

REVIEW ARTICLE

DENDROCHRONOLOGY AND PAST HUMAN ACTIVITY—A REVIEW OF ADVANCES SINCE 2000

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ABSTRACT

Since 2000, important advances have been made worldwide in the dendrochronology of wood associated with past human activity and cultural heritage. This review summarizes this recent progress in regions with a longstanding tradition of using tree-ring methods, such as Europe and the USA, as well as others such as Asia where developments have been particularly rapid in recent years. The oldest wood generally originates from archaeological sites and the largest amount of wood for research comes from historical structures such as monumental and vernacular architecture. In addition to construction wood, wooden doors, ceilings, furniture, objects of art (such as panel paintings and sculptures), Medieval books, musical instruments and boats can also be utilized. Dating is the first and crucial step of the research and is often difficult even in regions where dendrochronology has a long history of use. In addition to absolute dates, dendrochronology has provided extra information that has enhanced historical knowledge from other sources. Behavioral and environmental inferencing and dendroprovenancing are becoming major areas of research in regions with well-developed networks of reference chronologies and active cooperation among laboratories. The online Bibliography of Dendrochronology and information from conferences have been indispensable in this compilation, because much work related to dendrochronology in cultural heritage is still published in “gray” literature, making it difficult to access.

Keywords: dendrochronology, tree rings, cultural heritage, archaeology, review.

INTRODUCTION

This article presents an overview of advances in dendrochronology in cultural heritage studies since 2000, relying on recent published work, research reports presented at specialized conferences, or obtained during personal exchanges at the 7th ICD (International Conference on Dendrochronology) in Beijing, China in June 2006. Because of the great diversity and amount of work, the overview is necessarily selective, condensed and somewhat subjective.

At the beginning of the 3rd Millennium, the dendrochronological community initiated discussions on whether dendrochronology in cultural

heritage is still alive and whether we still need it. Why so? Dendrochronology in cultural heritage was very successful in the 20th Century. In the early 1900s, its development in the United States was tightly connected with archaeology, prehistoric culture, and Puebloan history in the American Southwest. Subsequent decades brought spectacular dendrochronological datings in the Old World and in the Far East, such as the dating of Viking-age settlements in northern Europe, prehistoric lake dwellings in the European Alps, panel paintings by Dutch and Flemish artists, cathedrals in England, and Japanese temples. However, at the end of the 20th Century, the focus of dendrochronological interest seemed to shift to climatology,

ecology, geomorphology, or forest management (Eckstein and Wazny, 7th ICD).

Currently, dendrochronological research takes place all over the world. Web pages such as Henri D. Grissino-Mayer's Ultimate Tree-Ring Web Pages, the Association for Tree-Ring Research and the Tree-Ring Society, the European Catalogue of Tree-ring Chronologies (Levanič 2001), the International Tree-Ring Data Bank (Grissino-Mayer and Fritts 1997), and those of individual research groups, indicate the largest number of dendrochronological laboratories in Europe, North America and in Asia. The majority of them have their roots in the natural sciences, but most of them are also interested in wood related to cultural heritage.

CHRONOLOGY BUILDING AND DATING OF WOOD

As the essential first step of dendrochronological research, dating is not simple when working with wood from the distant past if adequate reference chronologies are not yet available. A large number of long chronologies exist from all over the world: North America (*e.g.* Jacoby 2000; Nash 2002), Europe (*e.g.* Baillie 1995; Friedrich *et al.* 2004; Grabner *et al.* 2001; Haneca 2005; Helama *et al.* 2005; Nicolussi *et al.* 2005), South America (*e.g.* Wolodarsky-Franke *et al.* 2002; Roig *et al.* 2001), Asia (*e.g.* Yang *et al.* 2002; Panyushkina *et al.* 2005; Sheppard *et al.* 2004; Zhang *et al.* 2007), Australia/Tasmania (*e.g.* Cook *et al.* 2000), and New Zealand (*e.g.* Fowler *et al.* 2004). The number and quality of long chronologies is increasing. This improves the possibility of using dendrochronology in archaeology and cultural heritage studies and, at the same time, research in these fields helps to improve and extend the chronologies.

Several laboratories and regions already have long histories of successful dendrochronological research, such as southwestern U.S., Western Europe and Japan. New laboratories are also emerging all over the world and they need to build and improve their chronologies prior to applying them to the study of questions in archaeology and cultural heritage.

The results of dendrochronology in cultural heritage studies are usually reported in "gray" literature, which is often of national or local importance, published in local languages, and is therefore not usually accessible to the worldwide community (*e.g.* Nicolussi 2005; Čufar and Štamcar 2004). The online Bibliography of Dendrochronology (Kaennel Dobbertin and Grissino-Mayer 2004, 2005) is therefore an indispensable source of information, particularly if authors regularly contribute information on relevant references to keep it up to date. International conferences are also important sources of information and a report on some held between 2000 and 2006 is given below.

MEETINGS PRESENTING DENDROCHRONOLOGICAL WORK IN ARCHAEOLOGY AND CULTURAL HERITAGE

In the third millennium the world dendrochronological community has met at International Conferences on Dendrochronology (ICD) in Argentina, Canada and China and at the International Conference on the Future of Dendrochronology in Switzerland.

The leading topic at the 5th ICD for the "Third Millennium" in Mendoza, Argentina, in 2000 was dendroclimatology and no special sessions were dedicated to archaeology. This provoked discussion on whether we need it at all. The International Conference on the "Future of Dendrochronology — Tree Rings and People", in Davos, Switzerland 2001 was organized as a tribute to Fritz Schweingruber and included all aspects of dendrochronology. Two plenary papers on dendrochronology in archaeology by Baillie and Kuniholm, as well as a plenary session coordinated by Sass-Klaassen, were presented. The main message was that archaeological dendrochronology is generally alive and well, despite the fact that many small laboratories scattered around the world are struggling daily for their survival. The plenary papers and the reports from the plenary sessions were published in *Dendrochronologia* (Baillie 2002; Kuniholm 2002; Sass-Klaassen 2002) and other contributions as ab-

stracts or short articles in the proceedings (Kaenel-Dobbertin and Bräker (eds.) 2001).

The leading topic of the 6th ICD—"Dendrochronology, Environmental Change and Human History" in Québec, Canada 2002 was dendroecology. In a special session on dendrochronology in cultural heritage, the participants reported on the use of dendrochronology for dating and study of past environment in Bronze Age pile-dwellings in Germany (Billamboz), the importance of dating short sequences from archaeological sites and human impact on the forest environment during the Bronze Age in Switzerland (Tercier; Hurni), problems related to the development of a historical dendrochronology for Newfoundland, Canada (Bridge), and on investigations of Brabantine altarpieces (Haneca). Modern and historical chronologies have been constructed in the Vologda region, Russia (Katz) and for the Pazyryk culture settlements in the Altai Mountains, Russia (Panyushkina). There have been numerous applications of dendrochronology in archaeology in Japan (Mutsutani), while work on teak coffins represented one of the first such applications in Thailand (Pumijumngong). Reports from other sections that might be important for dendrochronology in cultural heritage can also be found in the proceedings of the conference (Begin (ed.) 2002).

Environmental variability was the leading topic of the 7th ICD "Cultural Diversity, Environmental Variability", in Beijing, China, in 2006. The session "Dendrochronology in Cultural Heritage" was coordinated by Eckstein and Wazny. Papers and posters presented there were also published in the abstract book (Lan Chen *et al.* (eds.) 2006).

In Asia, dendrochronology has amazingly progressed in the last few years. In China, finds of the Tu-Yu-Hun tribe from the 4th through 7th Centuries A.D. (Lan Chen) and tombs (Shuzhi Wang) have been investigated. Colleagues from Japan reported on investigations of ancient temples from Nara, the beech wood of folk craft artifacts and on progress in non-destructive methods using micro-focus X-ray computed tomography (Mitsutani, Hoshino, Okochi). In South Korea, the Bubju Temple and traditional Korean furniture (Won-Kyu Park, Yojung Kim) have been dated, and in Thailand further progress has been made with teak log

coffins (Pumijumngong, Wannasri). In Mongolia, long years of systematic work and work at the International Dendroecological Fieldweek prior to the 7th ICD, have contributed to important advances in the investigation of monasteries and graves (Nachin, Serjbaatar). Notable progress has been made with larch dendrochronology and investigations at archaeological sites in Central Asia, Russia (Panyushkina), and with the dendrochronology of wood-dependent cultures of High Asia (Wazny).

Advances in European dendrochronology in cultural heritage have been demonstrated by the examples of historical buildings in Venice, Italy (Pignatelli), the Church of St. Nicholas at Taormina, Sicily and other buildings in central and southern Italy (Romagnoli), and various objects in Trentino, northern Italy (Bernabei; Pollini). The importance of sapwood estimates in archaeological oak wood from Italy (Pignatelli) has also been reported. Furthermore, Italian Technical Standard UNI 11141, with guidelines for dendrochronological dating of wood was presented (Pignatelli, Romagnoli). In France, advances have been made in wood research from the Roman period and with investigations of wood from ancient Egyptian collections (Lavier, Asensi-Amoros). Dendrochronology is also progressing in areas with suboptimal conditions, such as in Flanders, Belgium (Haneca). Dendrochronology has also contributed to new views of woodland use and wood-working techniques in Roman times in the Alps (Tegel). The importance of analyzing short tree-ring series of the prehistoric German pile-dwellings (Billamboz) has been discussed as well. From North America there have been contributions to the tree-ring record of decadal drought during major social changes (Stahle), and on investigations of Acadian buildings in Canada (Leighton).

In addition to the aforementioned world conferences, mention should also be made of some smaller ones, such as the International Dendrochronological Symposium in Nara, Japan, in 2000 at which leading scientists reported on dendrochronology in cultural heritage in Europe (Baillie 2000; Eckstein 2000; Lavier 2000a), Japan (Mitsutani 2000), North America (Towner 2000), Ko-

rea (Park *et al.* 2000), and the Near East (Kuniholm 2000).

The conferences EuroDendro 2001 (Slovenia), EuroDendro 2003 (Austria), EuroDendro 2004 (Germany), and EuroDendro 2005 (Italy) presented a great diversity of dendrochronological topics including a considerable number of contributions on cultural heritage. Although the conferences were held in Europe, they were attended by participants from all over the world. The abstract books are available in PDF format on the web pages of the conferences or can be obtained from the organizers. They give concise information on staff and research topics of various teams and laboratories.

Conferences entitled TRACE (Tree Rings in Archaeology, Climatology and Ecology) have been organized every year since 2002. TRACE 2002, 2003, 2004, 2005, and 2006 were held in different European countries and had participants from Europe and all over the world. These conferences also presented work related to dendrochronology in cultural heritage, the abstract books from which are available on the web pages. The conference proceedings of TRACE 2002, 2003, 2004 and 2005 published selected contributions in the form of short articles. The contents and order forms for the proceedings are available on the web pages of the Association of Tree-Ring Research (ATR).

The International Association of Wood Anatomy (IAWA) strongly encourages the presentation of investigations in wood from archaeology and cultural heritage at its conferences and in the *IAWA Journal*. Two recent conferences supported by IAWA in particular should be mentioned in this context: the International Symposium on Wood Sciences in Montpellier, France 2004 organized by Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Montpellier, in cooperation with IAWA and the International Academy of Wood Science (IAWS), and the 6th Pacific Regional Wood Anatomy Conference (PRWAC) held in Kyoto, Japan, in 2006. Contributions related to dendrochronology in cultural heritage were presented at both conferences.

Last but not least, numerous dendrochronolog-

ical field weeks should be mentioned that are organized every year all over the world. Participants include students and young scientists, as well as senior researchers and teachers with various backgrounds. They encourage the exchange of knowledge and ideas and help to establish personal contacts and have contributed much to the progress of dendrochronology in archaeology and cultural heritage worldwide.

In the sections below, some of the most important recent achievements in dendrochronology in cultural heritage are reviewed, taking into account those published after 2000 that are accessible to the world community. They are arbitrarily divided into sections: (1) “Archaeological wood” and (2) “Wood from historic structures and artifacts”.

ARCHAEOLOGICAL WOOD

Among the oldest sites of dendroarchaeology are prehistoric lake shore settlements (pile dwellings) from the circum-Alpine region in Europe. They existed mainly in the late Neolithic, Copper Age and Bronze Age approximately 6000–800 B.C. and have been investigated for more than a century. Numerous sites in the northern area of the Alps in Switzerland, Germany, and France have been dendrochronologically dated and have provided a great deal of information on woodland development, human life and impact on the past environment (*e.g.* Billamboz 2003, 2006a, 2006b; Viellet 2002). They are in the vicinity of the longest tree-ring chronology in the world, the Hohenheim oak (*Quercus petraea* and *Q. robur*) chronology, reaching back to 8480 B.C. (Friedrich *et al.* 2004). In the southern area of the Alps in Italy, Slovenia and Austria, dendrochronological dating of very old archaeological sites has not been possible until recently because long reference chronologies did not yet exist, and because attempts to teleconnect floating chronologies with reference chronologies from the northern area of the Alps have failed. Supported by radiocarbon dating and wiggle-matching, dendrochronology has helped to obtain and better interpret information on human colonization of the area and the regional palaeo-environment (*e.g.* Čufar and Mar-

tinelli 2004; Velušček and Čufar 2002; Velušček (ed.) 2004).

Archaeological sites in the United Kingdom are equally well known, where the construction of millennia long chronologies and dating of numerous trackways, prehistoric bog settlements, horizontal mills and crannogs, among others, has helped to interpret past environmental changes (e.g. Baillie 2000; Baillie and Brown 2002; Boswijk and Whitehouse 2002; Crone and Mills 2002; Hillam and Groves 2003).

Hallstatt, the salt mine that operated from the Bronze Age until the Middle Ages and gave the name to the Hallstatt Period (Iron Age), is also one of Europe's important archaeological sites. Recent results of Grabner *et al.* (2007) will help improve understanding of activities in this area.

Dendrochronology has repeatedly given good results with wooden remnants of the Roman period in western and central Europe (e.g. Haneca *et al.* 2005b; Nicolussi 2001; Tegel, personal communication), whereas it has been less successful in Italy and the Mediterranean, where adequate reference chronologies are not yet available (Martinielli, Romagnoli, personal communication).

Dendrochronological support for archaeology has also made great progress in the Near East, the eastern Mediterranean and the Aegean (e.g. Hughes *et al.* 2001; Kuniholm 2000, 2001; Manning *et al.* 2001). Past environmental conditions in the region, particularly catastrophic events, have been linked to the observations of dendrochronology (e.g. Baillie 2001; Leuschner *et al.* 2002).

Lack of adequate reference chronologies is still among the main obstacles to the use of dendrochronology to date artifacts of ancient Egypt, where investigations of wood have depended on wood anatomy and typology (Asensi-Amoros, personal communication). Despite old wooden artifacts often having dendrochronological potential, the construction of long continuous chronologies reaching to modern times is less likely because of a lack of adequate recent wood. Some important wood species used by ancient civilizations in areas such as Egypt and Palestine have long been extinct in these regions. Nevertheless, investigations of past vegetation are of great importance (e.g. Liphshitz and Biger 2001).

In Japan, long master chronologies reaching back to 912 B.C. (*Chamaecyparis obtusa*, hinoki cypress), 1313 B.C. (*Cryptomeria japonica*, sugi cedar), and 22 A.D. (*Sciadopitys verticillata*, koyamaki pine) have helped to improve the dating of the Kofun and Yayoi periods from the first millennium A.D. (Mitsutani 2002) and to investigate natural disasters (Mitsutani 2000). Dendrochronology has also helped to check possible differences in atmospheric C14 between Japan and North America and Europe for the period 240 B.C. to A.D. 900 (Sakamoto *et al.* 2003).

Dendrochronological investigations of wood from the Chinese cultural heritage have been relatively few, bearing in mind its long history and vast amount of archaeological artifacts (Qui-Bin Zhang, personal communication). Recent cooperation between archaeologists and dendrochronologists in northeastern Qinghai helped to date wood from the tombs of the Tubo (Tufan) Kingdom, to construct a long chronology, and to use it for reconstructing annual precipitation back to 515 B.C. (Sheppard *et al.* 2004).

The rapid advances in dendrochronology in South Korea, Thailand, and Mongolia were reviewed at the 7th ICD. In addition, mention should be made of advances in Siberia, Russia, where Panyushkina and Sljusarenko investigated the tombs of Siberian Scythians and graves of Huns-Sarmatians and developed new chronologies that will help to revise the existing Iron Age archaeological chronology in the region (Panyushkina, personal communication). Work is also ongoing in the Himalayas and India (Bräuning, Schmidt, Wazny, personal communication).

A review of activities in America, particularly those of the US Southwest conducted by the Laboratory of Tree-Ring Research (LTRR) in Tucson, Arizona, which has the longest tradition in archaeological dendrochronology in the world, would need another paper entirely (e.g. Nash 2002; Towner 2000, 2002). The LTRR has investigated several thousand standing structures, including a large number of prehistoric and historic Native American sites of the Navajo, Ute, Hopi, Zuni, and Puebloan cultures (Towner, personal communication). They were among the first to use dendrochronology to study human behavior (Dean 1996).

In recent times, investigations have included the environmental characteristics of the A.D. 900–1300 period in the central Mesa Verde region (Van West and Dean 2000), and Towner (2000) has presented an overview of leading projects in the Mesa Verde cliff dwellings, the Navajo occupation of the Southwest, and human/climate relationships in the American Southwest. Towner *et al.* (2001) also studied the importance of sample context in dendroarchaeological interpretation and Towner (2002) published a review of archaeological tree-ring dating in the American Southwest.

The Cornell Tree-Ring Laboratory has made great progress in dating historic houses, buildings and structures in New York and northeast North America. They also work on old to very old wood from excavations, ponds, lakes, and road cuts, in order to build and improve tree-ring chronologies of common tree species in the region, reaching from the present back to the Late Pleistocene (*e.g.* Griggs 2006). Dendrochronology has also been applied in Portsmouth, New Hampshire, where investigations on wooden coffins from a slave burial ground contributed information lacking in the historical archives (Smith, personal communication).

The Tree Ring Laboratory at the Department of Geosciences, University of Arkansas has made great progress with investigations on past climate and its effects on human cultures in the U.S. and Mexico (*e.g.* Cleaveland *et al.* 2003; Therrell 2005; Stahle, 7th ICD).

WOOD AND ARTIFACTS FROM HISTORIC CONSTRUCTIONS

Standing historic buildings that are usually still in use can be entirely made of wood or contain wooden constructions that are valuable objects of dendrochronological research. Wood from monumental and vernacular architecture has been investigated around the world.

In the United States, the LTRR at the University of Arizona has dated around a thousand cabins, churches, homesteads, corrals, trading posts, mining structures and kilns, and they add to those numbers monthly, if not weekly (Towner, personal communication). Dendrochronology has been used

to date buildings in Virginia (Bortolot *et al.* 2001), Georgia (Wight and Grissino-Mayer 2004), Tennessee (Mann 2002) and in many other locations in the U.S. These articles represent pioneering efforts in dendrochronology of the region. Dendrochronology has helped to date buildings and, as a rule, has complemented information from other historic sources. These investigations have also contributed to improving and extending regional chronologies and to their use for climate research and reconstruction.

Investigations of vernacular architecture are also being conducted in Canada. On Vancouver Island, British Columbia, a traditional Nuu-chah-nulth plank house with elements dating from the 16th to the 19th Centuries was successfully investigated (Smith *et al.* 2005) and in New Brunswick, Acadian buildings have been investigated (Leighton and Laroque, 7th ICD). On the other hand, all attempts to date vernacular architecture in Newfoundland have been unsuccessful (Bridge, 6th ICD).

In Asia, Japan has the leading role in investigating historic buildings. It is especially worth mentioning the Horyuji Temple located in Nara Prefecture in Japan, which has been dated by dendrochronology to A.D. 594 and is possibly the oldest wooden building in the world (Mitsutani, EuroDendro 2004). Dendrochronology is also making progress in South Korea (Park *et al.* 2000, 2001). Among recent achievements of dendrochronology in the Asian part of Russia is work on 15th to 20th Century settlements in Siberia (Gurskaya 2005).

According to the European catalogue and the Association of Tree-Ring Research, there are more than 50 dendrochronological laboratories in Europe, and virtually all of them also investigate historical objects. Abundant information on European dendrochronology exists in this respect, thanks to personal contacts among laboratories, meetings such as EuroDendro and TRACE, as well as the publication and contributions to the Bibliography of Dendrochronology, although much of the work remains unpublished. It is impossible to list all the important work on historic buildings of Europe, which would also need an entire paper. The following is an attempt to list laboratories and authors

who exchange information internationally and contribute regularly to dendrochronological networking.

In Germany, the laboratory at the University in Hamburg recently presented work in the Medieval town of Lübeck, where dated buildings and objects of art have provided information on the growth of past forests, acquisition of timber, timber transport, season of tree felling and new knowledge on timber properties and quality (e.g. Eckstein 2007; Eckstein and Wrobel 2007, in press). The dendrochronological research group at the University of Hohenheim continues to improve the longest chronology in the world and other chronologies, in order to apply them in different ways, including to investigate historical constructions (Friedrich, Hofmann, personal communication). The laboratories in Berlin, Frankfurt, Göttingen, Hohenheim, Köln and other parts of Germany also regularly report on their work on historical buildings in Germany and abroad and on numerous possibilities of applying the results of dendrochronological investigations (Heussner, Westphal, Leuschner, Tegel, Billamboz, Schmidt, personal communication). Investigations on historic wood have also been done in Norway (Thun 2005), Denmark and Sweden (Bonde and Springborg 2005; Bartholin, personal communication), the Netherlands (e.g. Jansma *et al.* 2004; Vernimmen and Sass-Klaassen 2004), and in Belgium (Haneca 2005).

Much work is going on in the United Kingdom, where all aspects of historical dendrochronology are well developed and tree-ring research seems to be a routine method when investigating historic objects such as ecclesiastical architecture (Bridge 2006; Groves 2000; Tyers 2005), Medieval cities (Crone 2000), castles (Arnold *et al.* 2005), houses (Groves and Locatelli 2005) and vernacular architecture (Arnold *et al.* 2006; Bridge 2005) to name only some of the most recent references contributed to the on-line Bibliography of Dendrochronology. Oak (*Quercus* sp.) is here by far the leading timber, but use of softwoods, often imported ones, is not rare (e.g. Groves and Locatelli 2005).

France also has a long tradition of extensive work in the field of dendrochronology, which has greater potential in application to the vernacular

architecture with wooden frames in the northern half of France, because stone buildings predominate in the South of France (e.g. Lavier 2000a; Billamboz, personal communication). In Austria, historical dendrochronology recently helped solve contradictory hypotheses of historians on “Das Goldene Dachl” (the golden roof) in Innsbruck (Nicolussi 2005), and has been used to date many historic buildings in Vienna and other parts of the country (Grabner, personal communication), as well as to study past log-drifting in the mountainous part of Austria (Grabner *et al.* 2004). In Switzerland, numerous laboratories are working on historical dendrochronology but a search for recent references in the Bibliography of Dendrochronology on this topic gave no results for the period after 2000.

Dendrochronology is also well-developed in Poland (e.g. Wazny 2002; Krapiec, Szychowska-Krapiec, personal communication), Estonia (e.g. Läänelaid and Eckstein 2003), Lithuania (Pukiene and Ožalas 2007), Latvia (Zunde, EuroDendro 2005). Dendrochronology is also progressing well in the Czech Republic (Kynzl, personal communication).

In Italy, the laboratory in Verona has recently investigated many prominent buildings in Venice and other parts of northern Italy (Pignatelli, Martinelli, 7th ICD). The laboratory from Viterbo has worked on historical buildings in Central and Southern Italy (Romagnoli, 7th ICD). They attempt to solve problems of the dendrochronological dating of broadleaved tree species such as sweet chestnut (*Castanea sativa*) in Central Italy (e.g. Romagnoli *et al.* 2004). Dendrochronology is also in progress in Slovenia (e.g. Čufar and Levanič 2000; Levanič *et al.* 2001), Hungary (Grynaeus 2000), and Romania (Botar, EuroDendro 2005).

Most of the work discussed above has been dedicated to aboveground “dry” building constructions. In addition, many buildings have below-ground constructions such as foundation piles, where the wood is waterlogged. There has been increasing concern recently to protect such waterlogged wood, because many buildings are threatened as a result of problems with their foundation piles (Vernimmen and Sass-Klaassen 2004; Pig-

natelli, personal communication). Dendrochronology here also plays an important role.

WOODEN ARTIFACTS

Constructions in old buildings provide the majority of wood for dendrochronological analysis but other wooden objects, such as doors, ceilings, windows, and furniture, should not be overlooked. Several dendrochronologists have worked with wooden doors and found that they often have dendrochronological potential and can even be among the oldest wooden objects in buildings with a long history, because constructional wood has been exchanged or repaired (*e.g.* Miles and Bridge 2005; Bauer, EuroDendro 2003). A large number of historical buildings have wooden ceilings; dendrochronology can here enhance the historic and art historic information (*e.g.* Čufar and Štamcar 2004; Groves 2000). Surprisingly, there are few references on recent work on furniture, which is present virtually everywhere (*e.g.* Jansma *et al.* 2004; Pousset 2000).

Art objects, such as panel paintings, wooden sculptures and wooden altars, belong in the category of very valuable wood products, and therefore deserve special attention. Among recently published reports are investigations on panel paintings of the 16th Century painter, Henri Bles from Belgium (Fraiture 2002), the panel paintings of the Dutch artist Hans van Essen from the Estonian Art Museum of Tallin made of Baltic wood (Läänelaid and Nurkse 2006), two panel paintings with the same name for which dendrochronology helped art historians to identify the relationship between them (Bauch 2002), or new information on the use of wood in Rembrandt's workshop (Klein 2005).

In Japan many objects of art, among them sculptures, have been successfully dated (Mitsutani, EuroDendro 2004). Currently they focus on development of micro-focus X-ray computed tomography and its potential for non-destructive tree-ring analysis, which is of great importance because valuable objects must not be damaged (Okochi *et al.* 2007).

Examples of successfully investigated oak sculptures from northern Europe are the triumphal

cross with a number of statues in the Cathedral of Lübeck (Eckstein 2007) and sculptures in the late Gothic Brabantine altars from Belgium (Haneca *et al.* 2005a).

In parts of Europe where objects of art are mainly made of poplar (*Populus* spp.) and lime (*Tilia* spp.) investigations are usually limited to wood identification and dendrotypology because of lack of reference chronologies (*e.g.* Romagnoli and Sarlatto 2002; Zupančič *et al.* 2004).

Medieval books with wooden covers, mainly made of European beech (*Fagus sylvatica*) and oak, have also been successfully investigated dendrochronologically (*e.g.* Lavier 2005).

Much research has recently been dedicated to the tree-ring investigation of musical instruments (Burckle and Grissino-Mayer 2003; Grissino-Mayer *et al.* 2004, 2005; Klein 2003; Lavier 2000b; Topham 2001). In addition to dating and distinguishing between originals and imitations, the use of dendroprovenancing has made it possible to define the areas from which individual violin makers obtained wood for the production of their instruments (Beuting 2003).

Most of the objects discussed above have been preserved in a dry condition. Some wooden artifacts can also be water-logged, such as canoes, boats and shipwrecks that have been found in different parts of the world and originate from all periods of human history. Their investigation was in several cases supported by dendrochronology (*e.g.* Daalen and van der Beek 2004; Dobbs and Bridge 2000; Dudley *et al.* 2002; Lavier 2001). Investigation of such objects is also a challenge for the future, because they are often found far from the forests that provided the wood for their construction.

SOME FUTURE PROSPECTS

It is difficult to predict the future directions of dendrochronology in cultural history, but some innovative ways of exploring the data provided by dendrochronology already point to them.

Because the dating of tree rings will remain the first and essential step for any further analysis, building reference chronologies and their improvement should continue. Long chronologies have re-

cently been used for climate reconstruction in China (Sheppard *et al.* 2004), the Aegean (Hughes *et al.* 2001) and in Germany (Wilson *et al.* 2004), to reconstruct vegetation dynamics as an indication of climate change (Leuschner *et al.* 2002, 2007), to study the effects of climate on human cultures (Cleaveland *et al.* 2003; Therrell 2005), or to improve radiocarbon calibration (Friedrich *et al.* 2004; Sakamoto *et al.* 2003).

Dating to a calendar year is very precise but modern wood anatomy and wood biology techniques can improve dating to identify the season or even the month of tree felling (Eckstein 2007). However, it must not be forgotten that dendrochronology only dates the tree rings; it does not tell the date when the object was created. We need to know better what happened between felling the tree and creating the object. This involves better knowledge of the origin of wood, timber transport, seasoning and processing of wood, which all needs more interdisciplinary and international cooperation in the future (*e.g.* Eckstein 2007).

Recent investigations on dendroprovenancing of Baltic timber have already given new information on the origin of timber, logging activity and the timber trade around the Baltic Sea during the Middle Ages, which has enriched historical information (Wazny 2002; Haneca *et al.* 2005c; Läänelaid and Nurkse 2006; Eckstein and Wrobel 2007, in press) or even allowed specification of when certain forested areas were exploited (Haneca *et al.* 2005b). Such investigations should be extended in the near future and include other projects, such as that on imported wood in England (*e.g.* Groves and Locatelli 2005), dendroprovenancing in continental Europe, where timber was transported by raft on big rivers (Eissing, EuroDendro 2004 and 2005) or by systems of canals and dams on small rivers in mountainous areas away from the sea and big rivers (Grabner *et al.* 2004). Much should be done in this context in the Mediterranean where the lack of chronologies is among the main obstacles to better use of the many wooden artifacts from various periods. The questions of dendroprovenancing, timber transport and use, are of course interesting for all geographical areas and periods.

The work of several laboratories has shown that

woodland management and palaeodendroecology are interesting issues for all regions and periods of human history (*e.g.* Billamboz 2003; Haneca 2005; Velušček (ed.) 2004). An important and not yet entirely solved question is that of short and discontinuous tree-ring series, which are difficult to deal with but are indispensable to interpreting the past environment and activities (Billamboz 2003). Investigation of the past is, of course, important for predictions of future changes in the climate and environment.

Finally, it should be highlighted that exchange of data is still a problem and that standardization of equipment, techniques and data formats would facilitate networking, which will be indispensable for the future progress of dendrochronology in cultural heritage and in general.

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