The role of Dendrochronology in the protection of the Cultural Heritage.
Progress report of the dendrochronological analyses for BACPOLES

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Introduction

In Europe over the last ten years there has been a strong interest in active heritage management, because of ever increasing building activity and the treaty of Valletta (Malta)[1]. We, for instance, have become aware of the need to monitor protected archaeological sites, because the soil, as an environment for cultural heritage, is far from stable. In the EC-funded project BACPOLES[2] experts in heritage management, wood and soil research as well as bacteriology from Italy, Great Britain, Sweden, Germany and The Netherlands work together. They study the causes of degradation of waterlogged wood from terrestrial and marine archaeological sites as well as of foundation piles from historical buildings. Dendrochronology was used to determine the felling date and the origin of the trees that were used as building timber. This paper deals with the preliminary dendrochronological results of the ongoing BACPOLES project.

A great part of the above ground cultural heritage in north-western Europe is built on wooden piles. This technique was applied roughly since the Middle Ages when towns started to expand and new habitation areas had to be found on wet and unstable ground. These foundations were formerly considered safe from decay due to the waterlogged conditions where oxygen is absent until in the nineteen-eighties when it became clear that wooden foundations can be seriously damaged by bacteria (Fig. 1). In some cities even whole quarters are threatened by collapse.

[1] For the English text of the treaty of Malta go to http://www.archis.nl

[2] *Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites* (duration: 2002-2005; contract number EVK4-CT-2001-00043); http://www.bacpoles.nl

Figure 1: Collapsed foundation (Photo: Fugro)

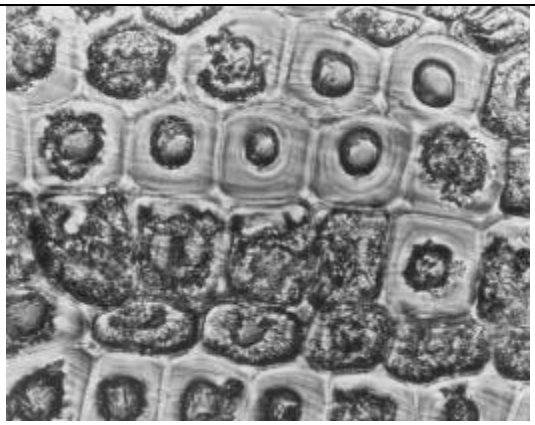

Figure 2: Cross-section of pine with bacterial degradation (Liese 1955).

Unlike soft rot, a fungal infection that occurs in the transition zone between wet and dry conditions, bacterial decay can also occur below the groundwater table, where the concentration of oxygen is low or even zero. The same holds true for waterlogged wood in archaeological sites. The bacterial degradation of waterlogged wood (Fig. 2) is a slow process. None the less it is a great danger, especially in the case of protected, not yet excavated archaeological sites. The problem is not only the deterioration of the wooden constructions but also the loss of important information about traces of woodworking or natural traits like sapwood and bark. There is already a vast amount of literature on degradation processes in waterlogged archaeological and historical wood (for an overview and further literature, see Kars & Smit 2003 or the BACPOLES website[3]).

When investigating the causes of degradation it is important to assess the time span in which these processes take place. Dendrochronology can provide the exact felling dates and the time period between felling and timber use in case of recent (nineteenth, twentieth century) historical buildings, where the building date is mostly documented.

Besides dating, dendrochronology offers the possibility to trace the origin of the trees used (=dendroprovenancing). Timber import and transportation have consequences for the time period between felling and use. It also offers the possibility of studying possible relationships between the origin and the quality of the wood, which again can affect its susceptibility to bacterial degradation.

Material

To be able to keep an overview of the large amount of samples and the variety of sampling contexts and wood species, we decided to include all information about the samples as well as the results of the dendrochronological analysis in five tables, which you'll find below.

[3] http://www.bacpoles.nl

Figure 4: Excavated foundation piles in Amsterdam (Photo: Fugro).

Figure 5: Archaeological wood: central pile of Roman farmhouse (Photo: ROB/RING).

Although BACPOLES is a European research project, most of the sampling of foundations of historical buildings has taken place in The Netherlands, where the problem of rotten piles has been recognized for some time and where the idea for the project originated. Until now the foundations of six houses in Amsterdam (Fig. 4), Rotterdam, Haarlem, Dordrecht, Leeuwarden and Koog aan de Zaan (The Netherlands) as well as the Parliament of Stockholm (Sweden) and a palace and bridge in Venice (Italy) have been sampled (Table 1).

Table 1: Historical foundations sampled within the BACPOLES project and the preliminary results of dendrochronological dating and provenancing of the wood samples.

Country	**Name of site and building date**	**Building date**	**No. and type of samples**	**Wood species**	**Dating result**	**Provenance of the wood**
NL	Amsterdam	AD 1918	4 complete stem discs	*Picea abies*	Not dated yet	-
NL	Dordrecht-Anna Paulownastraat	AD 1931	11 complete stem discs	*Picea abies*	AD 1816-1929	South Germany
			1 complete stem disc	*Pinus sylvestris*	AD 1875-1929	Lithuania
NL	Rotterdam-Joubertstraat	AD 1901-1905	1 complete stem disc	*Picea abies*	Not dated yet	-
			2 complete stem discs	*Abies alba*	Not dated yet	-
NL	Koog a/d Zaan-Irisstraat	AD 1937	3 complete stem discs	*Pinus sylvestris*	Not dated yet	-
NL	Haarlem-Jan Nieuwenhuizenstraat	c. AD 1900	(6 complete stem discs)	(*Populus* spec.)	(Not analyzed)	-
I	Venice, Ponte Balbi	16th century AD	3 stem discs	*Larix spec.*	Not dated yet	-
			1 core sample	*Quercus* robur/petraea	Not dated yet	-
I	Venice, Palazzo Balbi	9th-10th century AD	4 complete stem discs	*Pinus sylvestris*	Not dated yet	-
S	Stockholm, Parliament	AD 1895-1905	2 complete stem discs	*Pinus sylvestris*	AD 1748-1890	Nemdeö, Southwest Sweden
NL	Leeuwarden	19th-20th century AD	1 complete stem disc	*Pinus sylvestris*	AD 1849-1901	Nemdeö, Southwest Sweden

A list of the archaeological sites that have been sampled for BACPOLES so far -nine in The Netherlands and five abroad (Germany, Sweden)- is given in Table 2. At the terrestrial sites the aim was to sample so-called structures (i.e. houses, fences, wells) instead of mobile objects, but this wasn't always possible. Where possible, wood used for building foundations (Fig. 5) was sampled, because it provides an analogue to the foundation piles of historical houses. Another advantage of sampling foundation wood is that one might assume it was used when it was still quite fresh, so the felling date of the tree approximates the building date of the structure. In addition, there is less chance of sampling re-used wood.

Table 2: Archaeological sites sampled within the BACPOLES project and the preliminary results of dendrochronological dating and provenancing of the wood samples.

Country	**Name of site**	**Type of object**	**No. + type of samples**	**Wood species**	**Dating result**	**Provenance of the wood**
NL	Dokkum-Koningstraat	Well from town site	5 stem-disc fragments	*Quercus robur/petraea*	AD 1378-1479	Central-Southern Netherlands/Central-South Germany
NL	Dokkum-Koningstraat	Barrel from town site	5 stem-disc fragments	*Quercus robur/petraea*	AD 1128-1375	Baltic/East Pommern (Germany), Poland
NL	Borsele-Ellewoutsdijk	Rural house site	2 complete stem discs	*Quercus robur/petraea*	AD 22-99	Western Netherlands /Roman road near Utrecht (Netherlands)
NL	Vleuten-De Meern 4	Shipwreck on land	1 stem-disc fragment	*Quercus robur/petraea*	AD 35-99	Roman road near Utrecht (Netherlands)
		Embankment	1 complete stem disc	*Ulmus spec.*	AD 7-98	Central Germany
NL	Burgzand-Noord 3	Shipwreck, marine	1 stem-disc fragment	*Quercus robur/petraea*	AD 1503-1608	Netherlands/Central-North Germany
			1 stem-disc fragment	*Pinus sylvestris*	AD 1513-1626	Southeast Norway
NL	Burgzand-Noord 15	Shipwreck, marine	2 stem-disc fragments	*Quercus robur/petraea*	AD 1370-1628	Central-South Germany/Lower Saxony (Germany)
			1 stem-disc fragment	*Pinus sylvestris*	No date	-
G	Travenhorst	Castle site	4 complete stem discs	*Quercus robur/petraea*	No date	-
S	Stora Sofia	Barrel from shipwreck	3 stem-disc fragments	*Quercus robur/petraea*	AD 1487-1614	Wollin (Poland)/East Friesland (Germany)
S	Lidan	Shipwreck, marine	2 stem-disc fragments	*Quercus robur/petraea*	AD 1085-1384	Netherlands/Central-North Germany /Central Poland
N	Bryggen	Town site	1 complete stem disc + 2 fragments	*Pinus sylvestris*	No date	-
S	Mollösund	Shipwreck, fresh water	1 complete stem disc	*Quercus robur/petraea*	No date	-
NL	Elst-St.Maartenstr.	Temple site	6 stem-disc fragments	*Quercus robur/petraea*	58 BC-AD 86	Central-North Germany/ Netherlands
NL	Flevoland, plot no. GZ-80	Shipwreck on land	4 stem-disc fragments	*Quercus robur/petraea*	AD 1416-1533	Twente (Eastern Netherlands)/West Falia (Germany)
NL	Flevoland, plot no. KZ-47	Shipwreck on land	2 stem-disc fragments	*Quercus robur/petraea*	AD 1438-1503	Central Netherlands and Twente (Eastern Netherlands)

Because of the importance of studying the quality of archaeological wood in many different contexts, shipwrecks on land and under water were also included in the sampling. However, the period of time between the ships being built and sinking in many cases remains uncertain or unknown, as do the exact conditions the ships have been subjected to before they sank and became buried.

Methods

Sampling strategy

Standard requirements for dendrochronological sampling include collecting several samples from the same context or building phase that have an ample number of rings and, if possible, sapwood or waney edge.

Our aim was to collect at least four dendro samples per site. Some of the pre-selected (archaeological) sites did not yield more than one or two dendro samples. This was due to difficult sampling conditions (for instance under water), rarity of (suitable) wood in that particular site, or because the site proved to be of significant archaeological importance and it was decided not to continue excavating to find appropriate samples.

Where possible, complete stem discs were collected. For instance, at a number of the historical sample sites foundation piles are seriously affected and have to be replaced, which creates very good opportunities for sampling. In case of double rows of piles it was possible to extract complete piles too. In case of single rows of piles it was sometimes possible to replace a sampled part of a pile with different material. Otherwise radial slices or increment cores (diameter 1 cm) were taken. The quality of cores from waterlogged wood was less in comparison to the other samples. They tended to twist or compress and broke relatively easy.

Sample preparation and measurement

To prepare a radial trajectory to detect and measure ring widths razor blades or surgical blades (for the discs) and a Stanley knife (for the cores) were used. To visually enhance the cell structure powdered chalk was rubbed onto the surface of the wood. On conifer samples four radials were measured on each sample whereas for oak one or two were sufficient to establish a reliable tree-ring sequence for dating.

Dendrochronological dating and provenancing

To absolutely date the samples, regional standard chronologies of oak (*Quercus robur/petraea*), Scots pine (*Pinus sylvestris*), European spruce (*Picea abies*) and silver fir (*Abies alba*) from different European countries are available in the database of RING, The Netherlands Centre for Dendrochronology (Jansma *et al*., 2002).

Although conifers were extensively imported from Scandinavia and Germany for piling on a large scale, as in The Netherlands between approximately 1875 and 1960, the cultivation of Dutch Scots pine for coal mines and houses cannot be ruled out (Buis, 1993). Some experts (René Klaassen, SHR Foundation for Wood Research and Herman Keijer, Fugro Engineers,

personal communication) believe that foundation piles encountered in nineteenth- and twentieth-century houses in The Netherlands measuring over thirteen metres are mostly imported (German, Scandinavian) European spruce and those measuring up to seven metres are usually local (Dutch) Scots pine. Up to now no standard chronologies for *Pinus sylvestris* from The Netherlands are available. In previous attempts to date coniferous wood from historical buildings in The Netherlands (Sass-Klaassen, 2000), the same problem was encountered.

Results

From a total of over one hundred wood samples from historical buildings and archaeological sites that have been sampled for BACPOLES so far, 77 samples were selected for dendrochronological analysis (Tables 1, 2 and 3). The quality of the sample material and the results of the analyses are discussed below. Furthermore, Table 3 summarises some basic characteristics of the samples such as number of rings and the presence/absence of waney edge.

Table 3: Basic characteristics of the dendrochronological samples analyzed for BACPOLES.

Type of site	No. of samples	Wood species	No. of rings			Form of sample	No. of samples with	
			Min.	Max.	Average		Sapwood	Waney edge
Archaeological	38	Oak	20	294	91	(Part of a) disc	21	9
	1	Elm	82	82	82	Disc	-	1
	5	Scots pine	22	155	79	(Part of a) disc	?	3
Total	44							
Historical	1	Oak	55	55	55	Disc	1	1
	16	European spruce	39	113	62	Disc	-	16
	11	Scots pine	12	147	61	Disc or core	?	11
	3	Larch	43	52	48	Core	-	1
	2	Silver fir	53	98	76	Disc	-	2
Total	33							
Total from all sites	77							

Evaluation of sample material: historical wood samples

It appears that four different species of conifers were used for foundations: European spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), silver fir (*Abies alba*), and larch (*Larix* spec.) (Tables 1 and 3). Sometimes more than one conifer species was found in the same foundation. In one case the foundations consisted entirely of poplar (*Populus spec.*) and no suitable sample material for dendrochronology was retrieved. A piece of oak (*Quercus robur/petraea*) came from the bridge sampled in Venice, Italy.

The overall preservation of the pile samples is such that the cell structure of the wood is intact and tree-ring boundaries are clearly delineated. On most piles the waney edge is present, but on some samples the outer rings of the discs have broken off along the tree-ring

boundary. The cored samples, which were fragmented, were reconstructed before measuring.

Evaluation of sample material: archaeological wood samples

Most samples from the terrestrial archaeological sites, including two buried shipwrecks on reclaimed land, are oak (*Quercus robur/petraea.*) (Tables 2 and 3). One elm sample (*Ulmus* spec.) was taken from a Roman river embankment near Utrecht, The Netherlands. Bryggen, the terrestrial site in Bergen, Norway, yielded only Scots pine. The underwater-shipwrecks yielded oak samples as well as some Scots pine samples.

The preservation of the archaeological samples ranged from (visually) very good to “acceptable”. In the latter cases sapwood or waney edge were lacking, even if they could have been present earlier, the heartwood was partly degraded, or degradation caused discoloration and disappearance of the tyloses from the earlywood vessels in part of the heartwood so that itcould be falsely interpreted as sapwood. On the other hand, the central piles of a Roman farmhouse near Borsele, The Netherlands (Table 2), were perfectly preserved. They had clearly distinguishable sapwood as well as waney edge all around. Also worthy of mention are the foundation piles of the medieval castle Travenhorst, Germany, on which even the bark was still present.

Assessment of dating percentage

The success rates of the dendrochronological dating done so far are given below (Table 4). A distinction again is made between the archaeological sites (mostly oak) from which 75% of the analyzed samples were dated and the historical sites (mostly conifers) from which 39% of the analyzed samples were dated:.

When looking at the number of dated sites (Tables 1 and 2) instead of the number of dated samples (Table 3) we see different success rates: eleven out of fourteen (= 79%) for the archaeological sites and three out of nine (=33%) in case of the historical sites.

Table 4: Success rates of the dendrochronological dating of samples from archaeological sites and historical buildings for the BACPOLES project.

Type of site	No. of samples	Wood species	No. of samples		
			Undated	Dated	(%)
Archaeological	38	Oak	10	28	(74)
	1	Elm	0	1	(100)
	5	Scots pine	4	1	(20)
total	44		14	30	(75)
Historical	1	Oak	1	0	(0)
	16	European Spruce	7	9	(56)
	11	Scots pine	7	4	(36)
	3	Larch	3	0	(0)
	2	Silver Fir	2	0	(0)
total	33		20	13	(39)
Total	**77**		**34**	**43**	**(56)**

Age and provenance of the wood

The age (i.e. the ages of the oldest and youngest measured ring per site) of the analyzed wood samples is given in tables 1 (historical sites) and 2 (archaeological sites). The last column of each table also lists the region(s) of the standard chronologies that yielded the best matches. It shows the origin of the wood used to *comprise* these chronologies (see also Table 5), but it's difficult to say something about the *true* origin of the sampled wood (i.e. where did it grow?). For instance, in case of the terrestrial Roman sites in The Netherlands (Table 2) the wood in theory could be of "local"[4] origin or "imported" -rather: transported- from adjacent Germany (Table 5). The period between felling and use of the trees may have been longer for transported wood than for more local wood. This may have had implications for the quality of the wood. To draw any conclusions about the marine sites, one would have to know when and where the ships were built and when they sank. Were they built of local wood? How long had they been in use?

The youngest date given for the samples from historical buildings is also the felling date of the trees, because all foundations provided samples with waney edge. When comparing the felling dates of the pile samples with the documented building dates, a difference of several years was found in some cases. This may be due to necessary treatment and transportation time (in case of imported wood) or storage time (local/imported wood). For example, the trees for the foundation piles of the Parliament in Stockholm (Table 1) were cut in 1890 in the vicinity of Stockholm, five years before the actual construction (1895-1905, Charlotte Björdal, Lundt University, Department of Wood Science, personal communication), so they may have been *stored* for five years. The trees for the foundation of a house in Dordrecht (AD 1931), The Netherlands were also cut two years in advance (1929), in Germany.

[4] The meaning of the words *local* and *imported* in this case is relative. It is not our intention to discuss the regional validity of the chronologies that were used for dating in this paper. To be able to do so, more research is needed.

Table 5: Chronologies that were used for the dating of oak and conifer samples for BACPOLES and (roughly) indicate the provenance of the timber.

Chronology	Author(s)	Species	Country	Region/Description
0500029M	Bitvinskas, unpublished	*Pinus sylvestris*	L	Lithuania
3NEM0001	Eggertson, unpublished	*Pinus sylvestris*	S	Isle of Nemdeö (Southwest Sweden)
DHFIS300	Friedrich, Spurk & Becker, unp.	*Picea abies*	G	South Germany
DV1272MM	De Vries, unpublished	*Quercus robur/petraea*	NL	Twente (Eastern Netherlands)
EUBIG1ST	EU Contr.nr. ENV4-CT95-0127	*Quercus robur/petraea*	G	Netherlands, Central/North Germany
EUBIG2ST	EU Contr.nr. ENV4-CT95-0127	*Quercus robur/petraea*	G	Central/South Germany and Limburg (The Netherlands)
FLESBERG	Eidem 1959	*Quercus robur/petraea*	N	Southeast Norway
GBBALTI1	Hillam & Tyers 1995	*Quercus robur/petraea*	(UK)	Panel paintings from the Baltic in the UK
NLMIDDEN	Jansma 1995	*Quercus robur/petraea*	NL	Wood found in the Eastern Netherlands
NLZUID	Jansma 1995	*Quercus robur/petraea*	NL	Wood found in the South-eastern Netherlands and adjacent Germany (river Rhine import)
NLROMR9	Jansma 1995, extended version	*Quercus robur/petraea*	NL	Roman wood from wet Dutch sites + bog oaks
NLWF1040	Tisje, unpublished	*Quercus robur/petraea*	NL	Twente (Eastern Netherlands)/West Falia
NSSUB5HL	Leuschner, unpublished	*Quercus robur/petraea*	G	An area within Lower Saxony
OFR18MMM	Leuschner, unpublished	*Quercus robur/petraea*	G	Bog oaks from East Friesland/North Germany
POL457MM	Wazny, Eckstein (1987)	*Quercus robur/petraea*	P	Wollin
POL996MM	Wazny 1999	*Quercus robur/petraea*	P	East Pommern
POLWSTDM	Krapiec, unpublished (1996)	*Quercus robur/petraea*	P	Central Poland
ROMWEG	RING, unpublished	*Quercus robur/petraea*	NL	The Roman road near Vleuten, Utrecht (wood from Germany?)
WD400STD	Hollstein 1980	*Quercus robur/petraea*	G	Germany

Discussion

There are several reasons why some of the oak samples (mainly archaeological wood) could not be dated: a) the limited number of samples per archaeological context impedes the suppression of individual tree-ring patterns (by averaging with other trees); b) the sample exhibits too few rings so that no statistically reliable match with a standard chronology (or any other measurement series) is possible; c) tree-ring patterns are disturbed as a result of infestation by the cockchafer (*Melolontha melolontha*). Reasons why many of the conifer samples could not be dated a) inability to detect and then compensate for missing rings so that a match with a chronology becomes possible; b) the preponderance of so-called juvenile

wood with no strong common tree-ring signal in discs from young trees; and c) last but not least, no chronology available for a certain area or period.
The felling dates (AD 97 and 100) of two piles from a Roman farmhouse in Borsele, The Netherlands (Table 2) differ by three years. Was one of them stored for three years and the other used fresh? It may have something to do with the Roman custom to strip off the bark of living trees, leaving them to dry until the next year, when they would be cut (Vitruvius). Some of these dead trees might have been "forgotten" for several years or maybe left on purpose: a form of storage. Of course oakwood is easier to work when still "green", but in this case the stems of the trees were used whole.

Conclusions

Dendrochronological dating worked very well for the archaeological samples, which were almost exclusively oak, because of the many standard chronologies of oak (*Quercus robur/petraea*) that are available for Europe: 30 out of 44 samples (75%) and 11 out of 14 sites were dated. Finding a match for the mainly coniferous samples from foundations of historical buildings was less successful: only 13 out of 33 samples (39%) or 3 out of 9 sites were dated. The limited number of tree rings on the samples and the variety of possible origins complicates dendrochronological dating.

From the felling date and provenance of the dated samples some provisional conclusions about transport or storage of the wood can be derived: 1) considering the most likely provenance found for the samples through matching them with standard chronologies, the dated archaeological material probably consist of samples from transported as well as more local wood and the dated historical material mostly of imported wood; 2) the differences that were found between the felling dates of the trees used for foundations of historical houses and their documented building date mean we can conclude that the wood may sometimes have been stored for several years.

As for the preservation of the analyzed samples: damaged or degraded sample material in some cases may have prevented dating to the year, especially in the case of archaeological wood.

Expectations & future activities

Having successfully dated only part of the conifer samples with chronologies from -as expected- Germany and Scandinavia, the possibility still remains that some of the other Scots pines that were used as foundation piles in Dutch historical houses originated from forests in The Netherlands. A further research of the existing literature on this subject will be carried out. In the meantime an effort is being made to construct new chronologies of Scots pine for The Netherlands. Only few studies on living pine trees from The Netherlands have been undertaken (with different research questions) some of which are included in the International Tree-Ring Database (ITRDB; http://www.ngdc.noaa.gov/paleo/treering/html). Some of these data may be used, but only after careful checking and provided they don't derive from trees that are *too young* for the purpose of dating. Besides that, we intend to use wood samples from old living pines (*Pinus sylvestris*) at ten other locations in The

Netherlands. This part of the research is still ongoing. Possibly more pine samples from foundations of houses of the nineteenth and early twentieth century can be dated with these local[5] chronologies that can go back as far as AD 1750. The trees that were used as foundation piles usually have less than 155 rings, meaning that they will be largely covered by most of the newly constructed chronologies.

Whether or not the period of transportation and/or storage has implications for the quality of the wood samples -as is currently being studied by other participants in the project- still remains to be seen. The effect may be minor in comparison to that of the burial circumstances the wood has been subjected to for hundreds of years (Hans Huisman, ROB National Service for Archaeological Heritage, Research Department Soil & Degradation of Archaeological Materials, personal communication).

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[5] Questions concerning the regional validity of these chronologies for The Netherlands will hopefully be answered in a later stage of this research.

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[9] Unofficial English title: A handbook for the physical preservation of the archaeological heritage. Mechanisms of degradation encountered in features and materials. Monitoring the condition of the archive in the soil.

[10] Unofficial English title: Dendrochronological research of coniferous wood from Dutch monumental buildings.

[11] Unofficial English title: The development and use of dendrochronology for Oakwood in Poland.

[12] Unofficial English title: Dendrochronological dating of the early Middle Age Slavic settlement at Wolin.