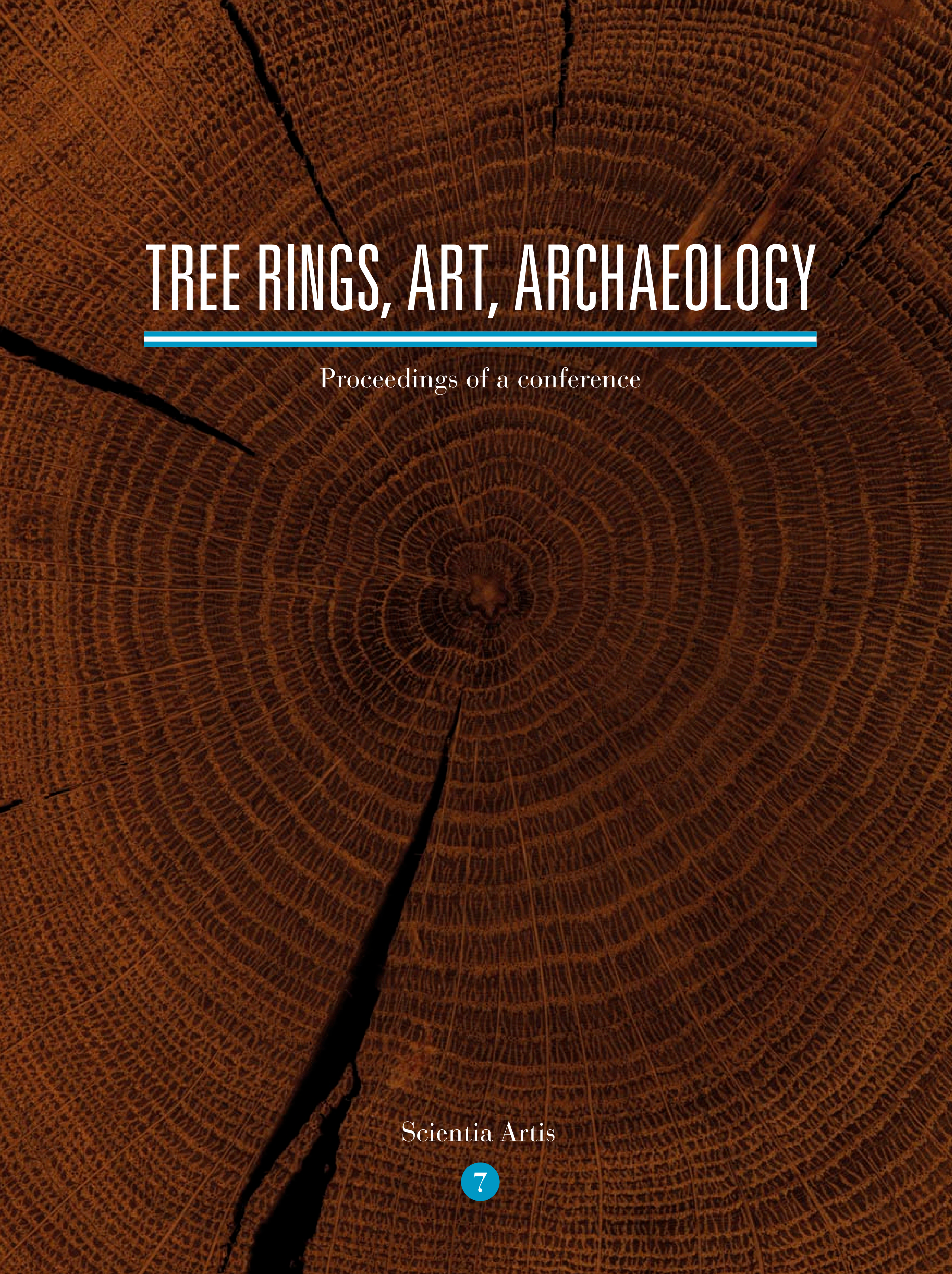

TREE RINGS, ART, ARCHAEOLOGY

Proceedings of a conference

Scientia Artis

7

Royal Institute for Cultural Heritage

SCIENTIA ARTIS

Conjunctione ad cognitionem

Volume 7

Brussels

2011

TREE RINGS / ART / ARCHAEOLOGY

Tree Rings, Art, Archaeology

Proceedings of an international Conference

Brussels,
Royal Institute for Cultural Heritage
10-12 February 2010

Directed by Pascale Fraiture

Brussels
2011

Royal Institute for Cultural Heritage

Published by the
Royal Institute for Cultural Heritage /
Institut royal du Patrimoine artistique /
Koninklijk Instituut voor het Kunstpatrimonium
Parc du Cinquantenaire, 1 / Jubelpark, 1
1000 Brussels, Belgium
Tel. + 32 (0)2 739 67 11
Fax: + 32 (0)2 732 01 05
CCP 679-200044759-60
IBAN BE73 6792 0047 5960
BIC PCHQBEBB
URL http://www.kikirpa.be

Illustrations: the authors, unless otherwise stated.

Responsible publisher
Christina Ceulemans

Direction and editing
Pascale Fraiture

Layout concept
Emmanuel van der Sloot

Translation
Rebecca Miller
Pascale Fraiture

Revision and final editing
Pascale Fraiture
Rebecca Miller
Sarah Crémer
Simon Laevers

Conventions adopted in this volume
The letter "d" following a year indicates that the date has been provided by dendrochronology (the inverse has not been systematically applied).
All of the dates cited are AD, unless indicated as BC.

Cover
Slice of an oak trunk from a forest in the surroundings of Liège, Belgium. © P. Fraiture, IRPA/KIK

ISBN 978-2-930054-13-1
D/2011/0613/3

Scientific committee

Financial support of the Conference and its Proceedings

Politique scientifique fédérale belge (BELSPO)
Royal Institute for Cultural Heritage (IRPA/KIK)
Ministère de la Région de Bruxelles-Capitale
Fonds Wetenschappelijk Onderzoek (FWO)
Fonds National de la Recherche scientifique (FNRS)

The *Tree Rings, Art, Archaeology* Conference, held in February 2010 at the Royal Institute for Cultural Heritage in Brussels, was recorded and is available on **http://www.kikirpa.be/uploads/traa/CD/bande_audio.htm**, which comprises all the oral presentations and discussions. The complete program with contact information for the participants is available on **http://www.kikirpa.be/uploads/files/TRAA_Program.pdf**

Tree Rings, Art, Archaeology

PART 2: TRADE

Timber transport and dendro-provenancing in Thuringia and Bavaria

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Key words timber transport / rafting / dendro-provenancing / dendro-ecology

Summary

In dendrochronology, knowledge about the origin of timber and the provenance of wood samples is of great interest. The provenance attribution allows the reconstruction of forest use in the past and the establishment of regional or local chronologies which improve the dating success and dating reliability of wood samples from a certain region. The establishment of local chronologies is not difficult, if logging took place in the surrounding area within a circumscribed circle of not more than around 20 km. If logging, however, took place far from the building site and timber from different provenances was used, wood grown under different conditions is present among the samples. In consequence, tree-ring series with different courses and signals are obtained reflecting the specific growth conditions of different provenances.

Historical sources about trade lanes in former times give only a general impression about the amount of historical timber transport. Sometimes archaeological evidence of timber transport can be found while sampling, e.g. signs and relicts on the beams. Another approach is to assign the samples to a specific provenance by using the characteristic properties of tree-ring series.

In the following contribution, a short overview is given about the knowledge of timber transport in Thuringia and Bavaria, some examples of relicts of timber rafting are described and a new methodological approach for the establishment of regional and local chronologies is introduced.

Timber Transport

Timber transport is associated with the growth of towns and shipbuilding places near the coast. This simple statement is valid since ancient times. The great civilisations – Egyptian, Persian, Greek or Roman – used timber imports for building and shipbuilding purposes. The oldest proof of timber transport is recorded on a relief of a Persian palace in Khorsabad from the 8th century BC (Fig. 1a). Lebanon cedar and cypress trees were used for Phoenician and Egyptian ships as well as for beams for Persian and Jewish palaces and the temple of King David (Meiggs, 1982, p. 68). A remarkable detail of the relief from Khorsabad is that the logs were obviously cut to similar length and stored on ships or were drawn by galleys. The logs show typical holes at one end for ropes which were tied through the holes to attach the logs on the ships. These holes may be found in beams of an ancient palace and can be recognised as typical relicts of timber transport.

Sea transport of timber was usually organised by ship. There is only rare evidence for rafts across the Mediterranean Sea. It is probable that the transport of the Egyptian obelisk in the time of Emperor Augustus was only possible using a special raft with a load-carrying capacity of about 200 tons.[1] Sea or lake crossing rafts were floated for example on the Bavarian Ammerlake up to the 19th century (Filser, 1991, p. 21). The raft was built with hundreds of tied logs and driven by sail or drawn by rowboats.

It is not known when rafting and timber transport first began north of the Alps. Rafts were used before the Roman conquest, especially for transport of people and commercial goods, but less for timber trading. It seems that timber transport was a

1. In the Vatican Museum in Rome, Galleria Delle Carte Geografiche, a wall painting shows a raft with an obelisk tied with rops.

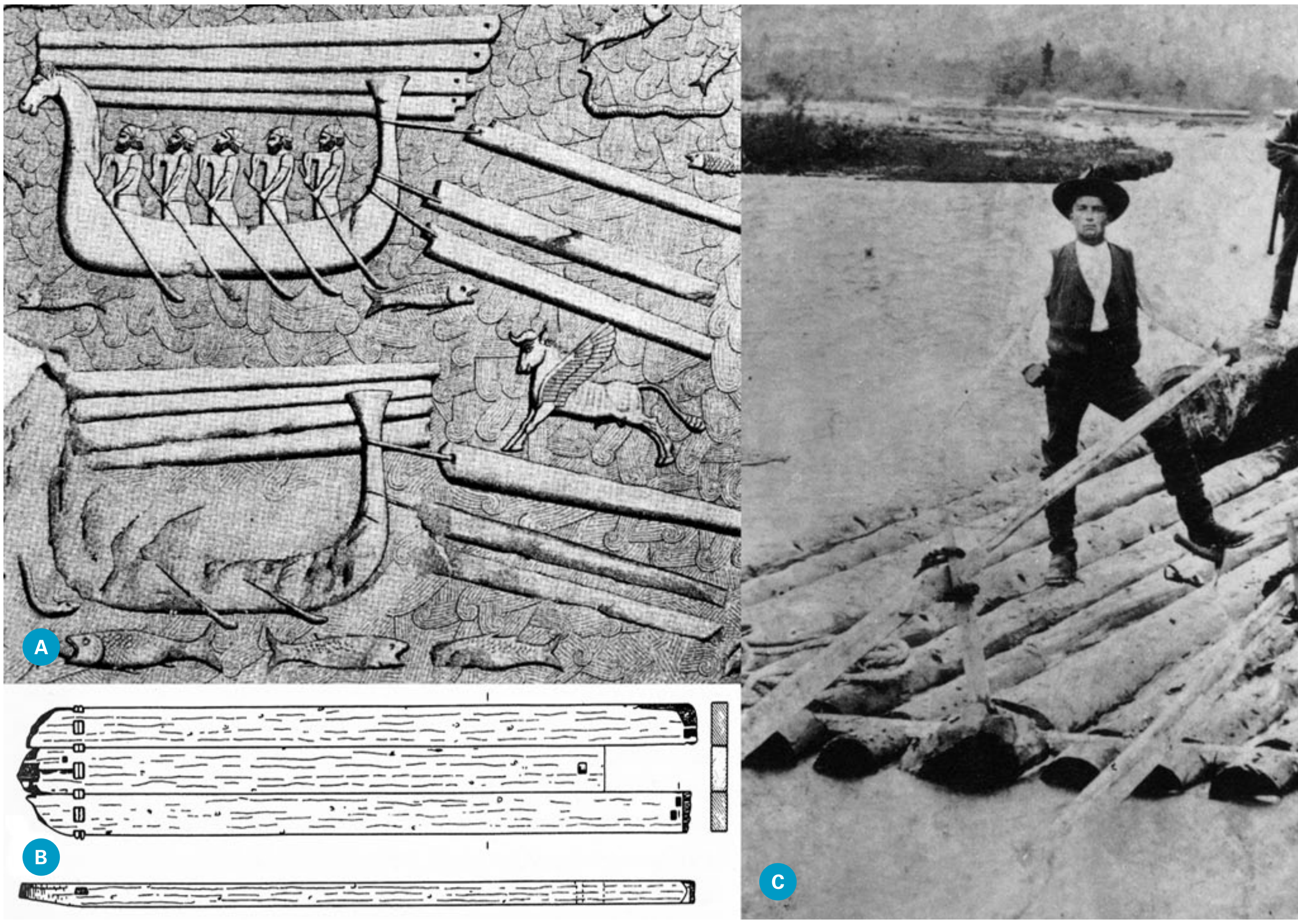

Fig. 1

Tying techniques.

A Logs drawn by galleys, Khorsabad 8th BC (Klengel, 1967, p. 70).

B Roman raft, Strasbourg (Ellmers,1985, p. 19).

C Pole tied raft on the Loisach, early 20th century AD (Filser, 1991, p. 9).

common phenomenon during the Roman period during the 1st–5th centuries AD. The oldest evidence of rafted beams is dated to the Roman period and was found in Strasbourg (Ellmers, 1972; Fig. 1b). It is remarkable that beams, but no logs, were tied together with a pole inserted through holes or mortised grooves. After the Roman period, during the period of human migration, commercial timber transport on the Rhine and Danube Rivers stopped. We do not exactly know at what time timber transport appeared again, but the earliest relicts of rafting are recorded on beams in the towers of the Bamberg cathedral and in a patrician house in Erfurt in the late 12th century (Eißing, 2007). Written sources and pictures from the 12th to the 19th century provide a comprehensive survey of rafting. Rafting was a common phenomenon on the rivers Rhine, Danube, Elbe, Weser and their tributaries (Keweloh, 1988). The map drawn by Ebner in 1912 obviously shows this (Fig. 2). Generally, we can assume that 50-80% of the timber needed for building purposes in the towns located at rivers was carried by rafts. The last period of rafting took place in the early 20th century. In the following decades, rafting disappeared, replaced by railway and motorised ship transport.

Fig. 2

Rafting on German rivers (Ebner, 1912).

Rafting relicts

Rafting relicts can be recorded in old frame and roof constructions. A raft-plate was built with 10 to 20 single logs. Several raft-plates could be connected to a bigger raft with hundreds of logs. The colossal Rhine rafts were assembled with a thousand or more single logs. Their maximum length was about 400 m and a few hundred raft-men were needed to steer the raft. Special raft-types were assembled only with semi-finished products like beams or boards. The tying technique is quite different. Some tying techniques were only used in a specific region or a specific time span, and others were used commonly.

The oldest tying technique was used during the Roman period. The stems or beams were connected with poles, which were put through holes or mortises. A similarly built raft from the 9th century was found on an island near the coast of the North Sea (Ellmers, 1985). In Bavaria, pole-tied rafts were floated on the river Loisach up to the 20th century (Filser, 1991, p. 9).

Other tying techniques used ropes to connect the logs, beams or boards. The ropes were made of slim softwood rods and called "*Wieden*" (Fig. 3d). The ropes were put through holes, mortises or fixed in notches. Rope-connected rafts were common in Thuringia on the river Saale but also on the rivers Murg and Neckar in the region of the Black Forest (Bock and Rosenkranz, 1968; Fig. 3a and 3b). On the Murg and the Neckar, special rafts were built only with beams or sawn boards (Scheifele and Braun, 1996, p. 68 and 189). Written sources, historical paintings and photos show that sawn board rafts were floated on the rivers Werra, Main and Viechtach (Fig. 3c).

The most common tying technique combined ropes and wooden nails. We can distinguish between different types with one or two nails (Fig. 4a and 4b). The nail sections were rectangular or round. Relicts of this tying technique are recorded on beams which were floated on the rivers Weisse Elster in Thuringia, Main, Isar and Danube in Bavaria and on the Rhine and its tributaries (Eißing, 2009, p. 28).

Other relicts of tying techniques are still not well reconstructed. Wedge-like nails made of beech were found on beams in buildings near the Main, Lech and Isar. We do not know their function or how they connected the logs.

In the final decades of the 19th and the early 20th century, iron rings and nails became a common tool for connecting the logs. In general, the iron nails and rings were displaced before erecting the frame.

Consequently, rafting was common all over Germany and rafting traces and relicts were found from the south to the coast. In some regions, especially in towns near the rivers Rhine, Danube, Main or Elbe, rafted timber dominates over timber from local cut trees.

Methodological approach for the establishment of local chronologies

The Thuringia basin is the central part of Thuringia and would be naturally covered with a beech or a beech-oak forest. The town Mühlhausen is located at the river Unstrut in the northwest of the Thuringia basin. If the timber for building purposes was cut in the directly surrounding area of Mühlausen we would expect that oak would be used for all frame works and roof constructions. Eight church roofs were built from 1300–1400 in Mühlhausen. All roof constructions, however, are of fir. Oak was only used for some special beams. The fir beams show relicts of rafting and the first questions arise about the provenance of fir timber. The next remarkable point is the fact that the rafts would have been drawn up the river against the flow direction of the current. The map in Figure 5 shows Thuringia and the distribution of the timber species. About 8,000 samples were investigated and dendrochronologically dated. On the map, the samples were pooled for different towns and the diameter of the dots represents the number of investigated samples. Three parts can be distinguished. In central Thuringia fir and spruce dominates the building timber. Oak, although with a naturally high occurrence in this region, surprisingly represents less than 5–10% of timber used. Spruce dominate the building timber contingents in the northern mountain region of the Harz. Oak only became dominant in southwest Thuringia in contact with the Bavarian Rhön and north of Mühlhausen in the region called "Eichsfeld". The mountain region of the Thüringer Wald is the northern border of the natural extension of fir (Aas, 2004), the Harz region the northern natural extension of spruce in northern Germany. The map shows the different areas of timber utilisation. All fir and spruce timber used in the towns in central Thuringia was transported in rafts from the mountain region of the Thüringer Wald. Four rivers connect the mountain area with the centre of Thuringia: the Gera, Saale, Weiße Elster and Pleiße. The river Werra is located on the opposite side of the watershed and flows to the North Sea. Because timber transport was mostly done by rafts, the historical logging areas were close to these rivers. If a local chronology should represent forest stands of only a few square kilometres, it is necessary to choose the core and tree-ring series only from buildings from this area. In Figure 5, these areas are marked by dark green ovals and the chronologies are indicated by the name of the river (Werra, Gera, Saale chronology). Regional chronologies in the centre of

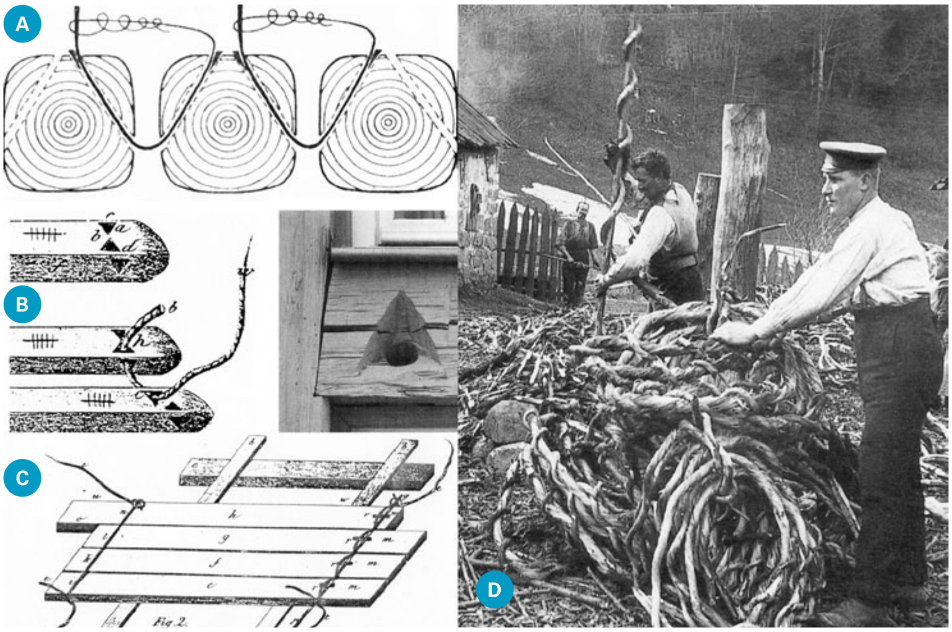

Fig. 3

Tying techniques with *Wieden*.

A Thuringa, Saale (Bock and Rosenkranz, 1968, p. 1).
B Black Forest, Murg and Necka (Scheifele and Braun, 1996, p. 187).
C Board raft (Scheifele, 1988, p. 300).
D *Wieden* (Scheifele and Braun, 1996, p. 173).

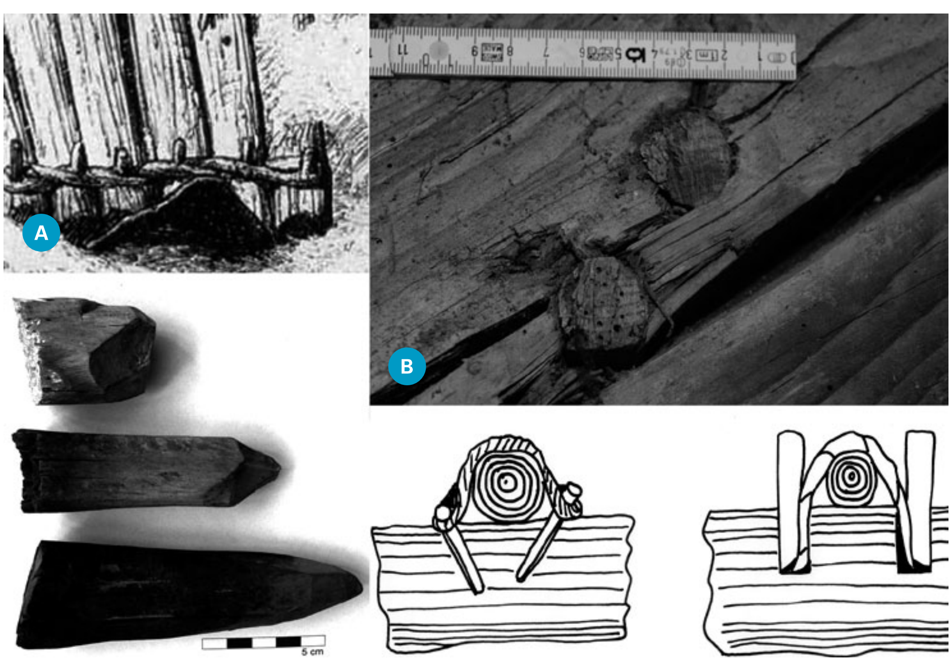

Fig. 4

Tying techniques with *Wieden* and nails. © T. Eißing

A One nail type.
B Two nail types.

Thuringia (Halle or Mühlhausen) established with series from rafted timber are marked by blue ovals.

The rafted fir timber in Mühlhausen could only be cut in the forest on the lee side of the Thüringer Wald and floated over the rivers Gera or Saale. The fir forest near the Werra on the other windward side of the watershed is not reachable for exploitation of wood and timber transport to Mühlhausen. A simple *t*-value calculation yields evidence concerning the origin of the fir timber of Mühlhausen. The best match, with a *t*-value of 16.9, is obtained with the Gera chronology, the *t*-value with the Saale

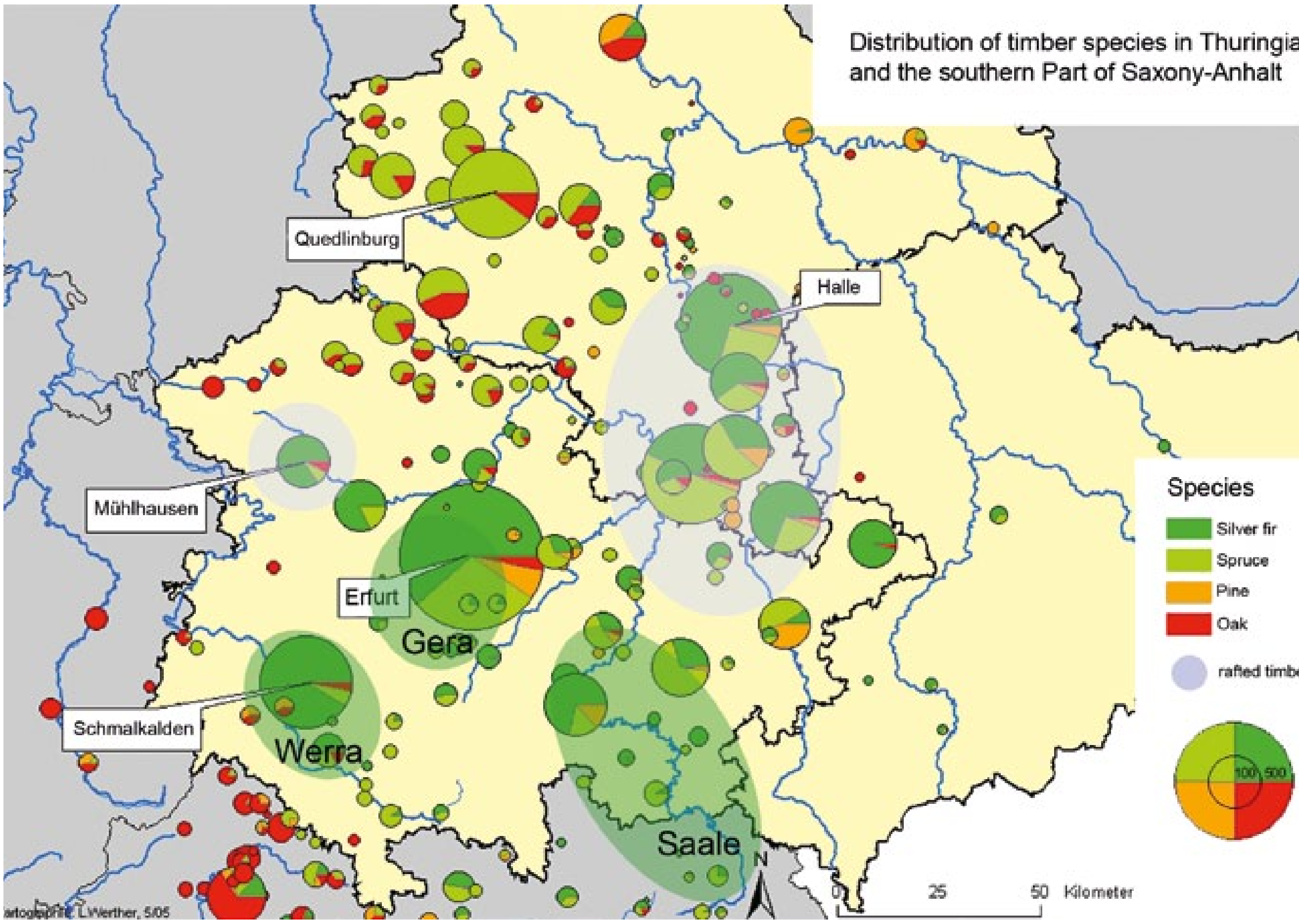

Fig. 5

Distribution of timber species in Thuringia and Saxony-Anhalt. Areas for local chronologies: dark green; rafted timber area: light grey.

chronology is about 12.5 and with the Werra chronology 10.0. The difference of accuracy is 30–40% less with the Saale chronology and the Werra chronology compared to the Gera chronology. In conclusion, the firs used in Mühhausen must have been cut in the area of the river Gera.

Another example for the determination of timber provenance can be demonstrated at the small village of Hendungen in the Bavarian Rhön. Oak is the naturally growing species in this region and was commonly used for frameworks and roof constructions (Fig. 6). The frame work of the building Wirtsgasse 2 was made of oak, cut in winter 1566/67d. Only the mechanical swan boards in the wood cabinet were made from fir of the best timber quality with narrow rings. Because of the natural spread of timber species around Hendungen, it is obvious that the boards were imported. The next nearest forests with fir stands were located in the region between Schmalkalden and Meiningen and west of the Bavarian side of the Thüringer Wald in the Frankenwald. Comparison of the fir tree-ring series with more than 100 rings with the Werra chronology and the Franken chronology indicates that the best result with a *t*-value of 8.6 is obtained with the Werra chronology. The *t*-value with the Main chronology is only about 5.6. The most plausible assumption is that the boards were imported from the Werra region. This interpretation finds further support by the fact that Hendungen was in the possession of the Earl of Henneberg in the 16th century (Faber, 2001, p. 176).[2] The

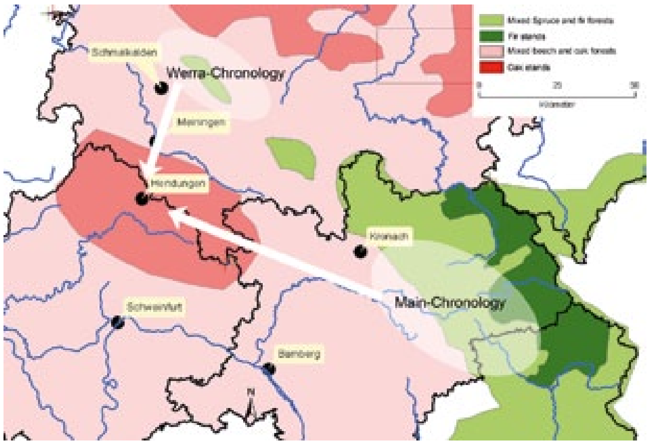

Fig. 6

Hendungen, Wirtsgasse 2. Localisation of fir timber origin in Hendungen. Best match with Werra chronology (t_{BP} = 8.6) in comparison to the Main chronology (t_{BP} = 5.6). ©T. Eißing

boards, and this is a new aspect, were transported about 20 km on wheels to Hendungen, because Hendungen has no direct contact to a river or stream for rafts.

Timber transport and dendro-provenancing in Bavaria

In contrast to Thuringia, master chronologies for fir, spruce and oak have existed in Bavaria for several decades (Becker and Giertz-Siebenlist, 1970; Becker, 1991).[3] The fir chronology integrates different provenances of all of southern Germany. Although this chronology is an important tool for dating, it is not suitable for the determination of timber origin. Since 2007, cooperation between the University of Applied Science in Weihenstephan and the University of Bamberg has aimed at reorganising the dendrochronology in Bavaria to obtain a set of local chronologies for fir, spruce, pine and oak in Bavaria. After the end of the project in 2011, about 18,000 single series will have been measured and clustered in local chronologies.

2. Henneberg lies near Meiningen at the west side of the Thüringer Wald.

3. Becker presented in 1991 a local spruce chronology for Franken (Becker, 1991).

The problem of rafted timber was mentioned above. The map in Figure 7 shows the rivers and streams used for rafting until the early 20th century. In the northern part of Bavaria, the river Main and its feeders were important trade lanes. The Main headwaters region is located in the Fichtelgebirge and the river flows west into the Rhine. On the Main and Rhine, logs and boards were transported up to the Netherlands. The southern part of Bavaria is bordered by the river Danube. The flow direction is opposite to the Main: from west to east. Like the Rhine, the Danube was very important for timber trade and has many feeders, especially in the south. All southern feeders, like the Iller, Lech, Isar and Inn, have their source in the Alpine region. On these rivers, rafting was a common phenomenon documented since the beginning of the 13th century. The oldest beams with rafting relicts were recorded in the Freising cathedral and dated to 1223/24–1227 (Fig. 4b). The area between the Main and Danube is the only region of Bavaria with less rafting activity. This region is called Middle Franconia (*Mittelfranken* in German) and includes famous towns like Nuremberg and Rothenburg ob der Tauber. These towns have no direct connection to the river systems of the Main and Danube and therefore could not be the direct destination for rafted timber. Consequently, these towns supported cultivated forest and tried to ensure the sustainable use of timber by restrictive laws. Locations of logging and timber use are located close together and rafting has no influence on the establishment of local chronologies.

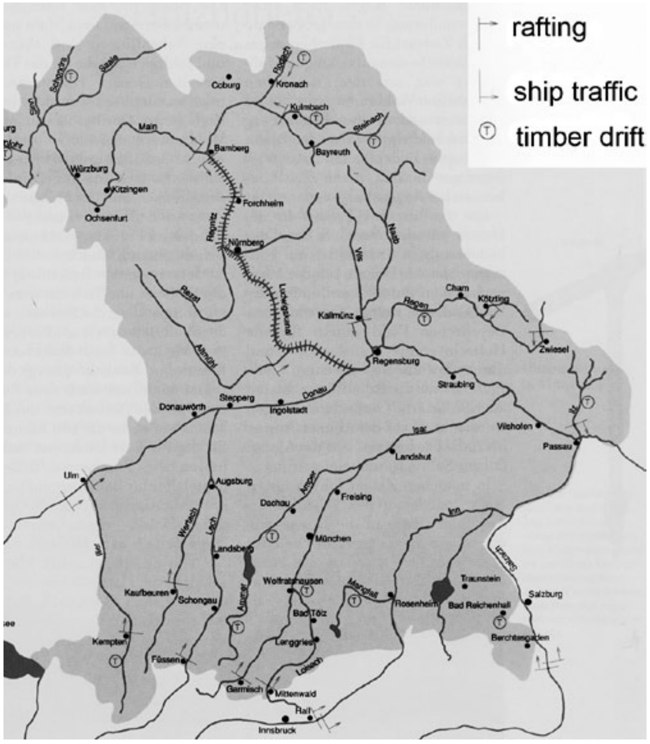

Fig. 7

Hydrological system of Bavaria (after Filser, 1991, p. 13).

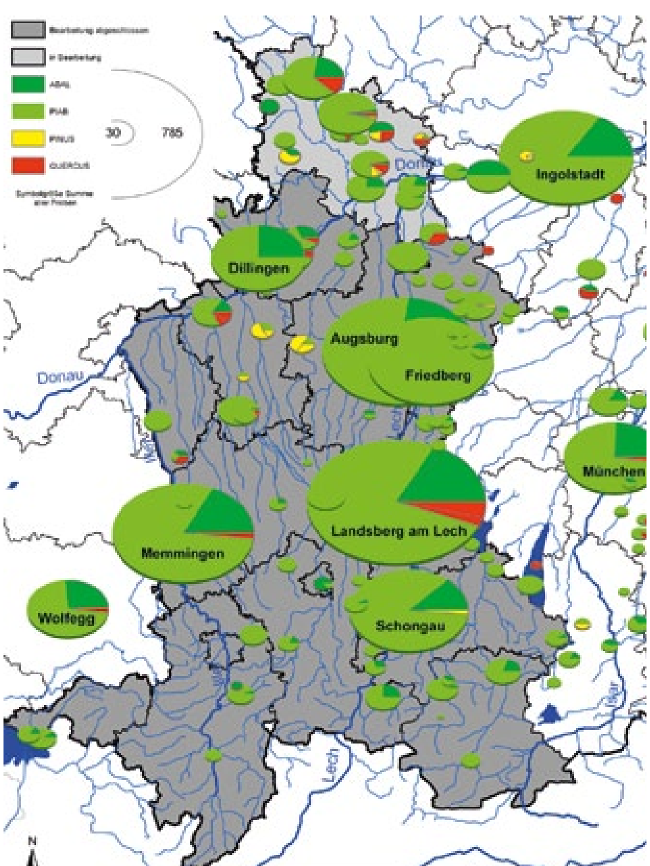

Fig. 8

Schwaben region between the River Iller and Lech. Distribution of timber species.

This is not the case in the Main region and the southern part of the Danube. Fir and spruce were cut in the Frankenwald and Fichtelgebirge and rafted westward on the Main. On the upper Main, only small rafts were assembled. Near Bamberg, these rafts were disassembled on the banks of the Main and the logs were tied to bigger raft-plates. In the middle Main region, oaks from the forest regions of Steigerwald and Spessart were stored on these rafts or the rafts were disassembled again and softwood and oak logs were tied together in combined raft plates. Oak stems were usually destined for shipyards in the Netherlands. The timber export to the Netherlands became an important part of the trade in the 17th and 18th centuries (Schenk, 1996, p. 242). In the upper and middle Main region, rafted softwood was used for building purposes in a 20 km wide corridor on both river sides from the 12th century. Hence, rafted and non-rafted timber were simultaneously used in this region. The timber species can give an initial determination of rafted or non-rafted origin, because pine and oak were normally cut in local forests. Boards made of softwood were often stored on rafts or special board rafts were assembled. In hundreds of sawmills in the Frankenwald, the sawing of boards was organised and boards were second important trade products (Kuff, 1985, p. 139). Local chronologies were built for spruce and fir with samples from buildings in the Frankenwald and Fichtelgebirge in combination with series from rafted timber of building sites downstream.

In southern Bavaria, the dendrochronological approach for the establishment of local chronologies is much more complicated. Rafting was a common phenomenon too, but caused the mixture of timber from very different forest sites, from low elevation sites up to mountain sites more than 1,600 m a.s.l. The map in Figure 8 shows the region of the Bavarian Swabia (*Schwaben* in German) between the rivers Iller, Wertach and Lech. This region is coloured dark grey. The dots indicate the provenance of the investigated buildings accumulated for different towns and villages. Spruce dominates with 78% of the sampled contingents, fir reaches 17%, pine, oak and larch together amount to not more than 5% on the whole. Rafting is known from historical documents on the Lech from the late 13th century (Filser, 1989).

Timber rafts started in Reutte in Tyrol (Austria) and reached Schongau. Augsburg was the most important town in this region with extensive trade connections over the Alps to Venice. Additionally, Augsburg was the town with the highest timber consumption. Rafting on the Lech to Augsburg hit its peak around 1600. It is assumed that 7,000 rafts were floated to Augsburg per year. About 50% of the rafted timber was consumed in Augsburg, the other 50% floated downstream to the Danube. Parts of the timber were sold in Regensburg, Passau, Vienna and Belgrade (Dreißler, 1927). The map in Figure 9 presents the forest sites coloured light green. The regions of timber utilisation are indicated in dark green. The yellow and red triangles indicate rafting places and tax stations. The years printed in the map indicate the first time this region was mentioned in a historical document.

In the region around Schongau, timber utilisation seems to have been concentrated to local forests at elevations below 800 m, whereas the more northerly regions were supplied with timber from southern mountain regions with elevations up to 1,800 m. Consequently, different elevation origins and the mixture of timber from different elevation origins by rafting distinctly complicate the dating of historical wood in Augsburg in comparison to Schongau. Samples taken from buildings in Schongau could be successfully dated 85% of the time. In Augsburg, dating success at 60% is significantly lower. We assume that this is the consequence of a stronger mixture of timber from different origins characterised by divergent growth conditions.

Dendrochronological elevation model for the establishment of regional and elevation specific tree-ring chronologies

Recently and in historical times, Norway spruce was and is an often used timber species. In southern Germany, this tree species grows under different climatic conditions, at lower elevation sites under warmer and dryer conditions as well as at high elevation sites, e.g. in the Northern Alps, under cold and wet conditions (Dittmar and Elling, 1999).

The diagram in Figure 10a illustrates two chronologies of Norway spruce trees growing under these different conditions in recent forest sites: the red chronology is established with tree-ring series from spruce growing at a low elevation site near Landsberg/Lech at around 500 m a.s.l. and the blue chronology from spruce at a high elevation site at around 1,700 m a.s.l. in the Bavarian Alps. In many years, both chronologies indicate common signals. In several years, however, signals are opposing; the series show disagreements (*Gegenläufigkeiten* in German).

This is the case for example in some known dry and warm years which are responsible for good growth conditions at high, but worse growth conditions at low elevations sites. Two examples are the years 1934 and 2003.

These disagreements are the reasons why we intend to establish region – and altitude – specific chronologies in order to improve and assure the dating of historical wood samples.

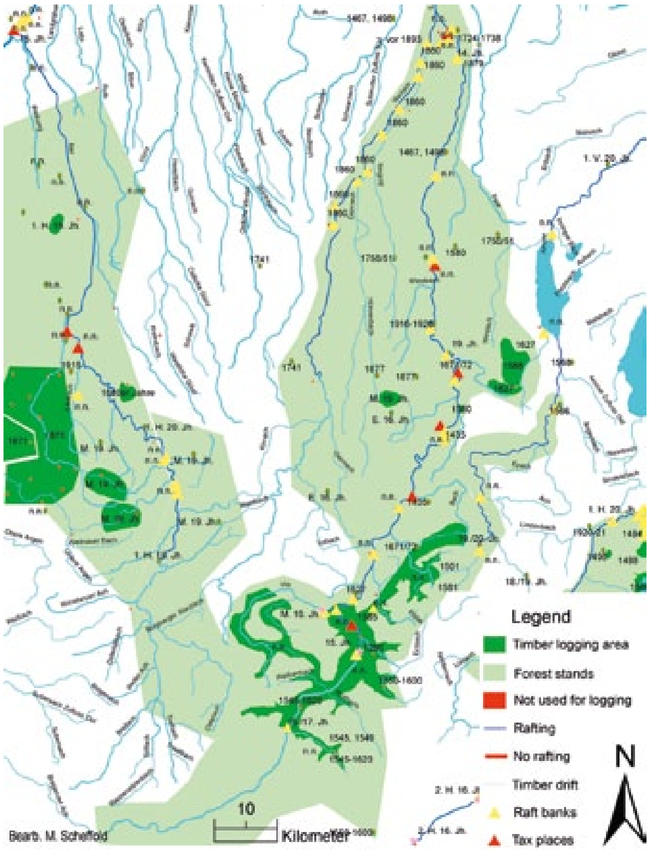

Fig. 9

Timber logging areas along the river Lech.

To do so, around 500 spruce trees were sampled in southern Germany at different forest sites and at different elevations. The sampled elevations range from 200 to over 1,700 m a.s.l.

These data were used to select tree-ring parameters which are specific for Norway spruce tree-ring series from different altitudes. Both the mean tree-ring width and the mean sensitivity are strongly related to the elevation of the growing site (Fig. 10b). With a non-linear regression model, it is possible to estimate the elevation of the growing site by use of the two dating-independent parameters: mean tree-ring width and mean sensitivity. The mean sensitivity is an expression of the degree of growth variations from year to year. The coefficient of determination (R^2) of the model is 76%.

In the next step, the elevation model was used to separate all our historical spruce samples from buildings south of the river Danube into different elevation provenances. The used data set include over 5,000 single series. According to their mean sensitivity and mean tree-ring width, around 840 series were allocated by the model to sites below 500 m a.s.l. and 450 series were allocated to sites above 1,200 m a.s.l.

After assessment of dating and synchronisation, the single series were detrended[4] and summarised to elevation-specific chronologies. The curves in the lower part of Figure 11 show the comparison between the low and the high elevation site chronology during the 15th century. Obvious are the differences in sensitivity: the low elevation site chronology has a high sensitivity and the high elevation site chronology a low sensitivity, i.e. a complacent course. In the upper part of the diagram, the results of signature disagreement calculations are illustrated. Signature disagreement (*Gegenläufigkeit*) means a different changing of two time series levels in relation to their previous levels, e.g. an increasing growth in relation the previous year of one chronology meets with a decreasing growth of the other chronology.

In this century, the two chronologies have a percent agreement (*Gleichläufigkeit* in German) of 57%, but 43 years show a signature disagreement, indicated by empty markers.

4. The age trend and the geometric trend of a single tree-ring series have been removed by a 5-year running mean.

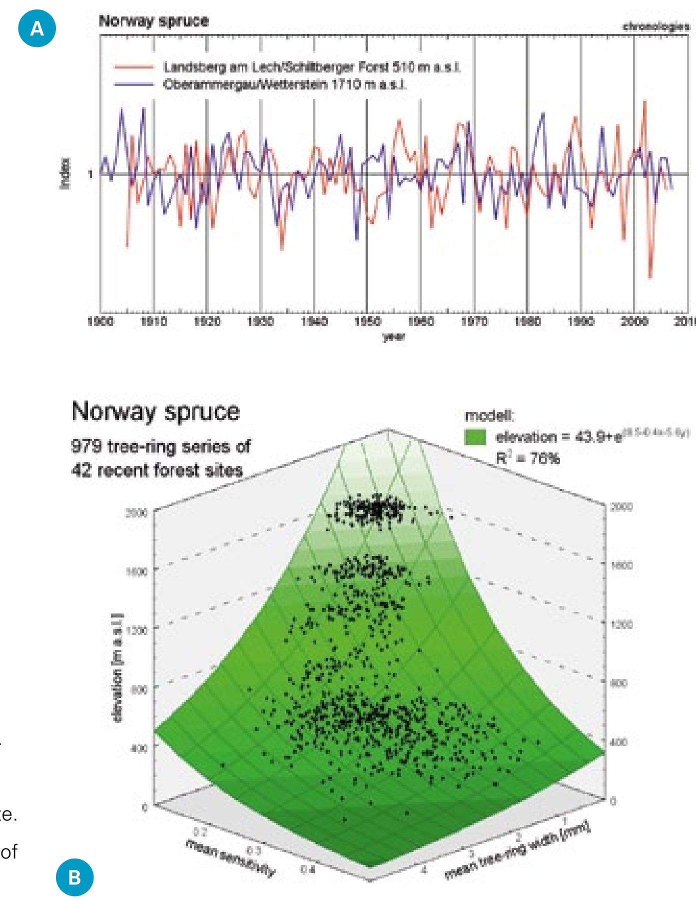

Fig. 10

Chronologies of Norway spruce at two forest sites in southern Bavaria.

A Both chronologies are formed by 20 series from ten trees at each site.

B Non-linear regression model for the assignment of tree-ring series of Norway spruce to different elevation provenances.

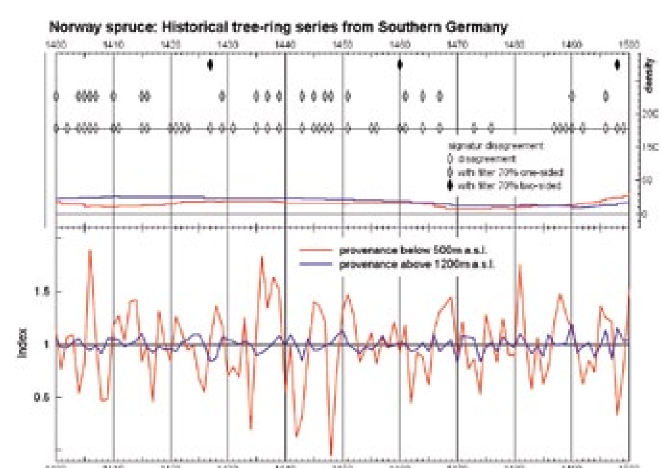

Fig. 11

Comparison between the spruce chronologies for high and low elevation sites in southern Germany (below). In the upper part the results of the disagreement calculations are plotted.

A 70% filter for the signature frequency of the single series within a chronology reduces the number of years with a signature disagreement (filled marker). This filter selects only those years of disagreement in which at least 70% of the single series within a chronology reacts in the same way. In 23 years, one of the two chronologies has a signature frequency of at least 70%

(grey filled markers), in 3 years both chronologies have different signatures and a signature frequency of at least 70%. These years are indicated with black filled markers and indicate an especially strong signature disagreement.

This is the case for example in 1427: more than 70% of the single series within the high elevation site chronology have decreasing growth in relation to 1426 and more than 70% of the single series within the low elevation site chronology have increasing growth in relation to 1426.

One of our upcoming investigations aims to interpret these disagreements by meteorological conditions in the specific years. Another question is whether these regional and elevation specific chronologies are suitable for regional climate reconstructions.

Conclusions

Timber transport on rafts and ships even over long distances is documented since ancient times. In Central Europe, timber transport was a common phenomenon during the Roman period from 1st–5th centuries AD. In later times, between the 12th and the 19th centuries, all river systems were used for extensive transport of different timber species. It is assumed that a predominant amount of timber needed for building purposes in towns located at rivers was carried by rafts.

For the construction of rafts and the fixation of boles, stems and beams on the rafts, different techniques were used. Relicts are often recorded on old frames and roof constructions and thus document the former timber transport.

In Thuringia, different timber species within historical buildings point out various forest origins and various distances between logging and timber utilisation. The accessibility of building sites by rafts was determinant in the application and mixture of timber species.

In Bavaria, the Main in the north and the Danube in the south with their feeders were the main trade lanes for timber transport. An increasing use of forests in higher mountainous regions in the south since the beginning of the 13th century caused an increasing mixture of timber from different provenances, especially from high and low elevation sites. The parallel presence of wood grown under various climatic conditions impedes the dating of historical wood samples and requires the establishment of regional and elevation specific chronologies.

Recent tree-ring series from different forest origins in southern Germany are analysed in order to establish a regression model which enables the assignment of historical wood samples to different elevation provenances. The model is used for the formation of regional and elevation specific chronologies.

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TREE RINGS / ART / ARCHAEOLOGY

Printed in October 2011 by Snel Grafics (Vottem, Belgium)
D/2011/0613/3

Tree Rings, Art, Archaeology

In 2010 the Royal Institute for Cultural Heritage (IRPA/KIK) organised the *Tree Rings, Art, Archaeology* conference. Its main objective was to bring together dendrochronologists and other researchers – historians, archaeologists and art historians – to discuss the uses of dendrochronology.

The proceedings of this conference bring together articles by authors from fifteen European countries, from different backgrounds and skills. They successively explore the different facets of dendrochronology with a common motto: "Beyond dates". Indeed, more than just a dating tool, dendrochronology provides data through time and space in fields as varied as provenance of the wood, ecology, climate, environment, etc. It is clear that such data obtained are not an end in themselves; they must be integrated within a broader historical approach in order to realise their full potential and significance. To achieve this goal, the need to compare and integrate approaches from researchers with the different skills involved should be self-imposed. However, this is rarely the case. Moreover, such indispensable collaboration should lead to a better knowledge of the potential and limits of the tree-ring approach and thus to better understanding of its contributions. These proceedings are, we hope, a significant step in this direction.

Pascale FRAITURE was the organiser of both the conference and this publication. Doctor in archaeology and art history, she is specialised in the dendro-archaeology of works of art and heads the Laboratory of Dendrochronology at the IRPA/KIK.

The *Scientia Artis* series is published by the Royal Institute for Cultural Heritage (IRPA/KIK, Brussels). The works in this series – monographs, exhibition catalogues and conference proceedings – present the results of research projects and scientific events (co)organized by IRPA/KIK. Since 1948 this Federal Scientific Institution has been charged with the study, protection and promotion of Belgium's cultural heritage.

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ISBN 978-2-930054-13-1