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TREE-RING RESEARCH IN EUROPE

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ABSTRACT

In the last ten years tree-ring analysis in Europe and its application has been extended considerably. By varied methods, a number of chronologies have been established for conifers and deciduous trees from different climatic regions that partly reach back to periods before the birth of Christ. The focus of dendrochronological research is usually dating and climatological studies are carried on only sporadically.

INTRODUCTION

It is not known exactly who first recognized that trees grow in annual layers. A summary of the early history of crossdating was done by Studhalter (1955). In North America Douglass (1919) was probably the first to do systematic research in dendrochronology. In Europe Švedov (1892) and Kapteyn (1914) independently had similar ideas. Whereas in the U.S.A. a central laboratory was established, dendrochronological work was done somewhat randomly in Europe, mainly in Scandinavia, Russia, and Germany.

According to Kolčín (1965), there are two main reasons for the slow development of European dendrochronology. First, in Europe trees do not grow to as old ages as in America. Second, climatic relationships are much more complex. Some developments were bound to reach a dead-end; for example E. H. De Geer's attempt to synchronize European tree-ring series with the American sequoia ring sequence. In 1956 she was still advancing her theory of a worldwide teleconnection. Huber (1941), on the other hand, made an essential contribution to European dendrochronology which will be looked into more closely in this study.

In the course of time a substantial body of literature has developed in numerous periodicals and various languages. An extensive survey was made by Glock (1955) with 359 references, while hardly considering the European studies.

In addition, a short summary was done by Huber, Merz, and Fürst (1961) in Germany. Another survey by Kolčín (1965), written in Russian, deals with eastern European dendrochronology. Other surveys were published for Norway and Finland by Høeg (1956) and Mikola (1956).

The present contribution deals solely with the dating of the annual growth layers and the exploitation of the information they contain. The numerous papers on tree-ring analysis done in forestry and wood research are not taken into consideration. Although these papers analyze the annual increment, dating to the precise year is not necessary. The literature of the last decade will be included, the most recent of an individual's studies often standing as examples for the whole of his work. I regret not being able to mention extensively enough all the studies on the subject in question. This is due in part

to a necessarily subjective selection and partly to the fact that information was not available to me.

METHODICAL ASPECTS

Dendrochronological dating is based on the same principle everywhere and has been described extensively by Bannister (1963) and Stokes and Smiley (1968). On the basis of this principle, different methods have been developed in different laboratories. In the following the dendrochronological methods presently in use will be briefly explained. A description of the numerous possibilities of climatological calculation would, however, exceed the scope of this study.

The samples for a tree-ring analysis are taken as cross-sections or beam sections or in form of cores. The measuring of the tree-ring widths is done with an eye piece micrometer, a microscope, or a semi-automatic tree-ring measuring equipment which registers the measurements and punches them on a paper tape at the same time. With a plotter the tree-ring diagrams can then be drawn mechanically (Eckstein and Bauch 1969). Whereas in North America the tree-ring sequences can be synchronized with the skeleton-plot method (Stokes and Smiley 1968), in Europe the whole length of a tree-ring curve has to be taken into consideration because of the more balanced climatic conditions.

The dating method introduced by Huber (1941, 1942) and commonly used in central, southern and western Europe is based on a semi-logarithmic scale. On this scale the same percentage of change in growth results in the same slope and the same length of the curve independent from the absolute tree-ring widths. In addition, the maxima of a curve are smoothed and the minima emphasized. This fact makes the visual comparison of two diagrams easier. Lately the synchronization has been rationalized by the use of computers (Eckstein and Bauch 1969) but the semi-logarithmic paper continues to be in use, since the results still have to be checked visually. Huber's method does not eliminate the age trend of the ring series which is not very marked in the oak. As a measure for the similarity of two tree-ring curves the value of agreement ('Gleichläufigkeitswert') is accepted. It is defined as the percentage of parallel intervals in two different curves, not taking into account the absolute tree-ring widths. The percentage of parallel intervals of non-synchronous curves averages 50. The single values vary more around this mean the less two curves overlap. In the same way the values of agreement between synchronous pairs of curves vary about a mean value (>50) depending on the length of their overlap. Both distributions (the variations around the two means of 50 and >50 , respectively) cover each other considerably when the overlap of two curves is short. When the length of the overlap increases, this covering decreases.

A reliable chronological synchronization of tree-ring curves using only the value of agreement is often not possible. On the contrary, from a number of equally useful positions reported by computer, the best one has to be selected visually. A valuable help are the significant years of a curve. These are years where the single curves that have been included in a mean curve have the same trend. However, of several single curves in a synchronous position more than 50 percent may rise or fall in a certain year by chance. How many curves of a mean curve must show the same trend in a year in order to be acknowledged as significant depends on the number of single curves. Whereas there must be 90 percent with the same trend in a group of 20 curves, 65 percent will be sufficient in a group of 100 curves.

Eastern European dendrochronologists also do not eliminate the age trend when the aim of the research is the dating of an object. Mostly several methods are combined. For example, a ring width diagram with a semi-logarithmic scale is used together with the depression diagram (Vichrov and Kolčín 1962). The value of agreement is used to measure the similarity (Kolčín and Bitvinskás 1972). If the objects are very difficult, tree-ring indices are calculated on the basis of 20-year-moving-averages with 5-year intervals.

In northern Europe, where dendrochronology developed from tree-ring analysis in forestry, methods to eliminate the age trend were used at an early date (Ording 1941). The similarity between such index series is tested with the simple coefficient of correlation, which has recently been rationalized through the use of computers (Brandt 1969). The coefficient of correlation itself is in its significance dependent on the overlap of the two curves.

Other possible ways of making a statistic comparison of tree-ring series have been suggested by Munaut (1966), Brandt (1969), and Alestalo (1971).

EUROPEAN TREE-RING CHRONOLOGIES

Figure 1 indicates the dendrochronological laboratories presently at work. By means of the different methods discussed above, numerous tree-ring chronologies have been established which are summarized in Table 1. The short chronologies that exist occasionally, for example for yew, lime, alder, ash, and other tree species have not been dealt with, as they seem to be of no further importance at the moment.

In eastern Europe there are three chief chronologies of pine and spruce, covering the whole of the Russian plain. These chronologies show considerable resemblance to each other. Because of the strong partitioning of the Scandinavian countries by mountains, it is necessary to establish several independent chronologies there for pine and spruce. There are also separate chronologies for the different species of conifers in the southern German area and the Alpine region. In central and western Europe, however, the chronologies for deciduous wood become more prevalent. Whereas the oak chronology that has been established for south and southwest Germany is valid from Czechoslovakia in the east to Normandy and, partly, to the south of England in the west, the northern and northwestern area of Germany must be divided into small regional sections together with Denmark and the Netherlands.

APPLICATION

Architectural History

In the examination and preservation of historical buildings a major problem is often precise dating. Archival information frequently does not allow reliable conclusions about the architectural history of a research object. The application of art-historical criteria in the dating of an object does not always lead to precise results, either. Not even the radiocarbon method reaches the required degree of accuracy when it is applied to the period of the past 1000 years; the period most in question. For these reasons, dendrochronology, which is in the most favorable cases able to date the very year of origin of an object, meets with special attention in the research of architectural history.

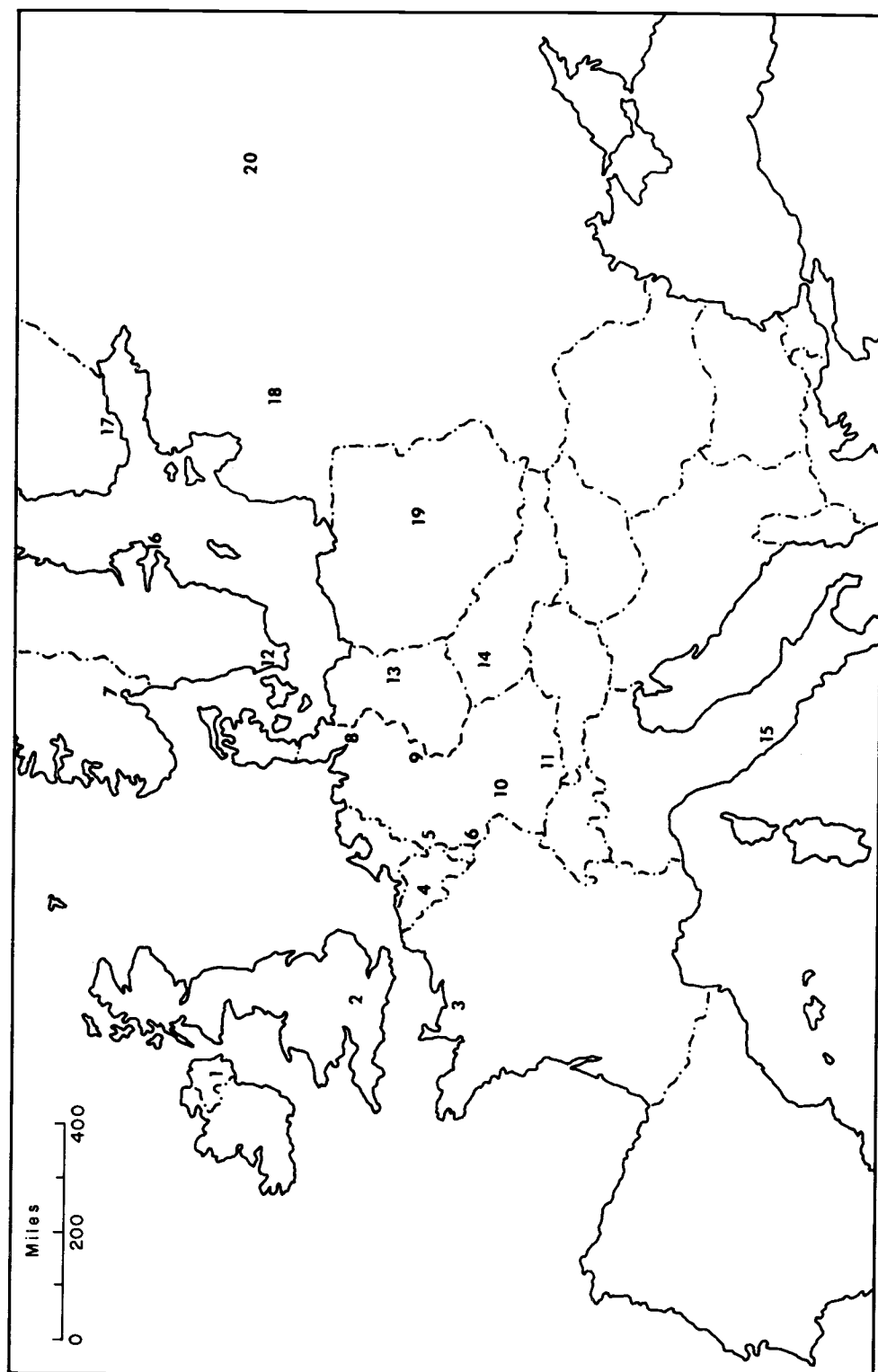


Figure 1. Dendrochronological laboratories in Europe. 1, Belfast; 2, Oxford; 3, Caen; 4, Louvain; 5, Cologne; 6, Trier; 7, Oslo; 8, Hamburg; 9, Göttingen; 10, Stuttgart; 11, Munich; 12, Lund; 13, East Berlin; 14, Zbraslav; 15, Rome; 16, Stockholm; 17, Helsinki; 18, Kaunas; 19, Warsaw; 20, Moscow.

Table 1. European chronologies.

Region	Species ¹	Period	Source
Ireland	oak	AD 1970-1381	Baillie 1973
Southern England	oak	AD 1550-0850	Fletcher, unpublished
Netherlands	oak	AD 1970-1680	Brongers, unpublished
Netherlands	oak	AD 1613-1140	Bauch, Eckstein, and Meier-Siem 1972
Belgium	pine	2300-2500 BC ²	Munaut and Casparie 1971
Northern France	oak	AD 1610-1280	Giertz, unpublished
Eastern Norway	spruce	AD 1937-1690	Ording 1941
Eastern Norway	pine	AD 1937-1639	Ording 1941
Eastern Norway	pine	AD 1940-1556	Aanstad 1960
Eastern Norway	pine	AD 1950-1687	Slåstad 1957
Eastern Norway	pine	AD 1954-1383	Eidem 1959
Western Norway	pine	AD 1959-1535	Brandt, unpublished
Central Norway	spruce	AD 1937-1460	Eidem 1953
Central Norway	pine	AD 1938-1424	Eidem 1953
Northern Norway	pine	AD 1936-1396	Ording 1941
Denmark	oak	AD 1971-1630	Bartholin 1973
Northern Germany	oak	AD 1970-1266	Eckstein, Bauch, and Liese 1970
Northern Germany	oak	AD 1100-0500 ³	Eckstein and Liese 1971
Northern Germany	oak	AD 1967-1338	Eckstein, Mathieu, and Bauch 1972
Weserbergland	oak	AD 1970-1004	Delorme 1972
NW Germany	oak	0500-6000 BC ²	Schmidt 1973
South, SW Germany	oak	AD 0200-6700 BC ²	Becker 1972a, b
South, SW Germany	oak	AD 0339-0717 BC	Hollstein 1965 and unpubl.
South, SW Germany	oak	AD 1973-0383	Hollstein 1965 and unpubl.
South, SW Germany	oak	AD 1960-0832	Huber and Giertz-Siebenlist 1969
South, SW Germany	beech	AD 1948-1320	Jazewitsch 1953; Hollstein 1973
South, SW Germany	fir	AD 1965-0820	Becker and Giertz-Siebenlist 1970
South, SW Germany	spruce	AD 1961-1583	Fürst 1963
Switzerland	oak	2400-3000 BC ²	Huber 1967; Giertz, unpubl.
Switzerland	oak	0952-1282 BC ²	Huber 1967; Giertz, unpubl.
Austria	stone pine	AD 1971-1468	Giertz, unpublished
Austria	larch	AD 1971-1333	Brehme 1951; Giertz, unpubl.
Finland	pine	AD 1960-1181	Sirén 1961
Sweden	pine	AD 1973-1530	Jonsson, unpublished
Northern Russia	pine, spruce	AD 1970-0884	Kolčín and Bitvinskás 1972
Northern Russia	pine, spruce	AD 0800-0600 ³	Kolčín and Bitvinskás 1972
Northern Russia	oak	AD 1420-0900	Kolčín, unpublished
Northern Russia	larch	AD 1969-1103	Šijatov 1972
Western Russia	pine, spruce	AD 1970-1050	Černych 1972
Eastern Russia	pine, spruce	AD 1970-0980	Černych 1972

Note 1. Oak = *Quercus petraea*, *Q. robur*; Beech = *Fagus sylvatica*; Pine = *Pinus sylvestris*; Spruce = *Picea abies*; Fir = *Abies alba*; Stone pine = *Pinus cembra*; Larch = *Larix decidua*, *L. sibirica*.

Note 2. Discontinuous chronologies, placed by radiocarbon.

Note 3. Relative chronologies, placed by archaeological context.

In northern Europe, especially in Norway, farm buildings, storehouses, and stave-churches from the 18th and 19th centuries, made out of pine and spruce, are of interest (Slåstad 1957). To date the exact year of origin is difficult, since the timber for a certain building project was not necessarily all cut at the same time. On farms the timber would be felled during the short periods between the seasons and stored for future building purposes. Frequently old timber was re-used.

These problems do not arise in Germany. Numerous dendrochronological datings of objects whose time of origin is known precisely, have shown that, as a rule, the timbers were cut immediately for the purpose of building and that the construction was done without delay after the cutting. Hollstein (1966) was able to prove that the wood, mainly oak, was even used in green condition. According to his observations, building timbers often show a characteristic curvature due to the shrinkage that occurred after it had been used. The pores are still clearly visible on the cross-cut ends, which is only possible, if the wood was in green condition when shaped with an axe.

An impressive example of dendrochronological dating of historical buildings is the dating of the Trier and Speyer Cathedrals (Hollstein 1968). Square and round poles of a former scaffold appeared in the stone walls of the Trier Cathedral after the removal of recently applied plaster. These poles had been in green condition when they were used in the construction. Together with lining boards and other building timber, an exact and differentiated sequence of the different stages of the construction was found. The phases of A.D. 1042 to 1047, 1054 to 1056, and 1074 are laid open as in a diary. Two scaffolding poles of the Speyer Cathedral from the year A.D. 1045 prove that the construction had at that point reached a height of 18.30 m.

In other cases tree-ring chronology has contradicted already existing dating results. The dating of foundation poles made of fir in the church of St. Martin's at Landshut (south of Munich) established A.D. 1441 as the date of cutting (Becker and Giertz-Siebenlist 1970), which is nine years later than the death of the supposed mason. The present dating of the completion of the main entrance based on the date of A.D. 1432 in the tympanon cannot be maintained any longer.

New knowledge in architectural research and in folklore has also been achieved in Northern Germany by dendrochronological means (Eckstein, Bauch, and Mathieu 1972). Isolated areas of rural culture can be found with buildings whose construction can only be dated to a 100 years at the closest. The focus of the present research is the farm house typical of the 16th century. Numerous buildings have been discovered which have outlasted the Thirty Years' War. In several instances, evidence could be found that the house inscriptions that had been taken for the dates of construction had been added as much as 150 years later and only referred to minor additions to the buildings.

Other objects of German frame-work architecture were dated in the southern part of Lower Saxonia (Delorme 1972). The first results of historical examination of buildings were published in East Germany (GDR) on a 16th century castle (Jährig 1972) which was dated by means of the west German master curve.

Dendrochronological examinations of 15th century market halls and barns in the north of France (V. Giertz, personal communication) have shown, besides new information about the dates of origin, that the southern German master curve is applicable even to those distant areas as a basis for the dating.

Similar examinations have been conducted on several large barns in England (V. Giertz, personal communication). However, the results are not as unequivocal as the one gained in France. Some specimens show a good resemblance to the southern German oak curve, but most of the wood samples are of a strongly local character as to their tree-ring structure. For these reasons a regional chronology is required for the dating of such specimens, which is being worked on at present (J. M. Fletcher, personal communication).

In southern Europe, above all in Italy, several kinds of wood were frequently used in a building. Beside oak, they also took chestnut, pine, larch, and other species.

Therefore it is difficult to obtain sufficient material for comparisons from one and the same object. In addition, no regional chronologies of Italy have been established yet. As an example, the dating of the Roman church of St. Antimo's at Montalcino (Siena) may be mentioned (Corona 1971). The approximately 60 year tree-ring sequence of five oak beams have been dated with the southern German master curve to cover the time between A.D. 1067 and 1127.

Historical monuments have of course been examined dendrochronologically in the USSR as well. Buildings with a well-known architectural history are often examined to establish an absolute chronology.

Art History

The problems of placing an object chronologically is often of major interest to the art historians. It proves difficult to find objective criteria for individual creative works of art, when, for example, changes in style are to be recognized, or, when the original work of art is to be distinguished from a copy. To solve these problems various scientific methods, such as the x-ray method, infra-red photography, and others have been developed, and, most recently, the method of dendrochronology (Bauch and Eckstein 1970).

So far this method has almost exclusively been applied to paintings of Dutch painters of the 16th, 17th, and 18th centuries that were painted on oak panels. As these boards were usually formed radially because of the better technical quality, they can contain as many as 300 tree-rings that are measured directly on the object without any specimens being taken. Frequently sapwood remainders are found which make the precise dating of the cutting year possible. The aim of such a dendrochronological examination is the establishment of a "terminus post" for the year of origin of a painting. To that purpose, the earliest possible cutting time of the tree that provided the board of the painting is determined. The analysis of 300 paintings of 30 old masters proved that only eight years had passed on the average between the cutting time of the tree and the execution of the painting (Bauch, Eckstein, and Meier-Siem 1972). Recently, further paintings of English galleries, particularly Tudor portraits, have been evaluated (J. M. Fletcher, personal communication).

Dendrochronology is also used to date sculptures carved out of wood (Bauch, Eckstein, and Brauner 1974). Hollstein (1970) examined a medieval oak carving whose authenticity is very much debated. Its origin has been dated by dendrochronological means to be between the year A.D. 1222 and 1330, so that the period most likely for an imitation must be excluded.

In the area of art forgery belongs also the imitation of string instruments of the Italian masters of the 17th and 18th centuries. The tree-ring analysis of violin bodies which in most cases were made of fir, sometimes provides additional criteria for a decision (Lottermoser and Meyer 1958). As a basis for comparison, tree-ring curves of several violins of one and the same master that are doubtless genuine are used.

Archaeology

In the science of archaeology relative chronologies have been established for almost all past civilizations by means of stratigraphic and typologic methods. Criteria for the dating are the thickness of refuse layers and the rate of the development of various new techniques, respectively. As there are no historical sources for these periods, there is not a

great amount of evidence for the time-scales thus obtained. Therefore dating methods of the natural sciences are used more and more. For the dating of wood, dendrochronology has proved very useful because of its great accuracy.

In the southern part of central Europe, the research done in the past decade relates to the Stone and Bronze Ages. In the Bronze Age settlement of Zug-Sumpf (Switzerland), the dendrochronological analysis of oak, ash, and alder samples showed that the settlement had been occupied over almost 200 years (Huber and Merz 1962). The oak tree-ring curve comprises 269 years and reaches from 1282 to 1014 B.C. according to placement by radiocarbon. It has been extended to 952 B.C. by the inclusion of additional material.

The neolithic Swiss lake settlements of Thayngen-Weier (near Schaffhausen) and south and southwest of Burgäschisee (near Bern) were inhabited only a few years or decades according to the dendrochronological results (Huber and Merz 1963; Huber 1967). An explanation for the relative short period of occupation is not yet possible. Chronologically the settlements follow in this sequence: Thayngen-Weier (lower settlement), south and southwest Burgäschisee, Thayngen-Weier (middle settlement). The time-span is approximately 35 years. On the whole, an oak chronology of 312 years was the result. The settlements had been built in the 38th century B.C. according to radiocarbon dating (Ferguson, Huber, and Suess 1966).

For the Rhine, Moselle, and Maas area an oak chronology has been established that covers wood specimens of the Latène, Roman, and Merovingian periods (Hollstein 1967). The tree-ring curves crossdate so well despite the great distances, for example between Aachen in the north and Avenches (Switzerland) in the south, that even wood samples from other sites can be placed correctly by means of this chronology. The wood samples come mainly from poles and beams of Celtic and Roman bridges, houses, wells, and fortifications in Cologne, Mayence, Trier and other historical centers. Because the connection to the medieval oak tree-ring curve is lacking, the years of the chronology from 717 B.C. to A.D. 339 are based on the time of the building of the Roman Bridge in Cologne, which is known to be around A.D. 310. After the closing of the gap between A.D. 339 and 383, the chronology will comprise 2690 years.

In northern Germany and Denmark archaeological research is presently concerned with the settling of the country between A.D. 800 and 1200. Of great importance in our knowledge about medieval urban development are the excavations of Haithabu. This former settlement is situated about 150 km north of Hamburg and belonged to the largest trading center in northern Europe at the time of the Vikings. Dendrochronology is of particular importance in the case of Haithabu because of the extremely unfortunate stratigraphic conditions. For that reason, an exact relative chronology is being established from the evidence of 4000 oak samples from houses, pavements, wells, and fences. At the moment it comprises 205 years and provides a mean-curve of 550 years (Eckstein and Liese 1971).

Of further interest are the remnants of Slavonic settlements in the eastern part of Schleswig-Holstein. In the centers of the political and economic life of that time, ramparts of wood and earth were erected. From such mounds, for example in the old part of Lübeck, samples are taken for dendrochronological analyses. An absolute dating is not yet possible, since no wood specimens before the year 1300 have been preserved above the ground in this region. Therefore, it is necessary to use exclusively the wood found during excavations.

In the harbor of Bremen, a trading ship, the so-called 'Hanse-Kogge' built at the time of Hanseatic navigation has been found. The cutting of the timber could be dated precisely at A.D. 1378 with the dendrochronological method (Liese and Bauch 1965). Since the tree-ring curves harmonize with the southern German master curve, it can be assumed that the timber came from the Weserbergland area and had been floated on the Weser down to Bremen. Generally, the dating of ships proves most difficult, because the origin of the timber is most frequently unknown.

The focus of dendrochronological work in Russian archaeology is the excavation in Novgorod (Kolčín 1972). The material consists of approximately 3000 pine and spruce samples from houses and roads from the period between the 10th and 15th centuries. During that time, 32 wooden pavement layers had been laid down, each on the top of the other, the oldest of which dates from the year A.D. 953. With these samples, containing up to 200 rings, a precise chronological sequence could be established for the different layers. Apart from the roads, numerous buildings were excavated, but the timbers were not so suitable for a tree-ring analysis since most contained less than 100 rings. Frequently the dates of origin of new street layers or buildings correlated with historically verified fires. The quantity of the specimens shows here as well that the timber had been cut immediately before the construction began.

A major point of interest is also the exploitation of timber discovered in the course of excavations of medieval towns in the eastern European plain (Černych 1972). A number of objects have already been dated precisely. From Smolensk (12th through 16th centuries) and Belosersk (12th and 13th centuries), there are sufficient wood specimens with enough tree-rings, whereas other excavations yielded only a few samples with a small number of tree-rings. These, in addition, belonged to a very long period of time. The timber consists of pine and spruce which makes absolute dating with the Novgorod master curve possible. In Smolensk, 76 buildings could be dated from 405 wood samples with 31 to 260 tree-rings. The entire tree-ring series comprises 635 years, the youngest of which is A.D. 1605.

In the ruined polar city of Mangazeja, between the tundra and the taiga, excavations brought forth remains of the timbers of former buildings (Šijatov 1972). Siberian spruce and larch are the predominant species. The establishment of an absolute chronology with recent trees from the northern Ural showed that within a range of about 700 km along the northern timber line synchronous fluctuations of tree-ring widths occur. On the whole, a chronology has been established for this region that covers 867 years from A.D. 1103 to 1969.

Dendrochronological research in British archaeology centers on Roman and Saxon remains (Schöve and Lowther 1957). Relative chronologies have been developed for the period between the 2nd century B.C. and the 4th century A.D., and for the 8th and 9th centuries, respectively. The statements made about the absolute dates of this material result from a correlation with archaeological finds such as coins and pottery, and meteorological records. However, a dating of that kind cannot be accepted as strictly absolute as long as there is no extension of those relative chronologies to the present time, nor a synchronization with already existing master curves of adjoining regions. Recent British analyses have been dealing with a Middle Saxon cistern whose planks had been cut out of a 240-year old oak tree. That tree had been felled in A.D. 832±30 according to radiocarbon (Fletcher and Switzer 1973).

All the research programs mentioned require intensive co-operation with archaeologists. But apart from those studies, there are also several single examples of dating work. Molski (1965) reports on the relative dating of the vegetable market of Szczecin (Poland) which was, however, based on only short tree-ring curves and which, moreover, belong to different species of deciduous trees. The same applies to the study of Jährig (1971) of wood samples from a Slavonic settlement near Neubrandenburg, East Germany (GDR). From ten oak samples with 32 to 95 tree-rings, a relative sequence was established for seven stages of construction. Finally, Dabrowski and Ciuk (1972) described the dating of samples from Ostrówek in southern Poland using the Novgorod chronology over a distance of about 1200 km.

Geomorphology of the Postglacial Period

The geomorphological changes that have taken place in Europe during the past 10,000 years, simultaneously with the development of the flora and fauna, have been dated previously by means of varve chronology, the C-14 method, and pollen analysis. In the future, however, more precise chronological information will be required.

Dendrochronological investigations of subfossil trunks of oak trees in the southern part of central Europe which are buried under gravel and sand along the rivers have been started to develop a complete Holocene tree-ring chronology. The purpose is to study the paleogeographical changes of the river systems – most of all of the rivers Danube, Main, and Rhine (Becker 1972 a,b). Analyses of about 850 cross-sections developed 15 floating chronologies with tree-ring series up to 650 rings. According to radiocarbon, they cover a period from 6700 B.C. to A.D. 200. Three main horizons of subfossil oak trunks have been found in a wide distribution along the rivers examined, showing simultaneous periods of gravel-accumulations. During these phases series of big floods that lasted up to 500 years destroyed the riverine oak forests. They date from the Bronze, Iron, and Roman Ages. A comparison of the growth ages of the buried trunks shows that they never reached their possible natural age – each oak forest within the valleys studied must have been destroyed by floods or by the meandering river itself two or three times within one millenium. According to radiocarbon, the floating chronologies show a good overlap within the period of the years A.D. 200 to 2500 B.C. Thus the conditions for establishing a complete tree-ring series up to Neolithic times seem to be favorable.

As the growing conditions in the southern part of central Europe differ from those in northern Germany, suitable oak tree-ring chronologies ought to be set up for this area (Schmidt 1973). Further relative chronologies covering several hundreds or thousands of years B.C. exist for the Dutch coastal area for pine stubs (Munaut and Casparie 1971) and for oak from northern Ireland (Baillie 1973).

The chronological placement of geomorphological changes by means of dendrochronology has also been the aim of Alestalo (1971), who has named this method "dendrogeomorphology." Research of this kind is based not only on tree-ring analysis. Studies of form growth of trees and roots as well as studies of changes in tree communities will be used to establish further criteria. Then a dendrogeomorphological analysis will allow statements about the rising or lowering of water levels, about volcanic processes, mass movements – most of all on river banks – cryopedological processes that are the results of the freezing and thawing of the ground, and fluvial processes such as degradation of slopes through the influence of the rain. Moreover, it will provide

information about degradation and aggradation caused by waves and ice thrusting, about aeolian processes that led to erosion, about the burial of trees, advance of dunes, and organogenic processes such as those occurring in moors.

The term "dendrogeomorphology" can also be applied to the studies of LaMarche and Fritts (1971). A good agreement has been found between the ring widths of recent stone pines (*Pinus cembra*) and the advances of the glaciers in the Austrian and Swiss Alps. If chronologies reaching back a great number of years were established, the history of the glaciers of the Alps could be traced back even further.

Dendroclimatology

Dendroclimatology is dendrochronological analysis that uses climatic information in dated growth layers to study variability in present and past climates (Fritts 1971). Dendroclimatological analyses in Europe have been restricted to regions where a single climatic factor dominates. Under northern conditions, it is the temperature of the growing season that masks the other possible factors exerting an influence. The effect of summer temperature increases from the south to the north and is most prominent at the northern timber line (Mikola 1962). Finnish studies confirm the results of Swedish and Norwegian research (Eklund 1957; Høeg 1956).

The northern European studies mentioned mainly deal with Scots pine and Norway spruce, which show slight differences in their reactions to temperature. Whereas low winter temperatures are favorable for the growth of spruce, high temperatures in March and April favor the growth of pine (Jonsson 1969). In addition, growth accelerates with increasing rainfall in summer up to a certain amount, and diminishes afterwards.

According to the connection between growth and climate, there is also a close correlation between the northern timber line and the weather. Thus a climatic amelioration between the turn of the century and the 1930s led to increased natural reproduction and temporary reforestation as well as to an expansion of the wood-working industries in Lapland (Mikola 1971). The climatic improvement included a lengthening of the growing season and an increase of the temperature during the vegetation period (Jonsson 1969). From the 1930s onward temperatures have been falling again. According to Sirén (1961), this trend can be expected to continue until the end of the 20th century. In future planning of forest management, this prediction will have to be considered.

Kärenlampi's examinations of Scots pine (1972) have for the first time shown a significant influence of rainfall on the growth of trees close to the timber line. This is assumed to be the case because temperature determines the general range within which the growth will vary, and the water supply causes a considerable part of the variation within this range; a tendency more pronounced on drier sites.

Further south, for example in Denmark, rainfall proved to be a dominant factor for most tree species (Holmsgaard 1955). In the temperate regions of central Europe, the ring width cannot be correlated closely with any single climatic factor. According to Elling (1966), temperature affected the growth of alder in a southern German site before the growing season and rainfall during it. On some northern German sites only half of the tree-ring variations of oak trees could be explained by the influence of climatic fluctuations; the influence of the temperatures dominating somewhat (Eckstein and Schmidt 1974).

Dendroclimatological studies on spruce in the Tatra mountains in Poland show a strong positive correlation of growth with high temperatures in the vegetation period from June to August. The correlation with precipitation is negative. On the other hand, the growth in the year following a very favorable year seems to decrease. This deterioration is perhaps a result of the faster aging and falling of the needles (Feliksik 1972).

According to von Jazewitsch (1961), sites with a predominant single weather factor can also be found in central Europe. To examine the correlation between the tree-ring growth and the temperature she chose a larch forest on the alpine timber line and found a positive correlation for the months May to July. To study the correlation with precipitation she selected a pine wood near Würzburg which was extremely warm and dry for central European conditions. The result of this study was a positive correlation with the amount of rainfall in the months April to July.

Russian scientists are searching for a solution of paleo-climatological problems, mainly of the past 1000 years (Adamenko and Lovelius 1968). Furthermore, the possibility of longterm forecasts of the productivity of forests, climatic forecasts in order to evaluate the probability of catastrophic conditions for agriculture, and other issues of that kind are being discussed.

Fürst (1963) tried to interpret the tree-ring width of fir, spruce, beech, and oak of various proveniences and different periods of time concerning their climatological evidence. The mean sensitivity served as a parameter. Thus the mean sensitivity increases in central Europe from west to east, probably because of the increasingly continental climate. The comparison of the mean sensitivities of samples from the present time, the Middle Ages, the Bronze, and Neolithic Ages, taken in Switzerland, demonstrated that the climate of the Neolithic Ages was more continental than today. In the Bronze Ages, however, it was more temperate. In the Middle Ages a period of higher variation from 1650 onwards ("little ice age") followed after a period of low mean sensitivity. Ermich (1960) suggested using trees as living meteorological stations in order to divide forest areas into uniform climatic spaces and exploit them for forestal purposes.

The need for dendroclimatological analyses is being realized in Europe more and more. In the course of the next years further results are to be expected from this field of research.

Radiocarbon Analysis

Dendrochronology is also respected in other than the above mentioned fields of applications. It has, for example, provided a means to check radiocarbon dating. The accuracy of a C14 dating depends mainly on the knowledge of the variations of C14 content in the atmosphere in past times. Ferguson (1970) succeeded in establishing a tree-ring sequence for bristlecone pine (*Pinus aristata*) which reaches an age of about 4600 years in the White Mountains of California. He included fallen trees and large remnants, and by overlapping, extended the sequence to the year 5142 B.C., and thus provide a series of organic substance, including every single year, as a gauge.

Using these exactly dated samples Suess (1969) obtained a calibration for the C14 values. This calibration has been compared with European wood samples (Ferguson, Huber, and Suess 1966; Vogel, Casparie, and Munaut 1969; Suess and Strahm 1970). In addition, the establishment of absolute oak chronologies ranging over several thousand

years is in progress for southern and northwest Germany, as mentioned above (Becker 1972 a,b; Schmidt 1973), after whose conclusion a C14 comparison between America and Europe will be possible.

Environmental Control

Dendrochronology has become a special discipline of environmental control. Industrialization has very much expanded during the last decades and caused increasing emissions of industrial fumes which have done considerable damage to the surrounding forests. Smog and salt in towns also pollute the trees, which are necessary for climatic and esthetic reasons.

Dendrochronology can aid greatly to the solution of these problems together with air, leaf, and soil analyses. With the analysis of the tree-rings the beginning of the damage can be determined and the decrease in growth can be calculated (Vinš 1965; Pollanschütz 1971; Jonsson and Sundberg 1972; Havas and Huttonen 1972). As soon as it is known when the damage began, important evidence can be given concerning the specific cause of the damage and possible measures suggested to prevent it.

Legal Matters

Occasionally dendrochronology is also used in detective and legal matters. Examples for this are given by Rozanov (1968) and Liese and Eckstein (1971).

CONCLUSIONS

The present survey shows that European dendrochronology has constantly extended its range of application during the last decade. Almost all European countries possess dendrochronological laboratories or use laboratories in adjoining countries for the evaluation of their research.

The establishment of chronologies alone has lessened in importance. Of major interest today is the solution of archaeological and art-historical problems and questions of architectural history on the basis of the existing chronologies.

Stimulated by the recent discussions of environmental problems, the climatological and ecological aspects of dendrochronology will become more and more important in the near future. In the United States research of that kind has been done for many years (Fritts 1971). Komin and Šijatov (1968) discussed the necessity of analyses of that kind for the Asiatic part of the U.S.S.R., as the conditions there are very favorable because of the 2000-year juniper species and the larch species which are up to 1200 years old. Some results have come from Lovelius (1971) concerning the mountain regions and the northern timber line of Siberia.

Still, dating work will maintain the same position in Europe where, from prehistoric times to the late Middle Ages, a vast amount of timber was used in the construction of a great number of buildings.

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