Dendrochronologia 35 (2015) 39–50

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

Original Investigation

Diverse construction types and local timber sources characterize early medieval church roofs in southwestern Sweden

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ARTICLE INFO

Article history:
Received 5 January 2015
Received in revised form 23 May 2015
Accepted 15 June 2015
Available online 27 June 2015

Keywords:
12th century
Church roofs
Dendrochronology
Early Middle Ages
Southwestern Sweden
Timber

ABSTRACT

A vast number of early medieval roof structures are still preserved in Swedish churches, yet country-wide surveys and detailed dendrochronological investigations, in tandem with building archaeology, are largely lacking. Here, we present new findings from four parish churches (Forsby, Forshem, Gökhem and Marka) in Västergötland, southwestern Sweden. The roof constructions, made from local oak and pine trees, were dated to the period between AD 1131 and 1157, making these some of the oldest preserved roof structures in Sweden and Europe. With the development of new regional pine and oak tree-ring chronologies covering the 10th to 13th centuries, we open up the discussion about medieval timber technology, wood utilization and the potential for future tree-ring based paleo-environmental exploration.

1. Introduction

Building traditions provide important insights into many historical and social aspects. In Sweden, a vast majority of the surviving buildings from the early Medieval Period (AD 1050–1350) are parish churches. Archaeological excavations have revealed that the first generation of churches were almost exclusively constructed of wood (e.g. Dahlberg and Franzén, 2008). It has been suggested that the development from those to the later, and larger, parish churches with walls of stone was complex (e.g. Axelsson and Vretemark, 2013). About a thousand parish churches remain standing today, fully or partially preserved, although almost none of them have kept their original shapes. Modifications and renovations carried out throughout the centuries have made it difficult to place them in chronological order based on their architectural styles (Dahlberg 1998; p. 343).

In recent years, several studies have focused on wooden roofs of medieval churches (e.g. Gullbrandsson, 2013; Thelin and Linscott, 2008). Two main truss-types have been described for the earliest, so-called Romanesque, period; one with a tie beam and struts and another with a collar beam and parallel braces. Whereas as many as 100 roofs with tie beam trusses have survived, mainly in the south of Sweden, only four examples of roofs with collar beams have been identified in the provinces of Jämtland and Hälsingland, in central Sweden (Thelin and Linscott, 2008). However, both types seem to belong in a Scandinavian or northwestern European context. For instance, Norwegian roofs have trusses similar to the roofs in northern Sweden (Storsletten, 2002), and surveys in Denmark (Madsen, 2007, 2013), France and Belgium (Hoffsummer, 2002, 2011; Epaud, 2002) and Germany (Binding, 1991) have described roofs with tie beam trusses. If confirmed, the large number of still existing and well-preserved Swedish tie beam roofs take a unique position in a European perspective (Thelin and Linscott, 2008; Courteney and Alcock, in press). However, little is known about the innovations in carpentry and changes in resource utilization connected to the building traditions in wood in the early Middle Ages.

In this study, we combine dendrochronology and building archaeology to make a detailed investigation of well-preserved early medieval roof constructions in four parish churches, Forsby, Forshem, Gökhem and Marka, in the Västergötland region, southwestern Sweden. We present dendrochronological analyses for seven identified medieval roof structures in the four buildings. The focus of our study is to increase our understanding of the history of these buildings by determining which tree species were used

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http://dx.doi.org/10.1016/j.dendro.2015.06.001
1125-7865/

in different parts of the roof constructions as well as the precise dating of the wood. Additionally, we highlight the potential of tree-ring based investigations regarding the developments in resource utilization, which are connected to changes in society and the environment during the 10th to 13th century in this region.

2. Material and methods

2.1. Sampling, tree-ring measuring and relative crossdating

During 2012 and 2013, the roofs of four parish churches in the Västergötland region, southwest Sweden (Fig. 1), were documented and core samples were taken from selected structural timbers. The churches are located in or nearby small villages in Marka (58°9′32″N, 13°28′48.3″E), Gökhem (58°10′25“N, 13°24′27“E), Forshem (58°37′10″N, 13°29′30″E), and Forsby (58°23′23.64″N, 13°56′13.2″E). Based on the construction techniques and shapes of the roofs they were assumed to be original and fully preserved (Fig. 2).

For the dendrochronological sampling, we used dry-wood increment borers with diameters of 5 and 6 mm powered by a cordless drill. In total, 12 cores were taken from Marka (ten in the nave and two in the chancel), ten from Gökhem (five in the nave and five in the chancel), 24 from Forshem (nave, chancel, and north extension), and 30 from Forsby (nave and west extension). All sampled elements were documented in roof sketches and can be found in individual reports for each church (Seim and Linderholm, 2012,2013,2014a,b).

Before measuring tree-ring widths (TRW), tree genus and, in unequivocally cases, the species of all sampled timbers were microscopically identified using wood anatomical features (Schweingruber, 1990).

The transversal surface of each core was slightly moistened and prepared using razor blades to make the annual rings clearly visible. Additionally, chalk was applied to enhance the contrast of the anatomical ring structures. TRW measurements were performed with an accuracy of 0.01 mm, using the LINTAB equipment and TSAPwin software (Rinn, 1996), and subsequently subjected to visual and statistical quality control. Statistics verifying the best overlapping position between all individual TRW series (i.e. crossdating) included the Student's *t*-test, with adaptations after Baillie and Pilcher (1973), the year-to-year synchronicity (Gleichläufigkeit (Gl)), and Pearson correlation coefficients (r) on high-pass (i.e., 3-year running average) filtered TRW chronologies. Correlation results given exceed the 99.9% significance level, unless otherwise noted.

For each church, TRW series of the same species and construction phase were internally crossdated, and mean curves (i.e. unstandardized average chronologies) developed when the tree-ring patterns visually and statistically matched. This procedure was repeated using the TRW series from all churches and subsequently the matching series were averaged into regional raw chronologies.

2.2. Absolute dating and comparative analyses

Absolute calendar dates for the TRW series were obtained by crossdating them with independent regional reference chronologies. The reference chronologies were developed from tree-ring data available at the International Tree-Ring Data Bank (ITRDB, http://www.ngdc.noaa.gov/paleo/treering.html) as well as data provided by U. Heussner (unpublished), A. Bråthen (Bråthen, 1982, 1995) and T. Bartholin (unpublished). Detailed documentation and dating results can be found in the individual dendroarchaeological reports (Seim and Linderholm, 2012, 2013, 2014a,b).

For accurate dating, special focus was given to (1) the presence of the last developed tree ring before felling and its stage of development (i.e., early- or latewood formation) to determine the exact year and season (i.e., waney edge dating) and (2) the number of sapwood rings to estimate the felling date (i.e., sapwood dating; Kaennel and Schweingruber, 1995). Oaks in western Sweden, in particular 100–200 year-old individuals, develop on average 16 sapwood rings with a minimum of 8.73 and a maximum of 26.55 rings ($p < 0.05$) (Bråthen 1982; Haneca et al., 2009). Based on this observation, we added 16 sapwood rings to the last heartwood ring yielding a felling date with an uncertainty range of ± 10 years. An earliest possible felling date, *terminus post quem*, was given when only heartwood was preserved and 10 sapwood rings were added to the last heartwood ring (i.e. heartwood dating; Kaennel and Schweingruber, 1995).

Finally, tree origin and forest stand density was estimated based on average growth rates (AGR), growth patterns, tree ages and mean segment lengths (MSL) of the dated series. AGR was calculated for each individual tree-ring series and then averaged with respect to the utilized species and construction phase. To avoid biases from the juvenile growth phase, we truncated all series with pith present so that the first 30 years of the series were removed (AGR30) following Haneca and Beeckman (2005). Standard deviation (SD) of the AGR and AGR(30), respectively, were provided to highlight the variability in growth rates in the series so that sudden growth changes could be detected (Haneca and Beeckman 2005 and references therein). The average of AGR (AGR(30)) of 1.15 mm/year for pine and 1.04 mm/year for oak served as thresholds for the evaluation of the stand densities of the analyzed species.

3. Results

3.1. Marka

During sampling, we observed that the timber structure of the nave, the wall plates and rafters in the chancel were made of conifers. All ten samples taken in the nave and one sample taken from a wall plate in the chancel were identified as Scots pine (*Pinus sylvestris* L.) (Table 1). One collar tie in the chancel was made of oak (*Quercus* sp.). Sapwood rings in the pines samples were not clearly distinguishable, but the waney edge in one of the rafters from the nave was present (Table 1). Internal crossdating showed that the pine sample from the chancel matched all samples from the nave with an interseries correlation of $r = 0.49$, allowing the development of a 153-year long object chronology (Fig. 3). The resulting object chronology showed the best correlation ($t = 5.14$, $r = 0.42$, Gl = 62.70%) with the South Scandinavian pine reference chronology for the period AD 1003–1155 (Fig. 4, Table 3; see also Seim and Linderholm, 2013). The presence of latewood in the waney edge of sample MA_DC01 suggested a felling of the trees between late summer of 1155 to spring of 1156. The oak sample (MA_DC12) taken from the collar tie in the chancel lacked sapwood and could not be dated due to the low number of tree rings (Table 1). The average AGR(30) for the pine samples was 1.07 mm/year with a SD of 0.50 mm and a MSL of 83 years.

3.2. Gökhem

The ten samples taken from timbers in the attic of Gökhem showed a dominant usage of Scots pine in the nave and oak in the chancel to the east (Table 1). For each construction part, five samples were analyzed. From the five pine samples taken in the nave, only two TRW series (GMR01 and GMR02) could be combined into a 119-year long object chronology covering the period AD 1022–1140. Samples GMR04 and GMR05 were absolutely dated but