland (Bartholin 1988, 285, mentioned in Fritzbøger 2004, 93). Bartholin suggests that the straight slow-growing forest oaks used to make the coffins in Lund are no longer to be found by around 1150. Such long slender oaks are not used though for stave church building, where he shows the example of Drottens stave church in Lund, dating to *c.* 1050. Instead the staves have been cleaved from fast-growing oaks, which had stood in a more open landscape, developing a large crown and a relatively short trunk. Bartholin suggests that this is because the oaks for the stave church are felled local to the church site, taking advantage of a short transport distance, whereas the coffins could be prepared and assembled at the timber-felling site and then were more easily transported (Bartholin 1988, 285). While long slow-grown oaks were available in the region, as shown by the oak coffin finds, shorter large-crowned trees were used in the stave church instead. Was it only ease of transport that determined the type of timber, or were the qualities of the fast-grown timber preferred? The shorter height of the tree to the branching out of the trees' crown for example, can have been specifically sought after, to use the attached branching in the assembly of the roof.

In Part III Fritzbøger deals with the period 1350 to 1800 as a single unit in terms of forest history, and suggests that the period is characterised by a mixture of property ownership and rights to commonage coexisting, but used on different levels of resources. The mature forest trees were reserved for the landlord while lesser trees and underwood could be utilised by tenants. According to Fritzbøger the "essential division of woodland resources appears, then, to have been formulated for the first time during the thirteenth century – though this could, in fact, have taken place even earlier" (Fritzbøger, 2004, 185). A gradual movement from the commonage system to ownership from the medieval period onwards is suggested. The most important driving force in this process was the imagined or real problem of wood shortage. These rules of ownership and usage rights were most often of the mature wood, while the underwood resource was still accessible. Interesting in the context of this study is that regulation of the trade of timber was also deemed necessary. In the 16th century a general ban on wood exports was in place, and in 1574 for the county of Varberg, Halland, it was decreed that vessels should not be built with a keel longer than 12 'alen' and neither should they "export bigger timber than has been done since time immemorial" (Fritzbøger 2004, 125). So there were regulations in place to prevent wood shortage from the 16th century.

11.8 *Oak availability*

The question of oak availability is key to the whole methodology in this study, and to results of analyses of shipwrecks. If we had timber shortage in some regions, then the timber in the historical buildings and on archaeological sites from these regions must be from outside that region. In practice though we most often see that there is oak available. We move, over the medieval period, towards an increased management of the timber resource, so that forest timber is reserved for major building work, while underwood can be exploited. The very long-lived forest trees were not the only source of construction timber. We should bear in mind that trees don't only grow in designated woodland. Hedgerows with mature trees would have been an extensive resource for timber as would areas where "natural or semi-natural combinations of trees with non-tree vegetation" (Rackham 1998, 2) which Rackham calls 'savana' (Rackham 1998, 3). It might be mentioned here that the material represented in the dendrochronological record consists only of mature timber, although for some sites trees as young as *c.* 60 years are analysed. In this study indeed only the oak is considered. So only a small segment of the whole timber story is detected here. When a site is sampled for dendrochronology the long-lived trees are taken, while many shorter lived oaks are not. Shorter lived timber can represent the usage of underwood and of small hedgerow trees, but they can also represent large fast grown oaks, that have grown in open locations without competition from other trees close by, for example in the hedgerow. This timber is well suited for construction, but is often not well suited for dendrochronological analysis. Such younger wide-ringed trees can very well have been selected for specific uses in a construction; for the framing in a ship for example. This varying selection of the timber resource for specific uses underlines the need for extensive sampling in a dendrochronological analysis.

At the same time, some of these fast grown oaks are represented in the dendrochronological record, if they have had enough rings that these examples were measured. We can take some land sites (as opposed to the shipwreck sites that comprise the many case studies) to illustrate some aspects of the timber resource over the period we are dealing with here. A lull in building activity is evident in research into several groups of material. In Sweden, Bartholin summarises the dendrochronological dates for churches in Skåne, Southwest Sweden (Bartholin 1989, 212). Here, several churches are dated to the second half of the 11th century and to the first half of the 12th, but a lull is evident from the last quarter of the 12th to the very end of the 14th centuries, where only two churches are dated to the last couple of decades of the 13th century. Bartholin builds on this picture when he summarises the datings of timber buildings in Southwest Sweden (Bartholin 1990, 58). Here the lull in dated buildings is from the 1360s to the *c.* 1450s. From the tree-ring datings of 712 historic buildings in England and Wales, a clear reduction in building in the 14th century is apparent (Pearson 1997; 2001). A similar picture is described for the town of Lübeck in Schleswig-Holstein in Germany where there are again fewer buildings dating to the mid 14th century (Wrobel et al 1996). For the Danish region, a similar dip in material from the 14th century can be seen in the tree-ring data (Daly 2005b, 26). Demographic changes in the 14th century, particularly tied in with the Black Death, are most often cited as the reason for this decline in activity, but in Denmark it is interesting that when sites are dated to the period, they tend to be of a particular type. Where timber from church building dominate in the preceding and following centuries, it is generally fortified sites that date to the lull period. However, in view of the explosion of population and in view of urban growth before the Black Death, can we say more, for this period, about the availability of structural oak timber? Can, in other words, some of the reason for a lull in dendrochronologically dated structures from the 14th century be a product of a reduction in the timber resource? If the resource was reduced, we could have had the usage of younger trees, trees which would not be suitable for dendrochronological dating. If this were the case, then these structures would simply not appear in the dendrochronology dataset. Several sites can be taken to illustrate the kind of material that appears in the dendrochronological record over this period. In the analysis of the two timber crossings from Western Jutland one striking difference between the Viking period site at Nybro and the Medieval site at Skjern is in the tree age for each site (Daly 2006, appendix 1 this volume). The diagram (Daly 2006, 38) illustrates the number of dated and undated samples from the two sites. There is a clear predominance of longer-lived trees in the Viking period Nybro site, while there are predominantly younger trees in the Medieval Skjern bridge. This affects indeed the success rate of dated samples, showing clearly how shorter-lived trees end up underrepresented in the dendrochronological record. Can we say something though about the availability of building timber between the early and the later site, given the differences in tree age between them? Now there are several aspects that need to be considered in this discussion. Firstly, we have no way of knowing in what social context each crossing was constructed, not to the extent of being able to directly compare their timber usage. Indeed the different makeup of materials in the two constructions can in fact reflect the different social context of the crossings, and not the timber availability between the two periods. In other words, if one site is built under a central authority concerned with transport over large distance, allowing the usage of finer materials, while the other is simply a locally built crossing to access river resources, using suitable but not the best materials, then a direct comparison of the timber resources used in each construction will be flawed. Secondly, the material used to build a construction will depend on the nature of the site's function. The best, most expensive timbers are surely not used for a fish weir. So we might doubt the representativity of the Skjern bridge and weir construction, in the question of the timber resource. Thirdly, good structural oak timbers do not necessarily have to be long-lived trees. Faster growing trees can be quite substantial in size while they are at the same time relatively young. Taking the 8th century Nybro site for example; though it was made of long-lived oaks, the rings were generally quite narrow. In other words the timbers used in the construction were not of enormous diameter. And despite the many building and repair phases, the material from Nybro seems to be quite homogeneous dendrochronologically (internal correlation), that we are probably dealing with a local timber resource. Again we are probably seeing the usage of the most conveniently accessible timber for Nybro. Indeed availability of substantially large oak timber was not an issue in the building of the bridge at

Ravning Enge at the end of the 10th century (Jørgensen 1997; 1998; Christensen 2003).

Let's look then at other types of sites which might help to shed light on the question of timber availability in the medieval period. Given the increasing control and management of the woodland resource over the period as described in Fritzbøger (2004), is it the case that in the dendrochronological record, only the controlled, managed timber is represented? This links into the discussion above, concerning the management of the overwood and the more free exploitation of the underwood, and to the probable presence of trees dotted around the countryside, outside the designated or managed woodlands. Can we determine whether the long-lived oak in the dendrochronological record is exclusively the mature woodland timber in the forests in the medieval period, or whether a variety of timber sources are identifiable?

We can for example take three sites, representative of different social contexts, and examine them in terms of the timber supply.

11.8.1 Boringholm

As mentioned above, fortified sites in Denmark are frequently found to date to the 14th century. One of these, at Boringholm in East Jutland, was originally excavated in 1905-1916 by Chr. Axel Jensen of the National Museum of Denmark (Kock 2005, 30). It was a timber built fortified site, or what can be described as a fortified farmstead. For the purpose of retrieving timber for dendrochronological analysis, the site was reopened in 1999 and 2000 (Johansen and Andersen 2005, 40) and a detailed chronology for a number of building phases was possible. The timber constructions were erected from AD 1368/69 to 1380 (Eriksen 2000a; Daly 2005a).

11.8.2 Stegeborg

This site, on the island of Møn in Southeast Denmark is situated on a narrow channel, which leads from the sound between Møn and the island of Zealand to a natural protected cove. Excavation, initially in the 1970s (Bekmose and Nielsen

1978) and subsequently more extensively in 2000, revealed remains of buildings and a bridge and of a large moat structure, whose sides were lined with large oak planking, preserved below the waterline (Rensbro 2001). Dendrochronological dating of oak from the site was undertaken of material from the earlier excavations (Bartholin 1978) and additional timbers from the new excavations were also analysed (Daly 2001d; 2005b). Some structures date from the second half of the 13th century but the major timber lined moat was built of timber that was felled in winter AD 1313-14. Some timbers from the bridge structure represent repairs in *c.* 1380. There were additional, substantially sized timbers at the bridge, which contained too few rings for analysis, and these could represent other, un-dated repair phases.

11.8.3 Nyborg Castle

The third site for comparison here is Nyborg Castle, on the eastern coast of Funen. Nyborg was one of the most important royal castles, the location where the Danehof (court of the Danes) was held, from the end of the 13th century. This castle had been modified many times during its usage and timbers preserved in the surviving castle building, which have been analysed dendrochronologically, attest to these many modifications (Daly 1999c; Bonde, Daly and Rasmussen 2000). While the earliest dendrochronologically dated phase in the castle is represented by four timbers, showing a felling date of *c.* AD 1323, another major building phase dates to winter AD 1400-01. We can take this phase in the discussion here of timber resources as it is from the same period as the other two sites.

The diagram showing the chronological position of the dated samples from the three sites (though for Nyborg only the 1400-1401 phase is indicated) can be used also to get an idea of the age of the trees used in the constructions (fig. 171). It might be mentioned here that for all three examples, indications from the dendrochronological analysis are that the timbers were not imported to the sites, but are probably from the higher status sites of Nyborg and Stegeborg have had access to plenty of long-lived trees. The trees from the Stegeborg construction were greater than 150 years old, while those from this phase of Nyborg Castle were greater than

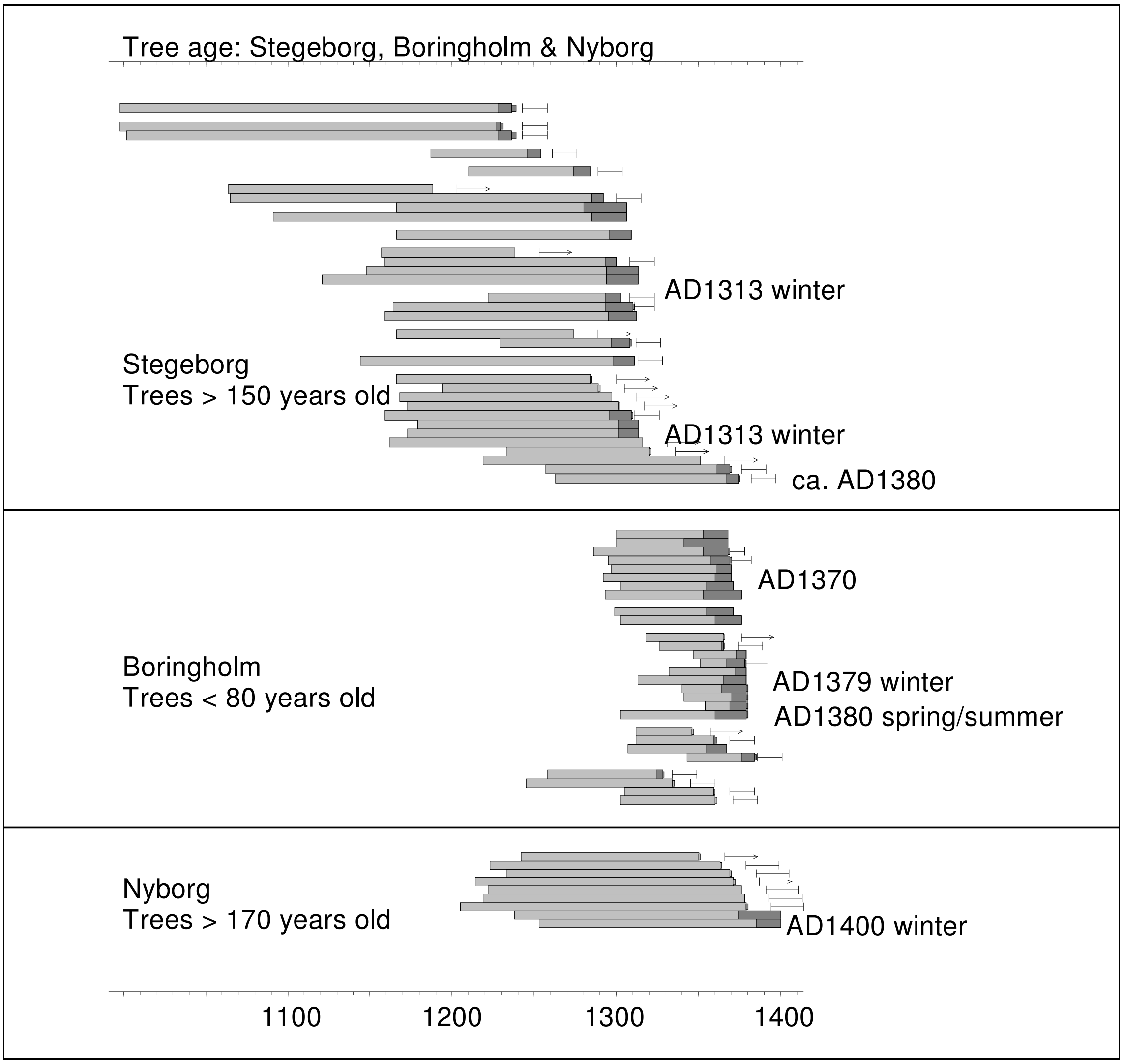


Fig. 171. Stegeborg, Møn, Denmark, Boringholm, Jutland, Denmark and Nyborg Castle, Funen, Denmark. Bar diagram showing the chronological position of the samples from the three sites, illustrating a difference in the age of the trees used in each construction.

regions where the constructions were built. It is clear that the builders of the two

170 years. For the lesser status site of Boringholm however only trees younger than 80 years old have been utilised. Three sites from the 14th century or very start of the 15th, from three different social levels, seem to indicate quite well that long-lived timbers were indeed to be found at this period, but that necessity dictated that shorter lived trees needed also sometimes to be exploited, perhaps because of an

urgent need for the building of fortified protection in a hurry. Buildings of lesser social status again will be underrepresented in the dendrochronological dataset, due to their probable use of younger wood, but to imagine a shortage of building materials for structures, say, of post and wattle, would not be easy, as the growth of new building materials for these kinds of structures is fast, and with a small degree of rotation management, of coppice or pollard stands, this kind of material should be available constantly (Rackham 1990).

It can be seen here that when sampling for dendrochronological analysis there is enormous potential for the recording of the types of timber utilised in historical buildings and in the remains of construction found in archaeological excavations, over time. With the possibility of precise felling dates and a review of the quality, dimensions, conversion and tree-age of timbers, we would come towards a detailed picture of the timber in terms of resource availability through time. Not only could we identify instances of imported timber by provenance determination, we could also identify trends in the availability of building timber. This discourse would though have to take into account the different status or social context of the buildings or other constructions, for which the timber is used. Account should be taken for the possibility that the type of timber used in any construction is not necessarily reflecting timber availability, but rather the choice of specific materials with specific qualities.

So this brings us back to the discussion of the management of woodland, and the representativity of the dendrochronological record in terms of shedding light on the timber resource. It is only the oak that is dealt with here, although this was a particularly valued species for construction, given its timber qualities, and therefore a valued resource in itself, over several other timber species. Only oaks of a certain age are taken into the dendrochronological dataset, due to the nature of the analysis. There must be plenty of rings, so the usage of the underwood, of younger trees, is not present in the material. Does this mean then that only the managed overwood is present in the dataset? Well we cannot rule out the presence of trees outside the woodland, in hedgerows and in smaller copses on otherwise arable land. There were undoubtedly mature trees which could be used. Indeed often, in a dendrochronological analysis of a construction, where tree-ring curves from a single phase don't match each other so well, we just might be seeing the exploitation, not of a group of homogeneous trees from a single forest, but of timber dotted around the landscape, in copses or hedgerows.

All in all it is logical that if oak is available nearby chances are that it is used, rather than going to all the trouble and expense of using long-distance transport. So the conclusion is that the predominant practice was the use of local oak. Imported oak being the exception, not the rule. It is not until the 16th century that we begin to see the necessity for the transport of oak, and this occurs for those regions which run out of native resources. The difference between the source of the oak timber in English and Scottish buildings underlines this point. As mentioned in the first section, timbers in Scottish buildings were imported from Scandinavia, while structural oak in English buildings is, apart from one exception, native. It is interesting in the light of this that the Scottish did not utilise oak from England. Does this underline the transport logistics case, where it is easier to transport over water than by land, or does it reflect the political climate between Scotland and England in the 16th century?

11.9 *Timber export/import*

The general picture, which is emerging from the dendrochronology literature, is that we can categorise the transport of bulk construction timber in terms of demand. In certain regions in Europe the forests become exhausted so that large long-lived oak timbers are imported for building. Specifically, we see it in Scotland and we see it in The Netherlands.

In Scotland, local woodlands were utilised throughout the 12th and 13th centuries (Crone and Mills 2002), that is, structural oak timber was still available locally. There is an exception to this pattern, though, where timbers from one building, Queen Mary's House, St. Andrews, dated to 1286, with Ważny's Gdansk-Pomerania chronology (Baillie 1995, 132). Analysis of an increasing number of oak roofing has revealed several examples of foreign oak timber in Scottish high status buildings (for example Crone and Fawcett 1998; Crone 2002; Crone and Mills 2002). It should be pointed out though in this context that these prestige Scottish buildings with Scandinavian oak are chiefly from the 16th century. Indications are that several Scandinavian sources are evident: the island of Zealand in Denmark, and Swedish and Norwegian sources. As mentioned above, evidence is observed in the timber construction that the beams were shaped while the timber was still green (Crone 2000). The dimensions of the imported timbers also are not enormous. She summarises that the buildings with Scandinavian imported construction timbers

> "were constructed using roughly squared baulks of relatively small scantling, approximately 150mm in diameter on average" (Crone 1998, 4).

Generally these small trees contained circa 100 tree-rings (a chronology of 117 years was dated from Guthrie Aisle (Crone 1998) and an oak chronology of 112 years was dated from the roof at Brechin (Crone et al 2004), indicating that they were felled from a relatively immature forest. What is interesting, in terms of the development of the dendrochronological methodology here though, is that the Scottish evidence indicates the abundance of timber in Southern Scandinavia in the period. Availability of oak timber in Southern Sweden and in East Denmark, for local use *and* for export, seems not to have been an issue.

In the Netherlands and Belgium (Haneca et al 2005), during the Middle Ages, exhaustion of the forest resources of large long-lived structural oak necessitated the importation of timber. While firewood and smaller wood requirements could be met by the local wood supply, long-lived construction timber seems to have been imported from wider distances. Rivers of course served as the transport means for this bulk commodity but we know that timber was also transported by ship, particularly in the late Middle Ages with the growth of the Hanseatic trading league. According to Haneca et al,

> "The oldest physical proof of Baltic timber in Flanders was found on archaeological sites as herring vessels, with

> felling dates situated at the end of the 14th century”.
> (Haneca et al 2005, 262).

The analysis of the timber from the Renaissance ship B&W1 in this study serves to underline the pattern emerging for constructions built in the Dutch region.

11.10 *Panels and the Baltic timber story*

One of the aspects of the movement of timber emerged in the 1980s with the dating of oak panels from paintings (Baillie et al 1985). A short research history of the dendrochronological dating of these oak panels which have been analysed in several countries, including England, The Netherlands and France etc is given in Ważny (2002). The tree-ring curves from these oak panels did not cross-match with local chronologies. It emerged, after the construction of a Polish chronology (Eckstein et al 1986) that the painted oak panels were in fact dateable using this Polish chronology, and equally that the oak trees had grown somewhere in the southeastern Baltic countries (Ważny 1990; 2002). There are probably many distinct sources for these oak panels but as yet no completely clear provenance is forthcoming. Attempts have been made by comparing two panel chronologies built by Hillam and Tyers (1995) with a network of Polish chronologies and also to compare different time windows along the chronologies, as the timber source did also most likely change through the centuries. We know also that timber was transported not only from Gdansk but also from other Eastern Baltic towns such as Riga in Latvia (Zunde 1998-1999), but due to the relative infancy of the dendrochronology of oak in the Eastern Baltic countries, a fuller identification of the timber origin for these art-historical chronologies is still under development (Ważny 2002).

The Polish chronologies now available, and the art-historical chronologies which also are available, allow dendrochronologists in countries west of the Baltic Sea (Denmark, The Netherlands, Belgium France, England and Scotland) to identify oak which has its origin in the Southeast Baltic countries. Fine oak panelling in particular is very often, when analysed, found to be “Baltic”. The panelling was not only used for paintings, but is also found in buildings, where for example the structural timber is of local origin while panelled ceilings are of Baltic oak panels as in the case of Guthrie Aisle church in Scotland where indeed the panels are shown to be of Baltic origin, while the structural timber is from Scandinavian oak (Crone 1998). Ship timbers are found often to be of Southern or eastern Baltic origin, and these also often date to the 14th and 15th centuries (for example Daly this volume; Eriksen 1992; Tyers 1996)

Another published example of Baltic timber in the west includes the shipwreck at Vejby. Here a cog was excavated in 1977 (Crumlin-Pedersen 1979). From the associated material from the wreck, including two silver coins under the mast step one of which was minted in Torun, in what is now Poland, a hoard consisting almost entirely of English gold coins (Bonde and Jensen 1995) and ballast stones from along the Atlantic coast, it was concluded that the cog had been built "on the southeastern Baltic coast and wrecked around 1380 on a passage home from western Europe (Crumlin-Pedersen et al 1976)" (Crumlin-Pedersen 1979, 29). The later dendrochronological analysis showed that the timbers for the ship were felled in winter 1371-72 (Bonde and Jensen 1995). Comparison of the ship's tree-ring curve with master chronologies available at the time showed that a very high correlation was achieved with the aforementioned Polish 'Gdansk-Pomerania' chronology (built by Ważny (1990))

Examples of furniture in France show interesting results also. In an analysis of an oak chest with both structural and ornamental components it was found that the structural parts were of local oak but the ornamental panelling was of Baltic oak (Pousset 2004a). A similar pattern was found in the analysis of a Flemish window where the frame is of local oak while the panels are Baltic (Pousset 2004b). So the dendrochronological record is indicating that the trade in Baltic oak in the medieval period is of these highly specialised timber products, not of large bulk construction timber. Working with dendrochronology in fact, it is often possible to confirm the initial impression when beginning an analysis. As soon as a panel or plank is sawn, it can be immediately seen if the tree-rings are extremely narrow.

More often than not, when the sample is finally measured and dated, it turns out to be Baltic.

11.11 *Timber for shipbuilding*

Indeed taking the evidence from the ships that are dendrochronologically analysed, we might be getting towards a point where we can suggest when the shipping of timber for shipbuilding begins to dominate. This is an important question for the study of the origin of ship timbers, as the question can remain: does the origin of the timber tell us where the actual building of the ship took place?

As can be seen from the discussion of the ship timber origins, we are reaching a stage where we can begin to point out instances where we can suggest that a ship is built from timber shipped from elsewhere to a shipbuilding site. In considering the methods of transport we find that water transport is by far the most convenient, and what might this tell us of the distribution of 'exotic' timber in the oak building timber dataset for northern Europe? We might expect that timber from sites adjacent to sizeable rivers can be from a local source but can also have grown farther upstream, and were rafted downstream. We might expect that timber in coastal market towns can also be of local origin, but can in addition be either from upriver, or can have been shipped from further along the coast or indeed over open sea from afar. We might generalise and say that timber found in inland buildings and sites, which lie far from a sizable watercourse, is unlikely to have been transported far over land, and that the most likely source for timber in these inland sites is local. The many sites in Scotland, from the late 15th and 16th centuries, which have been shown to have been built with oak imported from Scandinavia, chiefly Norway, can almost all be described as coastal. The only exception to this is Stirling Castle, which though lies not far from navigable water on the Firth of Forth (Anne Crone pers.comm.). These sites are indeed all on the east coast of Scotland, underlining the idea that navigability is the connecting factor between regions, at least in terms of the bulk timber trade. The same might be said of the Norwegian oak timber in Danish constructions. Quayside constructions in Aalborg from the 18th century (Daly

2000a; 2001b), and from Copenhagen Quaysides from the 1680s (Daly 1997a; 1997d) are both navigable sites. Both sites have oak that fits well with the emerging group of data that seems to be of Norwegian origin.

But let us take the evidence in analyses of the provenance of timber from ships to shed light on the question of the problem of the ship building location, in relation to the timber source. We might start this discussion with two ships from the late 14th century, continuing with later finds

11.11.1 Late 14th century

We have indications of the pattern of the acquisition of timber for shipbuilding from a number of cases where the building *location* is identified by other means. The Bremen cog, from *c.* 1380, having never sailed, as it became wrecked before it was complete, is one example (Abel et.al. 1969). Although only very few samples have been analysed from the ship, we can nevertheless see indications that the timber was harvested from up the Weser River around the Weserbergland, which can be translated to the Weser hilly region (Bauch 1969; Klein 2003). This is a good example of the rafting of timber downriver, and the Bremen cog's timber can have come at least 300 km in this way. However the very few samples analysed from this ship makes this conclusion somewhat preliminary (Daly, this volume). We have unfortunately no insight into the complexity of the timber composition of this ship.

We have another good example in the Vejby cog from winter 1371-72. Although the ship was found on the Danish coast, we know that the timber for the ship had grown on the Southern Baltic coast. Here the probability that the ship was also built close to the timber source is confirmed by the presence of coins under the mast step, minted by the Teutonic Order in Prussia (Bonde and Jensen 1995).

So with these late 14th century examples we are seeing that the location of shipbuilding is related to the location of the timber source, and this might be taken as a generalisation for this period. We can see now though that the evidence for the three Dokøen ships, from the first quarter of the 15th century, points not to the site of shipbuilding, but to the transport of specialised boards from the Southern Baltic, as we have also seen in the historical sources. We only spot this dendrochronologically because of the analysis of different components of the ships. Let's take other examples of ships built of Southern Baltic oak. Two wrecks from Norway have been analysed relatively recently and are presented in this study. The Avaldsnes wreck (Alopaeus and Elvestad in press) from west Norway is dated to *c.* AD 1395. The four dated samples are all from framing timbers, and no additional timbers have been analysed (Daly, this volume). The Bøle wreck from South Norway dates to the 1380s, but here nine samples are dated, four from planks and five from framing (Daly, this volume). For both ships, all the timber can be shown to be of Southern Baltic origin. Now as the evidence of the pattern of timber being exported out of the Southern Baltic in this period points towards a predominance of oak panelling, then we would expect that the framing timber is still harvested locally. In that way it can be argued that the two Norwegian finds, both of which have southern Baltic framing timber, were also *built* in the Southern Baltic region.

11.11.2 Early 15th century

Considering the veritable explosion in ship building that takes place in the Netherlands in the late medieval period and the Renaissance it is important to consider this region in terms of timber supply. It has not been possible to find any synthesis literature on the conditions of the native timber supply as shown in the dendrochronological record, but in discussions with dendrochronologists in The Netherlands some interesting points have emerged. The picture emerging is that there is no native oak in the Netherlands from the medieval period onwards (Esther Jansma, pers.comm.). Timber can from a very early period have come from up the major rivers and rafted downstream as is found in the case of the Roman barge Woerden 7 (Vorst 2005). Another interesting observation is that when, in a dendrochronological analysis of Dutch material, Scandinavian oak is identified, the tree-ring curves match very well with the other Dutch material of Scandinavian imports, indicating a common source region within Scandinavia for this timber (Elsemieke Hanraets pers. comm.). The discussion of the timber resource in Warde is interesting in this context. How depleted was the Dutch woodland in the late medieval and early modern periods? Was there no native timber, or was the native timber resource *supplemented* by timber import? Tossavainen indeed mentions the Netherlands and usage of native woodland, where regulations were already in place concerning the selling of local timber in the 13th century. He writes, "Naturally, all of the timber used in Netherlands was not imported. Firewood was supplied from the domestic forests and material for house-construction was transported from the Dutch forests as well" (Tossavainen 1994). By the second half of the 14th century though we have evidence for the import to the Netherlands of shipbuilding timber:

> "In the customs tariffs for the Hanse in 1358 there is no mention of timber, but in the customs documents in 1363 *knorhout* (thick oak boards) and *koggenbord* (timber for shipbuilding) are noted. The same commodities were also mentioned in the privileges and customs tariffs which the count of Holland gave to the Hanse in 1389" (Tossavainen 1994).

If we look at the dendrochronological evidence, we can see that some of the Dutch cog finds have been found to match best with Dutch chronologies (Oostvaardersplassen CZ46 Almere from after 1327 (Hanraets 1999) and Ketelhaven NZ43 from 1402-1414 (Hanraets and Jansma 1994a). If there were no native Dutch timber in the dendrochronology dataset then it would be impossible to identify Dutch timber in ships, so some native timber must be represented. The very few number of samples analysed in these two cases though (Oostvaarderplassen (CZ46) has three dated samples out of five analysed, while Ketelhaven (NZ43) had only two dated samples out of five analysed) means that only a preliminary conclusion is possible in terms of timber origin.

A group of ship finds from Denmark might give us an indication of when we first see the transport of timber for ship building in the archaeological record. The site Dokøen, in Copenhagen Harbour, was excavated in 2001 by Københavns Bymuseum (Gøthche and Høst Madsen 2001) and four shipwrecks came to light, three of which were found, by dendrochronology, to be of medieval date (Eriksen 2001b; 2001c; Bonde and Eriksen 2002). All three ships are from the first half of the

15th century and are interesting in terms of this discussion because of the results of the provenance determination of the timber. Let us take a look at the results for the three ships in chronological order.

Six samples are dated from Dokøen 2. Sapwood was preserved on five of these, and the dating indicates two felling phases, one *c.* 1405 and another *c.* 1425. The internal correlation is not strong, indicating that the timber for the ship came from a wide area, not from a single forest. The six samples are nevertheless averaged to a single tree-ring curve, which is shown to match best with Southern Baltic chronologies, specifically with Gdansk and Elblag chronologies, and with art-historical chronologies (Eriksen 2001b). Due to the low internal correlation it seems necessary to check the individual measurements with chronologies for Northern Europe, to test whether more can be said in terms of the spread of the timber source, and particularly to see if it is possible to identify different timber sources for the building than for the repair timbers. As can be seen in the table of correlation (fig. 172) we get a very spread pattern of the high *t*-values. Some trees match best with art-historical chronologies while others with chronologies based on construction timber from Poland. The two repair timbers are highlighted with heavy enclosing borders. It is not possible to see a grouping of building versus repair timbers in terms of provenance. If anything, the two repair timbers seem to come from quite different sources. This might not be so unusual, in that a repair phase might be more likely to make use of timbers left over from other major constructions, while original building timber might tend to be of a more unified nature, in terms of timber acquisition. It is interesting to note that we see high values appearing not only with the art-historical and Polish chronologies, but also with data from several sites in Scandinavia (at the bottom of the table). None of these Scandinavian sites are of construction timber per say, but of the kind of timber that we have seen has been transported predominantly, oak panelling. Each construction has also been shown to be of Southern Baltic timber. Of note is that one sample from Dokøen 2 matches very well with an altar piece from Endre Church on the island of Gotland, Sweden, which has been dated to *c.* 1357 (Bartholin et.al. 1999), while another picks up a

REGION	02071059	02071039	02071029	02071049	02071069	02071019	Filenames	
Art-hist	10,15	6,02	4,59	-	3,77	4,34	0M040004	Baltic 1 paintings
Art-hist	8,61	6,90	3,55	3,13	4,78	4,35	0M020001	Niederlande paintings
Art-hist	7,33	4,04	-	-	-	-	0M020002	Nederlandene Syd paintings
Art-hist	6,43	5,65	-	3,07	5,66	4,15	0M010004	Leiden paintings
Art-hist	4,73	7,17	6,12	6,05	8,19	6,22	0M010001	Weyden paintings
Art-hist	4,00	-	-	-	-	-	0M020003	Nederlandene Nord paintings
Art-hist	3,86	3,51	-	8,13	7,08	3,51	0M040005	Baltic 2 paintings
Art-hist	-	-	-	6,14	5,84	-	0M040002	Flanders paintings
Poland	5,08	4,43	-	-	3,70	3,97	P734002M	Bransk (Ważny pers.comm.)
Poland	4,91	3,85	6,37	4,44	-	-	P676001M	Kolobrzeg (Ważny pers.comm.)
Poland	4,76	-	-	4,15	-	-	P719014A	Tolkmicko (Ważny pers.comm.)
Poland	4,33	5,85	7,44	5,76	5,77	4,31	PM000004	Gdansk Pomerania (Ważny pers.comm.)
Poland	4,29	3,55	-	6,09	3,46	-	0628021M	Torun Joh K (Ważny pers.comm.)
Poland	3,78	-	\	4,47	-	-	0628003M	Torun Jacob (Ważny pers.comm.)
Poland	3,20	-	5,30	-	3,68	-	0693005S	Pl-Pruszcz (Ważny pers.comm.)
Poland	3,11	3,60	-	5,59	4,62	-	0628002M	Torun Joh Kir (Ważny pers.comm.)
Poland	3,07	4,24	5,61	5,24	4,29	3,35	0686003S	Pl-Przezmark (Ważny pers.comm.)
Poland	-	7,96	8,77	4,05	6,02	3,82	PM000007	Elblag (Ważny pers.comm.)
Poland	-	6,77	5,82	\	3,33	-	P773505S	Elblag (Ważny pers.comm.)
Poland	-	5,44	4,21	\	3,48	-	P727001M	Szczecin (Ważny pers.comm.)
Poland	-	4,92	3,97	\	3,12	-	P773303S	Elblag (Ważny pers.comm.)
Poland	-	4,32	4,06	4,58	4,19	-	P738001M	Dabrowno (Ważny pers.comm.)
Poland	-	4,06	4,61	3,02	5,61	4,60	0680001S	Gdansk-St,Nikolaus (Ważny pers.comm.)
Poland	-	3,27	5,42	-	3,03	-	0676001S	Kolobrzeg (Ważny pers.comm.)
Poland	-	-	4,53	-	-	3,04	0684004S	Pl-Starzyno (Ważny pers.comm.)
Poland	-	-	4,36	-	3,46	-	P720303M	Vistula (Ważny pers.comm.)
Poland	-	-	-	6,89	3,77	3,55	P720404M	Pultusk (Ważny pers.comm.)
Ship	4,71	4,44	6,06	4,15	4,48	-	0045M002	Vejby Skib (Bonde and Jensen 1995)
Panels	4,15	4,41	4,92	-	9,99	3,88	00940M01	Endre K (Bartholin et.al 1999)
Ship	3,87	3,17	8,51	-	5,16	-	CD40UM03	A7438 Brogade (EU-project)
Barrel	3,56	6,60	4,07	4,80	4,40	5,98	2129M001	Niels Hemmingsensgade (Daly 2000c)

Fig. 172. Dokøen Wreck 2, Copenhagen, Denmark. Table showing the correlation between individual measurements from the timber from the wreck and a selection of chronologies and site means.

high value with timber from Brogade in Svendborg on the southern coast of the island of Funen, Denmark. On further inspection we find that the Brogade timbers, analysed by Orla Hylleberg Eriksen at the National Museum of Denmark, are in fact ships' planks, reused in an urban context, and were felled after *c.* 1365 (Bonde 1995, 303). These planks' tree-ring curves show that the planks are also of Southern Baltic origin. So while in general Dokøen 2 can be seen to be built and repaired of oak timber from the Southern Baltic region, we can begin to look in more detail at the dendrochronological composition of the ship, and see that for the early 15th century, indications are emerging of the transport of timber from a wide area, for the purposes of ship building. Let's take a look at another of the ship finds from Dokøen.

Wreck 4 from Dokøen was analysed by Orla Hyllerberg Eriksen and is dated to *c.* 1415. Just four samples were analysed and there is only very weak internal correlation (highest *t*-value 2.99) so the samples are dated individually against master chronologies, and no mean curve was made. Three of the samples match best with art-historical chronologies, but one gives highest correlation with Lower Saxony (Eriksen 2001b). With this ship from Dokøen, we can see a similar diversity of sources for the timber, but while all analysed timbers from Dokøen 2 are of southern Baltic origin, this ship includes southern Baltic and Northwest German timbers. Assuming all these timbers are from the building phase of the ship, we get a picture of the diversity of timber sources being used.

Average ring width	conversion	rings	status	sapwood	sample	Filename
106,08	T	85	Undated	12	K12 11AS	02070129
108,71	R	191	Dated AD1200 to AD1390	0	K32S+K51	02070169
111,69	R	179	Dated AD1224 to AD1402	0	K8 7DS	02070109
117,18	R	170	Dated AD1226 to AD1395	0	K7 6AS	02070179
123,28	R	206	Dated AD1174 to AD1379	0	K9 8BS	02070119
134,00	R	152	Dated AD1204 to AD1355	0	K7 6{CE}S	02070189
138,85	R	92	Dated AD1291 to AD1382	0	k519	0207004A
150,29	T	73	Undated	0	k517	0207003A
189,20	Keel	69	Undated	0	Køl	02070159
199,32	T	53	Dated AD1358 to AD1410	7	K6 5B	02070069
210,09	T	56	Dated AD1353 to AD1408	7	k500	02070019
258,84	T	32	Dated AD1371 to AD1402	2	K5 4AS	02070059

Fig. 173. Dokøen wreck 3 (Bonde and Eriksen 2002), Copenhagen, Denmark. Table summarising the dendrochronological analysis carried out on timbers from the ship, listed according to the average ring width in each sample. Where two samples are found to come from one tree, only the resulting single tree is listed.

The third ship from Dokøen, wreck 3, is even more interesting. It was analysed by Niels Bonde, Orla Hylleberg Eriksen and myself and dated to *c.* 1420-25 (Bonde and Eriksen 2002). Twelve samples are dated, and the internal correlation shows that two distinct groups can be identified, while several single samples are treated individually as they don't match with the other samples from the ship. One of the mean curves, and three individual samples, date with art-historical chronologies, in other words they come from the Southern Baltic region. A second mean curve though is dated using Swedish and Danish chronologies. There is in addition a distinct difference between the Southern Baltic planking and the

Scandinavian pieces. The Southern Baltic planks are all radially converted from the parent tree, while the Scandinavian planks are tangentially converted. Fig. 173 summarises the information for each tree from Dokøen 3. The list has been sorted according to average ring width. As can be seen, the tangentially converted timbers are, with one exception, all from wider ringed trees, while the radial are slower grown trees. Now all the radial planks date with the Southern Baltic chronologies, while the three dated tangential planks date with Scandinavian references. The reason why this is being shown here is because there are three undated samples from this ship. Indeed the table serves also as a demonstration of the necessity for long-lived trees for successful dendrochronological dating. One of these undated samples though is a sample from the keel. If we might envisage the pattern of transport of specialised timber products that emerges in this study, that specialised radial split planking from tall straight slow-grown trees is a valued timber resource imported from the Southern Baltic region, while timber for other structural parts might be harvested locally, we might find that the keel timber will be a key to the region in which the ship was *built*. Here in Dokøen 3 we have a clue to other timber than the Southern Baltic material, both in the dendrochronological provenance identification and in the category of timber utilised. While the keel is unfortunately not dated, it does however belong, in terms of average ring width, to the faster grown Scandinavian timber group. We can by this suggest that the ship was built not in the Southern Baltic region, but in the Scandinavian region. The best match for the dated Scandinavian timber is with chronologies from northern Jutland and West Sweden. The values are not high enough that a confident provenance to a more local level can be suggested and this is most probably due to the short tree-ring curve (the mean curve for the three dated Scandinavian timbers is only 58 years long). What we can suggest from the results of this ship though is that it gives us an idea of the kind of timber available in the region, at least locally to where the ship was built. Short-lived fast-grown trees have been utilised from the local area, while the long straight planking is imported. This can indicate the composition of the larger trees in the landscape for this period. Again we are limited in terms of reaching this conclusion, as the local timber used for Dokøen 3 can have been selected by choice, not necessarily by necessity.

What the results of the analysis of the Dokøen wrecks do tell us is the importance of strategic sampling. Having analysed samples from several timbers of varying form and function, we are nearer the true picture of the timber origin, and the region where the ships were built, which are, by the 15th century, not necessarily one and the same thing! In this discussion it is important to note that in his analysis of medieval shipbuilding technology and traditions, Jan Bill has suggested that the three Dokøen ships fit, technologically, very well with the Scandinavian shipbuilding tradition (Jan Bill pers. comm.). One last piece of evidence that ties Dokøen wreck 3 into wreck 2 is that wreck two was predominantly made from radial planking but there are tangentially converted planks from this ship also (Bill, forthcoming). Could these, if analysed, be shown to be of Scandinavian oak, as those from Dokøen 3 have been? So taking the concrete and the circumstantial indications, all in all the evidence points to the conclusion that perhaps all three of the Dokøen ships are built of Southern Baltic timber that was shipped to a shipbuilding site in Scandinavia.

So for the many ships in the archaeological record that have been shown to be of Southern Baltic timber, is that actually telling us anything about the location of the actual shipbuilding? Do the many provenance identification results of ships' timbers reflect shipbuilding locations or are we seeing the transport of timber for shipbuilding at locations far from the timber source? Or can we identify a turning point, a date from which the shipbuilding can have taken place far from the timber source, to consider when we carry out the provenance determination of the timbers?

A new ship find in Sweden will undoubtedly give a wealth of information concerning the medieval timber trade. The ship was found in 2003 off the island of Skaftö, on the west coast of Sweden. Not only is the ship preserved, large parts of its cargo has also come to light. These include barrels containing tar and slaked lime, and timber planks. The ship is clinker built, where it has been possible to observe, and is 20 metres long and six meters wide. Further information on the building tradition is not yet available. Dendrochronological analysis of just four ship timbers has been carried out, and the result emerged that the timber was felled in circa 1440 and provenance determination showed that the timber was Southern Baltic oak (Linderson 2004). Even with so few samples, two different timber sources seem to be indicated, one in the eastern Polish region, and one inland up the Vistula River. Analysis of the plank cargo is in progress (Hans Linderson and Staffan von Arbin pers.comm.) and the results of this will be very interesting, not just to indicate when the ship sank but to find out where these planks had been harvested. It is not as yet clear what these planks were destined for. Were they wainscots, or boards, or were they larger planking perhaps for shipbuilding? The finding of this ship is fantastic in many ways as it represents a time capsule of evidence for mid 15th century shipping trade, and particularly in the light of this study, it has all the ingredients for shedding light on timber trade. The ship's timbers will on further analysis enable a detailed picture of shipbuilding in terms of the timber resource. The plank cargo similarly gives an insight into the timber trade. Will it confirm the hypothesis that planking is in this period a dominant cargo from the Southern Baltic, or will the planks be found to be Scandinavian? The barrels are also being currently analysed (Staffan von Arbin, pers comm.). Here it will be interesting to discover if there is a difference in the provenance of the barrels containing tar and of those containing lime. If the two products have come from different regions, does the provenance determination of the barrels indicate that difference, or are barrels a highly unreliable source of provenance for their contents, as barrel staves have been transported disassembled, as we have seen in "The Copper Wreck" from Poland (Litwin 1980). The Skaftö ship find gives also a very good picture of the way goods were shipped. A varied mix of cargo is present. In addition to the planking and the barrels of tar and lime there is brick, copper and iron in the cargo.

So we might argue that it is not until the 15th century that we see evidence for the transport of timber overseas to shipbuilding locations far from the timber source, in the archaeological or dendrochronological record. We see it because usage of imported timber is combined with the use of local timber in one structure. The same phenomenon is seen in the use of panelling in buildings in England that are otherwise built using native timber as cited above, and we see it in furniture construction. It was shown for example that timber from a Flemish window consisted of panels of Southern Baltic oak, while the actual frames were of local oak (Pousset 2004a). A chest from the 13th century was similarly built of a combination of Southern Baltic panelling and local structural oak (Pousset 2004b). In Denmark we have the late 15th century altarpiece in Århus Cathedral built by a Bernt Notke from Lübeck in 1478-79, which is again shown to be built of Southern Baltic panelling, while the oak sculpture components are of timber from the Lübeck region, in other words of local timber (Bonde 2002).

11.11.3 Late 16th century

Taking the example of the Dutch ship from the B&W site in Copenhagen, B&W1 (Daly, case study this volume) what does it tell us of the timber situation at the end of the 16th and beginning of the 17th centuries? Archaeologically this ship, built in *c.* 1584 and lengthened in *c.* 1608, belongs in the Dutch shipbuilding tradition, so there is little doubt that it was built, and modified, in the Netherlands (Lemée 2006). The dendrochronological results indicate several sources for the oak used to build the ship. By far the majority of the timbers match best with Lower Saxony and Dutch site chronologies. But there are three small timber groups which have different sources. One group matches best with Lübeck, Schleswig-Holstein, while the other two groups appear to be Scandinavian. Can we take this to represent the pattern of the timber source for shipbuilding in the Netherlands? The majority of the timber is from the region where the shipbuilding is taking place, while this is supplemented by timbers shipped from farther away. We might generalise from this and suggest that despite the growth in transport of timber by ship over the medieval and early modern periods, timber imports served as a supplement to the local timber supply, and did not replace it.

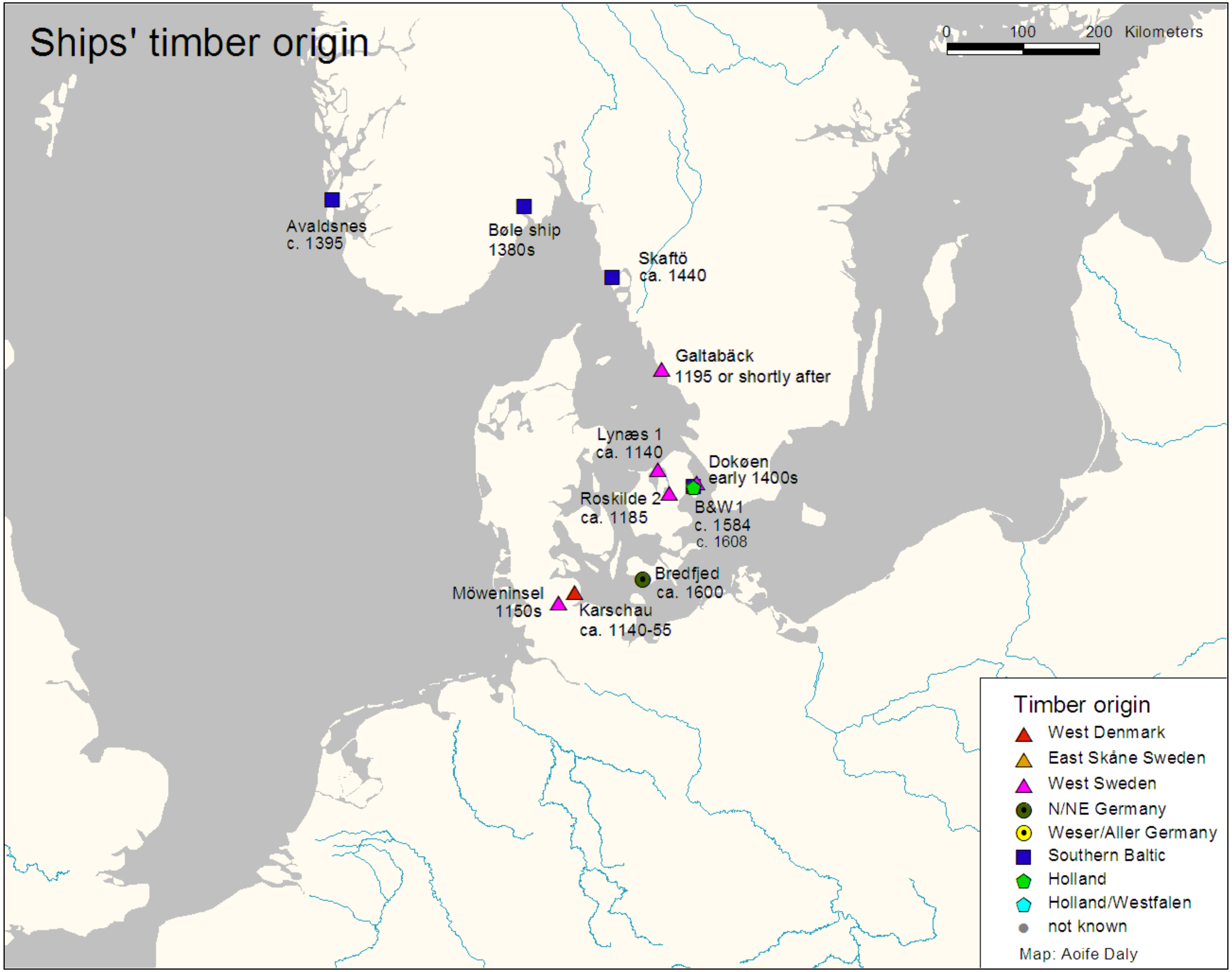


Fig. 174. Map showing the distribution of the ships, excluding the cogs (see fig. 51), examined or mentioned in this study with name, date and provenance.

The spread of high correlation between the largest group and many site chronologies geographically quite spread over the region, and the relative heterogeneity of the internal correlation within the group, indicate that the timber in this group did not come from a single area or forest, but rather from a wider region. This indicates also the mechanisms of the trade of timber as a commodity, that we no longer see a ship built from timber from a fairly limited area as we see with examples from the 12th century, but we see stock piling of large timber amounts to supply the shipbuilding industry of the late 16th century. If we take the B&W1 ship example, from *c.* 1584, we get an excellent idea of the pattern of the timber resource in the late 16th century. There are the majority of the timbers and these seem to have been derived from either the Netherlands or the adjoining German provinces, in other words in the region where the ship was built. But we see small amounts of timber from three other sources in this ship. It seems that we are seeing the evidence for a change in the relationship between shipbuilding activities and the location of the timber resource.

To round off this discussion, a map of the ships analysed or discussed in this study is produced, as a summary of the results of the provenance determination of the ships' timbers. A map of the cogs is shown above (fig. 51) and the map in fig. 174 shows the other ships mentioned. These ships are also listed in Fig. 175. The pattern emerging seems to point towards the start of the 15th century as the point where, at least in the archaeological record, we see that timber for ship building is shipped to a ship building site some distance from the site where the timber was harvested.

"name"	"Felling date"	"provenance"	"group"	"reference"
Avaldsnes	ca. 1395	S. Baltic	late 14th century cargo	Alopaeus and Elvestad forthcoming
Karschau	ca. 1140-55	Danish	12th century nordic	Kühn et.al. 2000
Bredfjed	ca. 1600	N German	late 16th century ferry	Bill, forthcoming
Bølevraket	1380s	S. Baltic	late 14th century cargo	Nymoen 2005; Daly this volume
Skaftö	ca. 1440	S. Baltic	15th century cargo	Staffan Arbin pers.comm.
Dokøen 2	c. 1405 / c. 1425	S. Baltic	15th century	Gøthche and Høst-Madsen 2001
Dokøen 3	c. 1420-25	S. Baltic/Scandinavia	15th century	Gøthche and Høst-Madsen 2001
Dokøen 4	c. 1415	S. Baltic/NW Germany	15th century	Gøthche and Høst-Madsen 2001
B&W1	c. 1584 c. 1608	Holland	late 16th century cargo	Lemée 2006
Möweninsel	1150s	Scandinavia	12th century nordic	Belasus 2004
Galtabäck	1195 or short after	Scandinavia	12th century nordic	Enqvist 1929
Lynæs 1	ca. 1140	Scandinavia	12th century nordic	Englert 2000
Roskilde 2	ca. 1185	Scandinavia	12th century nordic	Bill et.al. 1998; 2000; Gøthche 2006

Fig. 175. Table summarising the dating and provenance determination results for the ships (excluding the cogs fig. 50) examined in this study.

11.12 *The archaeological context*

An important discussion in the application of the provenance determination tool is of course related to the archaeological context of the item being analysed. If we are able to identify the origin of mobile oak structures, what does this tell us of the site of manufacture of the construction, or of the connections between regions? What does it tell us of the extent to which direct communication took place between the timber origin region and the site of deposition? Some generalisations can be put forward, also in terms of different groups of finds. Here, the applicability of Schiffer's 'flow model for viewing the life cycle of durable elements' can be tested (reproduced here fig. 176). In his model he describes the processes of manufacture and usage of materials before they end up in the archaeological record (Schiffer 1972). In his diagram legend he indicates the points where storage and/or transport of an item can take place, in the usage lifetime of a raw material. For the purposes of highlighting these they are coloured red here. The model is to explain all the possible usages that a material undergoes from procurement to manufacture and usage, and to modification and repair, and even recycling to be used as another object, before it is finally discarded or deposited, to end up in the archaeological record. Between all these stages in the life cycle of a material there are opportunities for storage and transport of the item. This model indeed applies to all archaeological material, but is particularly relevant in the context of this study because the felling date and provenance of the timber that is revealed indicates only the very beginning of the life cycle of this raw material. At each red point in the diagram, it is possible that storage and/or transport of the material can have taken place. In the case of barrels or ships indeed, even the usage of the construction entails transport, and therefore Schiffer's diagram is modified here where 'use' is also highlighted in red. This life cycle model underlines the importance of accounting for the archaeological context of the timber construction being tested. It can often be the case that many of the phases in this life cycle can be detected in the archaeological find. Especially in the case of timber constructions where the preservation of organic materials means that a very detailed construction sequence can be followed. Repairs, modifications and wear can be detected, allowing an estimate of the degree to which the timber has aged since the felling date, and styles or traditions of manufacture can be identified often to region, allowing some insight into the extent of transport of the material. Another advantage can be when a construction is not purposefully discarded, but is unintentionally lost, as in the case of a shipwreck for example. Here we get to see the construction interrupted in the course of its usage, allowing additional insight.

Ship finds can allow a more detailed analysis of their systemic context. In the case of the provenance of the ship timber we have a detailed shipbuilding technology description for each ship, with regional traditions and changes and developments over time. Archaeologically ships can be attributed to regional styles, and the timber provenance helps to confirm often the archaeological suggestions, at least for the period up to *c.* 1400. As the discussion of the main findings of the timber provenance determination of ships in this study, combination of the dendrochronological results with study of the position and context of the individual timbers in the ship, and the technology and traditions that the construction details present, we can reach additional conclusions on questions of timber trade, and the exchange of technology.

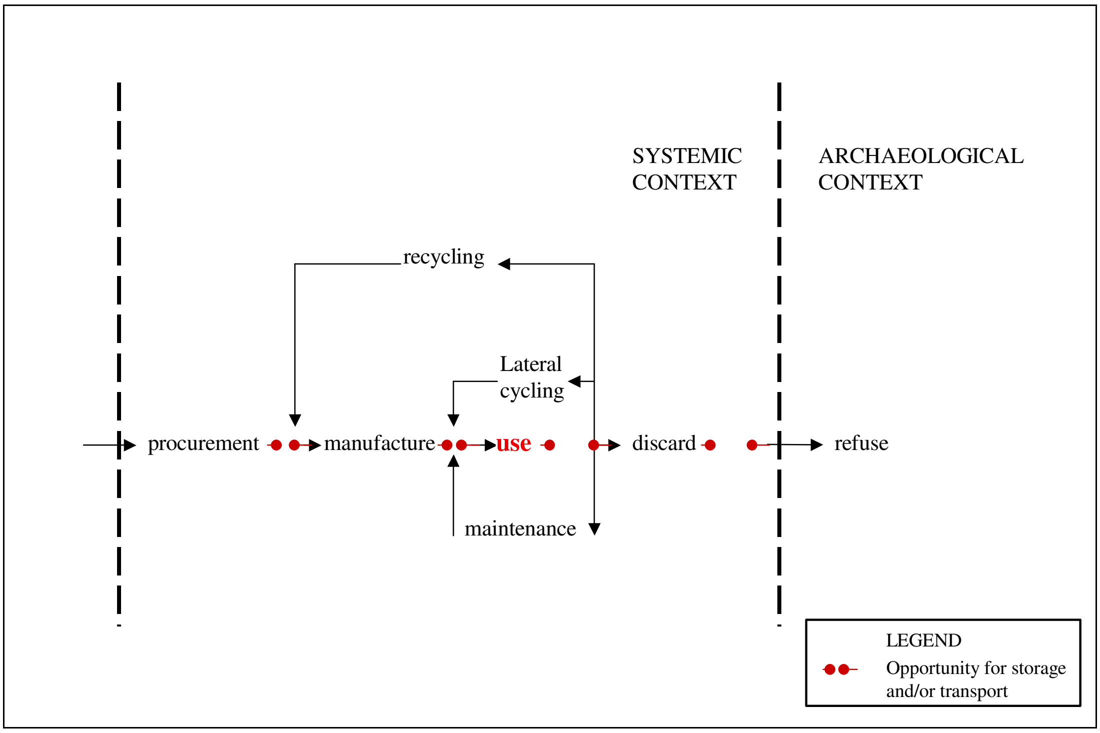


Fig. 176. 'Flow model for viewing the life cycle of durable elements' (after Schiffer 1972, fig 1, page 158), with added colour!

Because of the nature of the barrel construction and usage, the barrel finds do not easily lend themselves to a nuanced analysis of their systemic context. The uniformity of the technology of barrel making means that regional styles have not been identified, except for some mention of differences in the dimensions of some barrels, coinciding with differences in the dendrochronological provenance determination (Houbrechts and Pieters 1999; Daly 2005a). The nature of their usage means that we cannot be sure that the identification of the origin of the wood of a barrel actually tells us of the origin of the goods that were in the barrel. The dominance in particular of the specialised oak panelling from the Southern and Eastern Baltic region in the late medieval period means that especially in this period our Southern Baltic barrels might represent the timber export from the region, and not the export of some other Southern Baltic product, although the export of forest products like pitch and tar was also thriving, as was the export of grain. The usual find context of barrels is in their reuse as lining for wells or latrines. If remnants of the contents of a barrel are preserved on the oak staves then some analysis might be able to shed light on what might have been transported in the barrel, but if a barrel has been reused for different goods and has been transported to and from many markets before its final deposition, then we are potentially missing a considerable amount of its systemic context.

11.13 *Future uses of the methodology developed*

11.13.1 Limitations

As has been reiterated several times in this study, when discussing the results of specific cases, the success of the provenance determination is dependant on the quality of the dataset. By far the best results are achieved where many samples are analysed from the structure being tested, and where a dense network of sites for the region is represented. The high density of sites in Denmark and the Northern German states means that very good results were achieved for ships or barrels whose timber come from this broad region, with provenance determination to the local level. The distribution of the EU-dataset in other regions is less dense and often, for timber from ships coming from these regions, a more general regional provenance is possible but not a more detailed local provenance determination. In addition, the EU-dataset is by no means complete. The data collection was completed in 1996. So the tree-ring data of the last ten years of dendrochronological analyses is not included in the material. There are regions of Northern Europe that are very thinly represented in the dataset, or not represented at all. For the Scandinavian countries, while Denmark is well covered, Sweden's oak dataset is restricted to chiefly the Skåne region, and we could certainly benefit from more sites here. The Norwegian oak data is mostly from the living tree material and there is potential here for increasing the number of sites analysed for the late prehistoric and historic periods. For Germany, the oak data from two laboratories was gathered into the EU-dataset, which meant that the regions they cover are well represented. A third, very productive laboratory in Berlin has carried out many analyses of sites over the whole Northeast German region (the former East Germany) and it would benefit the provenance determination tool to incorporate this data in the dataset. Expansion of the regions covered by the dataset would also be beneficial. Eastwards along the Baltic Sea coast, to the eastern Baltic states, where, while extensive work on conifers has been carried out, dendrochronology of oak is really at its infancy. To be able to test western oak tree-ring data with oak data from the eastern Baltic would be of great interest, especially in terms of the trade of Baltic timber to the west. Westwards, expansion of the dataset into France and even to Spain and Portugal would enable identification of the timber source for many western European wrecks, and would expand the geographical potential of the provenance tool. For most of these regions this would not entail the acquisition of new samples for analysis, but the cooperation of the dendrochronologists working in these regions, so that their tree-ring data might be incorporated.

One of the aspects that need to be addressed is how this tool should be used, in a practical sense, in the future. The tree-ring data was collected by several dendrochronology researchers, belonging to several university or research institutions, over several decades, and a clause in the agreement, where all this data was shared, states that the data should only be used with written permission from the individuals that had contributed.

This consideration is also important and is something that has been discussed at length in the dendrochronological community; the right of access and availability of tree-ring chronologies. One argument is that the master chronology represents many years of data collection and analysis, and yet is just a simple long list of numbers. Dendrochronology is not only a research-based discipline; it is also a commercial one. Many dendrochronology laboratories are reliant on the commercial sample dating services they provide. So the master chronologies, which represent years of work, might be equalled to copyrighted work in the commercial sphere.

Permission has been given to use the data for this study, but the question needs to be asked: How can this new tool be used in the future? Rights to the provenance tool cannot be given freely. As it stands now only the dendrochronologists that have contributed to the dataset can have access. I would suspect that each would have to seek written permission, as is necessary to use the original EU-project data, so it is not the task of this study to distribute the cleaned data, nor the site chronologies that have been constructed.

One problem is that the process by which the analyses are carried out is not a simple one. It makes use of several commercial computer programs (DENDRO, Microsoft Word, Microsoft Access, Microsoft Excel, ESRI ArcView) for generation of the correlation statistics, conversion of the results to "dbase" format and generation of the GIS mapping. The complicated series of steps required means that the tool is not by any means ready to be used by simply putting the tree-ring data in at one end and getting three nice maps out the other. Several of the steps could probably, with a bit of programming, be automated in the future. However, for each case being tested, the tree-ring data needs to be correlated within the structure, to see whether there are timbers from several sources, and the maps need to be correctly interpreted. So this provenance determination tool cannot be made public, as such, but should always be operated by an experienced dendrochronologist. The methodology needs also to be managed. New measurements might be incorporated into the system with time, and these will need to be checked and screened in the same way as the existing data. Computer programs change over time too, and the system would need to be kept up to date with changing computer software and technology. Some sort of portal to this managed database is envisaged, whereby researchers who have submitted data can submit tree-ring data to be tested. This portal can of course be internet based, and a domain name is already purchased by the author to house such a concept (dendro.eu). The concept is different to the other tree-ring data web sites in that it would not be a list or database with chronologies. Neither would it be open access to these thousands of tree-ring measurements. It would be a non-commercial portal to assist in the determination of provenance of historical oak timber in Europe for the advancement of knowledge.

11.14 *Conclusions*

Well finally, several points have emerged in his study that can be highlighted here in conclusion. We set out to describe and refine the method by which we determine the origin of ancient oak timber using dendrochronology. Many aspects needed to be discussed, from the point of view of developing a method to determine provenance to a more local level than previously, and from the point of view of considering the problems in their historical or archaeological context. The main points that have emerged can be summed up in the following:

The technique

- It has been shown that we can refine the provenance determination technique by testing the tree-ring curve from a structure at three levels. The first level test checks the curve against master chronologies. The second level test is where we test the tree-ring curve with site chronologies. At the third level we check the curve with single tree-ring measurements or indices.
- In dendrochronological methodology, just as *t*-values of greater than 3.5 are interesting when looking for the *date* of an object, *t*-values greater than *c.* 9.00 are interesting when looking for the *provenance* of the object. But more importantly, as in dendrochronological methodology, where a *date* for a tree-ring curve is also checked visually before a position is accepted, the distribution of the correlations and the overlap and replication of the well matching sites is examined before a *provenance* is suggested. In other words we must look at the geographical distribution of the correlation results in every test.
- In keeping with a dendrochronological term where an undated chronology is called a 'floating chronology', we should refer to the dated but transported chronologies (the panel painting data, the Norwegian timber abroad, site chronologies identified as not native to the area in which they are found) as 'geographically floating'.

Timber availability and trade

- We know that timber transport increased over the period dealt with here, but forests, woodland and trees still grew and were utilised locally. It is this combination of usage of local and imported timbers for different uses that allows us to be able to map the movement of timber.
- Preparation at source is necessary, and thus the decision as to what use the timber will be put to must also already be made at source. While the market for the oak panelling that we see in the 14th and 15th centuries might be reliable and regular enough that the production of this timber product could have been a standard activity, it is possible that the preparation of timber for shipbuilding was carried out to fill specific orders, and not as a routine timber product.
- We can begin to conclude that the transport of bulk oak has to go hand in hand with other lighter timber species. Oak worked into planks and boards etc make them far more easy to handle, and thereby possible to export on a large scale, while substantial oak timbers, transported over long distances, are a relative rarity.
- All in all it is logical that if oak is available nearby chances are that it is used, rather than going to all the trouble and expense of using long-distance transport. So the conclusion is that the predominant practice was the use of local oak. Imported oak being the exception, not the rule. It is not until the 16th century that we begin to see the necessity for the transport of oak, and this occurs for those regions which run out of native resources
- What the results of the analysis of the Dokøen wrecks do tell us is the importance of strategic sampling. Having analysed samples from several timbers of varying form and function, we are nearer the true picture of the timber origin, and the region where the ships were built, which are, by the 15th century, not necessarily one and the same thing! Indeed the pattern emerging seems to point towards the start of the 15th century as the point where, at least in the archaeological record, we see that timber for ship

building is shipped to a ship building site some distance from the site where the timber was harvested.

The future

- In light of the frequent appearance of ancient oak from archaeological sites and from panels and inventory in historic buildings in Western Europe, which shows by dendrochronology to have an eastern Baltic origin, more tree-ring data from the Polish but also from the other Eastern Baltic countries would allow more detailed information of this extensive historic timber trade (Ważny 2002; Haneca et al 2005). Clearly, continuing cooperation with dendrochronology laboratories from the underrepresented regions will be an enormous asset for the provenance determination of ancient oak.
- It can be seen here that when sampling for dendrochronological analysis there is enormous potential for the recording of the types of timber utilised over time, in historical buildings and in the remains of construction found in archaeological excavations. With the possibility of precise felling dates and a review of the quality, dimensions, conversion and tree-age of timbers, we would come towards a detailed picture of the timber in terms of resource availability through time. Not only could we identify instances of imported timber by provenance determination, we could also identify trends in the availability of building timber. This discourse would though have to take into account the different status or social context of the buildings or other constructions, for which the timber is used. Account should be taken for the possibility that the type of timber used in any construction is not necessarily reflecting timber availability, but rather the choice of specific materials with specific qualities.

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increasing circle diameter for higher values, a large spread of large circles will result, leading to a conclusion that the tree-rings' climate signal is of a wider regional character.

Fig. 8. Matrix of the results of a correlation test between tree-ring measurements from a single site.

Fig. 9. Table showing the matrix of t-values for the Haderslev site as generated in the procedure used in this study. The matrix depicts the internal correlation between all series from the Haderslev site, from both periods (12th and 15th centuries). The tree-ring series which Visser's method groups together at $r \geq 0.4$ are highlighted in blue. The grouping that is used to make the early Haderslev site chronology includes more trees than the Visser group, although the Visser group is clearly made within my group.

Fig. 10. Map illustrating the result where the overlap of greater than 100 (red dots), or greater than 30 (orange dots) is chosen in the comparison of the Hasbruch living tree site chronology with the single tree data. Where comparison is made with data not fully overlapping with the site chronology in question, the resulting lower t-values do not ultimately affect the provenance result achieved. The lower values achieved where there is shorter overlap do not change the distribution, because, for provenance determination, it is the high values which are significant, not the lower.

Fig. 11. Table showing a test of the length of overlap, on a site chronology of the modern forest of Brahetrolleborg in Denmark. In this test, the site chronology for Brahetrolleborg (CD41CZ01) is divided into small sections, first 50 year long sections, then 30 year long sections.

Fig. 12. Bars indicating the different lengths of the smaller sections of Brahetrolleborg for the overlap test above

Fig. 13. Map of the correlation of the tree-ring curve for the ship Lynæs 1 with available master chronologies for Northern Europe.

Fig. 14. Diagram showing the chronological position of the ship average for Lynæs 1 and showing the positions of the master chronologies from Denmark and Sweden, which match best with the ship. The red arrows mark the position at which the Lynæs 1 average needs to be shortened (also shown, labelled "0085F001 truncated") so that when tested against the chronologies the same overlap length will apply. The table in this diagram shows the resulting correlation between the truncated and the original Lynæs 1 average and these key master chronologies. The t-values for the truncated version show that the highest match with the west Sweden chronology is confirmed.

Fig. 15. The Karschau, Kollerup and Eltang ships. Bar diagram showing chronological position of the three ship averages. The red arrows mark the period of time that all three ships' tree-ring curves cover, that is 198 years, or from AD 934 to 1131.

Fig. 16. Karschau, Kollerup and Eltang. Table of correlation between the ship averages and site chronologies in Denmark. The example shows the full

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14 Appendices: papers published in peer review journals

14.1 *Appendix 1:*

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

30 pages

14.2 *Appendix 2:*

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

12 pages