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*Remembe*RINGs

The Development and Application of Local and Regional Tree-Ring Chronologies of Oak for the Purposes of Archaeological and Historical Research in the Netherlands

Esther Jansma

ROB

Rijksdienst voor het
Oudheidkundig Bodemonderzoek

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COLOFON

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The Development and Application of Local and Regional Tree-Ring Chronologies of Oak for the Purposes of Archaeological and Historical Research in the Netherlands

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor

aan de Universiteit van Amsterdam,

op gezag van de Rector Magnificus

Prof. Dr. *P.W.M. de Meijer*

ten overstaan van een door het college van dekanen ingestelde

commissie in het openbaar te verdedigen in de Aula der Universiteit

op *maandag 4 december 1995* te *12.00* uur

door *Esther Jansma*

geboren te *Amsterdam*

Promotores:	Prof. Dr. J. Strackee Prof. Dr. W. Groenman-van Waateringe
Co-promotor:	Dr. A. Voorrips

CONTENTS

Perhaps old mayflies sit around complaining how life this minute isn't a patch on the good old minutes of long ago. Whereas the trees, which are not famous for their quick reactions, may just have time to notice the way the sky keeps flickering before the dry rot and woodworms set in.

Terry Pratchett

PREFACE

In this volume absolutely dated tree-ring chronologies are presented from oak series derived from Dutch anthropogenic and natural sites from the past. This study has been funded by the 'Albert Egges van Giffen' Institute for Pre- and Protohistoric Archaeology (IPP, Univ. of Amsterdam (NL); 1985 - 1987), the archaeological section of the Netherlands Organization for Scientific Research (ARCHON/NWO, Doss. No. 280-151-040; 1987-1991); the Dutch State Service for Archaeological Soil Research (ROB; 1991 - present); and the many archaeological and historical organizations that from 1985 onwards funded the dating of archaeological structures and historic buildings conducted by the former tree-ring laboratory of the IPP and the current Dutch Centre for Dendrochronology (RING Foundation, ROB). The verification of the datings on which this study is based was funded by the EC as part of the project *'Temperature Change over Northern Eurasia during the last 2500 Years'* (Contract no. CV5V CT94 0500; 1994-1996; under supervision of the Climatic Research Unit, Univ. of East Anglia (GB)). The tree-ring data discussed in this thesis that date after 500 BC were incorporated in this project in January 1995; the remaining tree-ring series will be incorporated in 1996 as part of the continuation of this project, entitled '*Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia - the last 10,000 years'* (1996-1998, forthcoming).

Parts of this study have appeared previously in the journals *Dendrochronologia* (Chapter 2) and *Helinium* (Chapter 3; Chapter 5 (in print)); Chapter 4 is published in the proceedings of the 1994 International Tree-Ring Conference (Tucson, Univ. of Arizona (US)).

Apart from my promoters Dr. J. Strackee and Dr. W. Groenman-van Waateringe and my co-promoter Dr. A. Voorrips, many people have contributed to the separate chapters in this volume: Dr. A. van Oosterom (Dept. of Medical Physics, Univ. of Nijmegen (NL)) was consulted during the analyses described in Chapter 2; A. van Drunen and E. Vink (*Bouwhistorische Dienst* 's-Hertogenbosch (NL)) provided part of the historical facts mentioned in Chapter 3; H. van Haaster and Dr. J.P Pals (IPP) made valuable suggestions on the content of Chapter 3; the bog oak samples discussed in Chapter 4 were collected by V. van Amerongen (IPP), P. van Rijn (RING) and members of ARCHEON Archaeological Theme Park (Alphen a/d Rijn (NL)); V. van Amerongen also sampled part of the bog oaks discussed in Chapter 5; and P.P.Th.M. Maessen (Holtland Dendroconsult, Veenendaal (NL)) gave valuable suggestions on the classification of ecological growth regions in the Netherlands used in Chapter 6.

This study would have been impossible without the earlier research of Dr. J. Bauch and Dr. D. Eckstein (Ordinariat für Holzbiologie, Univ. of Hamburg (D)), and Dr. J.A. Brongers (ROB); they were the first to apply dendrochronology in a systematic way as a dating technique on tree-ring series from Dutch contexts and objects, and their work has been of paramount importance in convincing archaeologists and historians in the Netherlands that

Dutch timbers from the past *can* be dated dendrochronologically. I am grateful to Dr. B. Schmidt (Labor für Dendrochronologie, Institut für Ur- und Frühgeschichte, Univ. of Köln (D)) for the dendrochronological training I received in 1984; to Dr. H. Kamermans (IPP) for helping me to develop software in 1984 for crossdating and printing tree-ring curves; and to Dr. M.A.R. Munro (Paleoecology Centre, Queens Univ. of Belfast (Ireland)) for supplying his crossdating program for the Apple IIe computer in 1986.

This study could not have taken place without the support of an international group of dendrochronologists for the development of tree-ring research in the Netherlands as a dating technique and as an independent analytical field with applications in archaeological and historical studies, geology, forestry and climatology. I especially thank Dr. F.H. Schweingruber (Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf (CH)) for introducing me to dendrochronology, creating an European network of young dendrochronologists through the annual Swiss fieldweek, and continuously reminding the statisticians and archaeologists among us that a tree is a living organism. I am very grateful for the biological, analytical and practical background provided by R.K. Adams, Dr. H.C. Fritts, Dr. L.J. Graumlich, T.P. Harlan, R.L. Holmes, Dr. M.K. Hughes, G.R. Lofgren, Dr. T.W. Swetnam and Dr. F.W. Telewski of the Laboratory of Tree-Ring Research (LTRR, Univ. of Arizona (US)), where I spent the academic year 1989/1990 as a visiting scholar and turned into a dendrochronologist. The analytical programs distributed by the International Tree-Ring Data Bank (ITRDB; NOAA Palaeoclimatology Program/World Data Centre A; Boulder, Colorado (US)), which have been written by, or after suggestions of R.K. Adams (LTRR), Dr. E.R. Cook (Lamont-Doherty Geological Observatory, Univ. of Columbia (US)), Dr. H.C. Fritts (LTRR), Dr. H.D. Grissino-Mayer (LTRR) and R.L. Holmes (LTRR) have been of great value during all parts of the analysis. Dendrochronological dating requires access to absolutely dated tree-ring chronologies, and I thank all dendrochronologists who have made their chronologies accessible through publications or personal communication. Most helpful were chronologies provided by: Dr. D. Eckstein (Ordinariat für Holzbiologie, Univ. of Hamburg (D)); Dr. A. Delorme (Institut für Forstbenutzung, Univ. of Göttingen (D)); Dr. P. Hoffsummer (Laboratoire de Dendrochronologie, Univ. of Liège (B)); Dr. H.-H. Leuschner (Institut für Palynology, Univ. of Göttingen (D)); J. Hillam (Archaeology Research School, Univ. of Sheffield (GB)); H. Tisje (Neu-Isenburg (D)); I. Tyers (Museum of London (GB)); and Dr. T. Wazny (Academy of Fine Arts, Conservation Faculty, Warschau (P)).

The support of the Dutch archaeological and historical community is greatly appreciated. Dr. W.A. Casparie (Biological Archaeological Institute, Univ. of Groningen (NL)), Dr. H.A. Heidinga (IPP), Dr. H. Kars (RING/ROB) and Dr. D.J. de Vries (State Service for the Preservation of Historic Buildings and Monuments (RDMZ), Zeist (NL)) have helped me considerably throughout the years.

My deepest gratitude goes to Dr. J. Strackee (Laboratory of Medical Physics and Informatics, Univ. of Amsterdam) who has guided me through many statistical labyrinths and eliminated my fear of formula's by his elegant and practical use of blackboard and chalk; Dr. W. Groenman-van Waateringe (IPP), who never stopped believing that the current volume would be produced and always picked the right time to remind me of this; Dr. A. Voorrips and S. Loving (IPP), who during the past decade have garnished their theoretical, practical and moral support with marvellous dinners and conversations about poetry; Dr. H. Kars who for years has been supporting dendrochronology as a science; Dr. H.-H. Leuschner who has welcomed me into his laboratory and home, has introduced me to 'big science' (the more exciting elements of current dendrochronological research in Northwest Europe), and as long as I know him has been such a loyal and inspiring colleague; P.P.Th.M. Maessen, whom I can talk to endlessly about all kinds of forest research; Dr. H.D. Grissino-Mayer, who has always reminded me that science and fun are not mutually exclusive

and in the process has provided me with excellent computer programs, his extensive bibliography and all reprints I could wish for; and my co-workers Pauline van Rijn and Elsemieke Hanraets (RING), who have run the tree-ring lab of RING so excellently during the periods I worked on this thesis and without whom the dating business would have been a lone venture indeed.
I thank Sue McDonnell for the correction of the English text, Ingrid Jansen (ROB) for designing the current volume and Bert van As (ROB) for typing all the formula's and general advice.

Mireille, Maaike and Barbara Jansma have patted my back during all phases of this research. My friends Marion Oskamp, Rita Horst and Inger Kolff have hauled me through the more difficult times, as has my friend and colleague in poetry Nydia Ecury. This study could not have been completed without Casper le Fèvre, who stuck with me for better and worse during the past decade, never tired of discussing tree-rings with me, and has given me all support a female doctor-to-be asks for in this liberated era - which is a lot.

Thank you all.

1

INTRODUCTION

1.1 DATING IN ARCHAEOLOGY AND HISTORICAL RESEARCH

The dating of structures and objects from the past is a prerequisite for most archaeological and historical research. Different methods have been devised to date the past. These approaches can be classified into a number of categories (Michels 1973): (a) periodization: the delineation of synchronic segments, (b) relative dating: establishing the correct order of events, and (c) absolute dating: relating events to an absolute time scale.

The earliest dating method, developed in the nineteenth century and often used in geology and archaeology, was based on relative time scales determined on the basis of *stratigraphy*. The main principle of stratigraphy is the 'law of superposition', which states that in an undisturbed succession of strata, the youngest deposits are on top and the oldest ones at the bottom. Dating by means of stratigraphy can give only relative dates. The development of radiometric methods, after the discovery of radioactivity at the end of the nineteenth century[1], led to the first breakthroughs in establishing an absolute time scale. In addition to radiometric techniques, such as the radiocarbon method, in the twentieth century other absolute methods (with varying chronological precision) were devised, among which are varve analysis[2], obsidian hydration dating[3], thermo-luminescence dating[4], and dendrochronology.

In research of the past, the *intended* precision of dating depends on the investigated period and region (the research topic), whereas the *feasible* precision is determined by the material remains that are available and the dating methods that are used. In the Netherlands, for instance, the intended chronological precision with regard to the tenth century is high, because a major cultural shift took place (the transition from the Carolingian period to the Late Middle Ages) and it is not clear when exactly this happened. The feasible precision in the tenth century is, however, low, because ceramics associated with the remains of settlements from this century cannot be placed on a refined time scale and, due to the spread of Christianity, finds associated with burials are scarce.

Besides stratigraphy, modern archaeology uses dating methods such as *typochronology* (the application of more or less precisely dated calendars of artefact types), the *radiocarbon method* and *dendrochronology*. Building history uses typochronology, dendrochronology, written sources and additional data.

For certain periods and regions, dating by means of *typochronology* results in chronological information that is exact to a few decades; applied to imported ceramics, for example, it results in satisfactory dates for Roman and Iron Age structures throughout the Netherlands (1st to 4th/5th century AD). Archaeological sites from this period that do not contain imported ceramics as well as sites from the following centuries are more difficult to date. In the northern Netherlands the period between the fifth and eighth century and the tenth century are problematic in terms of dating; in the southern Netherlands this applies to the sixth, early seventh and tenth century; the province of Drenthe is difficult throughout the Early Middle Ages (AD 500 - 1000). The

1. The French physicists Antoine Henri Becquerel (1852 - 1908), Marie Curie (1867 - 1934) and Pierre Curie (1859 - 1906).

2. Varve analysis was developed by Swedish scientists in the early twentieth century. A varve is a sediment layer or a sequence of sediment layers deposited within a single year in stagnant water. Geologists can establish the age of a geological event in years from the number of varve units deposited after this event (Dalrymple 1991).

3. Obsidian hydration dating calculates the age of volcanic glass from 200 to 200 000 years old by determining the thickness of hydration rinds produced by water vapour diffusing into their freshly chipped surfaces (Dalrymple 1991).

4. Thermoluminescence dating is based on the phenomenon of natural ionizing radiation inducing free electrons in a mineral that can be trapped in defects of the mineral's structure. These trapped electrons escape as thermoluminescence when heated to a certain temperature. By recording the thermoluminescence of a mineral the last drainage of the trapped electrons can be dated back to several hundred thousand years (assuming a constant natural radiation level; O'Reilly 1984).

fact that it is sometimes difficult to date archaeological sites from the Late Middle Ages (AD 1000 - 1500) by, for instance, ceramics and brick types, is illustrated by the discrepancy between the typochronological and dendrochronological dates of the recently excavated 'Castle of the Lords of Amstel' (Amsterdam; Jansma and Kars 1995). To summarize, we can say that for many historical periods typochronology does not result in the precise dates that are required within the research setting. In order to refine dates established through typochronology, and for independent verification, physical dating techniques are required.

The *radiocarbon method*, first developed by the American chemist W. F. Libby at the University of Chicago in 1947, estimates the age of organic material on the basis of the fraction of radioactive carbon it contains. During their life, organisms take up carbon from the atmosphere (^{13}C and ^{14}C). A fraction of this assimilated carbon is radioactive (^{14}C). After the death of an organism, this fraction decreases according to a known rate; ^{14}C has a half-life of 5730 ± 40 years. The approximate moment of death can be calculated from the remaining fraction of ^{14}C in organic material. The radiocarbon method can be used to date material up to 50 000 years old, although it is sometimes extended to 70 000 years.

Radiocarbon estimates of dendrochronologically dated tree rings have shown that the fraction of ^{14}C in organisms at the time of death is variable, i.e., atmospheric ^{14}C is not constant. In the curve of ^{14}C measured in tree rings dated by means of dendrochronology, the 'radiocarbon calibration curve', changes of atmospheric ^{14}C show up as wiggles and horizontal intervals ('plateaus'); the precise age of organisms that lived during these periods cannot be deduced from their radiocarbon content. Furthermore, a radiocarbon date is often based on a single measurement of ^{14}C, which has an inherent uncertainty. Another basic problem is postdepositional contamination of the material (incorporation of younger and older carbon) by, for example, percolating groundwater and by contamination during and after sampling. Wiggles and plateaus in the calibration curve and statistical fluctuation mean that radiocarbon dates often have a broad chronological margin. The method does not improve datings of material from periods that are well-known chronologically, such as the Roman period (AD 1 - 450) and the Late Middle Ages (AD 1000 - 1500), and periods that have anomalous values of ^{14}C (e.g., 800 - 400 BC, the ^{14}C 'Hallstatt Plateau').

Dendrochronology makes use of the growth rings in trees. In tree species from the temperate climatic zone the growth rings represent single years, i.e., they are 'annual' rings.[5] Because trees grow very old, their trunks contain many rings: from between 100 - 300 (oak) to 2000 - 5000 (Giant sequoia, Bristlecone pine). As a result, single tree-ring measurement series consist of many observations and are more precise than a single observation of ^{14}C.

In Europe, oak is most commonly used for dendrochronological dating (*Quercus robur* L. and *Quercus petraea* (Mattuschka) Liebl.). The growth patterns of oak reflect climatic conditions that operated over relatively large areas, with unfavourable conditions expressed as narrow rings and favourable conditions as wide ones. Because of their similar response to annual weather conditions, the patterns in oaks that grow in these areas can be matched, i.e. 'crossdated'. Long chronologies of oak have been established through crossdating for different regions in Europe; the patterns in living oaks were matched with the patterns in timbers used in buildings from earlier times, and these were matched with even older material, etc. If a measurement series of an undated growth pattern of oak is matched with a dated oak chronology, a calendar date can be determined; each ring width in the undated pattern is matched with an annual value in the dated chronology, including the last ring in the pattern, which is closest to, or formed during, the year in which the tree died.[6] Dendrochronology has a chronological restriction in comparison to the radiocarbon method: it cannot be used to date material older than 10 000 years, because absolutely dated oak chronologies do not extend back further.[7] For the last 10 000 years it has an advantage over all other methods, because it is exact to the year.

5. Conifers sometimes form one or more 'false' rings during a single year. Using a microscope these can, however, be distinguished from annual rings.

6. Sometimes a dendrochronological date is subject to a certain margin, in consequence of the fact that the outer, last formed, rings are not present in a wood sample. In this case the year of death is estimated by adding an estimated number of (missing) growth rings to the last ring in the sample. The rings that *are* present in the sample are, however, dated to the year.

7. Oak settled in Europe after the last ice age ended (around 8000 BC). Only a few Northwest European chronologies of oak extend back this far; the majority covers the last thousand years only.

1.2 A BRIEF HISTORY OF DENDROCHRONOLOGY

The earliest application in Europe of dendrochronology as a climate-analysing method was by the Dutch astronomer J. C. Kapteyn (1851-1922). He measured the ring widths in groups of Dutch and German oak, produced chronologies that extended back for several centuries, and compared these to existing meteorological records (Kapteyn 1914). As early as 1908, Kapteyn gave a lecture in Pasadena (US) entitled '*Tree growth and meteorological factors*'.[8] It was A. E. Douglass (Flagstaff, Arizona) who formulated the principles and techniques of dendrochronology as a tool to study climate and by crossdating built the first long chronologies of tree rings (Douglass 1909; Douglass 1914; Douglass 1919). The subsequent earliest applications of dendrochronology mainly involved living trees, concentrating on questions regarding forestry, biology and climate.

In the 1940's, B. Huber introduced dendrochronology to Europe in a systematic way. From tree-ring patterns that reflect more or less continental growth conditions, long chronologies of oak were developed in Germany (e.g., Huber 1941; Huber and Holdheide 1942; Huber *et al.* 1949). Dendrochronology was considered unsuitable for dating oaks from regions where oceanic conditions prevail. Botanists and palaeobotanists in England and Ireland in the 1960's were still convinced that climate and the multiplicity of site conditions affecting tree growth would make dendrochronology unworkable in their countries (Baillie 1982). The relatively high amount of rainfall was considered an impediment to crossdating; the absence of droughts was believed to result in tree-ring patterns with a low 'mean sensitivity', i.e. little variation of the annual widths.

The focus of European dendrochronology broadened from the late 1960's onwards. Researchers found that the narrow rings in tree-ring patterns of oak, which allow these patterns to be crossdated over relatively large regions, also occur in oak growing in wet surroundings and that the causes are also climatic; for example, the trees respond negatively to spring frost and drastic changes in the water table. From this time onwards, dendrochronological dating was more and more routinely applied to oak from wet, oceanic sites and long 'oceanic' oak chronologies began to be developed (e.g., Delorme 1974; Delorme 1976; Baillie and Pilcher 1976). In addition, dendrochronological methods of studying the European climate were devised (Schweingruber *et al.* 1978; Schweingruber *et al.* 1979).

In Europe, palaeodendrochronology concentrates on oak and is focused on the dating of cultural objects, whereas research on living trees involves a variety of coniferous species and is focused on climatology (e.g., Hughes 1987; Hughes *et al.* 1984; Briffa *et al.* 1988, Schweingruber *et al.* 1987; Schweingruber *et al.* 1991; Briffa and Schweingruber 1992).[9] This approach is in marked contrast to the US, where most sub-fields of dendrochronology, including palaeodendrochronology, have always concentrated on climate studies. There are several reasons for this difference. First, palaeodendrochronologists in northwestern Europe work with relatively short series (mainly based on oak) in regions where natural old-growth forests no longer exist; if long chronologies are to be produced, series from historical and archaeological structures have to be used. Dendrochronologists in the US, on the other hand, mainly use long-lived coniferous species from natural forests, and the dead trees in these forests are used to obtain tree-ring series from earlier periods. Second, the anthropogenic past that can be studied dendrochronologically extends back further in Europe than in the US, and the demand for dendrochronological dating of cultural objects in Europe is large. Third, climate studies using series of oak in northwestern Europe are complicated and do not result in unambiguous data due to (a) anthropogenic factors such as forest management, pollution and managed water tables, and (b) the fact that oak in many regions is not very climate sensitive because it does not grow at the limits of its natural distribution. Despite these complicating factors the focus in European palaeodendrochronology is currently shifting from chronology development to climatology, among other reasons because data

8. The authorized text of this lecture was printed in the newspaper *Pasadena Star* (19 December 1908, 11-12; Eckstein *et al.* 1975).

9. Since the mid 1960's European dendroclimatology has mostly used radiodensitometric data, i.e. wood densities determined by X-ray procedures, since these are better suited for climate reconstructions than total ring-width. Radiodensitometry is only suitable for the research of coniferous tree species. Since the wood must not be decomposed, recent material is used and most density chronologies do not extend back more than a few centuries. Climate reconstructions derived from these chronologies are necessarily short.

sets of absolutely dated oak tree-ring series are now available up to 8000 BC (Irish oak: 5289 BC - present (Pilcher *et al.* 1984); North German oak: 6255 BC - present (Leuschner and Delorme 1988); Central German oak: 8021 BC - present (Becker 1993)). In Europe, climate studies oak have been undertaken by, among others, Briffa *et al.* 1986, Hughes *et al.* 1978 and Kelly *et al.* 1989. Climate studies on a large temporal and spatial scale, based on combined data sets of coniferous species and oak, are currently undertaken by collaborating dendroclimatological and palaeodendrochronological laboratories.[10]

1.3 DENDROCHRONOLOGY IN THE NETHERLANDS

In the Dutch archaeological and historical fields there was little interest in dendrochronology until the dating of oak panel paintings by 17th century Dutch artists began in 1965 (Bauch 1968; Bauch and Eckstein 1970; Bauch *et al.* 1972). In the early 1970's, J. A. Brongers of the State Service for Archaeological Research (ROB; Amersfoort) produced chronologies of living oaks growing on various habitats on the Pleistocene soils, and crossdated these with German master chronologies (Brongers 1973). His collaboration with J. Bauch and D. Eckstein (Ordinariat für Holzbiologie, Univ. of Hamburg) lead to the establishment of *Chronology 1* (AD 1385 - 1973) representing living trees, timbers from windmills and panel paintings dating from after AD 1650. This chronology represents oak from the eastern higher parts of the Netherlands and from Germany. *Chronology 2* (AD 1140 - 1623), from panel paintings dated before 1650, was presumed to represent oak from coastal sites in the Netherlands and England (Bauch *et al.* 1972; Eckstein *et al.* 1975; Bauch 1978).[11]

Efforts to establish a 'Dutch' dendrochronology were complicated by crossdating problems whose causes were not well understood. Unfortunately, *Chronologies 1* and *2* did not result in many new datings of timbers from Dutch buildings and archaeological structures. We now know that the early interval of *Chronology 1* probably contains an amorphous signal[12], and therefore most likely represents oak from a variety of environmentally different regions in Germany (and possibly the Netherlands), and that *Chronology 2* represents oak that grew in the Baltic region. This could not be established at the time, for a number of reasons. First, the extent of Medieval importing of oak timber in the Netherlands was underestimated, in part because few regional chronologies from adjacent countries existed that could be used as a reference. Second, the lack of crossdating among ring-width patterns of 'Dutch' timbers from archaeological and historical contexts was still interpreted as the result of the oceanic conditions in the Netherlands. Third, computers were not widely available; tree-ring patterns were measured and plotted by hand, and the analysing techniques were simple. Fourth, no dendrochronological infrastructure existed nationally within which these and other research problems could be solved.

In the early 1980's, the fact that oak in oceanic regions *can* be crossdated had become widely recognized throughout northwestern Europe. (e.g., Baillie and Pilcher 1976; Baillie 1982; Delorme 1974; Delorme 1976; Delorme *et al.* 1981; Leuschner *et al.* 1987). Furthermore, E. Hollstein (Rheinisches Landesmuseum Trier) had published his Central German master chronology and the constituent regional chronologies (690 BC - present), which proved to be well suited to date oak from Dutch archaeological and historical contexts (Hollstein 1980). As a result, dendrochronology in the Netherlands began to develop more quickly. Using a home-made computer program, D. J. de Vries of the State Service for the Preservation of Monuments and Historic Buildings (RDMZ, Zeist) dated eleven oak staves from Voorst Castle (province of Overijssel) using the Central German master chronology (De Vries 1983). I dated oak posts from the Roman fortress *Velsen 1* (province of Noord-Holland; Jansma 1985) and bog oaks from the vicinity of Abcoude (province of Utrecht; Jansma 1987). The latter datings, which were also made using the

10. '*Temperature Change over Northern Eurasia during the last 2,500 Years*' (EC, Contract No. CV5V CT94 0500); '*Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia - the last 10,000 years*' (EC, forthcoming).

11. At about the same time, Munaut investigated sub-fossil pine from Terneuzen (province of Zeeland; Munaut 1966) and Emmen (Province of Drenthe; Munaut and Casparie 1971).

12. Of the hundreds of dates obtained for medieval wood samples from Dutch contexts, only five were made through matching with *Chronology 1* (Molengat: 1 sample; Genhoes: 2 samples; Yerseke: 2 samples (Appendix A)).

chronologies of Hollstein, led to the establishment of a small dendrochronological laboratory at the 'Albert Egges van Giffen' Institute for Pre- and Protohistoric Archaeology (IPP, Univ. of Amsterdam) in 1985.[13] The work by J. Bauch, J. A. Brongers and D. Eckstein was followed-up in 1986, when a dendrochronological laboratory was created at the ROB.[14]

1.4 RESEARCH OUTLINE

The main objective of this study was to provide archaeology and building history in the Netherlands with a dendrochronological yardstick based on oak, sufficiently refined to date Dutch archaeological and historical contexts which otherwise could not be dated, or only roughly. In the archaeological field, in the first millennium BC, these are contexts from the period between 800 and 400 BC, for which the radiocarbon method does not result in precise enough dates. In the first millennium AD, these include contexts from the Iron Age/Roman period that do not contain imported ceramics, as well as the period between the fifth and eighth centuries in the northern Netherlands, the sixth and early seventh century in the southern Netherlands, and the tenth century throughout the country. Building history requires precise datings for any historical period from which buildings exist, i.e. the twelfth century and later, in order to link construction dates of (phases of) buildings to events described in written sources.

The Dutch *Chronology 1* could be matched with German chronologies, whereas *Chronology 2* could not (Eckstein *et al.* 1975). This indicated that in the Netherlands distinct, and unique, groups of indigenous oak exist. Therefore, methods had to be selected, or new ones developed, to distinguish between these groups.

The first efforts to analyse the different signals in tree-ring series were based on the dendrochronological parameter 'Mean Sensitivity' (ζ); see Chapter 2). This parameter, developed by A. E. Douglass (1928), was commonly used in early dendrochronology to estimate the variability and climate sensitivity in tree-ring series (e.g. Fritts 1976). In Europe this parameter played a role in the argument that oak from oceanic regions is less suited for dendrochronological analyses (Fürst 1963; Fürst 1978). I used ζ to compare the signal in dated growth patterns of oaks from the Iron Age/Roman period that in all likelihood grew in surroundings with different hydrological characteristics (wet versus dry). The purpose was to establish whether marked differences occur in their values for ζ over time, and whether these differences reflect the growth response of oak to different types of environment. Although different signals were indeed found (Jansma, unpublished data), this approach was abandoned; in collaboration with Prof. Dr. J. Strackee (Department of Medical Physics and Informatics, Univ. of Amsterdam) it was established that ζ is an ambiguous parameter that is dependent on other statistical parameters (the auto-correlation and standard deviation of a time series), and that it does not give an accurate estimate of the variability present in a time series (Chapter 2).

In the early phases of this study two assumptions were common in European dendrochronology as regards the provenance of timber: (a) the location where timbers were used was in general close to the location of the forest where the oaks were felled, and (b) the strength of a dendrochronological match between tree-ring series from different trees is a function of the absolute distance between the locations where the trees grew, i.e., the provenance of imported timber is in the region represented by the chronology that produces the best match (Hollstein 1980). It took some years of dating research and (efforts towards) developing Dutch chronologies before I realized that these assumptions are invalid for the Netherlands. The first assumption does not hold for the Roman and Medieval periods because timber was often brought here from elsewhere; the second one does not hold for any period because coastal regions such as the Netherlands are characterized by a variety of micro-environments, in which case the strength of a match is related to the similarity between the environmental conditions of

13. The programs used for crossdating at the IPP were written by Munro (1984), and, after Baillie and Pilcher (1973) and Hollstein (1980), by Jansma and Kamermans. An automated measuring table was designed by Jansma and built at the instrument workshop of the Medical Faculty of the University of Amsterdam.

14. The crossdating and plotting programs used at the ROB were written by Aniol (1983), who also designed the automated measuring equipment (Aniol 1987). The dendrochronological datings between 1986 and 1991 were carried out by P. Schut (1986-1987); M. van Veen (1987); G. Vervoort (1987-1988); A. Runhardt (1988); and E. Hanraets (1988-1991), under the supervision of J. A. Brongers (ROB).

the sites where the trees grew, not to geographical distance.

I therefore adopted the assumption that data sets of tree-ring series from Dutch archaeological and historical structures do *not* contain a homogeneous environmental signal. Given heterogeneous data sets, the following is feasible: (a) using correlation techniques it might be possible to discern sub-groups with a similar signal; (b) chronologies of indigenous oak can be produced from trees that died naturally and are preserved in former bogs ('bog oaks'); if these chronologies can be dated by matching with chronologies from coastal regions in the neighbouring countries it is precisely *because* distance is less important for crossdating in the coastal region of Northwest Europe; (c) given an international dendrochronological data set that is large enough, and given correlation techniques that are suited to distinguish sub-groups in this set, in the future it might be possible to assess in detail the provenance of groups of tree-ring series representing imported oak.

At this point (1990) I concentrated, with regard to the Middle Ages, on oak from the Dutch town of 's-Hertogenbosch (province of Noord-Brabant), for which written sources referring to local oak plantations and a regional wood trade are available. The aim was to determine whether it is possible, using correlation techniques, to distinguish between locally grown and imported oak, and whether it is possible to assess in a general way from which region imported timber was derived. For this analysis I applied the 'Mean Correlation Technique' (Wigley *et al.* 1984), which is used in dendroclimatological studies to determine whether chronologies from trees that grow at the same forest site are suitable for climate reconstructions (Chapter 3).

In 1992, in order to collect a data set of oak that unquestionably grew in the Netherlands, I started the *Sub-Fossil Forests* (*SFF*) *Project*, which is dedicated to the research of bog oaks (RING/ROB). The methodological purpose of the study was to determine the strength of the 'Expressed Population Signal' (*EPS*) in tree-ring patterns of bog oaks from single locations using the Mean Correlation Technique, to be used later as a criterion for clustering tree-ring series of unknown provenance. For the analysis a bog oak chronology was produced that runs from 2258 to 1141 BC (*NLPre_ZH*; Chapter 4).

Another reason for analysing oak trunks from former forests was that dated growth patterns of oak from natural contexts could possibly cover chronological gaps in the existing archaeo-dendrochronological data set. The dating by dendrochronology of cultural structures in the Netherlands had become more successful. By developing and applying local Dutch chronologies derived from archaeological material it had become possible to date structures that were undatable with the established, mainly German, chronologies.[15] However, in the historical part of the Dutch data set chronological gaps still existed in the second century AD, and in the fourth up to the sixth century. These could be finally covered by tree-ring series of bog oaks collected in the *SSF* project. An Iron Age/Roman period chronology for the central Netherlands was developed which runs from 325 BC to AD 563 (*NLRom_R*; archaeological material and bog oaks). Three shorter chronologies that exclusively represent archaeological timbers run from 84 BC to AD 50 (*NLRom_W1*), 140 BC to AD 87 (*NLRom_W2*), and AD 190 to 395 (*NLRom_E*; Chapter 5).

The clustering of medieval oak tree-ring series in the Netherlands is complicated compared to clustering series from prehistoric times and the Roman period. Few Medieval oak finds date from before AD 1300 and those that do were often derived from objects that are relocatable, such as barrels, whose origin is necessarily uncertain. Furthermore, after AD 1300 in the Netherlands all tree-ring series that can be dated through dendrochronology are derived from timber that *may* have been imported. Also, no sub-fossil remains of natural forests have been found in the Netherlands that date from after the sixth century AD, i.e., there is no set of indigenous oak samples dating from after AD 600 that can be used as a starting point for a Dutch chronology. The analysis of Medieval oak was therefore postponed until analytical methods to discern groups of tree-ring data that differ in terms of their signal had been tested, and until the dendrochronological data set was sufficiently large to be

15. An example is the dating of the Roman Meuse bridge at Cuyk (province of Limburg; Chapter 5), an archaeological under-water site from the fourth century that could not be dated accurately by either the contextually related material finds or the radiocarbon method. The Cuyk chronology, which at the time consisted of six series only, could not be dated with established chronologies. It could, however, be matched with the chronologies of two fourth-century water wells in Gennep. Cuyk and Gennep are situated only 15 kilometres apart. The Gennep chronologies were well replicated and had been matched with the Central German chronology of Hollstein (1980).

reliable. This point was reached in 1995, when the data set contained about six-hundred dated Medieval tree-ring series. Using correlation techniques, 80% of the series could be clustered into distinct groups (Chapter 6). Three historic chronologies resulted that differ in terms of length, sample size, and geographical distribution of the locations where the timbers were used. The longest chronology, *NLHist_1*, runs from AD 427 to 1752 and mainly contains series from timber used in the southern Netherlands (the provinces of Limburg and Noord-Brabant). Chronology *NLHist_2* runs from AD 1023 to 1666 and represents timber used in the central and northern Netherlands. Chronology *NLHist_3* runs from AD 1041 to 1346 and represents timber from the coastal region and the IJssel and Vecht Valley.

The 'Mean Correlation Technique' is applied in this study to assess the strength of the signal shared by tree-ring series in a data set. With this technique, the 'Expressed Population Signal' (*EPS*) is calculated; this parameter estimates how well a tree-ring chronology resembles the hypothetical perfect chronology. The higher the value for *EPS*, the more the series in the data set resemble each other. In dendroclimatology this is taken as an indication of the trees' climate sensitivity (Wigley *et al.* 1984), and in the current study as an indication that the trees reacted to similar environmental influences, i.e., grew in approximately the same region, under approximately the same hydrological, pedological and climatic regimes. During the first analyses based on this technique (Chapters 3 and 4), I used an adapted version published by Briffa and Jones (1990), which distinguishes correlation coefficients between series representing samples from the same tree (the 'within-tree signal') and correlation coefficients between series representing samples from different trees (the 'between-tree signal'). During these and subsequent analyses I stumbled on some problems regarding the statistical relationship between these estimators and *EPS*, the most important one being that the within-tree-correlation is hyperbolically related to *EPS*, i.e., as the former increases the latter decreases. These and other problems associated with the Mean Correlation Technique are described in Chapter 7.

Chapter 8 contains a summary of this study as well as a critical discussion of the results and some considerations about the direction in which dendrochronology in the Netherlands is currently developing or might be developed in order to extend its application in archaeological and historical research and palaeo-environmental studies.

2

THE STATISTICAL PROPERTIES OF 'MEAN SENSITIVITY' - A REAPPRAISAL [1]

Abstract – This paper investigates some statistical properties of the dendrochronological parameter 'Mean Sensitivity', s, referred to in this chapter by ζ. It is demonstrated that if the underlying time series obeys a Lognormal distribution, ζ is directly related to the variance and the first order autocorrelation coefficient of the series. A model of this relationship is developed and applied to experimental tree-ring data. The main finding is that ζ is an ambiguous parameter and that, when characterizing time series, the combination of variance and first order autocorrelation is to be preferred.

2.1 INTRODUCTION

A variety of parameters and descriptive measures are routinely used to describe the characteristics of tree-ring chronologies. Of the basic measures, we mention average, variance and first order autocorrelation coefficient (e.g. Box and Jenkins 1971).

In this paper we investigate the Mean Sensitivity (ζ) of tree-ring series. This measure is often cited in dendrochronology as an indicator of the climate sensitivity of tree growth at different types of site. Mean Sensitivity is usually presented as a descriptive parameter comparable to mean, standard deviation and first order autocorrelation (e.g., Fritts 1976, 300-311; Cook and Briffa 1990, 157). It was introduced by Douglass to assess the usefulness of particular tree-ring series for absolute dating purposes (Douglass 1928). He defined it as

$$\zeta = \frac{1}{N} \sum_{n=1}^{N} \frac{|x_{n+1} - x_n|}{\frac{1}{2}(x_{n+1} + x_n)}$$

with x_n the ring-width in year n and N the number of observations. Douglass added that *'the practical application of handling mean sensitivity is to take the sum of all changes in 10 years without regard to the sign and divide them by the sum of the 10 years growth'* (Douglass 1928, 30). This is expressed as:

$$\zeta^{\star} = \frac{\sum_{n=1}^{N} |x_{n+1} - x_n|}{\sum_{n=1}^{N} x_n}$$

1. Corrected version of Strackee, J. and E. Jansma, 1992. *Dendrochronologia* **10**, 121-135.

Huber and Holdheide (1942) restricted the domain of x_n to x_N, such that

$$\zeta^{\star\star} = \frac{N}{N-1} \frac{\sum_{n=1}^{N-1} |x_{n+1} - x_n|}{\sum_{n=1}^{N} x_n}$$

Fritts (1976) nearly returned to Douglass' original definition, proposing

$$\zeta^{\star\star\star} = \frac{1}{N-1} \sum_{n=1}^{N-1} \frac{|x_{n+1} - x_n|}{\frac{1}{2}(x_{n+1} + x_n)}$$

Notwithstanding the slight differences, these ζ all measure the local deviations of a time series.

However, during the last decades some problems have arisen regarding the interpretation of ζ:

i) ζ measures year-to-year variations of the ring widths. Although high values of ζ have been shown to reflect the influence of growth-limiting phenomena (e.g. drought in semi-arid regions; Fritts 1976), the exact nature of these phenomena cannot be deduced from the value of ζ. However, in studies of undetrended ring-width series of oak, fir, silver fir and spruce from western and central European sites, the value of ζ has been used to deduce the degree of continentality of the central european climate during the Neolithic and Bronze Ages (Fürst 1963; Fürst 1978). Interpreting the value of ζ in terms of the continental climate only ignores the possibly growth-limiting effect of (a) local endogenous and exogenous environmental factors and (b) growth-limiting phenomena related to climate in oceanic regions.

ii) Modifying the original time-series, e.g., by removing the slope and/or low frequencies, may result in a decrease of ζ. However, the value of ζ is often treated as being relatively independent of the method of standardization. The exact stage at which ζ is calculated during the multistage process of chronology building generally remains implicit in the literature; the same is true of the detrending method that is used.

iii) The value of ζ is dependent on the variance of the variable represented by a time series. In living matter the magnitude of the variance is nearly always related to the nature of the variable itself. Whether or not standardization is performed, a series representing cell-wall thickness shows less variability, and therefore lower values for ζ, than a series comprised of ring width. This often remains implicit when the values of ζ for different tree-ring variables are compared.

Because methods to assess the magnitude of the climate signal within ring series have been refined or altered, the emphasis placed on ζ as a parameter for characterizing tree-ring time series has diminished. Currently, analysis of variance (ANOVA) and signal-to-noise ratio (SNR) are among the methods commonly used (Fritts 1976; Hughes *et al.* 1982; Cook and Kairiukstis 1990). However, to our knowledge, the assumption that ζ is a reliable parameter for characterizing time series has never been formally questioned.

We have therefore looked in more depth at the statistical properties of ζ. The original ring series we used were detrended by division with values from an estimated growth curve, rather than by subtraction. Standardizing by subtraction results in data with zero mean. This renders ζ meaningless; the summation in the denominator of a positive value and a negative one can result in a small value, thereby inflating ζ to infinity.

2.2 STATISTICAL ASPECTS

2.2.1 *General*

To investigate the statistical properties of ζ, we introduce a bivariate density - with positive variates - for the dendrochonological indices x_n and x_{n+1}. In the sequel the subscript *n* turns out to be redundant and is therefore dropped. Denoting this density by $f(x,y)$, we compute the density, $f(\zeta)$, of a variate ζ defined by $\zeta = (x-y)/(x+y)$. Both the factor 2 (factor ½ in the denominator of Douglass' original formula), and the fact that the ζ of interest involves the absolute value of $(x-y)$, $|x-y|$, is dealt with afterwards.

For the computation, let *t* be an auxiliary variable such that

$$(x-y)/(x+y) = \zeta$$
$$x = t$$

Solving these equations for *x* and *y* and denoting the solution as x_o and y_o, we first create a bivariate density $f(\zeta,t)$

$$f(\zeta,t)d\zeta dt = f(x_o,y_o)dx_o dy_o / J; \qquad -1 \leq \zeta \leq +1, t \geq 0$$

with x_o and y_o the solution of the above equations and J the Jacobian of the transformation, i.e., the determinant of the matrix

$$\begin{vmatrix} \dfrac{\delta \zeta}{\delta x} & \dfrac{\delta \zeta}{\delta y} \\[2ex] \dfrac{\delta t}{\delta x} & \dfrac{\delta t}{\delta y} \end{vmatrix}$$

For our transformation, J reduces to $J = - \delta\zeta / \delta y$. Now x_o and y_o solve as

$$x_o = t \text{ and}$$
$$y_o = t\,(1-\zeta)/(1+\zeta),$$

and one has

$$J = - (1+\zeta)^2/(2t).$$

The density of ζ follows from integrating $f(\zeta,t)$ over *t* from 0 to ∞. Since ζ as defined is symmetric on [-1,+1], the change to $|x-y|$ and the factor 2 are introduced by mapping $f(\zeta)$ onto [0,+2].

Possible candidates for $f(x,y)$ were restricted to those that complied with the following two conditions:

a) f(x,y) should be meaningful with respect to the data, i.e., x and y should have a positive domain;
b) to facilitate further analysis, f(ζ) should have a closed analytical form.

The following two densities meet these conditions:

a) the bivariate Gamma density (as product of two independent Gamma densities);
b) the bivariate Lognormal density.

2.2.2 *The bivariate Gamma density function*

The bivariate Gamma density can be used to describe series of tree-ring data in which the autocorrelation is insignificant. In practice, this implies that the series have been pre-whitened. It can be represented as

$$f(x,y)\,dx dy = \frac{\lambda^{2k} e^{-\lambda(x+y)} (xy)^{k-1}}{\Gamma^2(k)}\,dx dy$$

with $\Gamma(x)$ the gamma function (Abramowitz and Stegun 1965). This function contains the parameters λ and k and arises as the product of two identical independent Gamma densities.

The marginal expectations and variances of x and y are

$$E[x] = E[y] = k/\lambda$$

$$\mathrm{Var}[x] = \mathrm{Var}[y] = k/\lambda^2$$

The density of $\zeta = ½| x-y | /(x+y)$ turns out as

$$f(\zeta)\,d\zeta = \frac{\Gamma(k+\frac{1}{2})(1-\frac{\zeta^2}{4})^{k-1}}{\Gamma(k)\sqrt{\pi}}\,d\zeta \qquad 0 \leq \zeta \leq 2.$$

Figure 2.1 depicts f(ζ) for some values of k.

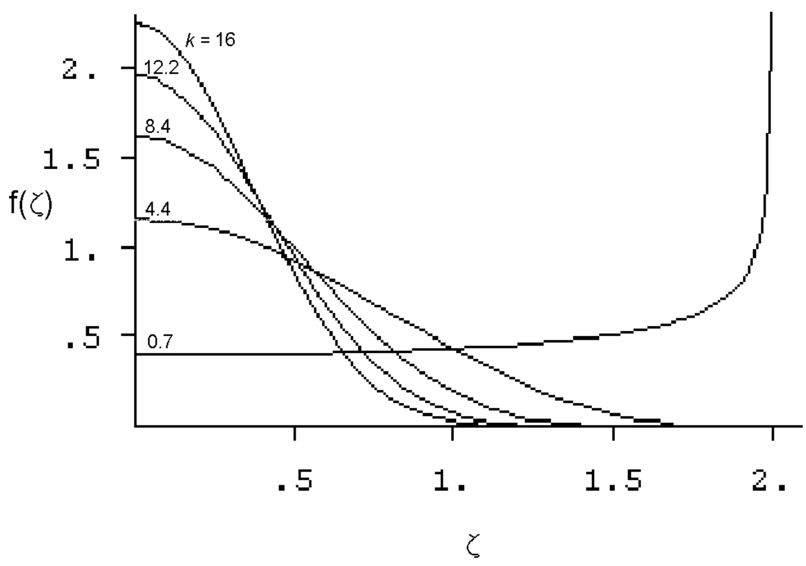


FIGURE 2.1 - Density f(ζ) for a bivariate Gamma density, k being a descriptive parameter of the latter density

The expectation and variance of ζ equal

$$E[\zeta] = \frac{2\Gamma(k+\frac{1}{2})}{\Gamma(k+1)\sqrt{\pi}}$$

$$\mathrm{Var}\,[\zeta] = \frac{4}{2k+1} - E^2[\zeta]\;; \quad \text{see Table 2.1.}$$

With respect to this outcome, we note the following:

a) For $k = 1$, $f(x,y)$ reduces to the product of two simple Exponential densities

$$f(x,y \mid k=1)\,dx\,dy = \lambda^2 e^{-\lambda(x+y)}\,dx\,dy,$$

and $f(\zeta)$ becomes the uniform density with

$$f(\zeta)d\zeta = \tfrac{1}{2}d\zeta, \quad 0 \le \zeta \le 2;$$
$$E[\zeta] = 1 \text{ and } \mathrm{Var}[\zeta] = \tfrac{1}{3}.$$

However, for biological material the value of k is generally larger than 1.

b) For large values of k ($k > 8$), one has

$$E[\zeta] \approx 1.13/\sqrt{k},$$
$$\mathrm{Var}[\zeta] \approx 0.73/k; \quad (1.13 \approx 2/\sqrt{\pi},\ 0.73 \approx 2(\pi-2)/\pi).$$

c) For the interpretation of k, note that for large values of k ($k > 8$), Gamma distributions approximate Normal distributions (mean μ and variance σ^2). Equating first and second order moments from both densities shows that

$$\lambda = \mu/\sigma^2 \text{ and } k = (\mu/\sigma)^2,$$

the approximation holding well for $\mu - 3\sigma > 0$.

Because the coefficient of variation, $CV[x]$, has $CV[x] = \sigma/\mu = 1/\sqrt{k}$, for large values of k we have the useful relation

$$E_{appr}[\zeta] \approx 1.13CV[x] \qquad (1.13 \approx 2/\sqrt{\pi}) \qquad \textbf{(1)}$$

As k increases, $E[\zeta]$ decreases while $SD[\zeta]$, due to the finite domain of ζ, first increases and then decreases (Table 2.1).

As an example, let a series of x_n be bivariate normally distributed with $\mu = 12$ and $\sigma = 3$. Approximating these data with a bivariate Gamma density function yields $k = 16$, and according to Table 2.1 $E[\zeta] = 0.280$ and $SD[\zeta] = 0.207$. Since $CV[x] = 3/12 = 0.25$, we derive from equation (1) $E_{appr}[\zeta] = 0.282$, demonstrating that the approximation works rather well. However, the large value for $SD[\zeta]$ indicates weak reliability of the estimation for ζ.

k	**E[ζ]**	**SD[ζ]**	***k***	**E[ζ]**	**SD[ζ]**
0.0625	1.845	0.390	2.0	0.750	0.487
0.125	1.719	0.496	4.0	0.547	0.381
0.25	1.526	0.583	8.0	0.393	0.285
0.5	1.273	0.616	16.0	0.280	0.207
1.0	1.000	0.577	32.0	0.199	0.149

TABLE 2.1 - E[ζ] and SD[ζ] (= $\surd$Var(ζ) for different values of *k*)

2.2.3 *The bivariate Lognormal density function*

The second density for f(*x*,*y*) we considered, was the standard bivariate Lognormal density function. This density function introduces a mutual dependence between *x*, *y*, i.e. between x_n and x_{n+1}. It can be used to describe autocorrelated tree-ring series.

Let Q = $[\{\ln(x)-\alpha\}^2 - 2r\{\ln(x)-\alpha\}\{\ln(y)-\alpha\}+\{\ln(y)-\alpha\}^2]$, then

$$f(x,y)\,dxdy = \frac{e^{\frac{-Q}{2\beta^2(1-r^2)}}}{2\pi\beta^2 xy\sqrt{(1-r^2)}}\,dxdy$$

containing the three parameters α, β and *r*.
For the marginal expectations and variances of ln(*x*) and ln(*y*) one has

$$E[\ln(x)] = E[\ln(y)] = \alpha$$
$$\mathrm{Var}[\ln(x)] = \mathrm{Var}[\ln(y)] = \beta^2,$$

and for the covariance

$$\mathrm{Cov}[\ln(x),\ln(y)] = r\beta^2$$

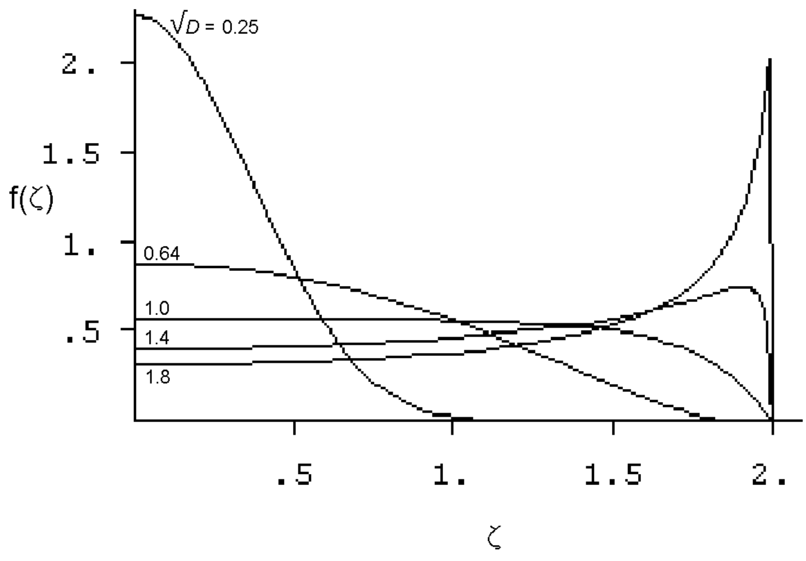
From this we see that α and β^2 represent the mean and variance of the logarithmically transformed data, while *r* is the correlation coefficient between ln(*x*) and ln(*y*). In our situation *r* also equals r_1.

The density of ζ can be computed as

$$f(\zeta)d\zeta = \frac{e^{\frac{-\ln^2\frac{2-\zeta}{2+\zeta}}{4D}}}{(1-\frac{\zeta^2}{4})\sqrt{(\pi D)}}\,d\zeta \qquad ; \quad 0 \le \zeta \le 2$$

with $D = \beta^2(1\text{-}r)$. Figure 2.2 gives f(ζ) for a series of values for $\sqrt{D}$.

FIGURE 2.2 - Density f(ζ) for a bivariate Lognormal density, $\sqrt{D}$ being a descriptive parameter of the latter density



E[ζ] and Var[ζ] are expressed by the following integrals

$$E[\zeta] = \frac{2}{\sqrt{(\pi D)}} \int_0^\infty \tanh\left(\frac{y}{2}\right) e^{\frac{-y^2}{4D}} dy \tag{2}$$

$$\mathrm{Var}[\zeta] = \frac{4}{\sqrt{(\pi D)}} \int_0^\infty \tanh^2\left(\frac{y}{2}\right) e^{\frac{-y^2}{4D}} dy - E^2[\zeta] \tag{3}$$

We failed to solve these integrals analytically. Table 2.2 lists E[ζ] and SD[ζ] (= $\sqrt{\mathrm{Var}[\zeta]}$) for a series of values of $\sqrt{D} = \beta\sqrt{(1-r)}$, with β the standard deviation and *r* the first order autocorrelation of the logarithmically transformed data.

Note that E[ζ] and SD[ζ] depend solely on the value of *D*, i.e. $\beta^2(1-r)$. This implies that differences between experimental values of ζ can arise from changes in β, in *r* or in a combination of both.

TABLE 2.2 - Expectation (E[ζ]) and standard deviation (SD[ζ]) of the Mean Sensitivity as function of a series of values of $\beta\sqrt{(1-r)}$, computed with equations 2 and 3

$\beta\sqrt{(1-r)}$	**E[ζ]**	**SD[ζ]**	$\beta\sqrt{(1-r)}$	**E[ζ]**	**SD[ζ]**
0.0625	0.070	0.053	4.0	1.629	0.537
0.125	0.140	0.105	8.0	1.806	0.424
0.25	0.276	0.203	16.0	1.902	0.315
0.5	0.525	0.362	32.0	1.951	0.228
1.0	0.901	0.532	64.0	1.976	0.163
2.0	1.312	0.599			

2.3 EXPERIMENTAL ASSESSMENT

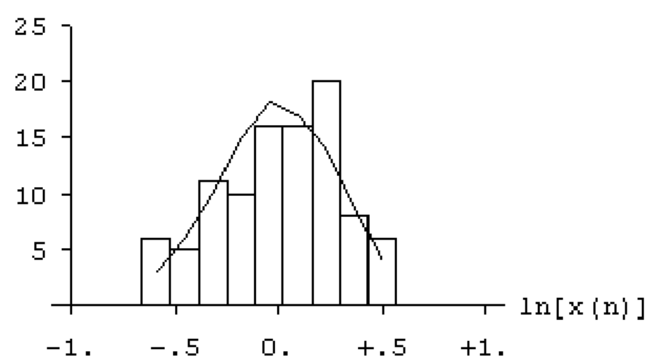
To test our theory, we randomly selected seven index series of oak from a Dutch archaeological context (the Roman fortress *Velsen 1*; Jansma 1985). The indices had been derived by dividing raw ring widths by predicted values, the latter obtained by fitting an exponential or linear growth curve on the data, using least squares.

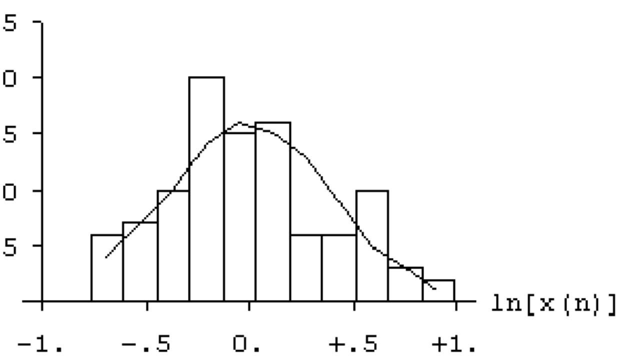
Each series was first tested against a Lognormal density by comparing the frequency histograms of the log-transformed data with their theoretical counterpart based on estimates of μ and σ^2. None of the series deviated ($p < 0.05$) from a Lognormal density (Figs. 2.3 and 2.4).

Table 2.3 summarizes the results for the seven series. For each logarithmically transformed series we calculated the mean (α_{est}), the standard deviation (β_{est}) and the first order serial correlation coefficient (r_{est}). ζ_{est} is an estimator for ζ using the non-log-transformed data. $\surd D_{est}$ represents the estimated $\surd D = \beta\surd(1\text{-}r)$.

It is apparent that while for some series (numbers 5288, 5291, 5292 and 5293) ζ_{est} hardly differs, the corresponding β_{est} and r_{est} are markedly different. When substituting $\surd D_{est}$ into equations (2) and (3) to obtain E[ζ] and SD[ζ], we find little difference between E[ζ] and ζ_{est}, thus confirming that the standard deviation and first order autocorrelation of a series can indeed be successfully used for predicting ζ.

Figure 2.3 - Histogram and fitted frequency distribution of series 5288 (left)
Figure 2.4 - Histogram and fitted frequency distribution of series 5291 (right)





2.4 DISCUSSION

Like estimates of the mean and standard deviation, ζ is also a stochastic variable. Assuming different bivariate densities for the tree-ring data x_n, we obtained two closed analytical expressions for the density of ζ. We actually found a third expression, using the dependent bivariate Exponential density (Johnson and Kotz 1969); this latter function is not, however, meaningful for biological data.

The bivariate Gamma density appears useful because it approximates bivariate Normal densities. However, detrended tree-ring time series may show small values for the coefficient of variation with corresponding small values for ζ. In pre-whitened tree-ring series the dependence between x_n and x_{n+1} is weak, such that ζ mainly reflects the standard deviation of the series. As previously noted, the large magnitude of SD[ζ] indicates weak reliability in the estimation of ζ.

As was shown for the indexed tree-ring series, the bivariate Lognormal density represents the statistical aspects rather well. Mean Sensitivity may therefore be redundant. Since E[ζ] depends solely on $\beta\surd(1\text{-}r_1)$, β being the estimated standard deviation of the series, the value of ζ can be derived from σ and r_1 of the series. Any change in β can be compensated for by a change in r_1 and vice versa. A large value for ζ may therefore result from a large value of σ^2, a small value for r_1, or a combination of the two. This indicates that the use of ζ will yield more ambiguous information than the use of r_1 and σ^2.

Sample No.	# Rings	α_{est}	β_{est}	r_{est}	ζ_{est}	$\sqrt{D}_{est}$	E[ζ]	SD[ζ]
5269	61	-0.051	0.316	0.659	0.189	0.184	0.206	0.153
5271	75	-0.067	0.364	0.571	0.274	0.238	0.264	0.195
5288	79	-0.041	0.296	0.580	0.202	0.192	0.214	0.159
5289	101	-0.072	0.382	0.628	0.248	0.233	0.259	0.191
5291	106	-0.084	0.385	0.770	0.209	0.190	0.211	0.157
5292	74	-0.052	0.337	0.686	0.199	0.189	0.210	0.156
5293	73	-0.045	0.306	0.629	0.207	0.186	0.208	0.155

Table 2.3 - Results for seven index series of Dutch oak. # Rings: the number of growth rings measured in each sample; α_{est}, β_{est} and r_{est}: estimates of the mean, standard deviation and autocorrelation coefficient of the logarithmically transformed data; ζ_{est}: estimated Mean Sensitivity (no logarithmical transformation); $\sqrt{D}_{est} = \beta_{est}\sqrt{(1-r_{est})}$; E[ζ] and SD[ζ] again from equation (2) and (3), respectively.

To summarize, Mean Sensitivity is simply related to the variance and first order autocorrelation of a time series. The estimator for ζ is not consistent since its variance does not converge to zero for increasing *N*. In addition, its variance is large over the domain of interest of ζ, making ζ even less attractive and its interpretation more problematic. Because of these questionable assets, data are better assessed solely by their mean, variance and first order autocorrelation.

3

DENDROCHRONOLOGICAL METHODS OF DETERMINING THE ORIGIN OF OAK TIMBER: A CASE STUDY ON WOOD FROM 'S-HERTOGENBOSCH [1]

Abstract - Dendrochronological methods to determine the origin of wood are few and unreliable. In the study presented here, dendroclimatological correlation techniques are used that have been developed for assessing the homogeneity of the growth patterns in living trees. The data set consists of fifteenth century oak timber applied in the Dutch town of 's-Hertogenbosch. The tree-ring series, with felling dates between AD 1463 and 1465, are compared to regional oak chronologies from Belgium and Germany. They are found to crossdate best with a chronology from the eastern Belgian Meuse Basin. The hypothesis of a Belgian origin for the timber is examined in the light of historical information on local trade and wood management. The correlation techniques are applied to the series from 's-Hertogenbosch and the Meuse Basin. The results of the analysis confirm that the timber came from eastern Belgium.

3.1 INTRODUCTION

Current dendrochronological research in the Netherlands focuses on the construction of average tree-ring chronologies of oak for dating purposes. In order to generate meaningful tree-ring chronologies of timber from archaeological and historical contexts, the origin of this timber should be known. In this chapter, methods are discussed with which the origin of oak timber can be established dendrochronologically.

Dendrochronology is a relatively young discipline in the Netherlands, and valid regional chronologies do not yet exist. Dated short chronologies of oak from Dutch locations range from 325 BC to AD 150, from AD 250 to 400 and from AD 825 to about 1800. Most of this data set has been derived from beams, planks and posts from archaeological and historical structures. The scarcity of quality construction wood in the Netherlands dates at least from the fourteenth century, when the expansion of urban centres must have involved the use of large quantities of timber. In historical terms, the local scarcity of tree species suitable for construction purposes is evidenced by the importance of centres of the wood trade like Dordrecht and Maastricht in the fourteenth and fifteenth century (Fig. 3.1), and, in the seventeenth century and later, by trade connections with areas as remote as the Baltic region. In dendrochronological terms, the application of timber from trees that grew outside the current Dutch borders is evidenced by the ease with which oak tree-ring patterns from Dutch Medieval contexts can be absolutely dated by means of regional chronologies from the surrounding countries. The regional chronologies best suited for dating timber from Dutch Medieval contexts have been derived from forested areas in Germany and Belgium (Table 3.1, Fig. 3.2).

When discussing tree-ring chronologies, we distinguish between site chronologies and regional chronologies. A *site chronology* represents the growth of trees at a single, well-defined site. A dendrochronological site is characterized by homogeneous growth conditions, such as altitude and slope,

1. Corrected version of Jansma, E., 1992. *Helinium* **32**, 195-214.

soil type and hydrology, distribution of light and shadow, and rain and temperature. A *regional chronology* represents the growth of trees at a large number of sites within a broadly defined geographical and climatological region. When analysing samples from living trees, the location of the site(s) and the nature of the growth conditions are known, but they are unknown for archaeological and historical samples.

The environmental influences that cause trees to grow as they do cannot be deduced from tree-ring patterns in any straightforward manner, because tree growth is influenced by a combination of factors. These factors can be divided into five categories (Cook 1990): (1) the age of the tree (the older the tree, the narrower its annual rings); (2) tree-specific, or endogenous, conditions such as the social position of a tree compared to the surrounding trees (a dominant tree has access to more light and food than its subdominant neighbours, and as a result forms wider rings); (3) exogenous non-climatological influences operating upon all trees growing at the same site (pollution, insect outbreaks, fires, flooding etc.); (4) climatological conditions such as rainfall and temperature; and (5) a random component, i.e., growth that cannot be explained in any of the above terms. When tree-ring patterns from relatively large areas are found to crossdate, this is mainly due to the influence of the climatic conditions (4). In a chronology that is constructed for purposes of dating, the climate signal[2] should therefore be strong.

Because climatological and exogenous factors both influence all trees that grow at the same site, good dendrochronological crossdating between the trees from a single site can be explained in both climatological and non-climatological terms. Whenever chronologies from different sites are found to crossdate, however, it is most likely caused by the fact that the climatological signal in the chronologies agrees well. The reason is that exogenous influences vary from site to site, whereas climatological influences are less variable. When site chronologies that represent the same type of site and climatological region are averaged into a regional chronology, the effects of exogenous influences tend to cancel each other out while the climatological signal is strengthened. This means that a regional chronology should be better suited for the purposes of dating than the separate site chronologies that were used to generate the regional chronology.

Which kind of climatological signal a chronology contains (e.g., a precipitation signal, a temperature signal, or a combination of the two), is dependent on the type(s) of site where the trees grew. Several statistical methods exist with which one can establish the nature of the climatic variables to which living trees from a given site or region respond (e.g., Response Function Analysis; Fritts 1976). These methods assume that the location of the site(s) is known, and involve the use of average monthly meteorological data.

It is impossible to establish the exact nature of the climatological signal contained in a chronology that is based on archaeological or historical material. First of all, no monthly meteorological data exist for Medieval and earlier times. Second, the location of a wooden structure does not necessarily coincide with the place where the timber came from. The exact location of the site(s) where such trees grew is always unknown, which means that the site conditions that influenced the growth of the trees (altitude, slope, soil type, etc.), cannot be known.

When the absolutely dated tree-ring series from a single wooden structure are averaged, the result is not necessarily a meaningful chronology; the inclusion of trees from different types of site could (and often does) result in a chronology that does not represent specific climatologic and exogenous influences, but an amorphous mixture of growth conditions. A chronology that, for example, would include oaks from both extremely wet and extremely dry sites, the former yielding trees that are mainly stressed by moisture, the latter yielding trees that are mainly stressed by drought, would not contain a clear signal. In years in which the former trees would show a narrow ring, the latter ones would show a wide ring (and vice versa). When these ring widths were averaged, the values would cancel each other out. In the resulting chronology, the growth response

2. Climatological signal: the pattern or variation in a series of ring widths that can be contributed to climate (Keannel 1992).

to precipitation and ground water levels would therefore be absent. The quality of such a chronology would be low, because it would be difficult to date and not well suited for the absolute dating of as yet undated tree-ring patterns.

For Medieval times, the Dutch data set of absolutely dated tree-ring patterns in part consists of locally grown oak, and in part of oak that was brought here from what is currently Germany and Belgium. Before these tree-ring patterns are averaged into chronologies, we suggest that statistical techniques be applied in order to establish which of these patterns represent the same *general* (unknown) growth conditions. Based on the outcome, the available patterns could then be clustered into homogeneous groups, each group yielding an average chronology with as strong a signal as possible. As long as the nature of such a signal remained unexplained, the signal could be described in statistical terms. Comparison with available regional chronologies from the neighbouring countries and with the ring-patterns of sub-fossil oaks from Dutch contexts, i.e. indigenous oak found *in situ*, could provide information about the type(s) of site such a chronology would represent and the nature of its signal. This would allow for a discussion of the signal in more geographical, environmental and climatological terms.

Trees growing at the same site often show remarkably similar ring-width patterns. This observation has prompted efforts to express the degree of similarity between any two tree-ring patterns as a function of the distance between the two trees from which the samples were taken (Hollstein 1980, 18-24). Determinations of the origin of oak timber have accordingly been based on the degree of crossdating between patterns of unknown origin and regional tree-ring chronologies representing the growth of oak in well-defined regions (Hollstein 1980; Weiss, verbal communication 1992). According to this approach, the regional chronology that most resembles the tree-ring patterns is taken to represent the area where the trees came from.

Some objections can be raised against this approach. First of all, one may not have access to the regional chronology that represents the area where the studied timber came from, in which case a region of origin might be deduced that does not coincide with the region the wood actually came from. Second, the region formally represented by a published chronology may differ from the region it represents in reality. Hollstein (1980) assumes that the region where the wooden structures he dated were located is the region where the trees actually grew (although he makes an exception for relocatable objects like barrels and ships). As will be shown below, this assumption is wrong for at least part of one of the regional chronologies he published. Third, the majority of the regional chronologies that are available, like the chronologies from Germany (Table 3.1, Fig. 3.2), have not been tested for homogeneity. Whenever these chronologies are used for determining the origin of timber, it is only *assumed* that they do not include tree-ring patterns from multiple climatological and geographical regions. Fourth, within a climatologically homogeneous region the climatic variables are constant, and only the exogenous factors and site characteristics vary. When the average rainfall and temperature are the same for all trees, oaks that grow at similar sites must broadly respond in the same manner. This means that the degree of similarity between oaks that grow in a climatologically homogeneous region can not be a function of distance.[3] Finally, the similarity between tree-ring patterns is in part influenced by the severity of the climatic conditions in the studied period and region. When a severe summer drought occurs in Northwest Europe, for instance, oaks growing in its more southern parts, and on well drained soils, tend to form a narrow ring (Kelly *et al.* 1989). When summer droughts occur during several years, the section of the ring pattern formed by these oaks during this period should crossdate well and show strong similarity. During years in which weather conditions are less growth-limiting for oak, the growth of the trees would in part be determined by weather conditions, and in part by site-related (exogenous) or even tree-specific (endogenous) factors. During such a period, their patterns should not crossdate as well and their degree of

3. Within a climatologically homogeneous region oak ***a***, which grows on a site of type ***x***, should crossdate well with oak ***b*** which grows kilometres away but also on a type ***x*** site, whereas it should show less similarity with oak ***c***, which grows only a few hundred meters away but on a site of type ***y***. This phenomenon occurs when the environment is characterized by a diversity of micro-environments (e.g., in mountains and coastal regions).

similarity should be lower. In other words, both the severity of the weather conditions and the size of the region where these conditions occur vary through time. The relationship of the distance between trees to their degree of crossdating varies accordingly. By generalizing observed values of statistical agreement and distance between trees into one single formula, assumed to be valid for all times and regions, this variability is ignored.

This study uses a more careful approach. The dendrochronological data set is derived from fifteenth century buildings in the Dutch town of 's-Hertogenbosch (Van Drunen and Glaudemans 1995). The bulk of the oak timber applied in Medieval 's-Hertogenbosch and studied dendrochronologically contains wide ring widths and can neither be dated relatively (by means of other undated tree-ring patterns from 's-Hertogenbosch and other locations), nor absolutely (by means of absolutely dated chronologies). The samples that could be dated, on the other hand, contain small ring widths and crossdate well among each other. This means that this subset of trees must have come from a region and/or type of site that differs from the region(s) and/or type(s) of site where the majority of the wood applied in 's-Hertogenbosch came from.

The absolutely dated subset of timber mainly consists of beams from oaks that were felled between AD 1463 and 1465. The degree of crossdating between their average chronology (C_{sH}) and the available regional chronologies from the surrounding countries is used to develop a hypothesis regarding the origin of the timber. The regional chronology that most resembles C_{sH} is taken to represent the area where the timber came from. Dendroclimatological methods are then used to estimate the strength of the climatological/exogenous signal common to (1) the individual tree-ring series contained in the average 's-Hertogenbosch chronology (C_{sH}), (2) the individual series included in the selected regional chronology, and (3) the *combination* of the individual series contained in C_{sH} and in the selected regional chronology. The underlying assumption is that if the tree-ring series contained in C_{sH} do not reflect the same growth conditions as the tree-ring series contained in the selected regional chronology, the combination of these series should result in an average chronology in which the signal is weaker than the signal that is present in the original two chronologies. The results of the analysis are compared to historical evidence of transactions in timber by merchants and institutions in fifteenth century 's-Hertogenbosch.

3.2 MATERIAL

The wood samples that provided the tree-ring patterns used in this study were taken from Medieval houses in the Dutch town of 's-Hertogenbosch (Van Drunen and Glaudemans 1995). This town, founded in the twelfth century by the Duke of Brabant, is situated near the river Meuse in the southern part of the Netherlands. Over the next few centuries it developed into one of the major towns in the Duchy of Brabant, which stretched southward into Belgium and included towns like Leuven and Brussels (Fig. 3.1). In AD 1419 and again in AD 1463, part of 's-Hertogenbosch was destroyed by fire. The consequent building activity and expansion lasted well into the sixteenth century.

The wood samples mainly consist of complete cross-sections of oak beams. Two radii were measured on each of these cross-sections.[4] When cores had been taken with an increment borer, only one radius was available. Of the wood that could be dated, the timber with felling dates in and just after AD 1463 should, in combination with incomplete samples that crossdate well with this timber, provide a data set suitable for determining the origin (Table 3.2, Fig. 3.3).[5] In and outside the recorded area of the fire of AD 1463, felling dates between AD 1463 and 1465 are common, which means that timber must have been bought in large quantities during this period. This improves the chance that the wood originated from a restricted number of areas. The ring patterns in this data set crossdate well with each other and cover the period between AD 1299 and 1465. They overlap optimally between 1360 and 1460.

4. Radius: a stretch of wood which runs from the pith (or oldest ring present) to the bark (or youngest ring present). When more radii are measured on a piece of wood, the approximation of the average growth pattern of the tree becomes more accurate.

5. The number of separate trees in this data set is smaller than the number of sampled beams (table 3.2), because occasionally several beams had been cut out of a single tree.

FIGURE 3.1 - The Duchy of Brabant in the fifteenth century.
1 = 's-Hertogenbosch;
2 = Brussels;
3 = Leuven;
4 = Maastricht;
5 = Schijndel;
6 = Dordrecht;
7 = Liège

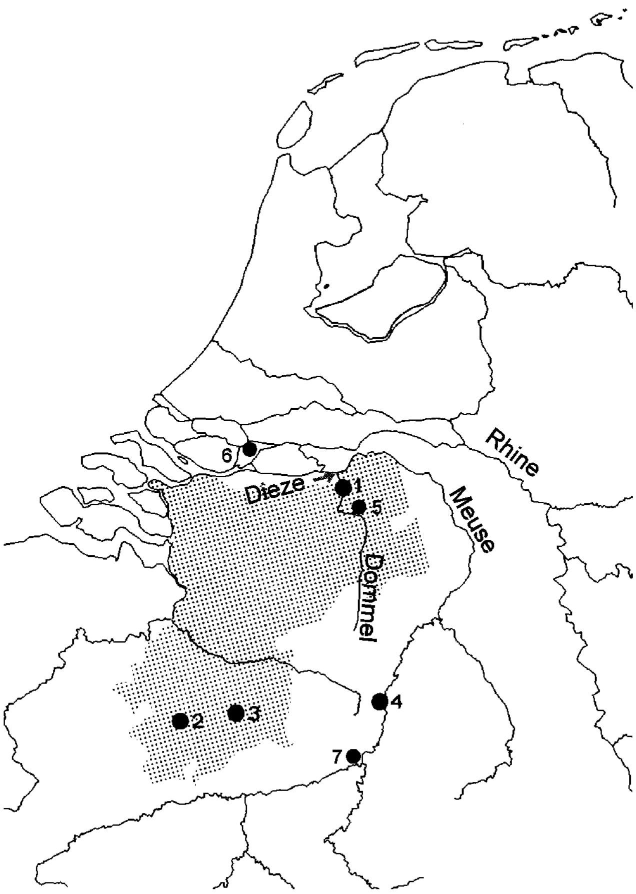
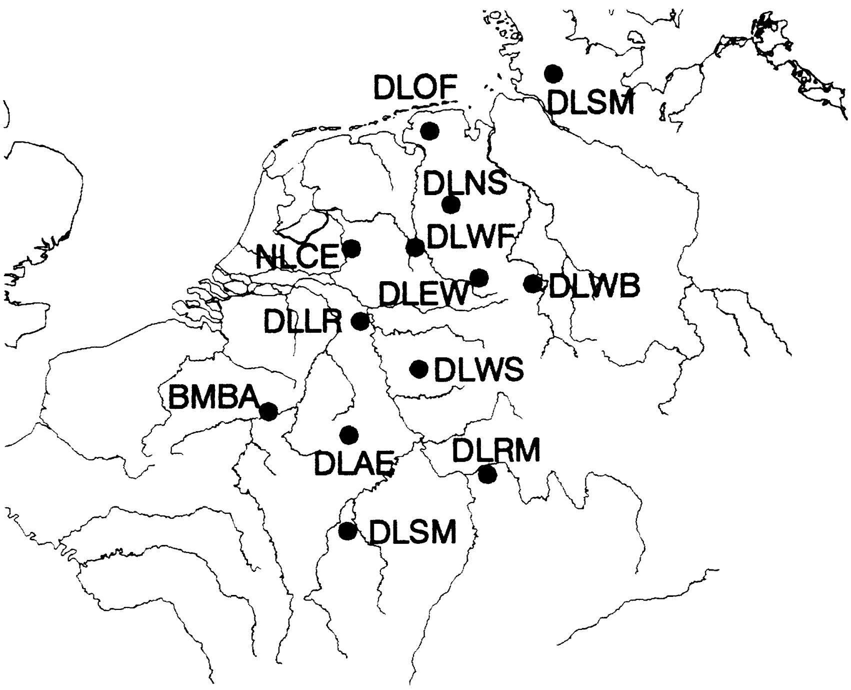


FIGURE 3.2 - Geographical origin of the regional oak chronologies (assumed). Abbreviations: see Table 3.1



Region	**Author**	**First year**	**Last year**	**Abbrev.**
Ardennes-Eiffel	Hollstein (1980)	AD 94	AD 1756	DLAE
Central and eastern Netherlands	De Vries (unpubl.)	AD 1272	AD 1578	NLCE
Ems-Weser	Hollstein (1980)	AD 1314	AD 1618	DLEW
Lower Rhine	Hollstein (1980)	AD 1327	AD 1631	DLLR
Lower Saxony	Leuschner (unpubl.)	AD 915	AD 1873	DLNS
Meuse Basin	Hoffsummer (1989)	AD 672	AD 1986	BMBA
Ostfriesland	Leuschner (unpubl.)	AD 18	AD 1873	DLOF
Rhine-Main	Hollstein (1980)	AD 440	AD 1787	DLRM
Schleswig-Holstein	Eckstein *et al.* 1970	AD 436	AD 1968	DLSH
Saar-Mosel	Hollstein (1980)	AD 730	AD 1975	DLSM
Weserbergland	Delorme (1972)	AD 1004	AD 1970	DLWB
Westphalia	Tisje (unpubl.)	AD 1260	AD 1669	DLWF
Westerwald-Sauerland	Hollstein (1980)	AD 1369	AD 1773	DLWS

TABLE 3.1 - Regional chronologies that are relevant to the Netherlands

Most of the regional oak chronologies used in this study (Table 3.1, Fig. 3.2) consist of averaged yearly growth values. They represent areas in Germany and Belgium. A preliminary chronology compiled from oak timber applied in the central and eastern parts of the Netherlands was used (De Vries, unpublished data). Both the average yearly growth values and the individual tree-ring series were available of the Meuse Basin (Hoffsummer 1989). No individual measurement series were available for the other chronologies; the dendrochronological quality of these chronologies could therefore not be established.

Documentary evidence of the trade in wood in the Duchy of Brabant is available from various sources. Written agreements dating from the end of the fourteenth and the beginning of the fifteenth century show that in this period hundreds of living oaks were bought and sold in the region around Schijndel, situated southeast of 's-Hertogenbosch (Fig. 3.1; Leenders 1991). Evidently, in this part of the Duchy of Brabant, oak was a valuable but common commodity during the fifteenth century. The trade in locally grown oak lasted well into the sixteenth century, and for the northern part of the Duchy does not seem to have been restricted to any specific area (Vink 1990). The written sources that are relevant to this study consist of financial accounts kept by two ecclesiastical charitable institutions in 's-Hertogenbosch, *De Tafel van de Heilige Geest* and *Het Gasthuis*. They date from AD 1453 to 1515 and from AD 1471 to 1502 respectively, and contain records of the trade in timber in which the institutions engaged (Vink 1993). This information is not necessarily meaningful for this study, because it concerns wood used in buildings that at the time were owned by the institutions themselves, whereas most houses in 's-Hertogenbosch that were investigated dendrochronologically had private owners. However, civilians may have bought wood from these institutions from time to time. Furthermore, the accounts sometimes mention the origin of the timber that was bought, and in this manner provide information about the trade routes that were commonly used, and the nearby and more distant regions where wood was abundant enough to be exploited on a large scale.

The fifteenth century accounts from *De Tafel van de Heilige Geest* en *Het Gasthuis* have no bearing on forest management policies. Sixteenth century sources from 's-Hertogenbosch refer to oak being planted, protected and harvested, and explicitly mention disasters befalling the forests, like flooding and the effects of war (Vink 1993). This means that oak, although available, must have been a valuable commodity during the sixteenth century in 's-Hertogenbosch. The account from *De Tafel van de Heilige Geest* affirms that during the fifteenth century part of the demand for wood could be met using trees that grew on the properties of local land-owning institutions. Between AD 1460 and 1480, for instance, *De Tafel* sold large quantities of wood from sick and dead oak trees (Vink 1993).

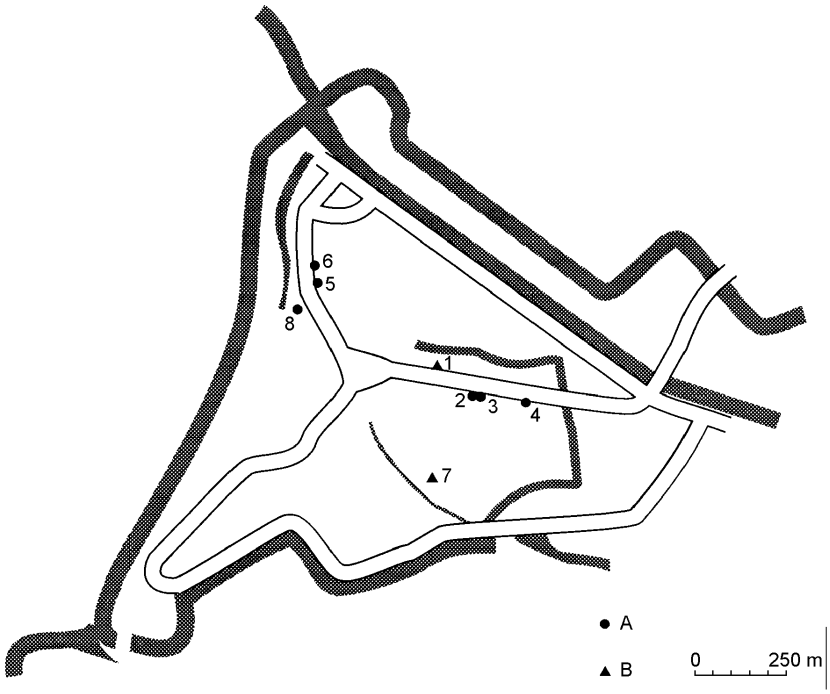


Figure 3.3 - Map of 's-Hertogenbosch: the houses that provided the timber used in the 's-Hertogenbosch chronology C_{sH};
A = timber felled between AD 1463 and 1465; B = timber dated terminus post quem;
1 = Hinthamerstraat 36/38;
2 = Hinthamerstraat 85/87;
3 = Hinthamerstraat 89/91;
4 = Hinthamerstraat 113;
5 = Orthenstraat 23/25;
6 = Orthenstraat 41;
7 = Verwerstraat 78;
8 = Visstraat 23

Table 3.2 - Tree-ring series used in chronology C_{sH}

Building	No. of Timbers	No. of Trees
Hinthamerstraat 36/38	1	1
Hinthamerstraat 85/87	2	2
Hinthamerstraat 89/91	7	4
Hinthamerstraat 113	5	4
Orthenstraat 23/25	4	4
Orthenstraat 41	4	4
Verwerstraat 78	1	1
Visstraat 23	1	1

Maps dating from the eighteenth century show that the southern part of the former Duchy of Brabant was largely deforested at that time (Tulippe 1942). Regardless of the degree of forestation in this part of the Duchy during the fifteenth century, it is questionable whether it was worth exploiting the area. No water routes connected 's-Hertogenbosch to this part of the Duchy, which means that the utilization of any trees growing here would have involved their transport over land. In periods of wood scarcity, it may well have been more profitable to buy wood that could be rafted most of the way to 's-Hertogenbosch. During the fifteenth century Maastricht (province of Limburg) and Liège (Belgium), both situated along the Meuse, were important regional centres of the wood trade (Hoffsummer 1989). The Dieze connected 's-Hertogenbosch with the Meuse. This means that wood could easily be rafted from Maastricht and Liège to 's-Hertogenbosch. The accounts of *De Tafel van de Heilige Geest* and *Het Gasthuis* confirm that some of the wood that was bought was transported along the Meuse and Rhine rivers, the former being the route most often mentioned in sources dating from the fifteenth century, the latter route appearing more often in sources from the sixteenth century (Vink 1993).

3.3 STATISTICAL METHOD

For all statistical analyses a time interval of 150 years was used, running from AD 1316 to 1465. In order to obtain a clearer understanding of the geographical domain of each regional chronology, the correlation between the regional chronologies was calculated. Then, standard statistical dating techniques were applied to determine which available regional chronologies crossdated best with the mean chronology from 's-Hertogenbosch. The parameters describing the goodness-of-fit are *PV* (the coefficient of parallel variation); *r* (the correlation coefficient between two series), and *St* (the value resulting from a Student's t-test on the highest value of *r* found when comparing the two series[5]; Hollstein 1980; Baillie 1982; Munro 1984; Chapter 5, section 5.4.1). The regional chronology showing the best fit was renamed C_{reg}.

For C_{reg}, the similarity between the individual tree-ring series in this time interval was assessed using COFECHA, a computer program designed for dendrochronological quality control at the Laboratory of Tree-Ring Research, Univ. of Arizona, USA (Holmes 1983). Using this program and a collection of individual tree-ring series, each series was broken up into segments of 50 years and then compared to the mean chronology of all other series. Individual tree-ring series that did not agree with the overall signal, and series that appeared to contain measurement errors, were removed from C_{reg}.

The signals in the corrected regional chronology C_{reg}^*, the 's-Hertogenbosch chronology C_{sH} and their combined chronology C_{all} were analysed by means of dendroclimatological procedures. The signal of a chronology is defined as a statistical quantity that represents the common variability present in all of the tree-ring series at a particular site (Briffa and Jones 1990). The climatological research of tree-ring patterns, of which this and similar statistics are an inherent part, usually involves living trees that grow at sites whose environmental conditions are well known. Because working with living trees implies the possibility of site selection (i.e., the selection of trees that optimally respond to the environmental factor(s) one seeks to investigate or reconstruct), the statistical criteria that climatological tree-ring data have to meet are quite strict.

One of two methods is in general used to assess in detail the strength of the signal that is contained in a tree-ring chronology. Both methods are based on the assumption that a group of tree-ring series from a specific site makes up one sample from a hypothetical population that represents the perfect chronology (Briffa and Jones 1990). The first method is Analysis of Variance (ANOVA; Fritts 1976). This method of measuring the common variability within and between trees can only be applied to sections where all tree-ring series overlap (the common interval). Since some of the series in both C_{reg}^* and C_{sH} are short and the series in general do not overlap very well, the common interval in this

5. Student's t-values are usually referred to by *t*. In this study *t* stands for the number of trees; in order to avoid confusion we refer to Student's t-values by *St*.

case covers only a few decades. We did not, therefore, apply this method. The second method is the Mean Correlation Technique. This method is discussed in detail in Briffa and Jones (1990). It consists of calculating the correlation between all pairs of series, using the maximum overlap between them. We used a minimum overlap of thirty years between each pair of series, hence correlations between series with a shorter overlap were omitted from the calculations. Second, it requires that the means of the individual series are the same. This demand was met by detrending all series in C_{sH} and C_{reg}^{*} before the analysis took place.[6]

The mean correlation between the series that represent different trees ($\bar{r}_{bt}$) was calculated for C_{reg}^{*}, C_{sH} and C_{all}. For C_{sH} the mean correlation was calculated between series that represent the same trees ($\bar{r}_{wt}$). It was impossible to calculate $\bar{r}_{wt}$ for C_{reg} because here all trees were represented by a single series of ring widths. Consequently, the value for $\bar{r}_{wt}$ was the same for C_{sH} and C_{all}.

The effective mean correlation $\bar{r}_{eff}$, which is an estimate of the chronology signal that includes both the signals within trees ($\bar{r}_{wt}$) and between trees ($\bar{r}_{bt}$), was calculated using the method described by Briffa and Jones (1990). First, one computes c_{eff}, the effective number of measurement series per tree:

$$\frac{1}{c_{eff}} = \frac{1}{t}\sum_{i=1}^{t}\frac{1}{c_i} \qquad (1)$$

where t is the number of trees, c_i the number of samples taken from tree i, and c_{eff} the effective number of samples in the chronology. Briffa and Jones (1990) define $\bar{r}_{eff}$ by

$$\bar{r}_{eff} = \frac{c_{eff}\,\bar{r}_{bt}}{1+(c_{eff}-1)\,\bar{r}_{wt}} \qquad (2)$$

Note that when each tree is represented by one single sample, c_{eff} equals 1 and $\bar{r}_{eff}$ equals $\bar{r}_{bt}$.

For C_{reg}^{*}, C_{sH} and C_{all} the degree was quantified to which the chronology signal is expressed when the individual series in the respective data sets are averaged. When expressed as a fraction of the total chronology variance, the chronology signal quantifies the degree to which this particular sample chronology reflects the hypothetical perfect chronology. This Expressed Population Signal (*EPS*; Briffa and Jones 1990) is calculated as:

$$EPS(t) = \frac{t\,\bar{r}_{eff}}{1+(t-1)\,\bar{r}_{eff}} \qquad (3)$$

where t is the number of separate trees included in the chronology. Wigley *et al.* (1984) suggest that values for *EPS* of 0.85 and higher are of acceptable statistical quality for dendroclimatological studies.

The standard error (*SE*) of the chronologies is calculated as

$$SE = \sqrt{\frac{1-\bar{r}_{eff}^{\,2}}{t}} \qquad (4)$$

with t the number of separate trees.

6. The 's-Hertogenbosch chronology consisted of detrended and pre-whitened growth indices of which the variance was stabilized. The regional chronologies used in the analysis were standardized in exactly the same way. The detrending of tree-ring patterns, in this case the removal of low frequency variations in order to enhance the high frequency climate signal, is discussed in Fritts (1976) and Cook *et al.* (1990). Pre-whitening, i.e. the removal of the auto-correlation in tree-ring series, is discussed in Box and Jenkins (1970) and Cook *et al.* (1990). In tree-ring patterns, auto-correlation is a function of the growth conditions in previous years. Its removal enhances the climate signal.

From (3) it can be seen that the values of *EPS* and *SE* are dependent on both the value of $\bar{r}_{eff}$ and on the number of trees (t) included in the chronology. As t becomes smaller, the chronology error increases. How well a chronology based on a subset of t' samples (here C_{reg}^{*} and C_{sH}) estimates a chronology based on t samples (here C_{all}), is expressed by the sub-sample signal (*SSS*):

$$SSS = \frac{EPS(t')}{EPS(t)} \qquad (5)$$

Briffa and Jones (1990) suggest that *SSS* values of 0.85 or higher are of acceptable statistical quality when reconstructing climate from tree rings. They are less explicit about advisable levels of *SE* (standard chronology error). However, values of *SE* equal to or lower than 0.15 should be adequate in most cases.

3.4 RESULTS

Of the thirteen regional chronologies included in the analysis (Table 3.1, Fig. 3.2; AD 1316 to 1465), in particular the Lower Rhine and Ems-Weser chronologies crossdate poorly with the chronologies from the adjacent areas (Table 3.3). The Lower Rhine chronology (first year: AD 1327) correlates negatively with five chronologies, the lowest correlation (r = -0.60) occurring with the Ardennes-Eiffel chronology. The Ems-Weser chronology correlates negatively with three chronologies, the lowest correlation (r = -0.52) occurring with the Rhine-Main chronology. Both chronologies crossdate well with the Westerwald-Sauerland chronology (first year: AD 1369), the Lower Rhine chronology giving a correlation of 0.72 and the Ems-Weser one of 0.68 (Table 3.3).

Table 3.3 - Correlations between the regional chronologies; n = 150 except in comparisons of DLWS (n = 97) and DLLR (n = 139); ◆ = correlation not significant at level of significance α = 0.01; abbreviations: see Table 3.1

Abbrev.	**DLAE**	**NLCE**	**DLEW**	**DLLR**	**DLNS**	**BMBA**	**DLOF**	**DLRM**	**DLSH**	**DLSM**	**DLWB**	**DLWF**
NLCE	0.48											
DLEW	-0.50	◆										
DLLR	-0.60	-0.44	0.42									
DLNS	◆	◆	◆	◆								
BMBA	0.25	◆	◆	◆	◆							
DLOF	◆	◆	◆	-0.29	0.89	◆						
DLRM	0.32	◆	-0.52	◆	0.27	0.30	◆					
DLSH	0.31	0.52	◆	-0.50	0.48	◆	0.66	◆				
DLSM	0.45	◆	◆	◆	◆	0.54	◆	0.53	◆			
DLWB	◆	-0.27	◆	◆	0.76	0.23	0.55	0.40	◆	◆		
DLWF	0.45	0.52	-0.30	-0.40	◆	0.29	0.34	◆	0.53	0.23	◆	
DLWS	◆	◆	0.68	0.72	-0.37	0.31	-0.42	◆	-0.36	0.48	-0.40	◆

Oak timber from Dutch fifteenth century contexts usually crossdates well with the Westphalia chronology. The Westphalia chronology in fact constitutes one of the most useful chronologies for obtaining absolute dendrochronological dates for fifteenth century timber from Dutch contexts (Jansma, unpublished data; De Vries, unpublished data). However, the material from 's-Hertogenbosch does not crossdate well with this chronology (r = 0.22; Table 3.4). The 's-Hertogenbosch chronology crossdates best with the Saar-Mosel and the Meuse Basin chronologies (r = 0.50 and 0.51 respectively). Of these two chronologies, the Meuse Basin chronology yields the highest values of *PV* and *St* (Table 3.4) and is included in the subsequent analyses as C_{reg}.

Table 3.4 - C_{sH} compared to regional chronologies; n = 150 except in comparisons made with DLWS (n = 97) and DLLR (n = 139); *PV* = coefficient of parallel variation; r = correlation coefficient; *St* = Student's t-value

Abbreviation	***PV***	***r***	***St***
C_{reg}*	79%	0.67	11.7
BMBA	74%	0.51	10.4
DLSM	71%	0.50	9.4
DLRM	64%	0.26	7.0
DLWB	66%	0.25	6.6
DLAE	66%	0.20	5.8
DLWF	62%	0.22	5.0
DLWS	≈50%	-	-
DLNS	≈50%	-	-
DLSH	≈50%	-	-
DLEW	≈50%	-	-
NLCE	≈50%	-	-
DLOF	≈50%	-	-
DLLR	<50%	-	-

It proved possible to correct C_{reg} by the removal of individual tree-ring series that showed no agreement with the overall signal. In the corrected chronology C_{reg}* the average correlation between each separate series and the mean chronology of the other series has improved from 0.38 to 0.55 (program COFECHA; Holmes 1983). The correction of C_{reg} caused the correlation with C_{sH} to increase from 0.51 to 0.67, and the coefficient of parallel variation (*PV*) from 74% to 79% (Table 3.4). The corrected chronology C_{reg}* is shown together with C_{sH} in Fig. 3.4.

The chronology statistics are listed in Table 3.5. All three chronologies C_{sH}, C_{reg}* and C_{all} have a value for *EPS* (Expressed Population Signal) that is higher than 0.85; all three therefore adequately represent the hypothetical perfect chronology. Both C_{sH} and C_{reg}* have sufficiently high values for *SSS* (Sub Sample Strength). However, their values for *SE* (Chronology Standard Error) exceed 0.15. The highest value for *EPS* and the lowest value for *SE* belong to the combination of the two chronologies, C_{all}.

Table 3.5 - Chronology statistics

	C_{sH}	C_{reg}^{*}	C_{all}
Number of trees (*t*)	21	17	38
Number of cores	46	17	63
c_{eff}	2.10	1	1.78
$\bar{r}_{bt}$	0.37	0.32	0.35
$\bar{r}_{wt}$	0.81	-	0.81
$\bar{r}_{eff}$	0.43	0.32	0.39
EPS	0.94	0.89	0.96
SE	0.20	0.23	0.15
SSS	0.98	0.93	-

3.5 DISCUSSION

Strong negative correlations like those that occur between the Lower Rhine and Ems-Weser chronologies and some of the other regional chronologies used in this study (Table 3.3), cannot be completely explained in terms of the climatological and ecological differences between the regions. The samples used to construct the Ems-Weser chronology, for instance, were in part derived from sites in the province of Westphalia (Hollstein 1980, 4), whereas this chronology does not crossdate at all with the independently constructed Westphalia chronology. A similar problem exists for the chronology of the Lower Rhine. Although this chronology is considered to include Dutch tree-ring patterns (and therefore to represent Dutch growth conditions; Hollstein 1980), it is in our experience not useful for dating wood from Dutch archaeological and historical contexts. It is possible that the Lower Rhine chronology was compiled from wood from multiple climatological regions and types of site, and that the resulting signal is amorphous. However, between AD 1369 and 1465 the Lower Rhine chronology is almost identical to the Westerwald-Sauerland chronology (r = 0.72), which implies that the Lower Rhine chronology in this time interval, when oak was becoming scarce, most likely represents trees from the forested Westerwald-Sauerland area. In other words, between AD 1369 and 1465 the origin of the tree-ring series that were used in the Lower Rhine chronology is different from that previously assumed. In addition, this chronology is clearly not suitable for determining the origin of oak from this period that did in fact grow in the region of the Lower Rhine.

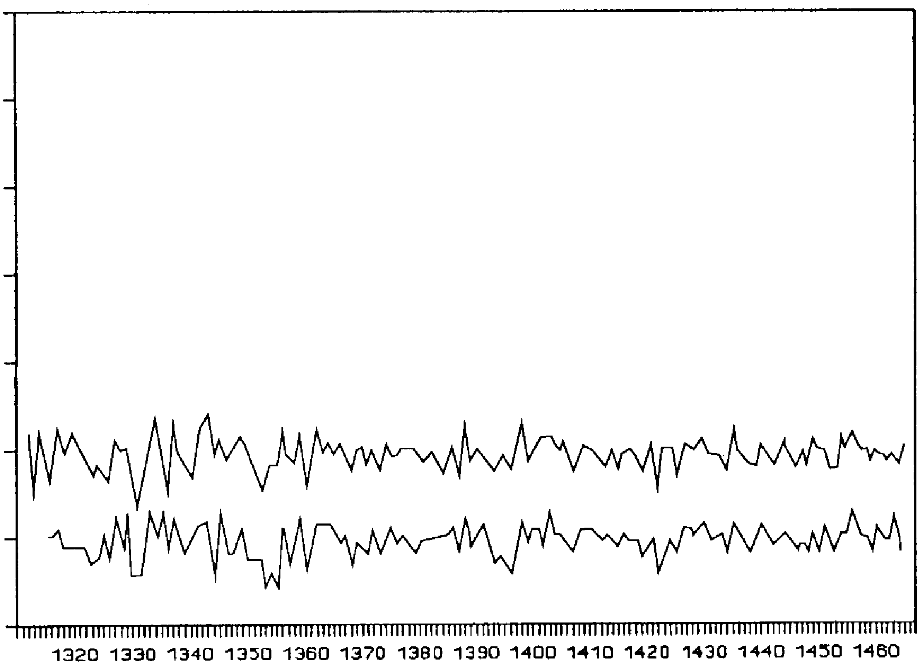


Figure 3.4 - The detrended chronologies from the Meuse Basin and 's Hertogenbosch between AD 1316 and 1465; upper: 's-Hertogenbosch chronology; lower: corrected Meuse Basin chronology

From the documentary evidence it is clear that during the fifteenth century the demand for construction wood in 's-Hertogenbosch could in part be met by using trees from the properties of local land-owning institutions (Leenders 1991; Vink 1993). Since no fourteenth and fifteenth century absolutely dated oak chronologies exist for the vicinity of 's-Hertogenbosch, it is impossible to assess whether C_{sH} (the 's-Hertogenbosch chronology) represents local growth-conditions. However, many of the fifteenth and sixteenth century oak samples from 's-Hertogenbosch cannot be dated by means of either C_{sH} or any of the available regional chronologies (section 3.1). Given the fact that locally grown oak provided the fifteenth century institutions in 's- Hertogenbosch with part of the timber that was needed, this undatable timber may well have come from the vicinity of 's-Hertogenbosch. If this is true, the lack of agreement between this material and C_{sH} would indicate that the trees included in C_{sH} did *not* come from the vicinity of 's- Hertogenbosch.

The values of $\bar{r}_{bt}$, $\bar{r}_{eff}$, *EPS*, *SE* and *SSS* are higher for C_{sH} ('s- Hertogenbosch chronology) than for $C_{reg}{}^*$ (Meuse Basin chronology), which means that C_{sH} contains the stronger signal. This might in part be caused by the larger number of samples included in C_{sH}. In addition, more series of measurements per tree are available for C_{sH}. This allowed an estimate of an improved $\bar{r}_{eff}$ for C_{sH}, which resulted in more accurate and higher values for *EPS*, *SE* and *SSS*. The highest value for *EPS* and the lowest value for *SE* belong to the combination of the two chronologies, C_{all}. This means that no statistical objection exists against averaging the series constituting C_{sH} and $C_{reg}{}^*$ into a new chronology, C_{all}. If the signal in $C_{reg}{}^*$ is indeed a climatological one and reflects the growth responses of oak that grew in the Meuse Basin between AD 1316 and 1465, then the extended chronology C_{all} reflects these responses more accurately and is a better Meuse Basin chronology for oak than $C_{reg}{}^*$.

The higher values for *EPS* and *SE* in the combined chronology C_{all} mean that in this chronology the ring-width variations that were caused by exogenous and endogenous factors are less marked than in the original C_{sH} and $C_{reg}{}^*$ chronologies. The removal of such non-climatic variations improves the usefulness of a chronology for the purposes of dating. Even if both C_{sH} and $C_{reg}{}^*$ would reflect a wide range of climatological conditions (which is unlikely because of their high values for *EPS*), their combined chronology C_{all} should, on the grounds of its stronger signal, be better suited for dating purposes.

The documentary evidence of the use of timber from eastern Belgium is indirect: occasionally the sources mention the Meuse as a route of transportation (Vink 1993), but the exact geographical origin of the timber that was transported along this river remains implicit. The high degree of crossdating between C_{sH} and the Meuse Basin chronology, and the improved quality of their combined chronology C_{all}, indicate that the timber used in 's-Hertogenbosch after the fire of AD 1463 came from eastern Belgium. The application of the Mean Correlation Technique, in other words, results in independent data that complement the information contained in documentary sources on the trade in wood in 's-Hertogenbosch during the fifteenth century.

3.6 CONCLUSION

The dendrochronological quality of the Meuse Basin chronology improves when tree-ring series of fifteenth century timber from 's-Hertogenbosch are included. If, for the period between AD 1316 and 1465, the Meuse Basin chronology is indeed compiled from oaks that grew in the Meuse Basin, and the exact soil and weather conditions that influenced the growth of oak in the Meuse Basin did not occur elsewhere, then the improvement of the Meuse Basin chronology points to an eastern Belgian origin for the timber. This means that during periods of increased building activities (e.g. after the fire of AD 1463), locally grown oaks could not fulfil the demand for timber in 's-Hertogenbosch.

Current dendrochronological research in the Netherlands aims to construct average chronologies of oak for dating purposes. The stronger the signal in a chronology, the better suited it is for dating tree-ring patterns from the same climatological region and/or type(s) of site. The dendroclimatological techniques used in this study prove useful for grouping tree-ring series of unknown origin into climatologically homogeneous chronologies with a strong signal, and in this respect contribute to current tree-ring research. Moreover, these techniques constitute a quantitative and verifiable approach to questions that concern the origin of timber.

4

AN 1100-YEAR TREE-RING CHRONOLOGY OF OAK FOR THE DUTCH COASTAL REGION (2258 - 1141 BC)[1]

ABSTRACT - The *Dutch Sub-Fossil Forests (SFF) Project* was initiated in 1992. The aim of the project was to extend oak tree-ring chronologies in the Netherlands back in time, using tree-ring data of known origin. One of the results of the project is an 1100-year bog oak chronology, that runs from the Late Neolithic Period to the Middle Bronze Age (2258 to 1141 BC). The overall value for its Expressed Population Signal (*EPS*) is high. The values for *EPS* and sample depth at different times, however, indicate that more samples should be included in order for *EPS* to reach acceptable levels at some intervals of the chronology. The results of the statistical analysis indicate that for a long chronology, which in part consists of series that do not overlap, an overall estimate of the signal may result in values that overestimate the actual chronology signal.

4.1 INTRODUCTION

During the last decade, dendrochronology in the Netherlands has become an accepted tool for archaeological, historical and environmental studies. Currently, in this country, two organizations are engaged in tree-ring analysis: Holtland Dendroconsult (Veenendaal), which deals with living trees (e.g. forestry, climate), and the Centre for Dendrochronology RING (Amersfoort), which researches oak and other tree species from archaeological/historical and natural contexts from the past.

RING was founded in 1992 to replace the dendrochronological laboratories of the University of Amsterdam ('Albert Egges van Giffen') Institute for Pre- and Protohistorical Archaeology (IPP, Univ. of Amsterdam) and the State Service for Archaeological Research (ROB). Its activities include dating and chronology development (Fig. 4.1), the reconstruction of forest management in the past (Jansma and Casparie 1993) and, occasionally, the study of living trees (e.g. the reconstruction of former layouts of parks and gardens on the basis of the planting dates of living trees (Jansma 1993).

Until 1992, the efforts to generate Dutch reference chronologies, i.e., chronologies that are useful for crossdating undated tree-ring patterns from contexts in the Netherlands, mainly involved oak timber from archaeological and historical sites. This approach is subject to several restrictions. First, the provenance of the majority of timbers from Dutch cultural contexts is unknown. In cases where the region of origin could be estimated with statistical methods, the studied material (fifteenth century timber) has proven to be unsuitable for the construction of Dutch reference chronologies, because the statistical evidence implied that it was brought in from neighbouring countries (Chapter 3). Second, the selection of dendrochronological samples from these sites, which in general is made by archaeologists and historians, often does not correspond to the dendrochronological aim of building well-replicated chronologies. Due to lack of funds, for example, there is a tendency to keep the number of dendrochronological wood samples from archaeological and historical structures at

1. Jansma, E., 1995. In: J. S. Dean, D. M. Meko and T. W. Swetnam (eds.), *Tree-Rings, Environment and Humanity - Proceedings of the International Tree-Ring Conference 1995, Univ. of Arizona* (provisional title). Radiocarbon, Tucson (in print).

a minimum. As a result, many data sets of absolutely dated tree-ring series from Dutch sites are at this moment too small to be used independently to generate average chronologies. Last, the supply of oak samples from archaeological sites depends on the extent to which the material has been preserved. In the Netherlands, prehistoric sites are mainly located in soils that have been well-drained since the fifties and sixties (sand and boulder clay; Fig. 4.2), and the organic component of these sites has been deteriorating quickly. As a consequence, in the Netherlands there is only a limited supply of prehistoric wood samples from cultural contexts. This means that other sources of samples are needed.

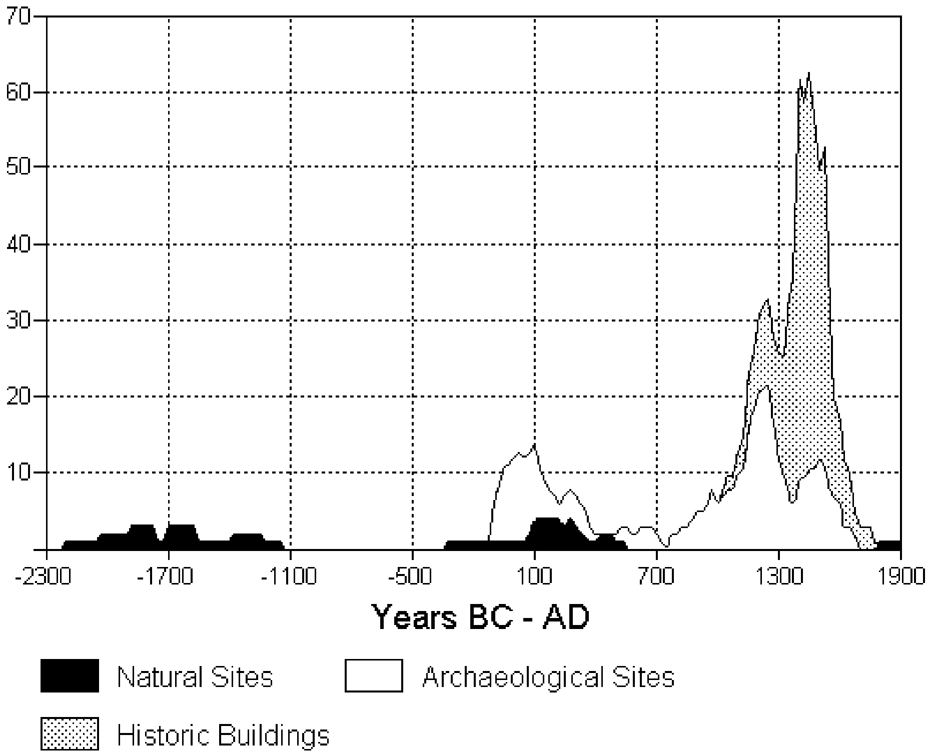
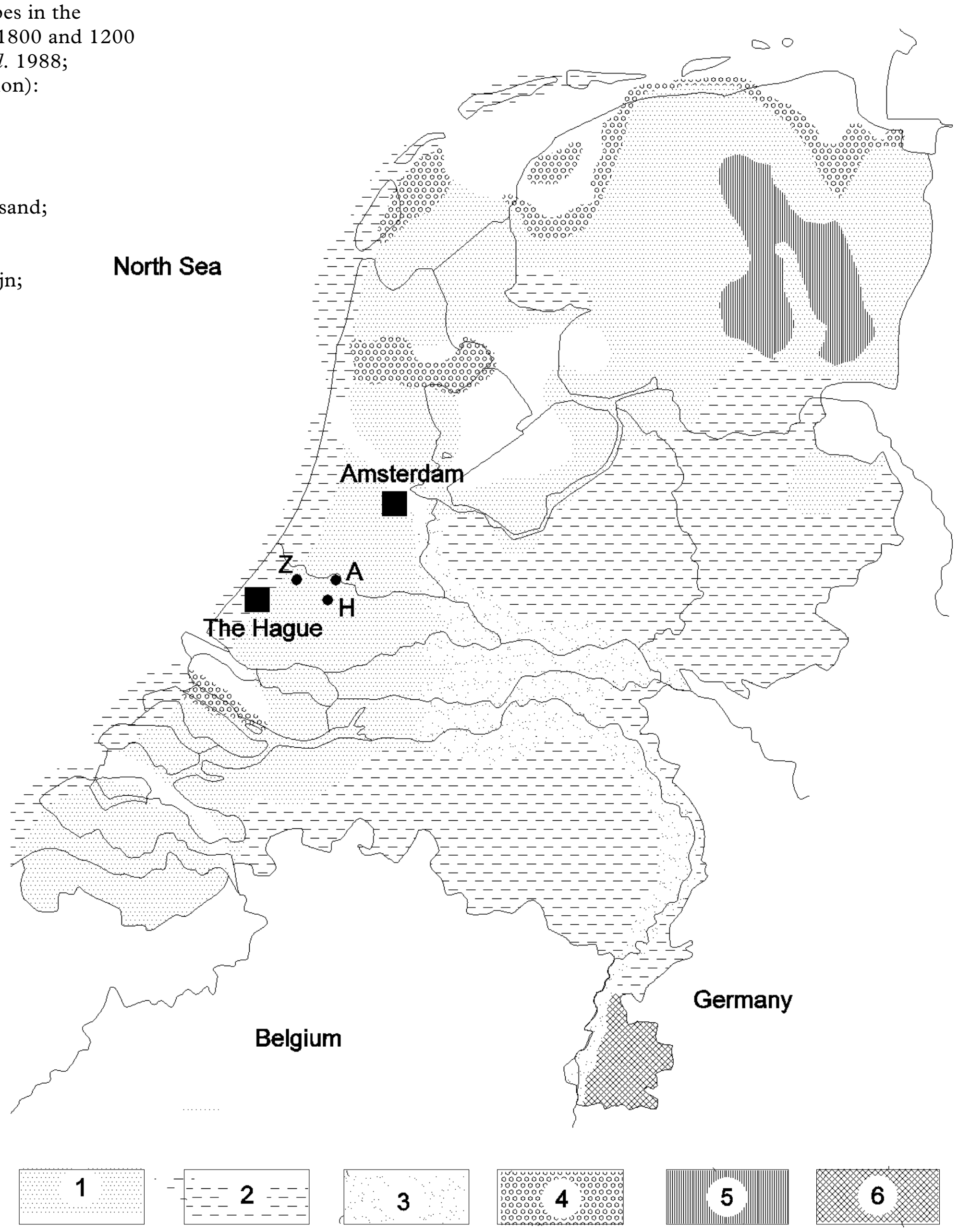


FIGURE 4.1 - Oak tree-ring chronologies with $2 \leq t \leq 40$ (t = number of series; data set of RING (1994))

German and Irish laboratories have in the past overcome these and related restrictions of their data sets by collecting samples from bog and river oaks that belonged to natural forests and were deposited in the soil without human interference (Pilcher 1973; Baillie 1982; Baillie *et al.* 1983; Leuschner *et al.* 1987; Becker 1993). Bog oaks are particularly well-suited for chronology development. First, their provenance is known; it coincides with, or was situated near, the location where their remains are found today. Provided that they can be absolutely dated, they can therefore be used to generate chronologies whose environmental context is known. Second, bog oaks are often found together in large numbers; they appear in former bog peat, where they have been preserved in large numbers below the water table. In terms of sample size, therefore, tree-ring data that are derived from bog oaks are well suited for the generation of average chronologies.

In addition, bog oaks that are found together reacted to the same general environmental conditions. This means that their patterns as a rule have a strong common signal. They are therefore easy to crossdate with each other and with absolutely dated chronologies that represent similar environmental conditions (in this case existing bog oak chronologies from North Germany), and they are well suited for the generation of average chronologies with an unambiguous environmental signal. Last, the number of growth rings in bog oaks is relatively high, compared to the number of rings in oak from archaeological and historical sites. This means that relatively few samples

FIGURE 4.2 - Soil types in the Netherlands between 1800 and 1200 BC (after van Es *et al.* 1988; schematic representation):
1 = bog and fen peat;
2 = sand/dunes;
3 = fluvial deposits;
4 = marine deposits;
5 = boulder clay and sand;
6 = löss
Bog oak sites:
A = Alphen aan de Rijn;
H = Hazerswoude;
Z = Zoeterwoude



are needed in order to generate average chronologies that span centuries. Based on the Dutch situation and on the experiences of foreign laboratories, in 1992 I decided to broaden the strategy of sample collection and drew up plans for the *Sub-Fossil Forests (SFF) Project*. In its first year, the *SSF* project included a survey of locations in the Netherlands where tree trunks had been reported, sample collection and measurement, and the generation of average chronologies from those samples that could be crossdated. This was followed by efforts to absolutely date the chronologies.

4.2 MATERIAL

In the province of Zuid-Holland (western coastal region) samples were taken at three sites situated in former bog peat (Fig. 4.2): Alphen aan de Rijn (18 trees), Hazerswoude (24 trees) and Zoeterwoude (13 trees). Sapwood is absent on most of the trunks.

4.3 METHODS

We measured the ring widths in hundredths of millimeters. In most cases, two radii were measured per cross-section. Whenever the tree-ring patterns were difficult to read or measurement errors were suspected, more radii were measured. Occasionally, we used microscopic slides. The quality of the measurement series was verified visually and with COFECHA (Holmes 1983).[2]

The samples were relatively dated by visual comparison of their plotted curves and with computerized dating methods. Computerized crossdating involves sliding two tree-ring series past each other in increments of one year; at each position of overlap, three values are calculated (see Chapter 5, section 5.4.1). The first value is *PV*: the coefficient of parallel variation between two tree-ring curves (Baillie 1982). Whether a value for *PV* is meaningful depends mainly on the length of the overlap between the series. The second value is the correlation coefficient (r) between the two series. To assess whether a value for r deviates from zero, the Student's t-test is invoked. The Student's t-value (*St*) indicates the probability that the observed and more extreme values for r deviate from $r = 0$ for a sample size of n (n being the overlap between the series). This test requires that the series are pre-whitened, i.e., that the auto-correlation has been filtered out. In practice, this requirement is often ignored.

The ring-width series were detrended and standardized into indices with ARSTAN (Cook 1985). I used a flexible spline in order to suppress the low frequency variance and to enhance the dating potential of the series.[3] In order to arrive at absolute dates, the resulting average chronologies were compared to bog oak chronologies from North Germany (Leuschner *et al.* 1987; Leuschner and Delorme 1988).

Two methods are available to assess in detail the strength of the signal that is contained in an index chronology: analysis of variance (ANOVA) and the Mean Correlation Technique (Briffa and Jones 1990). ANOVA requires that the series have a large interval in common. The Mean Correlation Technique, which already proved useful for the analysis of the provenance of oak timber (Chapter 3), only requires a minimum of 30 years of overlap between the series. Sub-fossil trunks are the residual of natural forests that existed for centuries or even millennia, and their index series do not meet the common interval criterion of ANOVA. I therefore used the Mean Correlation Technique to estimate the Expressed Population Signal (*EPS*) of the chronologies. This method requires that the means of the individual series are the same. This demand was met by standardizing all series before the analysis was carried out.

The Mean Correlation Technique uses an improved estimate of the average cross-correlations among all series. This effective mean correlation, $\bar{r}_{eff}$, is an estimate of the chronology signal that includes both the signals within trees ($\bar{r}_{bt}$) and between trees ($\bar{r}_{wt}$). First one computes c_{eff}, the effective number of measurement series per tree,

$$\frac{1}{c_{eff}} = \frac{1}{t}\sum_{i=1}^{t}\frac{1}{c_i} \qquad (1)$$

where t is the number of trees and c_i the number of samples taken from tree i. Briffa and Jones (1990) define $\bar{r}_{eff}$ as

$$\bar{r}_{eff} = \frac{c_{eff}\,\bar{r}_{bt}}{1+(c_{eff}-1)\,\bar{r}_{wt}} \qquad (2)$$

2. The computer programs COFECHA (quality control and crossdating), ARSTAN (chronology development) and CHRONOL (chronology development) were provided by the International Tree-Ring Data Bank (ITRDB); we also used CATRAS (measurement and crossdating; Aniol 1983) and programs developed by the author (for the calculation of correlations and values for *EPS*).

3. The concept is described in detail by Fritts (1976), Cook (1985) and Cook *et al.* 1990.

Note that when each tree is represented by one sample, c_{eff} equals 1 and $\bar{r}_{eff}$ equals $\bar{r}_{bt}$.

When expressed as a fraction of the total chronology variance, the Expressed Population Signal (*EPS*) quantifies the degree to which this particular sample chronology reflects the hypothetically perfect chronology (Briffa and Jones 1990). *EPS* is calculated as

$$EPS(t) = \frac{t\,\bar{r}_{eff}}{1+(t-1)\,\bar{r}_{eff}} \qquad (3)$$

where t is the number of separate trees included in the chronology. Wigley *et al.* (1984) suggest that values for *EPS* of 0.85 and higher indicate that a chronology is of acceptable statistical quality for dendroclimatological studies.

The standard error (*SE*) of the chronologies is calculated as

$$SE = \sqrt{\frac{1-\bar{r}_{eff}^{\,2}}{t}} \qquad (4)$$

with t the number of separate trees.

From (3) it can be seen that the values for *EPS* and *SE* are dependent on both the value for $\bar{r}_{eff}$ and the number of trees (t). As t becomes smaller, the chronology error increases.

The Mean Correlation Technique was then used to estimate the changes within the signal. The values for *EPS* of the standard and residual chronologies were calculated in 100 year segments (using lags of 50 years), and compared to (a) changes within the sample depth (the number of tree-ring series included in the chronology), and (b) changes within the correlation with the reference chronology used to absolutely date the material.

4.4 RESULTS

Of the 55 trunks that were sampled in the province of Zuid-Holland (Fig. 4.2), at first only 26 could be relatively matched. From this material three separate index chronologies were generated. Although I noted that these chronologies probably overlapped, the length of the overlap (and therefore the strength of the match) was minimal and I refrained from averaging the material into a single chronology.

The three chronologies were recently matched against the North German bog oak chronology that was developed by the tree-ring laboratory in Göttingen (Germany; Leuschner and Delorme 1988). This chronology, which runs from 6069 BC to AD 928, represents about 1600 bog oaks from 100 sites in Lower Saxony and the Emsland region, including sites at the eastern border of the Netherlands (Leuschner, personal communication). The statistics that accompany the match are given in Table 4.1. The match showed that the expected overlap between the ZH chronologies was correct. At this stage, the measurement series of ten as yet undated bog oaks from the same sites could be dated and included in the data set. This extended the chronology from 1163 to 1141 BC.

Table 4.1 - The match with the North German bog oak chronology;
n = length of compared interval;
St = Student's t-value;
PV = coefficient of parallel variation

	First Year	**Last Year**	***n***	***St***	***PV***
ZH Interval 1	2258 BC	1690 BC	569	7.2	61%
ZH Interval 2	1727 BC	1358 BC	370	6.7	62%
ZH Interval 3	1393 BC	1163 BC	231	6.2	61%

The dated series, 70 in total, were converted into indices and compiled into the 1118 year *NLPre_ZH* chronology (Appendix C).[4] Its match with the North German bog oak chronology is given in Table 4.2.

Table 4.2 - The match between *NLPre_ZH* and the North German bog oak chronology;
n = length of compared interval;
St = Student's t-value;
PV = coefficient of parallel variation

Chronology	***n***	***St***	***PV***
Standard *NLPre_ZH*	1118	11.7	61%
Residual *NLPre_ZH*	1116	10.2	60%

Figure 4.3 shows the sample depth of *NLPre_ZH*, its running correlations with the North German bog oak chronology, and its values for *EPS* versus time. Here, the sample depth reflects the actual number of samples at each point in time shown on the X-axis. It varies from 1 to 21 series, with minima at the beginning and end of the chronology and at 1750, 1700, 1550 and 1400 BC (3, 5, 5 and 4 samples respectively).

The running correlation with the North German bog oak chronology varies between 0.48 and 0.02, and is somewhat higher for the standard than for the residual chronology (Fig. 4.3). Minimal correlations occur at the end of *NLPre_ZH* and around 2050 - 1950, 1750 - 1700, 1300 and 1200 BC. Maxima occur at 2200 - 2150 BC, 1800 BC, 1650 BC and 1400 - 1350 BC.

The running values for *EPS* are somewhat higher for the standard than for the residual chronology; they vary around 0.82 and 0.80 respectively (Fig. 4.3). Minima occur at the end of *NLPre_ZH* and at 2100 - 2050 BC, 1750 - 1650 BC and 1400 BC (residual chronology only).

Figure 4.4 shows the relationship between sample depth and *EPS*, again calculated for intervals of 100 years (lag = 50 years). Here, the sample depth reflects the number of series that have contributed to each value for *EPS*, i.e., the total number of series that during each 100 year interval overlap more than 30 years with any of the other series. It is clear that the value for *EPS* depends on the sample size: for intervals where the chronologies consist of 5 to 10 series, most values for *EPS* are lower than 0.85, whereas intervals that contain 10 or more series are mostly, and intervals containing 15 and more are always characterized by values for *EPS* higher than 0.85.

The chronology statistics are listed in Table 4.3. The overall value for *EPS* is 0.96 (*SE* = 0.15) for both the standard and residual chronology. This is markedly higher than the average values for *EPS* in intervals of 100 years.

4. Because of the large number of series, the program CHRONOL was used at this stage and no 'arstan' chronology could be produced. Program ARSTAN can now only be applied to data sets that consist of less than 60 series, whereas CHRONOL accepts larger data sets. CHRONOL produces two types of chronologies: (a) a 'standard' chronology, compiled of detrended tree-ring series; (b) a 'residual' chronology, consisting of series that also have been pre-whitened, i.e. from which the autocorrelation has been removed. ARSTAN also produces an 'arstan' chronology: the residual chronology in which the estimated autocorrelation has been re-introduced.

FIGURE 4.3 - The standard and residual *ZH* chronology versus time; sample size (*t*), correlation with the North German bog oak chronology (*r*) and values for *EPS* (100 - yr. intervals, lag = 50)

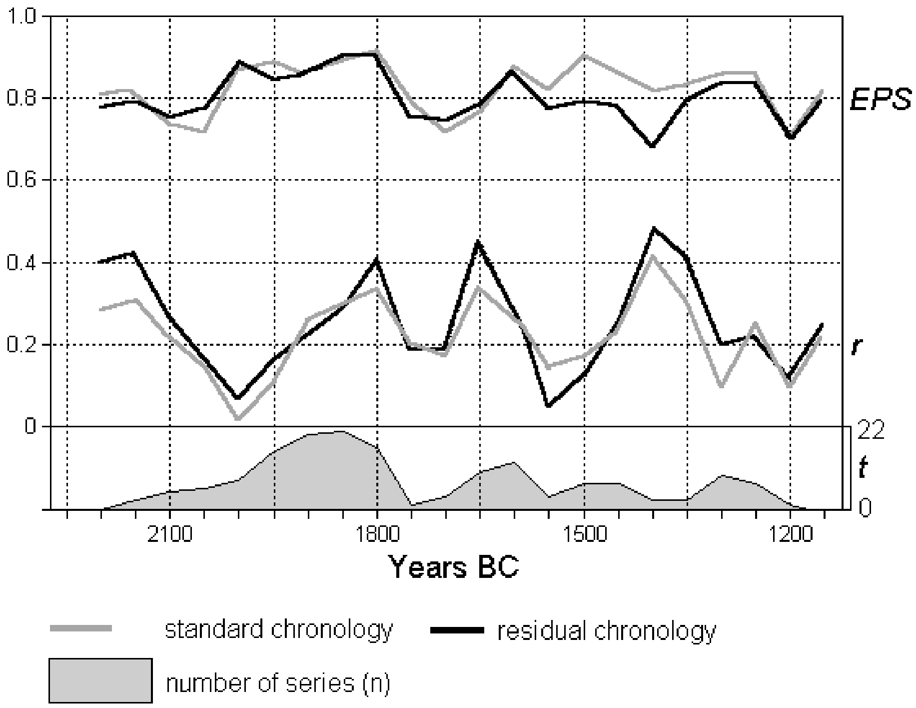


FIGURE 4.4 - The relationship between sample depth and values for *EPS* in the *ZH* standard chronology

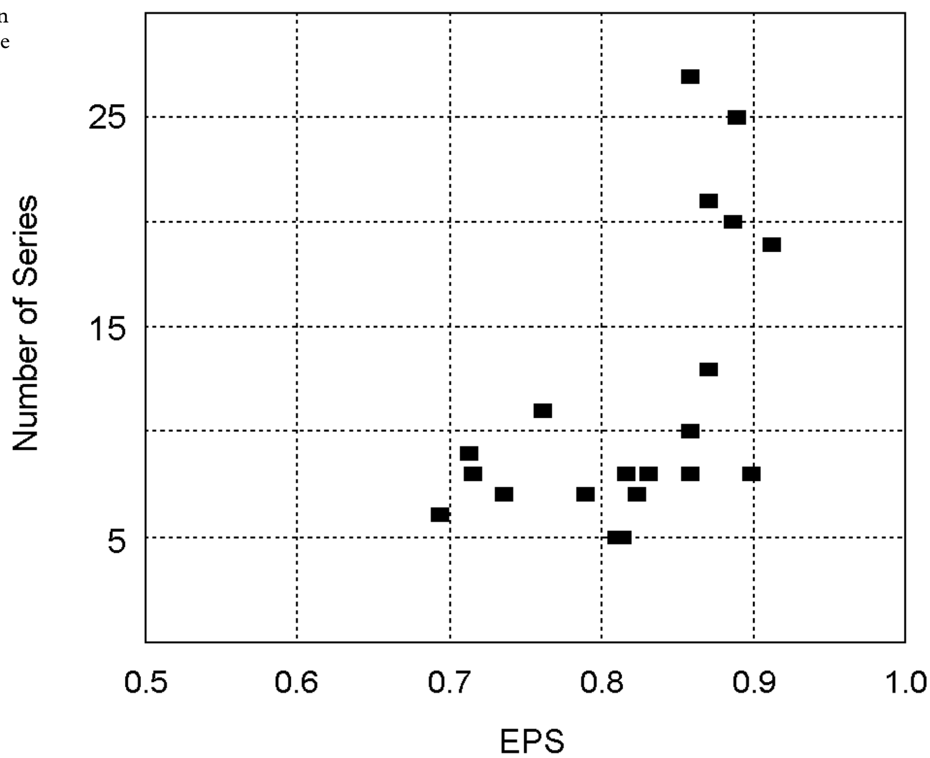


Table 4.3 - Chronology Statistics *NLPre_ZH* (standard)[5]

Length in years	1118
Number of trees (t)	36
Number of cores	70
Effective number of cores/tree (c_{eff})	1.71
Between-tree signal ($\bar{r}_{bt}$)	0.38
Within-tree signal ($\bar{r}_{wt}$)	0.74
Effective chronology signal ($\bar{r}_{eff}$)	0.42
Expressed Population Signal (*EPS*)	0.96
Standard Error (*SE*)	0.15

4.5 DISCUSSION

The values for *EPS* indicate that the *NLPre_ZH* chronology contains a strong environmental signal. The investigated sites in Zuid-Holland are situated below sea level in an area of former bog peat (Fig. 4.2), where the growth limiting environmental conditions must have included periodic high ground water levels. Provided that ground water levels in the Dutch coastal region were in the past related to large scale phenomena such as oceanic transgressions/regressions and changing precipitation levels and/or evaporation rates, the *NLPre_ZH* chronology probably contains information about these phenomena.

Low correlations between *NLPre_ZH* and the North German bog oak chronology occur simultaneously with small sample sizes and low values for *EPS* (for *NLPre_ZH*) during the intervals 2100 - 2000 BC, 1800 - 1650 BC and 1250 - 1150 BC (Fig. 4.3). For these intervals the low correlation between the chronologies is most likely the result of small sample sizes in *NLPre_ZH*. The good match between *NLPre_ZH* and the German chronology during the interval 1850 - 1750 BC is probably also related to the number of series in *NLPre_ZH* (> 10). However, the relatively high correlation between the chronologies that occurs between 1450 and 1350 BC does not coincide with maxima of sample depth and *EPS* for *NLPre_ZH*. During this interval the low replication of *NLPre_ZH* ($4 \leq t \leq 8$) does not impair its match with the North German bog oak chronology. This means that between 1450 and 1350 BC similar growth limiting conditions may have influenced the growth of the oaks in both regions. Given the locations of the sites this suggests raised ground water levels and an increased development of bogs during this period in both regions.

For the *NLPre_ZH* chronology a minimum sample depth of 10 to 15 is required in order to obtain a chronology signal of 0.85 or higher (Figs. 4.3 and 4.4). In about one third of the chronology, between 2020 - 1790 BC, 1680 - 1580 BC and 1320 - 1250 BC (400 years in total), this requirement is met. In the other two thirds of the chronology (700 years) the number of samples is too small. Provided that the Expressed Population Signal adequately measures the quality of a chronology, this means that more samples from the investigated sites, or from similar ones, should be included. This may be difficult to attain for periods during which oaks could not germinate in this region because of an increased development of bogs. However, due to stress the few oaks that remain from such periods should have an environmental signal that is strong enough to be expressed by the variability of their annual ring widths and therefore in their average

5. The residual chronology shows slightly higher values for $\bar{r}_{wt}$ and $\bar{r}_{bt}$, and a lower value for $\bar{r}_{eff}$.

chronology, even if the small number of series in such a chronology prevented this quality from being expressed by values for *EPS*.

Although *NLPre_ZH* has an overall estimated value for *EPS* of 0.96 (Table 4.3), its values for *EPS* through time vary around 0.81 (Fig. 4.3). It has already been noted that *EPS* is in part a function of sample size: the overall value for *EPS* is related to the total number of series that are included in a chronology and does not reflect the strength (and periodic weakness) of the signal in different intervals of the chronology. When the Mean Correlation Technique is applied to long chronologies that largely consist of series that do not overlap at all, it is therefore advisable to treat the results with caution.

4.6 CONCLUSION

The *SFF* project, which the Dutch Centre for Dendrochronology (RING) initiated in 1992, has already contributed to the data set of indigenous absolutely dated oak tree ring series. For the Late Neolithic period to the Middle Bronze Age, the project has resulted in an 1100 year chronology for the Dutch coastal region. This chronology, which runs from 2258 to 1141 BC, may contain information on changes in the water table during this period. However, its Expressed Population Signal is insufficient during at least half of this time interval. Given the relationship between values for *EPS* and sample size, and provided that the signal of a chronology is related to its quality as a reference chronology, i.e., as a tool for dating as yet undated tree-ring series, this means that we have to sample more bog oaks in the Dutch coastal region and include them in the chronology.

The value for *EPS* overestimates the actual signal in long chronologies; with such chronologies it is better to analyse the signal in shorter intervals. The advantage of such interval-analysis is that the results show clearly which parts of the chronology have a sufficient sample size, and which parts require additional series.

5

OAK TREE-RING CHRONOLOGIES FOR THE NETHERLANDS BETWEEN 325 BC AND AD 563[1]

ABSTRACT - An 888-year oak chronology is presented, developed from archaeological material as well as from bog oaks collected through the *Dutch Sub-Fossil Forests Project* (RING/ROB). This chronology, *NLRom_R* (46 trees), runs from 325 BC to AD 563 and represents the growth of oak on low, wet sites in the central Netherlands. In addition, three shorter chronologies are presented from oak timber from Iron Age/Roman sites in the East and the coastal region in the West of the Netherlands: *NLRom_E* (92 trees; AD 190 - 395 (Cuyk, Gennep, Heeten)); *NLRom_W1* (14 trees; 84 BC - AD 50 (Leidschendam, Velsen)); and *NLRom_W2* (42 trees; 140 BC - AD 87 (Nieuwenhoorn, Velsen)). These four chronologies contain a strong signal and are used as a reference for dating oak timber from this period in the Netherlands.

5.1 INTRODUCTION

The growth of oak trees is affected by yearly fluctuations in weather conditions. In large numbers of trees from the same area, favourable and unfavourable conditions are recorded by the trees in the form of sequences, or patterns, of wide and narrow growth rings. Dendrochronology is a method of dating these patterns absolutely. To that end patterns in undated wood are matched with absolutely dated chronologies that represent the average growth of the same tree species.

In the Netherlands the dating of Roman structures with dendrochronology goes back about ten years (Jansma 1985). In order to date tree-ring patterns, suitable chronologies must be available as a reference. Best suited are chronologies that represent the same growth conditions as samples bearing the undated patterns. Dutch local and regional oak chronologies are best suited for dating oaks that once grew in the Netherlands. This is why dendrochronology in the Netherlands focuses not only on the dating of oak from Dutch excavations, but also on the development of average chronologies from this material.

Until 1992, efforts towards generating Dutch chronologies for the Iron Age and Roman period mainly involved dated patterns from oak derived from *archaeological* sites. Various short archaeological chronologies were constructed (Jansma 1985; Van Rijn 1987; Van der Sanden 1987; Bult *et al.* 1989; RING, unpublished data). These, however, do not overlap sufficiently in time to allow the construction of a long, well-replicated, chronology. To improve the data set the dendrochronological laboratory of the State Service for Archaeological Research (RING/ROB, Amersfoort) broadened its strategy of sample collection in 1992 through the *Sub-Fossil Forests (SFF) Project*, which involved the collection and research of 'bog oaks', i.e., oak trunks preserved in bogs.

Bog oaks are well suited for chronology development. First, bog oaks that are found together grew on the same site and often at the same time. This means that their patterns as a rule crossdate well, and can be used to construct average chronologies with a strong signal. We found that

1. Jansma, E., 1994. Helinium **34** (in print).

chronologies from Dutch bog oaks crossdate well with absolutely dated chronologies from different locations where the environmental conditions were similar (Chapter 4).[2] Second, bog oaks contain more rings than oak timber (the trees grew older), so fewer crossdated bog oak series are needed in order to generate long chronologies. Last, bog oaks grew near the bogs (or former bogs) in which their remains are found today, i.e., they can be used to generate chronologies from trees whose provenance is known.

This paper presents the average chronologies that are now used to date oak from Iron Age/Roman and Early Medieval excavations in the Netherlands. The longest chronology was developed through the *SFF* project and represents bog oaks and archaeological timber. Three shorter chronologies represent archaeological timber derived from Dutch Iron Age/Roman sites.

5.2 TERMINOLOGY

A *tree ring* is the layer of wood that most trees in the temperate climatic zone produce annually. The distance from one ring boundary to the next, nearly always expressed in hundredths of millimetres, is referred to as a *ring width*. A *tree-ring pattern* is the sequence of growth rings in wood. When the successive ring widths are measured, a *tree-ring measurement series* results which can be plotted as a *tree-ring curve*.

A tree-ring pattern reflects the growth response of a tree to various types of environmental influences. In a tree-ring curve this response shows up as abrupt and gradual changes in the ring widths. A tree-ring curve is regarded as the sum of various growth responses, or *signals*, with different periods (Cook 1990). Growth signals comprise ring-width variability related to (1) the age of the tree (the 'age trend'), (b) local 'endogenous' factors (e.g. competition of a tree with its neighbours for light/food), (c) stand-related 'exogenous' factors (e.g., insect attacks, forest fires), and (d) climate (fluctuations of temperature and precipitation).

The subject of a dendrochronological study determines which signal is studied. For dating purposes the most important one is the *climate signal*, which in a tree-ring curve is expressed by the variation of the ring widths from year to year.

Detrending entails the removal of growth signals that obscure the studied signal from a tree-ring measurement series. A detrended measurement series is called a *growth-index series*. The *common signal* of crossdated growth-index series is the fraction of the growth signal(s) the series have in common. It is estimated from the correlation coefficients between the series.

2. The water table is the main condition assumed to have governed the growth of 'bog oaks' in North Germany (Leuschner *et al.* 1985; Leuschner 1990). Research into the environmental growth responses of oaks that have been deposited in bogs is only just beginning (EC Research Project EV5V CT94 0500; 'Temperature Change over Northern Eurasia during the last 2500 years'). The growth responses of trees are usually assessed by the correlation of their ring widths to monthly temperature, precipitation, ground water levels, etc. Given the time interval spanned by the meteorological record (a few centuries at most), this is only possible with living trees. Research on the growth responses of bog oaks is complicated by the fact that no living stands of oaks that border on bogs are known today throughout Northwest Europe. Because the environmental causes of the ring-width variability in bog oaks cannot be assessed through the study of living trees, these causes will to a degree remain a matter of conjecture.

TABLE 5.1 - Classification of tree-ring chronologies

Chronology type	**Living trees**	**Dead wood**	**Observation valid for**	**Geographical Scale**
Tree curve	1 tree	1 tree	1 tree	point
Site chronology	1 forest stand	1 bog oak site	1 forest stand	micro scale
Object chronology	-	1 arch./hist. object	1 forest stand?	
Local Chronology	2 to 5 forest stands	2 to 5 arch./hist. objects	º 1 forest stand in º 1 forest?	local scale
Regional chronology	º 6 forest stands in well-defined geographical region	º 6 arch./hist. objects and bog oak sites in broadly defined geographical region	> 1 forest stand in > 1 forest	regional scale

Figure 5.1 - Soil types in the Netherlands during the Iron Age and Roman period (after van Es *et al.* 1988; schematic representation):

A = bog and fen peat;
B = marine deposits;
C = fluvial deposits;
D = sand;
E = boulder clay and sand;
F = dunes;
▲ = archaeological site;
● = bog oak site;
1 = Abcoude (ABC);
2 = Colmsgate (COW);
3 = Cuyk (CUY);
4 = Emmeloord (EOF);
5 = Empel (EMP);
6 = Flevopolder (FLE);
7 = Gennep (GENa; GENb);
8 = Heeten (HRWa; HRWb);
9 = Leidschendam (LRC);
10 = Mariënberg (FMB);
11 = Nieuwenhoorn (NWH);
12 = Olst (OLF);
13 = Ouderkerk a/d IJssel (OKF);
14 = Velsen (VELa; VELb; VELc)

Dendrochronological dating is referred to as *crossdating*. It involves finding the correct match of two series. If one of the series is dated and the other one is not, this process results in a dendrochronological date for the latter. It is easier to date an average chronology than single tree-ring series, since averaging reduces part of the non-climatic variability that is present in single series.

An *average chronology* consists of the yearly averages of crossdated growth-index series. In this chapter several types of tree-ring chronologies are distinguished (Table 5.1). A *site chronology* represents series from a single, known location. This term is used for chronologies of living trees and the *in situ* remains of past forests. Archaeological and historical *object chronologies* represent series from one single archaeological or historical object (e.g., a water well, bridge, ship or (phase of) a building). Archaeological and historical *local chronologies* represent series from two to five archaeological or historical objects. A *regional chronology* represents series from six or more locations in a broadly defined geographical region, such as the province of Ostfriesland in Germany (Leuschner, unpublished data) or the Meuse Basin in eastern Belgium (Hoffsummer 1989). This concept is used for chronologies of bog oaks, archaeological/historical timber, living trees, and combinations thereof.

5.3 MATERIAL

The aim of this study was to produce chronologies with a strong common signal, so tree-ring series from the same archaeological object that did not crossdate with each other were excluded from the analysis, as were deviating tree-ring series from imported barrels and ships' timbers. Eight archaeological and six bog oak sites contributed to the current study (Fig. 5.1). The archaeological sites are: Colmsgate (a water well), Cuyk (a bridge; Goudswaard 1995), Empel (a water well; Hiddink 1994), Gennep (two water wells; Heidinga and Offenberg 1992), Heeten (two water wells; Erdrich and Verlinde 1995), Leidschendam (the *Canal of Corbulo*), Nieuwenhoorn (a farmhouse; van Trierum 1992) and Velsen (the Roman fortress *Velsen 1*: the western jetty (Morel 1988), ships' timbers and the foundation of a watch tower (Bosman, unpublished data)).[3] The bog oaks were derived from Abcoude (Jansma 1987), Emmeloord, the Flevopolder, Mariënberg, Olst and Ouderkerk a/d IJssel (RING, unpublished data).

5.4 METHODOLOGY

5.4.1 *Methods of dating*

- ***The reference chronologies used for dating***

Only a few oak chronologies available to RING extend back as far as the Iron Age/Roman period. These are the *North German bog oak chronology* (6069 BC - AD 928; Leuschner and Delorme 1988; Leuschner, unpublished data) and the *Central German oak chronology* (690 BC - AD 1975; Hollstein 1980). The former reflects the average growth of oak in oceanic regions east of the Netherlands (Ostfriesland and Lower Saxony), the latter the growth in regions southeast of the Netherlands, where a continental climate prevails. Both are well suited as a reference to date oak from Dutch archaeological and natural contexts.

- ***Visual comparison***

The most important crossdating technique is visual comparison of plotted curves (tree rings as well as indices), which is done by sliding curves alongside each other on a light table. An experienced dendrochronologist can at a glance shift the two curves for a proper match, at least with series up to a few hundred years in length. When longer series are compared, a computer is used to give a first indication of possible matches, each of which is checked on the light table.

- ***The coefficient of parallel variation***

A non-parametric test for dating involves sliding two series alongside each other and calculating the *coefficient of parallel variation* (*PV*) for each position of overlap. This test can be used to compare undetrended series, because it only takes into account the differences between directly adjacent ring widths. *PV* expresses the fraction of ring widths that at a given position simultaneously show an increase or decrease relative to the preceding width. It is usually expressed as a percentage. If there is no match, the expected value for *PV* is 0.5, with a standard deviation (S) of $1/(2\sqrt{n})$, n being the overlapping years between the curves. The significance of an observed *PV* is calculated by transforming it into a z-score:

3. The ships' timbers from Velsen were included because their measurement series crossdate well with the series from Nieuwenhoorn.

$$z = \frac{PV - 0.5}{S} \tag{1}$$

The standard normal curve is used to determine the probability (P) that the observed or an extremer value of z occurs when in reality no match exists between the series (the probability of exceedence).[4]

The dating of a tree-ring curve, by sliding it alongside dated chronologies, involves the examination of *hundreds* of possible matches. For example, 900 possible matches exist between a curve of 100 rings and a 1000 year master chronology, and non-matches with a probability of exceedence (P) of 0.01 will crop up about 9 times when these series are compared. Therefore, in dendrochronologocal dating only those matches that have a value for P smaller than 0.001 are considered, and also other dating techniques are used.

- ***Correlation coefficients and Student's t-values***

The second statistical procedure involves calculating the coefficient of correlation, r, between the two series at each position of overlap. This procedure is unsuitable for undetrended ring-width series, because non-zero correlations may occur between their non-climatic low frequency components.

The correlation between the detrended series x and y is estimated by:

$$r_{xy} = \frac{1}{n} \sum_{i=1}^{n} \frac{(x_i - \bar{x})}{S_x} \cdot \frac{(y_i - \bar{y})}{S_y} \tag{2}$$

with n the number of values in each series; x_i and y_i the observed values in year i; $\bar{x}$ and $\bar{y}$ the mean of the series; and S_x and S_y their standard deviation. To assess whether r_{xy} deviates from zero one uses the fact that the stochast

$$\frac{r_{xy}\sqrt{n-2}}{\sqrt{1-r_{xy}^{\;2}}}$$

has a Student distribution (*St* distribution; see Chapter 3, footnote 5) with (n-2) degrees of freedom. The distribution of this statistic is well tabulated (e.g. Thomas 1976). In dendrochronological dating an *St*-value of less than 3 is meaningless and a value over 6 almost always indicates that two patterns can be matched visually.[5]

5.4.2 *Chronology development*

For all object/site chronologies we estimated the average correlation ($\bar{r}$) between each individual growth-index series (g_i) and the average chronology of the remaining series (all series in the data set except g_i; with i = 1 to t and t the number of trees in the chronology).[6] Next, we looked at the degree of crossdating among the chronologies. The index series from chronologies that crossdate were combined, after which the signal was again assessed. If all series fitted well, i.e. $\bar{r}$ did not decrease, the combination was considered a success. Then, the same procedure was repeated with the extended chronology and the remaining (unclustered) site/object chronologies. This procedure was repeated until the cluster chronologies could not be improved further with the available material.

4. The foregoing holds only if approximately 0.2 < *PV* < 0.8, since *PV* is not normally distributed. For *PV* < 0.2 and *PV* > 0.8, which seldom occurs in dendrochronological dating, more precise estimators should be used, e.g. arcsine transformation of *PV*, which is a variance stabilization transformation (Strackee, personal communication).

5. This applies to series that have not been pre-whitened, i.e. auto-correlated series. Pre-whitened series require less high *St*-values in crossdating.

5. COFECHA computer program (Holmes 1983).

5.4.3 *Estimating the chronology signal*

The common signal of the average chronologies was estimated according to the Mean Correlation Technique. This technique is well-suited for analysing tree-ring series from the past, because it does not require that the series completely overlap. The Mean Correlation Technique was first presented by Wigley *et al.* (1984). They defined the Expressed Population Signal (*EPS*) of a chronology as

$$EPS = \frac{t\,\bar{r}_{bt}}{1+(t-1)\,\bar{r}_{bt}} \qquad (3)$$

with t the number of trees and $\bar{r}_{bt}$ the average correlation between the series. This definition only considers data sets that consist of one measurement series per tree. If a tree is represented by more series, these are averaged before the analysis takes place.[7] Wigley *et al.* (1984) suggest that values for *EPS* of 0.85 and higher indicate that a chronology is of acceptable quality for dendroclimatological analyses.

5.5 RESULTS

5.5.1 *General*

A total of 194 trees were used in the analyses. The series represent 12 archaeological objects and 6 bog oak sites. One archaeological site (Colmsgate) and one bog oak site (Mariënberg) are represented by a single tree curve only.

The two tree curves and 16 object/site chronologies are listed in Table 5.2, together with the number of trees, the first and last year, details of their signal ($\bar{r}$ and *EPS*), and their match with the Central German oak chronology (Hollstein 1980) and the North German bog oak chronology (Leuschner and Delorme 1988, Leuschner unpublished data). Figure 5.2 shows the position of the chronologies in time.

Three local chronologies and one regional chronology were constructed based on (a) the degree of crossdating among the Dutch object/site chronologies (Table 5.3) and (b) the correlation ($\bar{r}$) among the index series in combined data sets.

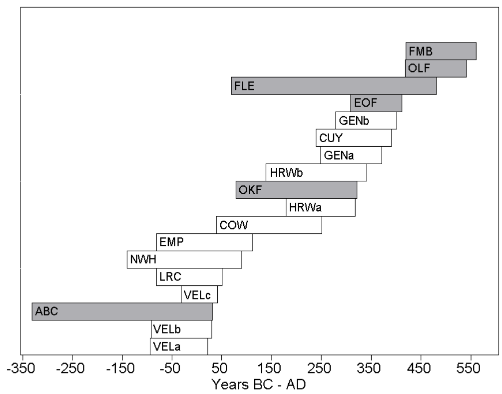


FIGURE 5.2 - The position of the object and site chronologies in time (gray bar = bog oaks)

7. An alternative that considers more than one measurement series per tree was developed by Briffa and Jones (1990). It involves estimates of the average *between-tree* signal ($\bar{r}_{bt}$; the average correlation between cores from different trees), and the *within-tree* signal ($\bar{r}_{wt}$; the average correlation between cores from the same tree over all trees). From these two estimates, the *effective chronology signal* ($\bar{r}_{eff}$) is estimated, from which *EPS* is derived. In Chapter 7 it is shown that the mathematical relationship between the within-tree signal and the effective chronology signal is statistically problematic. This approach was not, therefore, used.

Code	Location	Context	*t* Number of Trees	*n* Length in Years	First Yr.	Last Yr.	Chronology Statistics		The match with the Central German chronology			The match with the North German chronology		
							$\bar{r}$	*EPS*	*St*	*PV*	P < than	*St*	*PV*	P < than
ABC*	Abcoude	bog oaks	10	355	325 BC	AD 30	0.53	0.92	5.67	62%	0.0001	6.16	60%	0.0002
COW	Colmsgate	water well	1	217	AD 35	AD 251	-	-	2.09	54%	◆	5.35	62%	0.0005
CUY	Cuyk	bridge	74	143	AD 245	AD 387	0.34	0.97	5.96	61%	0.01	5.62	65%	0.0005
EOF*	Emmeloord	bog oaks	2	144	AD 305	AD 408	0.74	0.85	4.07	66%	0.0002	4.50	63%	0.005
EMP	Empel	water well	9	173	67 BC	AD 106	0.36	0.84	5.70	67%	0.0001	6.23	62%	0.005
FLE*	Flevopolder	bog oaks	8	410	AD 68	AD 477	0.39	0.84	6.60	60%	0.0001	10.22	68%	0.0001
GENa	Gennep A	water well	7	111	AD 248	AD 373	0.50	0.87	5.51	65%	0.005	9.30	79%	0.0001
GENb	Gennep B	water well	6	112	AD 284	AD 395	0.65	0.92	3.55	59%	◆	3.26	51%	◆
HRWa	Heeten A	water well	5	126	AD 190	AD 315	0.40	0.77	4.41	70%	0.0001	6.74	76%	0.0001
HRWb	Heeten B	water well	4	200	AD 136	AD 335	0.45	0.77	3.75	58%	0.025	6.25	65%	0.0001
LRC	Leidschendam	canal	8	134	84 BC	AD 50	0.44	0.86	4.55	65%	0.001	2.39	57%	◆
FMB*	Marienberg	bog oak	1	149	AD 415	AD 563	-	-	2.35	59%	0.03	5.99	64%	0.001
NWH	Nieuwenhoorn	farmhouse	39	227	140 BC	AD 87	0.51	0.98	8.26	65%	0.0001	7.29	66%	0.0001
OLF*	Olst	bog oaks	2	117	AD 424	AD 540	0.78	0.88	1.87	61%	0.02	2.96	61%	0.02
OKF*	Ouderk. a/d IJssel	bog oaks	2	244	AD 81	AD 324	0.63	0.77	4.33	62%	0.0005	5.91	65%	0.0001
VELa	Velsen	Velsen 1 Western jetty	7	109	88 BC	AD 21	0.53	0.89	3.56	62%	0.02	3.95	60%	0.04
VELb	Velsen	Velsen 1 ships timbers	3	121	91 BC	AD 28	0.57	0.80	5.88	60%	0.0001	4.85	64%	0.005
VELc	Velsen	Velsen 1 watch tower	6	65	28 BC	AD 37	0.57	0.89	3.68	65%	0.02	5.89	68%	0.005

Table 5.2 - Oak object and site chronologies from Dutch locations between 325 BC and AD 563; * = bog oaks; $\bar{r}$ = average correlation between each individual index series and the average chronology of all other series in the data set; *EPS* = Expressed Population Signal; *St* = Student's t-value; *PV* = coefficient of parallel variation; P = probability of exceedence; ◆ $p > 0.05$; - = single curve

Table 5.3 - The degree of crossdating between the Dutch object and site chronologies; upper right: *PV* = coefficient of parallel variation; lower left: *St* = Student's t-value; $30 \leq n \leq 244$ (*n* = length of overlap between the series); * = bog oaks; - = $n < 30$

	ABC*	**COW**	**CUY**	**EOF***	**EMP**	**FLE***	**GENa**	**GENb**	**HRWa**	**HRWb**	**LRC**	**FMB***	**NWH**	**OLF***	**OKF***	**VELa**	**VELb**	**VELc**
ABC*		-	-	-	63%	-	-	-	-	-	65%	-	60%	-	-	66%	63%	55%
COW	-		-	-	53%	61%	-	-	63%	67%	-	-	51%	-	58%	-	-	-
CUY	-	-		54%	-	54%	72%	70%	71%	51%	-	-	-	-	54%	-	-	-
EOF*	-	-	3.79		-	60%	66%	58%	-	52%	-	53%	-	-	-	-	-	-
EMP	3.13	1.99	-	-		74%	-	-	-	-	60%	-	67%	-	-	66%	69%	59%
FLE*	-	6.70	2.82	4.71	3.27		61%	60%	64%	62%	-	58%	-	79%	63%	-	-	-
GENa	-	-	7.97	3.96	-	4.92		67%	74%	54%	-	-	-	-	61%	-	-	-
GENb	-	-	7.81	4.49	-	3.28	4.23		68%	62%	-	-	-	-	57%	-	-	-
HRWa	-	1.97	4.29	-	-	4.53	4.77	3.21		75%	-	-	-	-	57%	-	-	-
HRWb	-	5.08	1.27	0.41	-	4.14	0.86	0.80	6.63		-	-	-	-	58%	-	-	-
LRC	2.29	-	-		3.38	-	-	-	-	-		-	65%	-	-	61%	60%	73%
FMB*	-	-	-	0.81	-	1.94	-	-	-	-	-		-	60%	-	-	-	-
NWH	4.28	0.80	-	-	4.24	-	-	-	-	-	3.15	-		-	-	65%	76%	57%
OLF*	-	-	-	-	-	4.73	-	-	-	-	-	4.25	-		-	-	-	-
OKF*	-	2.74	1.34	-	-	4.77	1.83	0.71	2.74	6.39	-	-	-	-		-	-	-
VELa	5.16	-	-	-	4.10	-	-	-	-	-	2.50	-	4.78	-	-		65%	48%
VELb	2.88	-	-	-	4.39	-	-	-	-	-	3.43	-	10.75	-	-	4.00		53%
VELc	1.24	-	-	-	3.00	-	-	-	-	-	4.21	-	1.86	-		1.09	1.56	

5.5.2 *The local eastern chronology NLRom_E* (AD 190 - 395)

Chronology *NLRom_E* (Fig. 5.3; Appendix C) consists of the series from Cuyk (Roman bridge; 74 trees), Gennep (two water wells; 13 trees) and Heeten (HRWa; a water well; 5 trees). Their object chronologies crossdate with values for *PV* that lie between 67% and 74%; the values for *St* vary between 3.21 and 7.97 (Table 5.3). *NLRom_E* consists of 92 trees and has a value for *EPS* of 0.98 ($\bar{r}$ = 0.57; Table 5.4).

5.5.3 *Local western chronology NLRom_W1* (84 BC - AD 50)

Chronology *NLRom_W1* (Fig. 5.3; Appendix C) consists of the series from Leidschendam (the *Canal of Corbulo*; 8 trees) and Velsen (Roman fortress *Velsen 1* (watch tower foundation); 6 trees). The two object chronologies crossdate with *PV* = 73% and *St* = 4.21 (Table 5.3). They do not crossdate well with any other chronology from the same period. *NLRom_W1* consists of 14 trees and has a value for *EPS* of 0.92 ($\bar{r}$= 0.59; Table 5.4).

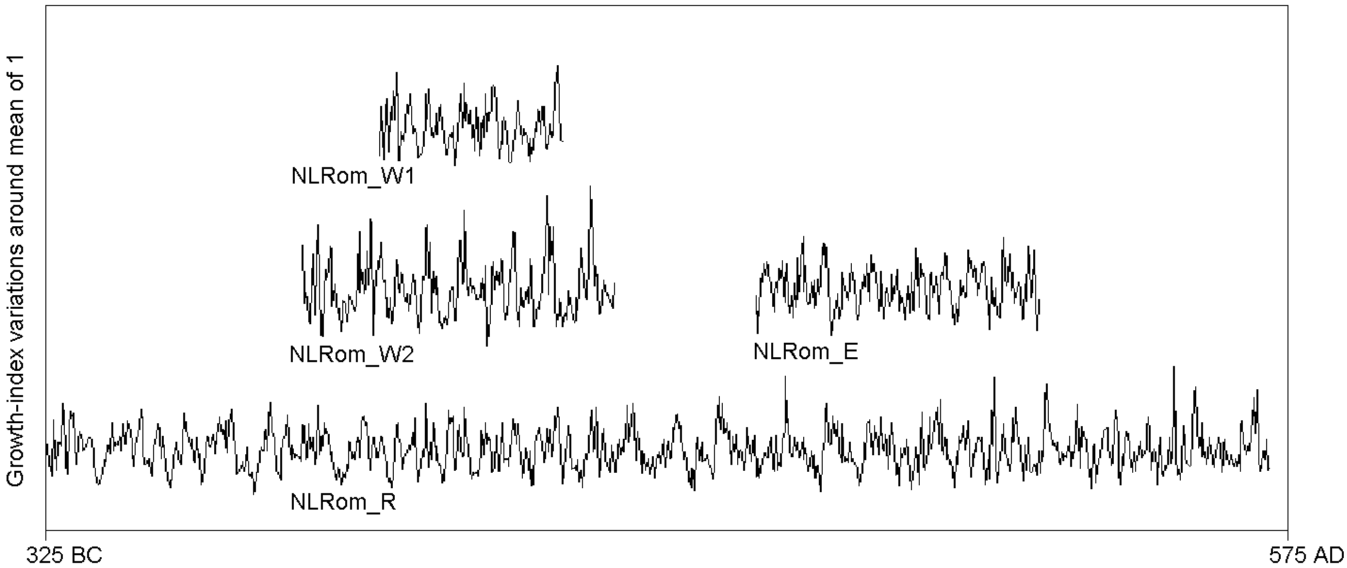


FIGURE 5.3 - Oak tree-ring chronologies for the Netherlands between 325 BC and AD 563

5.5.4 *Local western chronology NLRom_W2* (140 BC - AD 87)

Chronology *NLRom_W2* (Fig. 5.3; Appendix C) consists of the series from Nieuwenhoorn (farmhouse; 39 trees) and Velsen (Roman fortress *Velsen 1* (ships' timbers); 3 trees). The two object chronologies crossdate well: *PV* = 76% and *St* = 10.75 (Table 5.3). Their plotted curves are very similar; it is likely that the trees were collected in the same forest. *NLRom_W2* consists of 42 trees and has a value for *EPS* of 0.98 ($\bar{r}$= 0.66; Table 5.4).

5.5.5 *The regional low altitude chronology NLRom_R* (325 BC - AD 563)

Chronology *NLRom_R* (Fig. 5.3; Appendix C) consists of the archaeological series from Colmsgate (a water well; 1 tree), Empel (a water well; 9 trees), Heeten (a water well; 4 trees) and Velsen (Roman fortress *Velsen 1* (western jetty); 7 trees), and all bog oak series: Abcoude (10 trees), Emmeloord (2 trees), Flevopolder (8 trees), Mariënberg (1 tree), Olst (2 trees) and Ouderkerk a/d IJssel (2 trees). The crossdating between their chronologies in terms of *PV* and *St* is shown in Table 5.3. *NLRom_R* consists of 46 trees and has a value for *EPS* of 0.96 ($\bar{r}$ = 0.53; Table 5.4).

Name	Sites/Objects	First Yr.	Last Yr.	Number of Trees	Avgerage Tree Age	$\bar{r}$	*EPS*
NLRom_E	CUY, GENa, GENb, HRWa	AD 190	AD 395	92	69	0.57	0.98
NLRom_W1	LRC, VELc	84 BC	AD 50	14	81	0.59	0.92
NLRom_W2	NWH, VELb	140 BC	AD 87	42	102	0.66	0.98
NLRom_R	ABC*, COW, EMP, EOF*, FLE*, HRWb, FMB*, OLF*, OKF*, VELa	325 BC	AD 563	46	131	0.53	0.96

Table 5.4 - Local and regional chronologies for the Netherlands (325 BC - AD 563); * = bog oaks; $\bar{r}$= average correlation between each individual index series and the average chronology of all other series in the data set; *EPS* = Expressed Population Signal

5.6 INTERPRETATION AND DISCUSSION

The Expressed Population Signal (*EPS*) of the 16 separate object/site chronologies varies between 0.77 and 0.98 (Table 5.2). If the 0.85 criterion of Wigley *et al.* (1984) is applied, six out of these 16 chronologies are of insufficient statistical quality. These are the chronologies from Empel (EMP), the Flevopolder (FLE*), Heeten (HRWa, HRWb), Ouderkerk a/d IJssel (OKF*) and Velsen (VELb), which all consist of less then 10 trees. These chronologies do, however, crossdate with at least one of the two German master chronologies with a probability of exceedence (P) < 0.0001 (Table 5.2). This indicates that they are very similar to the master chronologies and that their low values for *EPS* reflect small sample sizes only (equation (3)). The clustered chronologies *NLRom_E, NLRom_W1*, *NLRom_W2* and *NLRom_R*, which consist of between 14 and 92 trees, all have an Expressed Population Signal over 0.90.

The provenance of the trees used for archaeological chronologies cannot be established in detail by dendrochronological methods. The *general region* from which the timbers were derived can be determined by combining various types of information: (a) the degree of crossdating with available regional and/or local chronologies; (b) characteristics of the timbers themselves (e.g. the age of the trees); and (c) the wood spectra of the archaeological sites where the timbers have been found.

NLRom_W1 represents timber from Leidschendam (the *Canal of Corbulo*) and Velsen (Roman fortress *Velsen 1*, watch tower foundation); *NLRom_W2* timber from Nieuwenhoorn (farmhouse) and, again, Velsen (*Velsen 1*, ships' timbers). These chronologies, both from archaeological sites situated directly behind the western coastal dunes, overlap between 84 BC and AD 50 (Fig. 5.3), but do not crossdate well (St = 3.15; PV = 63%; P < 0.005; Table 5.5). This indicates that *NLRom_W1* and *NLRom_W2* represent different environments.

Several arguments exist for a more eastern provenance of *NLRom_W2*. First, *NLRom_W2* crossdates better with the German chronologies than *NLRom_W1* (Table 5.5). Second, *NLRom_W1* in part represents young undressed timber (*Velsen 1*, watch tower foundation), whereas *NLRom_W2* represents older and more slowly grown trees, i.e., timber that is rarer and more expensive, and therefore more likely to have been transported over a distance. Last, tree species that are less suitable for construction than oak, such as ash (*Fraxinus excelsior* L.), were utilized in the harbour works of *Velsen 1* (Morel 1988). This means that oaks in the vicinity of Velsen must have been scarce in the first century. Given the many building activities of the Romans along and below the Central Dutch rivers, it is also unlikely that in the vicinity of Nieuwenhoorn old-growth forests still existed in the last quarter of the first century AD.

One object chronology from Heeten is incorporated in *NLRom_R* (HRWb), whereas the other belongs in the eastern chronology *NLRom_E* (HRWa). Heeten is situated in a transitional area between the IJssel and higher sandy soils (Fig. 5.1). In the fourth century the inhabitants of Heeten must have derived their timber from different forests situated to the west and east of their village.

NLRom_E crossdates well with *NLRom_R* (P < 0.001), but better with the German chronologies (P < 0.0001; Table 5.5). This chronology contains the ring patterns of both young, undressed trees (the bridge in Cuyk) and worked timber (two water wells from Gennep and one from Heeten). Given the difference between its signal and the signal in *NLRom_R*, the trees did not grow on low, wet sites. The young age of the trees from Cuyk (Table 5.4; Appendix A) indicates that they were collected close to the building site, which means that the trees grew on well-drained sandy soils near Cuyk in the southeastern Netherlands. It is possible that *NLRom_E* represents trees from the same area as *NLRom_W2*, but because the chronologies do not (yet) overlap in time, this cannot be confirmed.

Table 5.5 - The degree of crossdating between the local and regional chronologies; upper right: *PV* = coefficient of parallel variation; lower left: *St* = Student's t-values; P = probability of exceedence; X = $n < 30$; n = length of the overlap between the chronologies

Chronology	***NLRom_E***	***NLRom_W1***	***NLRom_W2***	***NLRom_R***	**Central Germany**	**North Germany**
NLRom_E		X	X	62% P < 0.001	67% P < 0.0001	66% P < 0.0001
NLRom_W1	X		63% P < 0.005	66% P < 0.0002	64% P < 0.005	59% P < 0.04
NLRom_W2	X	3.15		63% P < 0.0002	64% P < 0.0001	67% P < 0.0001
NLRom_R	6.97	4.65	5.78		63% P < 0.0001	64% P < 0.0001
Central Germany	7.89	4.61	8.37	11.24		62% P < 0.0001
North Germany	8.03	3.55	7.35	15.22	17.13	

The chronologies from bog oaks, which all fit into *NLRom_R*, represent sites that were situated near bogs and lakes in the central Netherlands, where high ground water levels are assumed to have been the main growth limiting factor (Fig. 5.1). The archaeological material included in *NLRom_R* must represent similar conditions, i.e., the trees used in Colmsgate (a water well), Empel (a water well), Heeten (a water well; HRWb) and Velsen (the Roman fortress *Velsen 1*; western jetty) grew in the vicinity of lakes and bogs in the central Netherlands.

5.7 CONCLUSION

After ten years of dendrochronology in the Netherlands, the data set of absolutely dated tree-ring series from archaeological Iron Age/Roman contexts has become large enough to construct meaningful average chronologies. Three archaeological chronologies have been produced (Fig. 5.3).

NLRom_E, which runs from AD 190 to 395, represents timber derived from forests in the southeastern Netherlands. *NLRom_W1*, which runs from 84 BC to AD 50, represents timber from forests in the western Netherlands. *NLRom_W2*, which runs from 140 BC to AD 87, most likely represents timber derived from forests in the eastern Netherlands and/or adjacent areas of Germany. A fourth chronology, *NLRom_R*, was developed through the *Sub-Fossil Forests (SFF) Project* (RING/ROB) and represents bog oaks as well as archaeological timbers (Fig. 5.3). It runs from the Middle Iron Age to the Early Middle Ages (325 BC to AD 563) and reflects the growth of oaks on low, wet sites in the central Netherlands. The chronologies have a strong signal and crossdate well with existing regional chronologies from Germany.

6

MEDIEVAL TREE-RING CHRONOLOGIES OF OAK FROM DUTCH ARCHAEOLOGICAL AND HISTORICAL SITES (AD 427 - 1752; AD 1023 - 1666; AD 1041 - 1346)

ABSTRACT - Absolutely dated tree-ring series from the Early Middle Ages and later, derived from Dutch archaeological and historical contexts, are clustered into three master chronologies. In geographical terms, the distribution of the sites represented by the chronologies differs markedly. Chronology *NLHist_1* (AD 427 - 1752; 259 series) mainly represents sites in the south of the Netherlands; *NLHist_2* (AD 1023 - 1666; 195 series) consists of timbers applied in the central and northern parts, and *NLHist_3* (AD 1041 - 1346; 30 series) is composed of timbers from sites along the coast and in the IJssel and Vecht Valley. The new chronologies are well suited as a reference to date oak from Medieval archaeological sites and historical buildings in the Netherlands.

6.1 INTRODUCTION

The aim of the research presented here was to produce average tree-ring chronologies of oak for the last 1500 years that are suited for dating oak from Dutch contexts. Such chronologies should meet the following criteria: (1) they should represent absolutely dated tree-ring series of oak from Dutch archaeological and historical contexts; (2) they should have a strong signal. Because the signal in a chronology depends both on the between-tree correlation as well as on the number of trees included in the chronology (Wigley *et al.* 1984), criterion (2) implies that the chronologies should consist of tree-ring series that crossdate well in terms of their correlation coefficients, and should include as many tree-ring series as possible.

6.2 MATERIAL

At the end of 1994, the dendrochronological data set at the Dutch Centre for Dendrochronology (RING/ROB, Amersfoort) consisted of 611 tree-ring series with end-dates in the seventh century or later (Appendix A). The series were dated in previous years using chronologies from abroad (Appendix B) and our own chronologies.[1]

6.3 METHODOLOGY

6.3.1 *Quality control*

Usually, several wood samples are available from the same cultural object, and the ring widths in each sample are measured at least twice along a different radius of the wood. The ring widths are plotted logarithmically along the y-axis and the (as yet undated) years along the x-axis. The graphs are compared visually, using a light table. By the comparison of independent measurement series from the same sample, errors can easily be detected and corrected. The similarity between graphs of different samples from the same

1. Jansma, unpublished data, in part available through the International Tree-Ring Data Bank (ITRDB, NOAA/NGDC; Boulder, Colorado).

object is a first indication of the degree of crossdating between the samples and also of the likelihood that the samples can be absolutely dated. After a wood sample has been dated with statistical methods, the date is checked visually by comparing its tree-ring curve with the curve of the chronology that produced the date.

6.3.2 *The detrending of tree-ring patterns*

The dendrochronological dating of ring-width patterns makes use of the variations of the ring widths that have been caused by climate, i.e. changes in temperature and precipitation. A series of values that represents the exact width of the growth rings in a tree often reflects more than the yearly fluctuations of the weather conditions: e.g., the increasing age of the tree, which is expressed by a gradual decrease in the ring widths towards the outside of the stem, the effects of competition with neighbouring trees for food and light, or the long-term influences of a sudden disaster like fire or an insect outbreak (Cook 1990). If the non-climatic component in a tree-ring pattern masks the ring-width variability caused by climate, the pattern does not resemble that of other trees from the same region and period and cannot be dated.

Detrending is the removal of unwanted information from tree-ring series. The assumption is that a ring-width pattern is the sum of various signals with different periods (Cook 1990). Detrending involves fitting a more or less flexible *estimated growth curve* (a model fitted to the data), to the ring-width series. A detrended series of *growth indices* is produced either by division of the original values by the estimated ones or by subtracting the estimated values from the original ones.

The focus of the dendrochronological study (e.g. climate, forest dynamics, dating) determines how the growth curve is estimated and which ring-width variability it is designed to remove. The influence of climate is mainly expressed in the difference between ring widths from year to year. When the objective is to date a pattern, detrending methods are therefore used which remove some of the *gradual* increases and decreases in the ring widths.

6.3.3 *Methods of dating*

Tree-ring patterns are dated by matching their growth-index series with dated master chronologies. The master chronologies used by RING are listed in Appendix B. The most useful Medieval chronologies are those of Lower Saxony and Ostfriesland (Leuschner, unpublished data), Weserbergland (Delorme 1972), Twente (NL) and Westphalia (Tisje, unpublished data), the Meuse Basin (Hoffsummer 1989), and the Central German master chronology (Hollstein 1980).

The most important dating technique is visual comparison of plotted curves. When long series are compared, the computer is used to give an indication of possible matches through (a) the coefficient of parallel variation (*PV*), and (b) the Student's t-value (*St*) derived from the correlation coefficient between the series. All possible matches are inspected visually. Further details are given in Chapter 5 (section 5.4.1).

6.3.4 *The clustering of tree-ring index series*

In view of the aim of the study, which was to produce average oak chronologies for the Netherlands that can be used to date as many dendrochronological samples as possible, the series were *not* clustered prior to the analysis according to their date or other *a priori* defined criteria. Instead, all 611 tree-ring series were combined into one large group, and those series that show least agreement with the behaviour of the majority of the series were identified. These series were removed from the data set. The assumption underlying this procedure is that no matter how heterogeneous the Dutch collection of absolutely dated tree-ring series is, the average variation of the annual values is most likely determined by some dominant environmental signal(s); these should become stronger as more and more tree-ring series with deviating characteristics are removed. Furthermore, any climatic signal that is not dominant in the complete data set, but is nonetheless shared by a substantial number of trees, should become recognizable by the clusters that occur among the deviating series.

The estimates of the degree of similarity between the tree-ring series are based on the correlation coefficient (r_i) of each single growth-index series g_i with the average chronology of all series except g_i ($1 \leq i \leq t$, with t the total number of trees in the data set).[2] Data sets of index series from the Netherlands that, when averaged, result in a chronology that is a suitable reference for dating, are characterized by a mean correlation ($\bar{r}$, the average of all r_i's) of 0.50 to 0.65 (Chapter 5, Table 5.4). Therefore, during the analysis a minimum criterion of 0.50 is used, and clusters of tree-ring series that show a lower value for $\bar{r}$ are rejected. To determine which series should be removed from a cluster to increase $\bar{r}$, the correlation between g_i and the average chronology excluding g_i is calculated in 50-year intervals (r_i^k), using an overlap of 25 years. Here, k is 1 to q and q is the number of 50 year intervals in g_i. Values for r_i^k equal to or lower than 0.32 are not significant at $\alpha = 0.05$. Series with more than two intervals showing values for $r_i^k \leq 0.32$ are rejected.

6.3.5 *Assessment of the reliability of tree-ring chronologies*

The Mean Correlation Technique is used to assess the strength of the chronology signal (Wigley *et al.* 1984; Chapter 7). With this technique the *Expressed Population Signal* (*EPS*) is calculated. *EPS* is a function of both the number of series in a chronology and the average correlation between these series. A value for *EPS* of 0.85 or higher is taken to indicate that a chronology is of sufficient quality for dendroclimatological analyses (Wigley *et al.* 1984).

The value for *EPS* overestimates the signal in long chronologies, i.e., chronologies in which not all tree-ring series overlap (Chapter 4). *EPS* is therefore calculated in 100-year intervals (using an overlap of 50 years). Intervals that have a value for *EPS* lower than 0.85 require more samples and better internal crossdating.

To determine which intervals of the new chronologies are suited as a reference for dating regardless of *EPS*, the correlation with the available master chronologies from adjacent countries is calculated in hundred-year intervals. Chronology intervals that have a low value for *EPS* and a high correlation with the master chronologies probably reflect climatic conditions well and do not require additional sampling, in contrast to intervals that have a low value for *EPS* and show low correlations with the existing chronologies.

6.3.6 *The environmental signal of the Dutch cluster chronologies*

Two types of information are used to determine the geographical domain represented by the new chronologies. The first is their degree of crossdating with available chronologies from adjacent countries. The second is the distribution of the locations where the timbers represented by each chronology were put to use. The locations are classified according to the criteria defined by Wolff, who designated the major ecological systems in the Netherlands according to the so-called information-carrying functions of nature, as expressed by a large range of geological and ecological criteria, and on these grounds divided the Netherlands into 26 geogenetical growth regions (Figure 6.1; Wolff 1989).[3]

2. COFECHA computer program (Holmes 1983).

3. This classification was chosen in consultation with Dutch foresters (Maessen, personal communication).

Figure 6.1 - Growth regions in the Netherlands (after Wolff 1989):

(I) *Pre-Pleistocene*:

a = cretaceous deposits;
b = löss;
c = Winterswijk sediments;

(II) *Pleistocene*:

d = Drenthe Plateau (including northern lateral morenes);
e = central Netherlands lateral moraines;
f = Twente Formation;
g = Hunze Depression;
h = IJssel and Vecht Valley;
i = 'Gelderse Vallei';
j = western Brabant;
k = central Brabant;
l = eastern Brabant;
m = Zeeuws Vlaanderen Pleistocene sand area;
n = Meuse terraces;
o = Oude IJssel valley;
p = Vecht valley;

(III) *Holocene*:

q = central Netherlands river area;
r = (former) perimarine peat area;
s = Dutch Wadden;
t = (closed) estuaries;
u = former sea;
v = northern marine sediments;
w = southwestern marine sediments;
x = IJsselmeer polders;
y = IJsselmeer and peripheral lakes;
z = coastal dunes

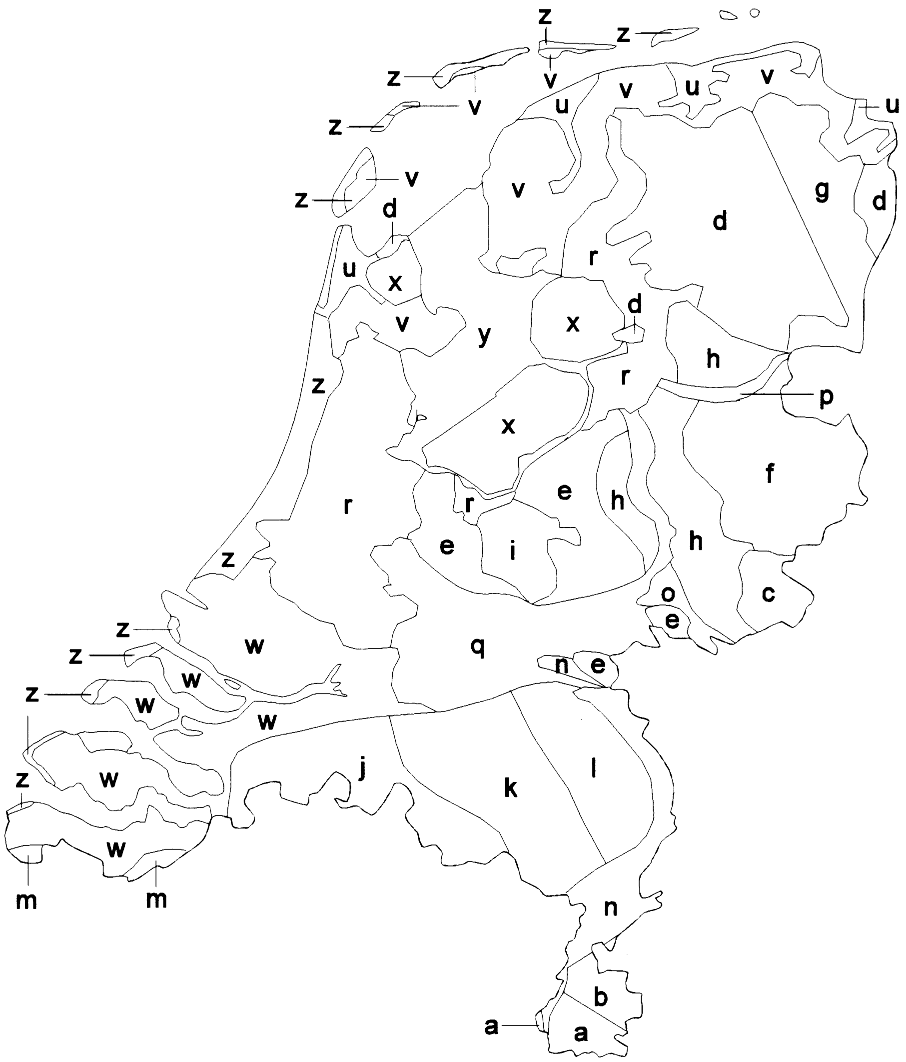


Table 6.1 - Chronology statistics before and after clustering; $\bar{r}_i$ = average correlation between single series and mean chronology of all other series; r_i^k = correlation between single series and mean chronology of all other series in 50-year intervals (overlap = 25).

	No. Trees	**First year**	**Last year**	**Length in years**	**Total No. of Rings**	$\bar{r}_i$	$r_i^k \leq$ **0.32**
All series	611	AD 427	AD 1752	1326	63 157	0.44	24%
NLHist_1	259	AD 427	AD 1752	1326	27 100	0.53	4%
NLHist_2	195	AD 1023	AD 1666	664	17 326	0.53	4%
NLHist_3	30	AD 1041	AD 1346	306	3359	0.55	6%
Unclustered	127	AD 906	AD 1749	844	15 373	0.30	59%

6.4 RESULTS

6.4.1 *General*

The averaging of all 611 series that cover the period between AD 427 and 1752 results in a chronology of which the quality is doubtful. The correlation between each individual series and the average chronology of all other series in 50-year intervals (r_i^k) is equal to or lower than 0.32 for 24% of the intervals and $\bar{r}$ is 0.44, i.e., lower than the 0.50 criterion employed (Table 6.1).

After the series that show low correlation coefficients are removed, the data set is reduced to 259 tree-ring series (Table 6.1; *NLHist_1*). Like the complete data set, this cluster covers the interval between AD 427 and 1752, but now only 4% of the 50-year intervals of the tree-ring series have a value for $r_i^k \leq$ 0.32, and the value for $\bar{r}$ has increased to 0.53.

Within the remaining data set of 'dissimilar' series (469 trees), two clusters can be distinguished (Table 6.1). *NLHist_2*, representing 195 trees, has a value for $\bar{r}$ of 0.53, and only 4% of the 50-year intervals of the individual tree-ring series show values for $r_i^k \leq$ 0.32. The respective values for *NLHist_3*, representing 30 trees, are 0.55 and 6%.

The three clusters contain a total of 484 series; 127 series remain unclustered. Figure 6.2 shows the shape of the average chronologies; the number of trees in the chronologies is shown in Figure 6.3.

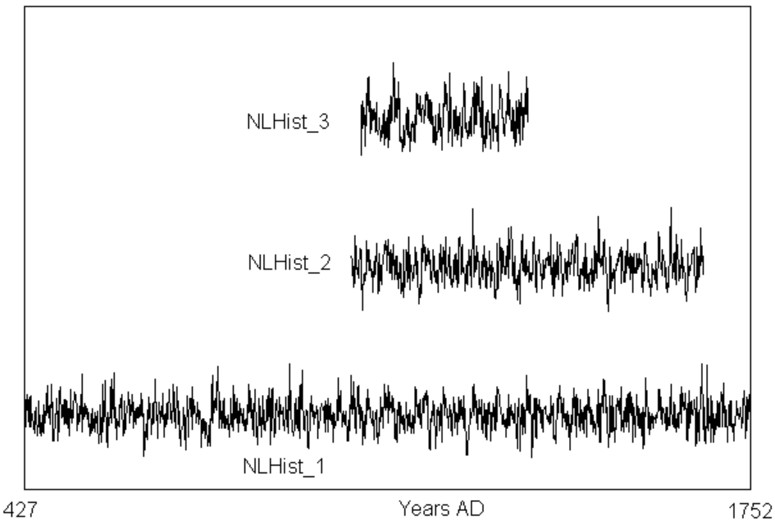


FIGURE 6.2 - Historical oak tree-ring chronologies for the Netherlands: *NLHist_1* (AD 427 - 1752); *NLHIst_2* (AD 1023 - 1666); *NLHist_3* (AD 1041 - 1346)

6.4.2 *The signal within the chronologies*

NLHist_1 (AD 427 - 1752) has a value for *EPS* of 0.85 or higher between AD 1150 and 1650 (Fig. 6.4; calculation interval AD 1100 - 1700). Before AD 1150 the signal is generally lower. However, the correlation between the chronology of *NLHist_1* and the available chronologies from abroad is not much lower before AD 1150 than afterwards (Fig. 6.5). The lowest correlation between *NLHist_1* and the master chronologies occurs at at the end of *NLHist_1* (AD 1650 - 1750). The correlation between *NLHist_1* and the master chronologies before AD 900 is higher than the correlation among the master chronologies themselves.

NLHist_2 (AD 1023 - 1666) has a value for *EPS* of 0.85 or higher from 1300 onwards (Fig. 6.4; calculation interval AD 1250 - 1650). The correlation with the chronologies from abroad before AD 1300 is low.

NLHist_3 (AD 1041 - 1346) shows values for *EPS* of 0.85 or higher for all intervals (Fig. 6.4; calculation interval AD 1050 - 1346). The correlation with the master chronologies is low (Fig. 6.5).

Figure 6.3 - The number of samples in the cluster chronologies

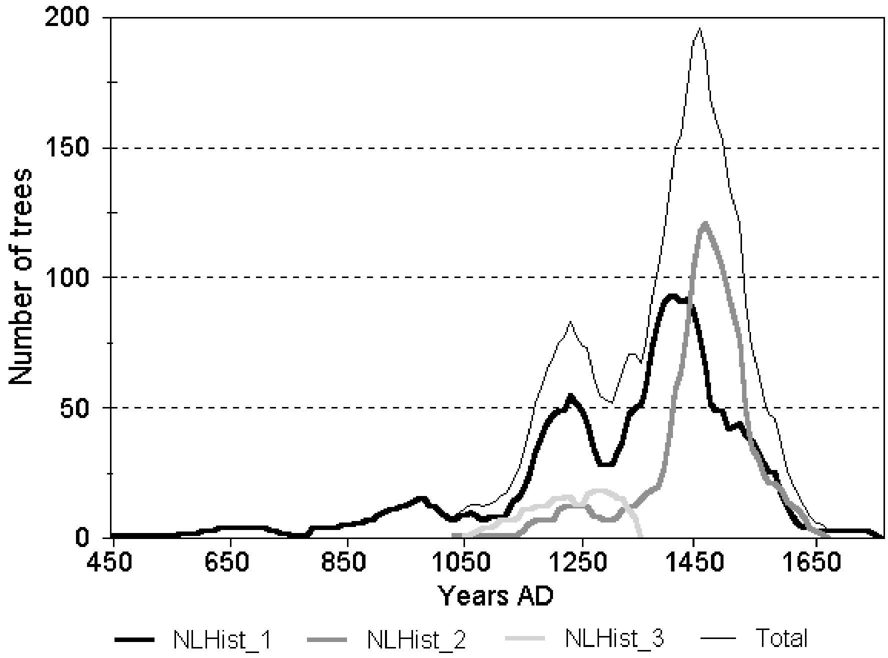
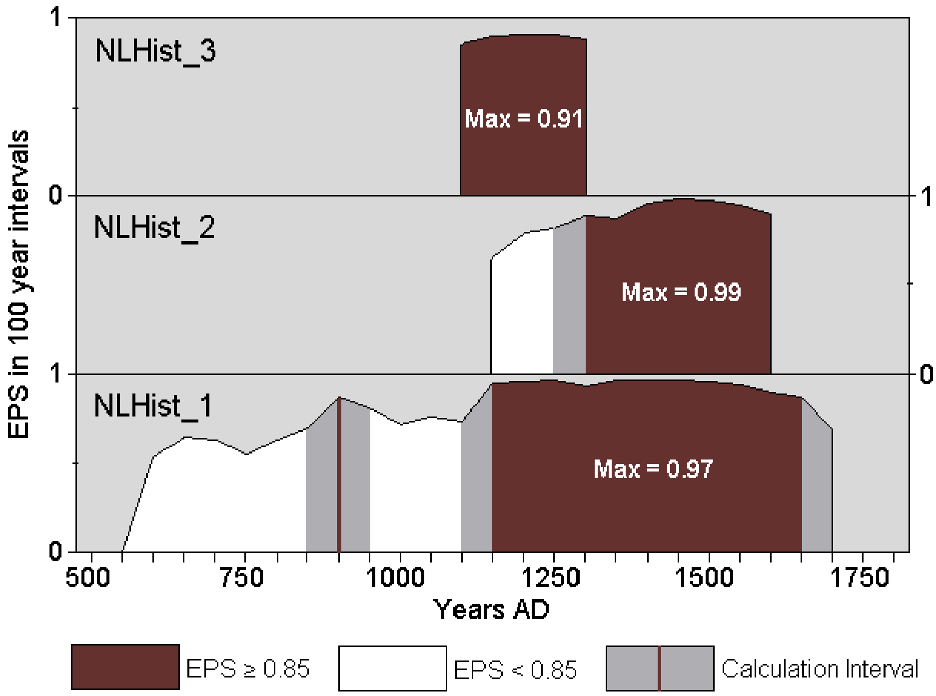


Figure 6.4 - The Expressed Population Signal (*EPS*) in hundred year intervals (lag = 50 years)



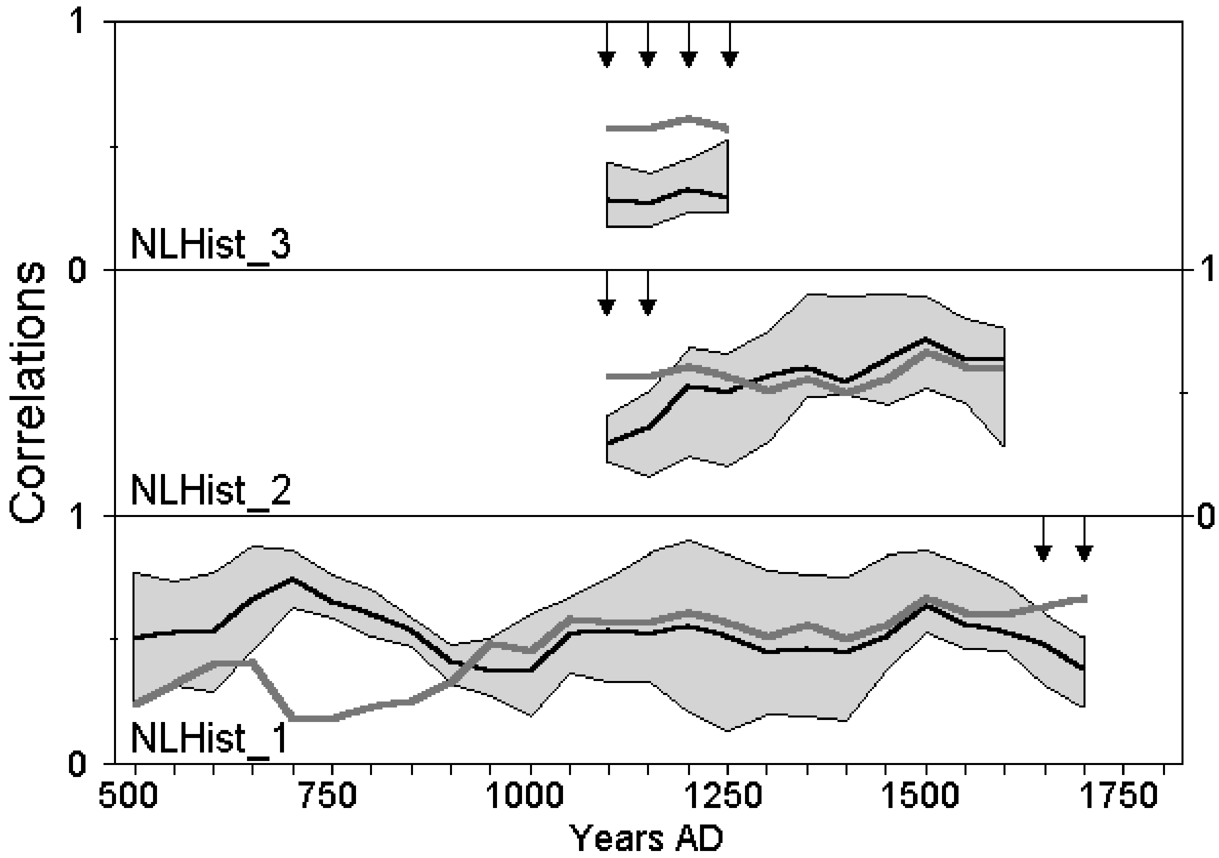


FIGURE 6.5 - The running correlation between the reference chronologies, and between the cluster and reference chronologies. Calculation interval: 100 years (lag = 50). Table 6.2 shows the reference chronologies used in the analysis

6.4.3 *Growth regions*

Figure 6.6 shows the number of samples per cluster and per growth region. Geographically, *NLHist_1* is dominant in regions a, b and n (Fig. 6.1; province of Limburg); k and j (province of Noord-Brabant); z (the coastal dunes, in this case in the province of Zuid-Holland); and w (province of Zeeland). In other words, *NLHist_1* is dominated by oak from sites that are located south of the central Dutch rivers. The trees in this cluster, which represent timber from 's-Hertogenbosch (region k) and have felling dates between AD 1463 and 1465, belonged to forests in the Belgium Meuse Basin (Chapter 3). *NLHist_2* dominates in regions c, d, e, f, i, q, r, s, v and x: all of the Netherlands north of the provinces of Limburg, Noord-Brabant and Zeeland, except region h. *NLHist_3* mainly represents timber from regions h (IJssel and Vecht Valley), v (marine sediments in the northern Netherlands and x (IJsselmeer polders), and only dominates in the first region. In Figure 6.2 the growth regions that are represented by 10 tree-ring series or more are shaded according to the dominant chronology.

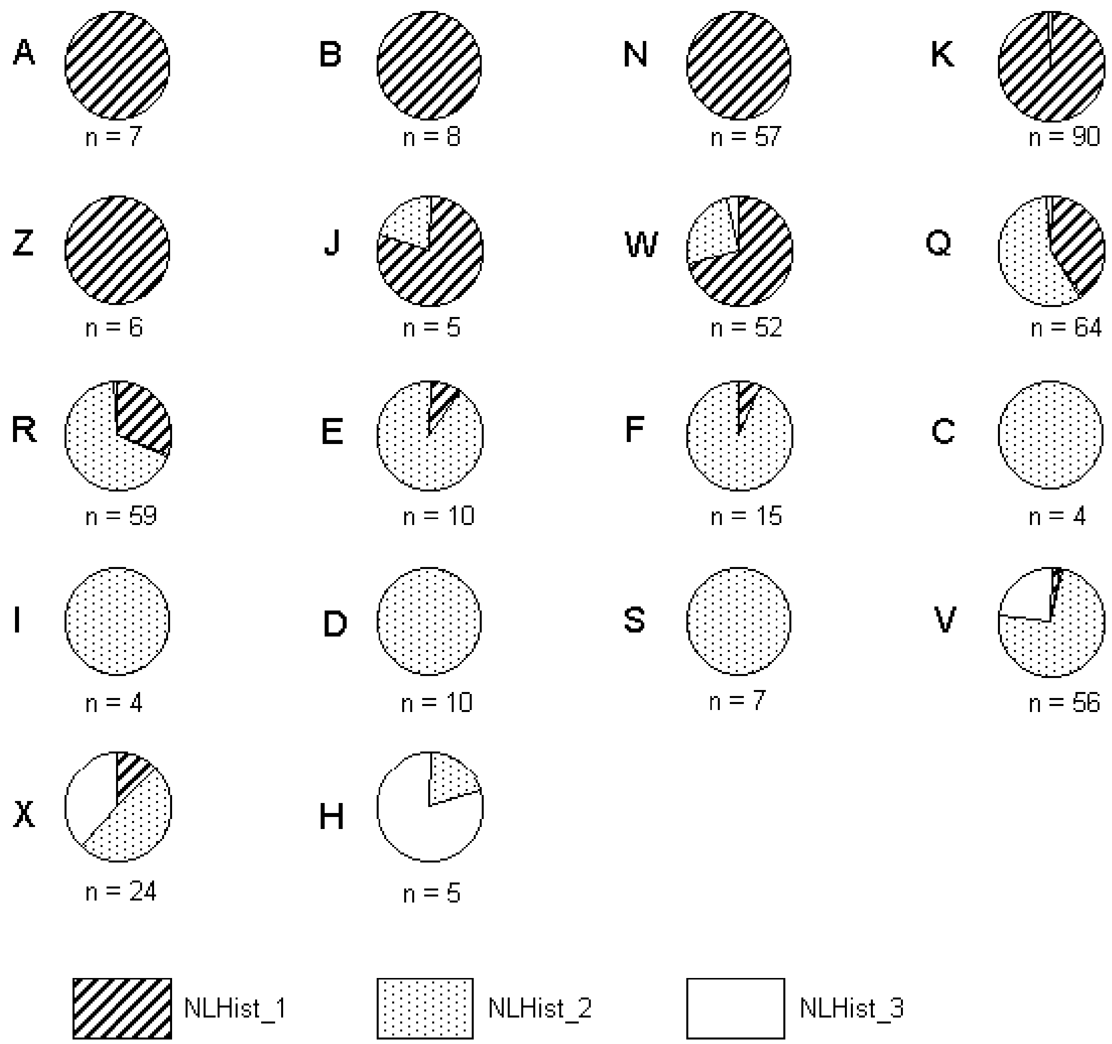


FIGURE 6.6 - The number of samples per clusters and per growth region

6.4.4 *Crossdating with existing master chronologies*

The correlation between the cluster and master chronologies, which is a measure of their degree of similarity, varies considerably (Table 6.2; see Appendix B for the abbreviations of the master chronologies). *NLHist_1* crossdates best with the Central German oak chronology (DLCE; $r = 0.62$; overlap = 1326 years). The next best match is with growth region 9 in Lower Saxony (DLS9; $r = 0.50$; overlap = 877 years), which represents the area of Lower Saxony adjacent to the Dutch province of Overijssel. *NLHist_2* crossdates best with chronologies of more northern and easterly regions in Lower Saxony (DLS5, 6 and 7), and with the Ostfriesland chronology (DLOF; Leuschner, unpublished data; $r \approx 0.60$). *NLHist_3* does not crossdate well with any master chronology: not a single correlation over 0.40 was found.

	NLHist_1				*NLHist_2*				*NLHist_3*			
	St	***PV***	***r***	***n***	***St***	***PV***	***r***	***n***	***St***	***PV***	***r***	***n***
DLS1	21.71	71%	0.49	838	16.59	73%	0.51	644	6.08	62%	0.21	306
DLS3	21.60	70%	0.49	838	17.32	74%	0.54	644	6.83	62%	0.22	306
DLS4	16.83	67%	0.41	878	16.64	73%	0.56	644	6.77	60%	0.23	306
DLS5	17.45	69%	0.43	873	18.34	74%	0.61	644	7.28	64%	0.27	306
DLS6	13.70	65%	0.31	872	16.19	71%	0.60	644	7.26	62%	0.24	306
DLS7	15.91	65%	0.41	888	17.44	72%	0.59	644	7.74	61%	0.27	306
DLS9	22.57	71%	0.50	877	17.79	74%	0.55	644	7.11	62%	0.23	306
DLNS	16.63	66%	0.26	838	18.42	74%	0.45	644	8.58	64%	0.22	306
DLOF	17.18	64%	0.36	1326	17.97	72%	0.59	644	7.74	62%	0.25	306
DLWB	19.11	72%	0.24	749	14.62	71%	0.24	644	4.04	56%	0.15	306
DLWF	12.44	69%	0.30	410	19.36	76%	0.47	407	1.76	56%	-0.04	87
NLTF	12.76	70%	0.33	713	11.11	74%	0.46	627	7.24	66%	0.30	306
NLTW	9.49	68%	0.23	368	18.17	76%	0.54	310	-	-	-	0
BMBA	23.85	73%	0.28	1081	10.32	64%	0.18	644	6.13	61%	0.24	306
DLCE	35.81	76%	0.62	1326	12.59	67%	0.42	644	6.46	62%	0.36	306
NLHist_1	-	-	-	-	12.87	71%	0.42	644	6.70	62%	0.34	306
NLHist_2	12.87	71%	0.42	644	-	-	-	-	4.50	57%	0.26	306
NLHist_3	6.70	62%	0.34	306	4.50	57%	0.26	306	-	-	-	-

TABLE 6.2 - The crossdating between the Dutch cluster chronologies and available reference chronologies;
St = Student's t-value;
PV= coefficient of parallel variation;
r = correlation coefficient;
n = length of compared interval (years)

6.5 INTERPRETATION AND DISCUSSION

6.5.1 *Chronology NLHist_1 (AD 427 - 1752)*

Geographically, *NLHist_1* represents oak timber that was used in the provinces of Limburg, Noord-Brabant and Zeeland (Figs. 6.6 and 6.7). The interval AD 1316 - 1465 mainly consists of trees derived from eastern Belgian forests (Chapter 3). However, the strong agreement with the Central German chronology (r = 0.62) indicates that outside this interval the timbers were derived from a wider area, viz., eastern Belgium and adjacent Germany.

Earlier, we defined the chronology intervals for which more samples are needed as those intervals where minimum values occur for both the chronology signal (*EPS*) and the correlation with other chronologies. Problematic in terms of *EPS* are the intervals AD 450 - 850/900, AD 900/950 - 1100/1150 and AD 1650 - 1750 (Fig. 6.4). Less than average correlation with existing chronologies occurs during the interval AD 1650 - 1750 (Fig. 6.5). This interval is covered by two series only (Fig. 6.3), and the conclusion that more samples are needed for this interval is justified.

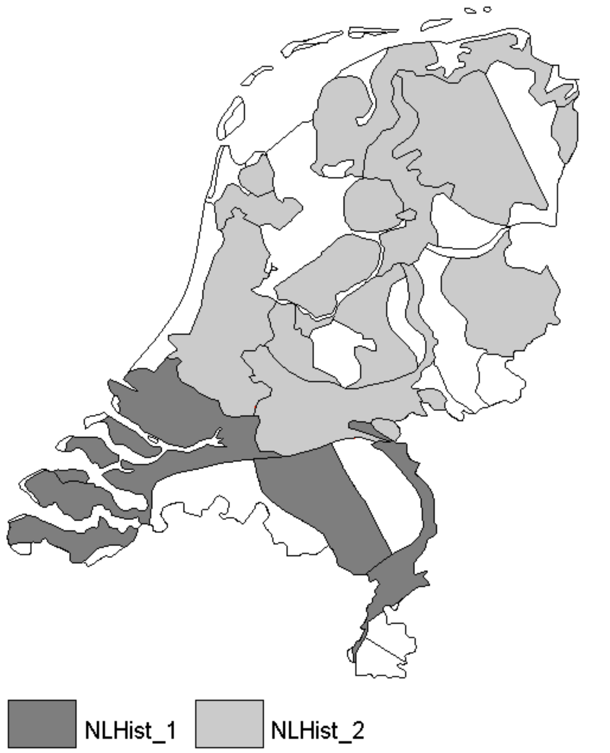


FIGURE 6.7 - The dominance of the Dutch cluster chronologies in growth regions represented by º 10 samples

It is interesting to note that some intervals with a low signal synchronize with known atmospheric ^{14}C anomalies. These anomalies, above average ^{14}C production related to sunspot minima, are termed *^{14}C minima*. For some periods, an association exists between ^{14}C minima and global cooling events (Davis *et al.* 1992). ^{14}C minima in the first millennium BC coincide with low similarity between existing chronologies of oak, which is interpreted in terms of a climatic change towards cooler and wetter conditions (Schmidt and Gruhle 1988). The ^{14}C minima that occurred during the interval covered by *NLHist_1* are: the *Roman* Minimum (AD 660 - 770); the *Medieval* Minimum (AD 940 - 1140); the *Wolff* Minimum (AD 1290 - 1350); the *Sporer* Minimum (AD 1400 - 1510); and the *Maunder* Minimum (AD 1645 - 1715; terminology by Davis *et al.* 1992). The chronology intervals that simultaneously show a weak value for *EPS* are: (a) AD 660 - 770; (b) AD 950 - 1150; and (c) AD 1650 - 1715. *EPS* is, however, in part a function of sample size, and each year of the chronology should represent the *same* number of tree-ring series (preferably ten or more) for a valid attempt to explain the values for *EPS* in terms other than sample size. Given the low replication of the first and last part of *NLHist_1*, it is too early for such an attempt.

6.5.2 *Chronology NLHist_2 (AD 1023 - 1666)*

The timbers in *NLHist_2* mainly were used in the central and northern Netherlands, and its match with *NLHist_1* is not optimal (r = 0.42; Table 6.2). It is therefore unlikely that the timbers in *NLHist_2* have a southern provenance. *NLHist_2* crossdates best with several Lower Saxony chronologies

($r \approx 0.60$) and the Ostfriesland chronology ($r = 0.59$), closely followed by the Twente/Westphalia chronology ($r = 0.54$). This indicates a more northern provenance than *NLHist_1*, most likely Twente/Westphalia and adjacent North Germany.

The chronology signal is mainly determined by the sample size: the earlier part of *NLHist_2* consists of a few trees only (Fig. 6.3), and the low correlation with the master chronologies during this earlier interval, which coincides with low values for *EPS*, must also be related to sample size (Figs. 6.4 and 6.5). The first 200 years of this chronology would therefore improve if tree-ring series were added.

6.5.3 *Chronology NLHist_3 (AD 1041 - 1346)*

The signal in *NLHist_3* is high and cannot be improved further by adding samples. Its correlation with the existing master chronologies is low (Table 6.2; maximum $r = 0.36$ (Central German chronology)). *NLHist_3* includes ship timbers from Zeeland (Fig. 6.1; growth region w), a tree that died naturally near Baarn and was found *in situ* (region r), thirteenth century posts from Hoorn (region v), staves from a barrel found in Alkmaar (region v) and foundation timber from Apeldoorn (region h). In terms of provenance, the fact that this chronology includes a tree found *in situ* might indicate that it represents indigenous oak. On the other hand, the chronology also includes ship timbers and a barrel, i.e. wood from relocatable objects, which means that the provenance of the wood could be further away. At this point of our research, the provenance of *NLHist_3* cannot be established with certainty.

6.5.4 *The use of the cluster chronologies for dating Dutch sites and objects*

Oak timbers that were used in the Netherlands during the Middle Ages came from different regions (e.g., De Vries 1994; Jansma 1995; Chapter 3), and their tree-ring patterns reflect a variety of different growth conditions (e.g. soil and forest types and meteorological conditions). By clustering these patterns into separate groups, chronologies result that also reflect different conditions or combinations of conditions. The precise location of the forests where these conditions occurred cannot be ascertained. Fortunately, the location of the forests does not need to be established in order for the chronologies to be useful for dating. Together, *NLHist_1*, *NLHist_2* and *NLHist_3* represent 80% of the tree-ring series from Medieval contexts that were available at the time of the analysis. Separately, they summarize the ring-width characteristics of three different groups of dated timbers used in the Netherlands.

Our experience with the new chronologies is positive: at present more than half of the datings by RING are achieved using these chronologies as a reference.[4] Noteworthy is the fact that it proved possible during the clustering to date some timbers that were previously undatable, and include them in the new chronologies.[5]

6.6 CONCLUSIONS

Three historical chronologies of oak have been produced.[6] Together, they represent 80% of the 611 medieval tree-ring patterns from Dutch locations available at the time of the analysis. *NLHist_1*, which runs from AD 427 to 1752, represents oak that grew in the southern part and south/southeast of the Netherlands. *NLHist_2*, which covers the interval between AD 1023 and 1666, represents oak from the eastern part of the central and northern Netherlands and areas to the east of the country. The geographical domain of *NLHist_3*, which runs from AD 1041 to 1346, is unknown. These chronologies are now used as a reference for dating oak from Dutch archaeological and historical contexts.

4. The next most successful chronology is the Ostfriesland chronology (Leuschner, unpublished data), followed by the chronologies of Twente (NL) and Westphalia (Tisje, unpublished data).

5. Dendrochronological codes (RING laboratory): NLE01005; NLE08001; NLE08002; NLR33001; NLR34001; NLV17007 (Appendix A).

6. The unpublished chronologies are property of the RING tree-ring laboratory (ROB; Amersfoort (NL)).

7

THE MEAN CORRELATION TECHNIQUE: THE 'EFFECTIVE CHRONOLOGY SIGNAL' AS AN ESTIMATOR OF THE SIGNAL IN TREE-RING CHRONOLOGIES

Abstract - The Mean Correlation Technique estimates the signal that a tree-ring chronology contains. Unlike ANOVA, it allows for different numbers of cores per tree. In this context it involves the definition of an 'effective number of cores' (c_{eff}). Using (1) c_{eff}, (2) the average correlation between cores from the same tree over all trees ($\bar{r}_{wt}$), and (3) the average correlation between cores from different trees over all trees ($\bar{r}_{bt}$), an 'effective chronology signal' ($\bar{r}_{eff}$) is estimated. From $\bar{r}_{eff}$ and the number of trees (t), the chronology signal (EPS) is derived. The relationship between and domain of $\bar{r}_{bt}$, $\bar{r}_{wt}$ and $\bar{r}_{eff}$ is analysed. It is shown that the effective chronology signal ($\bar{r}_{eff}$) is inversely related to the within-tree signal ($\bar{r}_{wt}$), and therefore cannot be an adequate measure of the chronology signal. The fact that $\bar{r}_{eff}$ is not restricted to the domain [-1,1] is problematic. Although anomalous values occur only when $\bar{r}_{wt} < \bar{r}_{bt}$, i.e., outside the domain that is relevant for dendrochronological analyses, it disqualifies $\bar{r}_{eff}$ as a 'correlation coefficient'.

7.1 INTRODUCTION

All forms of tree-ring research include (1) data collection and measurement, (2) assessment of signal and noise in the tree-ring series according to the aims of the study, (3) detrending and standardization of the series into indices, and (4) the development of average chronologies (Cook and Kairiukstis 1990). Before a chronology is used for the purpose for which it was developed (i.e. environmental studies or crossdating), its quality, which depends on the strength of its signal, is estimated. The chronology signal is a stochastic quantity which expresses the fraction of ring-width variability that the set of tree-ring series has in common (Briffa and Jones 1990).

One may choose from two methods to calculate the chronology signal. Both measure the amount of variability that is shared by a set of indices from different trees (the between-tree signal) and the amount of variability that is shared by the set representing the same trees (the within-tree signal). The first method, analysis of variance (ANOVA; Fritts 1976), must have fixed time intervals for which all individual series overlap completely. This means that series that are shorter than the selected interval have to be omitted from the analysis. ANOVA furthermore requires that all trees in the data set are represented by the same number of measurement series. The second method, the Mean Correlation Technique (MCT; Wigley *et al.* 1984; Briffa and Jones 1990), is less demanding in terms of replication; it does not require a common interval and can be applied to any interval where two or more series overlap for a number of years. In addition, it allows for a different number of measurement series per tree.

Tree-ring data from living trees often have a common interval that is larger than a hundred years, running from the year in which the trees reached 'breast height' (cores as a rule are taken at a stem height of 1.30 m.) to the year in which they were sampled. In addition, for living trees the sampling strategy is generally determined by dendrochronologists, which means that an equal number of cores is taken from each tree. Therefore ANOVA is well suited to estimate the signal in chronologies from living trees.

Many tree-ring series from archaeological, historical and bog oak sites, on the other hand, do not overlap for long intervals. In addition, the dendrochronologist often cannot control the number of samples that is taken from this material. When analysing the signal in chronologies that represent bog oaks or archaeological and historical timber, MCT, with its less strict demands, is often preferred to ANOVA (Chapter 3).

When estimating a chronology signal from correlation coefficients, one would expect the chronology signal to be positively related to both the between-tree signal (the average correlation between cores that represent different trees) and the within-tree signal (the average correlation between cores that represent the same trees). However, during a recent application of MCT I noted that while the values for the between-tree signal and the overall chronology signal showed a positive relationship, the values for the within-tree signal and the chronology signal were negatively related. In order to understand this phenomenon more fully, I analysed the domain of and the relationship between the variables that are used to calculate the chronology signal according to the Mean Correlation Technique.

7.2 THE MEAN CORRELATION TECHNIQUE

The Mean Correlation Technique was first presented by Wigley *et al.* (1984). They define the 'Expressed Population Signal' (*EPS*) of a chronology as

$$EPS = \frac{N\bar{r}}{1+(N-1)\bar{r}} \tag{1}$$

with N the number of trees and $\bar{r}$ the average correlation between the series. This definition only considers data sets that consist of one measurement series per tree. However, Wigley *et al.* (1984, 211) suggest that this method can also be applied when several cores per tree are available. In such a case, the series of each tree should be averaged into one single time series before the analysis takes place.

Briffa and Jones (1990) have adapted the definition of *EPS* to data sets that include more than one series per tree. They first calculate the correlation coefficients between all series of indices in the data set. Then, a total correlation mean is computed. The total number of coefficients involved is:

$$N_{tot} = \frac{1}{2}\left(\sum_{i=1}^{t} c_i\right)\left(\left(\sum_{i=1}^{t} c_i\right) - 1\right) \tag{2}$$

with $i = 1$ to t trees, each tree is represented by $j = 1$ to c_i #cores/tree, and N_{tot} is the number of correlations that is computed.

A within-tree signal is then estimated by averaging the correlation coefficients between series from the same tree over all trees. It is expressed as

$$\bar{r}_{wt} = \frac{1}{N_{wt}} \sum_{i=1}^{t}\left(\sum_{j=2}^{c_i} r_{ij}\right) \tag{3.1}$$

where

$$N_{wt} = \frac{1}{2}\sum_{i=1}^{t} c_i(c_i - 1) \tag{3.2}$$

A between-tree signal is estimated as the average correlation between all possible pairs of series that represent different trees:

$$\bar{r}_{bt} = \frac{1}{N_{bt}} \left(\bar{r}_{tot} N_{tot} - \bar{r}_{wt} N_{wt}\right) \tag{4.1}$$

where

$$N_{bt} = N_{tot} - N_{wt} \tag{4.2}$$

If the number of cores per tree is unequal, c_i is replaced by c_{eff}, the effective number of trees:

$$\frac{1}{c_{eff}} = \frac{1}{t} \sum_{i=1}^{t} \frac{1}{c_i} \tag{5}$$

where $i = 1$ to t trees and c_i is the number of series from tree i.

Using c_{eff}, an effective chronology signal is calculated that includes both the between-tree and the within-tree signal:

$$\bar{r}_{eff} = \frac{\bar{r}_{bt}}{\bar{r}_{wt} + \frac{(1-\bar{r}_{wt})}{c_{eff}}} \equiv \frac{c_{eff}\,\bar{r}_{bt}}{1+(c_{eff}-1)\bar{r}_{wt}} \tag{6}$$

If only one core is available per tree, c_i equals 1 and $\bar{r}_{eff}$ equals $\bar{r}_{bt.}$

Briffa and Jones (1990, 143) state that since by definition $\bar{r}_{wt}$ has a lower limit equal to $\bar{r}_{bt}$ it can be shown that equation (6) gives an estimated value of the chronology signal that is almost invariably higher and more accurate than measures derived solely from $\bar{r}_{bt}$.

The Expressed Population Signal (*EPS*) quantifies the degree to which the chronology signal is expressed when series are averaged:

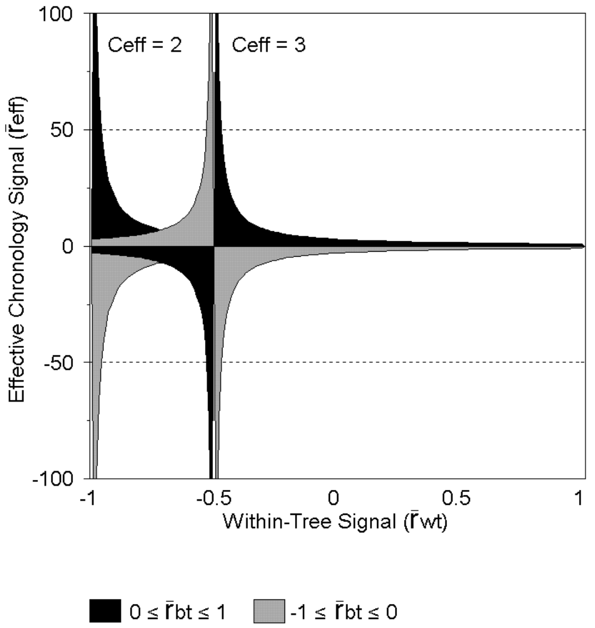
$$EPS(t) = \frac{\bar{r}_{eff}}{\bar{r}_{eff} + \frac{(1-\bar{r}_{eff})}{t}} \equiv \frac{t\,\bar{r}_{eff}}{1+(t-1)\bar{r}_{eff}} \tag{7}$$

with t the number of trees.

7.3 THE BEHAVIOUR OF $\bar{r}_{eff}$

In equation (6) $\bar{r}_{eff}$ depends on $\bar{r}_{bt}$, $\bar{r}_{wt}$ and c_{eff}. Because $\bar{r}_{bt}$ is in the nominator, its relationship to $\bar{r}_{eff}$ is proportional, i.e., *y* times larger values for $\bar{r}_{bt}$ result in *y* times larger values for $\bar{r}_{eff}$. Because $\bar{r}_{wt}$ is in the denominator, this variable is hyperbolically related to the value for $\bar{r}_{eff}$.

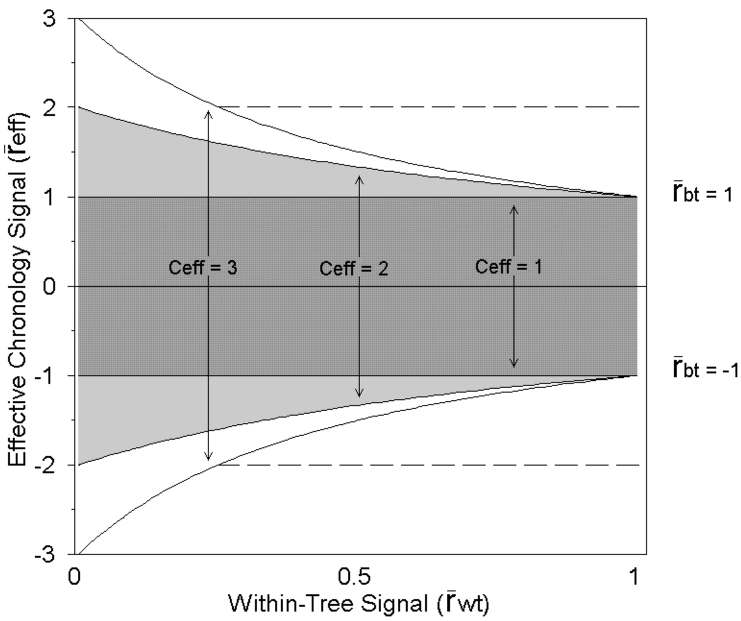
FIGURE 7.1 - The domain of $\bar{r}_{eff}$ (c_{eff}= 2 and 3)



Figures 7.1, 7.2 and 7.3 show the relationship between $\bar{r}_{eff}$, $\bar{r}_{bt}$ and $\bar{r}_{wt}$ for several values of c_{eff}. This relationship has the following characteristics:

- i $\bar{r}_{eff}$ is discontinuous for $\bar{r}_{wt} = 1 / (1 - c_{eff})$ (Fig. 7.1)
- ii if 0 ª $\bar{r}_{wt}$ ª 1 then $c_{eff}\bar{r}_{bt}$ ª $\bar{r}_{eff}$ ª $\bar{r}_{bt}$ (Fig. 7.2)
- iii if $\bar{r}_{wt} = 1$ then $\bar{r}_{eff} = \bar{r}_{bt}$ (Fig. 7.2)
- iv if $\bar{r}_{wt} = 0$ then $\bar{r}_{eff} = c_{eff}\bar{r}_{bt}$ (Figs. 7.2 and 7.3)

FIGURE 7.2 - The domain of $\bar{r}_{eff}$ ($\bar{r}_{wt}$ ª 0; c_{eff} = 1, 2 and 3)



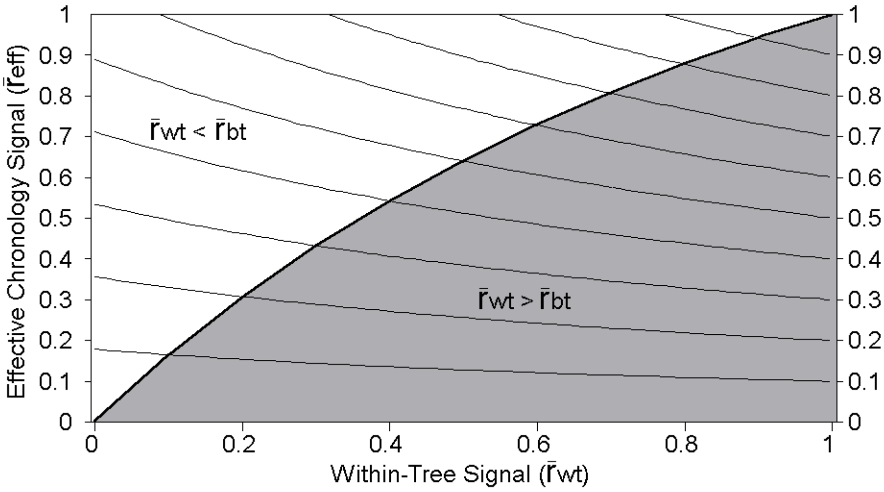


FIGURE 7.3 - The domain of $\bar{r}_{eff}$ ($\bar{r}_{wt} \geq 0$, $\bar{r}_{bt} \geq 0$, $\bar{r}_{wt} \geq \bar{r}_{bt}$; c_{eff}= 1.78 (arbitrary value)); the right Y-axis shows the values for $\bar{r}_{bt}$ that characterize the adjoining curves

In other words, (i) in the negative domain of $\bar{r}_{wt}$ the value for $\bar{r}_{eff}$ can become indefinite (Fig. 7.1). This occurs when the denominator of (6) equals 0; (ii) in the positive domain of $\bar{r}_{wt}$ the value for $\bar{r}_{eff}$ becomes no larger than $c_{eff}\bar{r}_{bt}$ and no smaller than $\bar{r}_{bt}$ (Fig. 7.2); (iii) in the positive domain of $\bar{r}_{wt}$ the value for $\bar{r}_{eff}$ reaches its minimum value of $\bar{r}_{bt}$ when $\bar{r}_{wt}$ = 1 (Fig. 7.2); (iv) in the positive domain of $\bar{r}_{wt}$ the value for $\bar{r}_{eff}$ approaches its maximum value of $c_{eff}\bar{r}_{bt}$ if the value for $\bar{r}_{wt}$ converges to 0 (Figs 7.2. and 7.3). Figures 7.1 and 7.2 show furthermore that if $\bar{r}_{bt} < 0$, the values for $\bar{r}_{eff}$ are positively related to $\bar{r}_{wt}$ and always lower than the corresponding values for $\bar{r}_{bt}$.

Figure 7.3 shows $\bar{r}_{eff}$ for $\bar{r}_{wt} > 0$, $\bar{r}_{bt} > 0$ and $\bar{r}_{wt} \geq \bar{r}_{bt}$, which is the domain of these variables when the chronology signal is calculated. In this case the values for $\bar{r}_{eff}$ are always higher than the values for $\bar{r}_{bt}$, and do not become larger than 1.

7.4 DISCUSSION

7.4.1 *The domain of $\bar{r}_{eff}$ and $\bar{r}_{bt}$*

In practice, only tree-ring patterns that match well are used for analyses of the chronology signal. This means that the correlation between the series is verified before the analysis takes place. Although the domain of $\bar{r}_{eff}$ that involves negative values for both $\bar{r}_{bt}$ and $\bar{r}_{wt}$ (Fig. 7.1) is not relevant in a dendrochronological context, its definition, as given by equation (6), disqualifies the variable as a correlation coefficient: it is *not* restricted to the domain [-1,1]. The problem does not occur if both $\bar{r}_{wt}$ and $\bar{r}_{bt}$ are positive and $\bar{r}_{wt}$ is larger than or equal to $\bar{r}_{bt}$ (Fig. 7.3).

7.4.2 *Estimating the mean of correlation coefficients*

The population correlation coefficient (ρ) applies only to correlation in a bivariate normal distribution. The Pearson correlation coefficient (*r*) estimates ρ from a sample of variates. Finding the confidence limits about *r* is complicated by the fact that ρ must be known prior to finding the standard error of *r*. This led Fisher (1935) to derive a second index, known as *z*.[1]

To average correlations without previously transforming them to Fisher's *z*-scores is problematic, especially when the correlations approach the limits of the domain of *r* [-1,1]. Averaging always results in an underestimation of the true correlation: if r_1 is 0.7 and r_2 is 0.9, then *r* equals 0.82 (not 0.80); if r_1 is 0.4 and r_2 is 0.6, then *r* equals 0.507 (not 0.50). It will be clear that the calculation of a chronology signal from $\bar{r}_{wt}$ and/or $\bar{r}_{bt}$ as defined in equations (3.1) and (4.1), whether by the Mean Correlation Technique or ANOVA, leads to an underestimation.

1. The transformation of *r* is given by $z_r = 0.5 \log_e((1+r)/(1-r))$ (Thomas 1976, 393).

7.4.3 *The hyperbolical relationship between $\bar{r}_{wt}$ and $\bar{r}_{eff}$*

Briffa and Jones (1990, 143) state that since $\bar{r}_{wt}$ has a lower limit equal to $\bar{r}_{bt}$, the value for $\bar{r}_{eff}$ gives a measure of the chronology signal that is almost always larger than measures derived solely from $\bar{r}_{bt}$. Within the domain given by $\bar{r}_{wt} > 0$, $\bar{r}_{bt} > 0$ and $\bar{r}_{wt} \geq \bar{r}_{bt}$, the one exception occurs when $\bar{r}_{wt}$ equals 1: then, $\bar{r}_{eff}$ reaches its lower limit of $\bar{r}_{bt}$ (Fig. 2). This is because the values for $\bar{r}_{eff}$ and $\bar{r}_{wt}$ are hyperbolically related; a stronger within-tree signal results in a weaker chronology signal as calculated from equation (6).

The implications of this relation can be illustrated by an example from our own research. When estimating the signal in a bog oak chronology that runs from 2258 to 1141 BC (Chapter 4), the following values were found: detrended ('standard') chronology:

c_{eff} = 1.708;

$\bar{r}_{bt}$ = 0.377;

$\bar{r}_{wt}$ = 0.740;

detrended and pre-whitened ('residual') chronology:

c_{eff} = 1.708;

$\bar{r}_{bt}$ = 0.379;

$\bar{r}_{wt}$ = 0.764.

These values result in an effective chronology signal ($\bar{r}_{eff}$) of 0.423 (standard chronology) and 0.419 (residual chronology). In other words, *although the residual chronology has both a higher within-tree signal and between-tree signal due to the removal of auto-correlation, its effective chronology signal as estimated by the Mean Correlation Technique is lower.*

According to the linear aggregate model of tree growth defined by Cook (1990), on which many forms of dendrochronological signal improvement (e.g. detrending, pre-whitening) are based, any ring-width series (*t*) is the sum of various sub-signals. These are: (1) the age-size-related trend in ring width (A_t); (2) the climatically related environmental signal (C_t); (3) the disturbance impulse caused by a local 'endogenous' disturbance ($D1_t$); (4) the disturbance impulse caused by a standwide 'exogenous' disturbance ($D2_t$); and (5) the mainly unexplained variability not related to the other signals (E_t). Because truly endogenous disturbances will be random events in space and time within a forest stand of sufficient size, the endogenous disturbance impulse in the ring widths of a given tree will be largely uncorrelated with endogenous disturbance impulses in other trees from the same stand (Cook 1990, 100). The detrending of single measurement series before they are averaged into tree curves is in part based on the fact that these disturbance impulses can even be limited to a restricted area in the stem of a tree, in which case they are uncorrelated with the disturbance impulse in other stem areas of the same tree.

From the linear aggregate model it can be seen that in a ring-width series the *proportional* contribution of the exogenous and climatic components ($D2_t$ and C_t) should increase as the endogenous signal becomes weaker. The removal from ring-width series of fluctuations that reflect growth responses limited to restricted areas in the trees' stems, therefore not only improves the within-tree signals ($\bar{r}_{wt}$), but also the signal shared by different trees from the same forest stand ($\bar{r}_{bt}$ and $\bar{r}_{eff}$). The hyperbolical relationship between the within-tree and effective chronology signal defined by the Mean Correlation Technique contradicts the fact that the ring-width variability caused by tree-specific 'endogenous' influences reduces or conceals the variability caused by more general environmental (exogenous and climatological) influences. If the chronology signal would be in truth hyperbolically related to the within-tree signal, the model by Cook (1990) would be invalid and the application of noise reducing techniques to tree-ring series from the same tree superfluous or even counterproductive.

7.5 CONCLUSION

The Mean Correlation Technique (Wigley *et al.* 1984, Briffa and Jones 1990) results in ambiguous, not wholly comprehensible estimates of the chronology signal. The derivation of $\bar{r}_{bt}$ and $\bar{r}_{wt}$ according to equations (3.1) and (4.1) results in an underestimation. The estimation of the 'effective' chronology signal ($\bar{r}_{eff}$), from which the Expressed Population Signal (*EPS*) is derived, contains irregularities that are incompatible with the dendrochronological assumptions and statistical demands. Problems include (1) the interpretation of the effective chronology signal ($\bar{r}_{eff}$) as a correlation coefficient, and (2) the inadequate expression of the within-tree signal ($\bar{r}_{wt}$) in $\bar{r}_{eff}$.

On these grounds, we suggest that the within-tree signal be omitted from the Mean Correlation Technique and that correlation coefficients are averaged using Fisher's *z*-scores. In cases where more than one measurement series is available per tree, prior to the analysis for each tree the same number of series should be averaged into a *single* series. Averaging reduces noisy components, and the correlation coefficients between averaged (crossdated) series should be higher than the correlation coefficients between single observations. The use of averaged series and the transformation of their correlation coefficients into *z*-scores prior to estimating their average function should result in more comprehensive estimates of the chronology signal.

8

SYNTHESIS: DISCUSSION AND CONCLUSIONS

8.1 INTRODUCTION

This study has looked at different methods and applications of dendrochronology. The outcomes are discussed in this chapter. Section 8.2 presents a discussion of the methods that were used; section 8.3 discusses the manner and results of applying the new chronologies to actual data sets. In this chapter directions for future research are suggested.

8.2 METHODOLOGICAL ASPECTS: THE ESTIMATION OF THE SIGNAL IN TREE-RING CHRONOLOGIES

In the mid-1980's, not much was known about the sensitivity of oak to climate in the Netherlands. It had been demonstrated that growth patterns of oak from living trees, timbers and panel paintings could be matched, which had resulted in the construction of *Chronology 1* and *Chronology 2* (Eckstein *et al.* 1975). No match could be established between these chronologies, indicating that in the Netherlands distinct groups of indigenous oak existed, which are characterized by a different *climate signal* (ring-width variability that trees from different sites have in common), and that some of these groups were exploited in the past to such an extent that they became extinct (Eckstein *et al.* 1975). *Chronology 1* and *2* were not useful as a reference to date oak tree-ring series from locations in the Netherlands (Chapter 1), which suggested that the signal in indigenous oak is frequently dominated by *local growth signals,* viz., ring-width variability that only occurs in the trees at one site, or only in one tree. However, the fact that patterns of bog oaks from the western Netherlands could be matched with the Central German oak chronology (Jansma 1987), showed that indigenous oak from oceanic sites could contain a climate signal similar to that in patterns from more continental regions.

In order to investigate the types of variability present in the ring-width patterns of Dutch oak, I analysed the descriptive parameter 'Mean Sensitivity' (ζ) for oak from natural and cultural sites from the Iron Age/Roman period. ζ was developed by A. E. Douglass (1928) to assess the year-to-year variability in tree-ring series, which to a degree reflects the sensitivity of tree growth to climate. High values for ζ were interpreted chiefly in terms of stress caused by *continental* climatic factors (Fritts 1976; Fürst 1963; Fürst 1978). Because trees that respond to climatic stress often have patterns that can be matched, ζ was furthermore taken as an indication of the value of tree-ring patterns for dating purposes. The main finding was that series of oak from natural and cultural sites in the western Netherlands show values for ζ that are as high as those of series from more continental regions (Jansma, unpublished data), i.e., if ζ is related to stress, oceanic sites can be as extreme as continental sites in terms of tree-growth. Furthermore it was established that ζ cannot reflect *continuous* environmental stress, since lasting stress results in sequences of narrow rings with little variation, hence low values for ζ. This study was not published because the data set on which these findings were based is small and, more importantly, ζ proved to be an ambiguous parameter.

We demonstrated that if the underlying time series is lognormally distributed, which is the case with indexed tree-ring series, ζ is directly related to the standard deviation and the first-order autocorrelation coefficient of the series (Chapter 2). A model of this relationship was developed and applied to experimental tree-ring data. The main finding is that ζ depends solely on $\beta\sqrt{(1-r_1)}$, β being the estimated standard deviation of the series and r_1 the estimated first-order autocorrelation. This means that the value of ζ can be derived from the standard deviation (σ) and first-order autocorrelation (r_1) of the series; a large value for ζ may result from either a large value of σ, or a small value for r_1, or a combination of the two. This, by the way, explains why ζ does not reach a high value for tree-ring series that reflect continued environmental stress; intervals of narrow rings (small values) are characterized by small values for σ and high values for r_1, which leads to low values for ζ.

Because ζ had proven ambiguous, I turned to dendroclimatology for techniques to assess the signal in tree-ring series. ANOVA (Fritts 1976) and the 'Mean Correlation Technique' (Wigley *et al.* 1984) are used in climatological studies to estimate the signal in series from living trees from the same forest or forest stand. Unlike ANOVA the Mean Correlation Technique does not require that all tree-ring series overlap; it is therefore suitable for analysing long chronologies that consist of short series (e.g. oak). The adaptation published by Briffa and Jones (1990) distinguishes between the *'within-tree signal'* (the average correlation between series that represent the same tree) and the *'between-tree signal'* (the average correlation between series that represent different trees). From these the *'effective chronology signal'* is derived, from which the 'Expressed Population Signal' (*EPS*) is estimated. Because in climate studies *EPS* is required to be 0.85 or higher (Wigley *et al.* 1984), a threshold value of 0.85 was used throughout the analyses, i.e., chronology intervals with *EPS* < 0.85 were considered unreliable.

The first step was to assess whether or not *EPS* can be applied to estimate the strength of the signal in Dutch tree-ring data (Chapter 3). A data set was used from a limited period and restricted geographical domain, consisting of timbers used between AD 1463 and 1465 in the town of 's-Hertogenbosch (province of Noord-Brabant) to rebuild houses destroyed by fire. 's-Hertogenbosch is situated near the Meuse. The oak chronology of eastern Belgium, produced from the patterns in timbers from historical buildings in the Meuse Basin, had just become available (Hoffsummer 1989) and, upon request, the individual measurement series were also made available.

The historical information on trade and forest management in the region shows that fifteenth century oak timber used in 's-Hertogenbosch was collected locally as well as being imported along the Rhine and Meuse rivers (Vink 1990; Vink 1993; Chapter 3). Over a hundred timbers from historical buildings were analysed. Most of the data set consists of undatable patterns from rapidly grown, young trees; they most likely represent locally grown oak. Different groups could be not distinguished in the set of 21 timbers with felling dates around 1465.

The match of the average 's-Hertogenbosch chronology with the chronologies from adjacent countries indicates that the timbers were derived from eastern Belgium. The average chronology of 's-Hertogenbosch has a higher *EPS* than the eastern Belgium chronology. This might in part be caused by the larger number of series in the 's-Hertogenbosch chronology. When the series from eastern Belgium and 's-Hertogenbosch are combined, the value for *EPS* increases and the match with established German chronologies improves. This indicates that in the combined chronology the ring-width variations caused by local factors are less marked than they are in the separate chronologies, i.e., the combined chronology reflects general climatic conditions more accurately than the separate chronologies.

Some of the regional chronologies used in the analysis represent different geographical regions than previously assumed. The most serious problem concerns the chronology of the Lower Rhine, which in part consists of tree-ring patterns from Dutch locations (Hollstein 1980). Between AD 1327 and 1465 it shows a correlation of -0.60 with the Ardennes-Eiffel chronology of Hollstein (1980), and the interval between AD 1369 and 1465 is practically identical to his more northern chronology of the Westerwald/Sauerland area ($r = 0.72$). This indicates that the provenance of the oak series used in the Lower Rhine chronology is in another region than Hollstein assumed. It also concurs with my experience that the Medieval part of the Lower Rhine chronology does not match with patterns of oak from Dutch contexts.

Several conclusions were based on these findings: (1) given restricted, geographically and chronologically well-defined data sets it is possible to produce oak chronologies with a homogeneous signal in the Netherlands; (2) the Mean Correlation Technique can be used to estimate the strength of the signal in oak chronologies from Dutch contexts; (3) access is required to the measurement series included in a chronology if the quality of this chronology is to be assessed; (4) parts of Hollstein's regional chronologies are not useful for establishing the provenance of oak timber; (5) many oak timbers used in the Netherlands were imported, i.e., cannot be used to construct chronologies of *indigenous* oak.

The *Sub-Fossil Forests project* was partly launched in order to collect a data set of indigenous oak. The methodological purpose was to empirically establish the strength of the environmental signal, estimated through the Expressed Population Signal (*EPS*), in data sets derived from oaks that simultaneously grew at the same (oceanic) site. The largest data set was derived from the province of Zuid-Holland, from locations near Alphen aan de Rijn, Zoeterwoude and Hazerswoude (Chapter 4). Of the 55 trunks that were sampled, 36 were found to match, resulting in a chronology of 1118 years (*NLPre_ZH*, 2258 -1141 BC). *NLPre_ZH* could be matched with the North German bog oak chronology (Leuschner and Delorme 1988).

One of the main findings was that *EPS* should be estimated on short consecutive intervals of a long chronology, not on the complete interval; in the latter case, the value for *EPS* overestimates the signal (Chapter 4). Hundred-year intervals of *NLPre_ZH* require 10 to 15 series in order to reach values for *EPS* higher than 0.85. This contrasts with chronologies of arid-site conifers in the western United States, which require a minimum of four series, and with chronologies of deciduous oak in the United Kingdom, which require a minimum of 25 series (Briffa and Jones 1990). It was noted that although the residual *NLPre_ZH* chronology has both a higher *within-tree* and *between-tree signal* than the standard chronology due to the removal of the auto-correlation, its effective chronology signal as estimated by the Mean Correlation Technique is lower. This was ignored because the differences between the values were small.

NLPre_ZH matches well with the North German bog oak chronology (Chapter 4). Both this match and the values for *EPS* indicate that the patterns of bog oaks from Zuid-Holland contain a strong environmental signal. This means that contrary to former expectations oaks in the western Netherlands are stressed by *non-local* environmental factors. Given the fact that bog oaks are found in former bogs, whereas living oaks in the Netherlands prefer well-drained Pleistocene soils, the bog oaks started growing in relatively dry conditions and became stressed as a result of raised water tables (which also increased the development of local bogs, in which the remains of the trees were preserved). The water table is related to precipitation and temperature, i.e. climate. This means that the variability in bog oak chronologies reflects climate as well. The main conclusion is that, contrary to the dendrochronological findings of the 1960's and 1970's, oaks from Dutch sites are well-suited for developing climate-sensitive, indigenous chronologies.

This finding was tested by the analysis of a heterogeneous data set from the Iron Age/Roman period, consisting of 195 series of dated bog oaks and archaeological timbers from a wide variety of sites (Chapter 5). Using correlation techniques and dendrochronological matching, four groups could be distinguished. *NLRom_R*, from 46 trees derived from six natural and four archaeological sites throughout the Netherlands, runs from the end of the

Middle Iron Age to Early Merovingian times (325 BC - AD 563; *EPS* = 0.96). Given the fraction of bog oaks in this chronology, *NLRom_R* represents indigenous oak. The three other chronologies exclusively represent timbers from archaeological sites. The first, *NLRom_W1* (84 BC - AD 50), consists of 14 series from Leidschendam and Velsen and has an Expressed Population Signal (*EPS*) of 0.92. This chronology most likely represents indigenous oak from the western Netherlands, since it contains young, undressed timber and matches better with *NLRom_R* than with established chronologies from neighbouring countries. The second chronology, *NLRom_W2* (140 BC - AD 87; *EPS* = 0.98), represents 42 timbers from Nieuwenhoorn and Velsen. In Chapter 5 it was argued that this chronology represents trees from the eastern Netherlands and adjacent areas of Germany, but this is contradicted by new evidence (see below). The third chronology, *NLRom_E* (AD 190 - 395; *EPS* = 0.98), represents the series of 92 trees from archaeological sites at Cuyk, Gennep and Heeten. Given the distribution of the sites and the number of young, undressed trees (Cuyk), this chronology most likely represents forests in the southeastern Netherlands that were situated close to the archaeological sites. In other words: (1) in Dutch tree-ring data from cultural contexts (about which no *a priori* assumptions can be made regarding the provenance) sub-groups are characterized by different signal contents; (2) the most likely provenance can be deduced from the geographical distribution of the sites represented by these groups and from additional evidence such as the age of the trees and whether oak was commonly used in this period and district.

Over 80% of the dated series of timber from Dutch Medieval contexts were clustered according to their match as expressed by correlation coefficients (Chapter 6). Three historical chronologies resulted: *NLHist_1*, running from AD 427 to 1752 (259 trees), *NLHist_2*, running from AD 1023 to 1666 (195 trees) and *NLHist_3*, running from AD 1041 to 1346 (30 trees). The analysis of *EPS* showed that *NLHist_1* and *NLHist_2* contain too few samples before AD 1100 and 1300, respectively, but that *NLHist_3* contains sufficient samples. It was noted that intervals in *NLHist_1* with low values for *EPS* synchronize with intervals in the radiocarbon calibration curve that are characterized by anomalous values for ^{14}C. Based on the match with chronologies from neighbouring countries it was established that (1) the variability in *NLHist_1* closely matches that in the established chronologies, with the exception of the first and last century. Excluding the first and last part *NLHist_1* should be useful as a reference for dating, even if no series are added; (2) *NLHist_2* does not match well with established chronologies before AD 1300. It requires more series between AD 1023 (its first year) and AD 1300; (3) *NLHist_3* does not match with any established chronology and this situation is not likely to improve if series are added.

In the Netherlands the provenance of Medieval timbers is heterogeneous, which is illustrated by the problems of interpretation regarding the provenance of *Chronologies 1* and *2* (Eckstein *et al.* 1975). In order to investigate the provenance of Dutch timbers, and to reduce the chance that chronologies of locally grown oak would not be recognized, a regional analysis of the new timber chronologies was attempted. To this end, the classification by Wolff (1989) was used; he divides the Netherlands into 26 geogenetical growth regions. This classification does not result in detailed information, but nonetheless shows that *NLHist_1* dominates in the southern Netherlands, *NLHist_2* in the central and northern Netherlands, and *NLHist_3* in coastal regions and an occasional river valley. From this it can be concluded that the signal in the tree-ring patterns of Medieval timbers used in the central and northern Netherlands differs markedly from the signal in the patterns from timbers used in the southern Netherlands. This difference might be caused by (1) different trade routes for importing oak in the southern and central/ northern Netherlands, and/or (2) differences in the environmental conditions that govern the growth of indigenous oak in both regions.

Given the early date of *NLHist_3*, and given the fact that it does neither match with established chronologies nor with *NLHist_1* and *NLHist_2*, the timbers in this chronology may be indigenous. If this is the case, dendrochronology in the Netherlands should accept the explanation for deviating characteristics in Dutch chronologies offered by Eckstein *et al.* (1975), namely that some areas in the Netherlands were exploited to such an extent that in later times no wood from these areas was available, and hence chronologies that represent wood from these areas cannot be matched with established chronologies. Before doing so, however, one should investigate the possibility that *NLHist_3* represents trees from one of the neighbouring countries.

I then turned to the question of why, compared to the standard chronology, the residual *NLPre_ZH* chronology is characterized by a higher *within-tree* and *between-tree signal*, but by a lower *effective chronology signal*. The introduced hyperbolical relationship between these variables (Briffa and Jones 1990) contradicts the fact that ring-width variability caused by tree-specific endogenous influences reduces and/or conceals the variability caused by more general environmental (exogenous and climatological) influences. If the chronology signal is indeed hyperbolically related to the within-tree signal, the application of noise reducing techniques to series that represent the same tree would be superfluous or even counterproductive. In order to investigate the relationship between the *within-tree* and *effective chronology signal* the domain of these variables was analysed (Chapter 7). It was found that: (1) the derivation of the signals according to the definition by Wigley *et al.* (1984) and Briffa and Jones (1990) results in an underestimation of the actual signal, especially when the correlations approach the limits of the domain of *r* [-1,1].
The correlation coefficients from which the signal is estimated should be transformed to Fisher's *z*-scores before they are averaged; (2) the *effective chronology signal*, from which the Expressed Population Signal (*EPS*) is derived (Briffa and Jones 1990), is treated as, but in fact is not, a correlation coefficient; (3) the *within-tree signal* is inadequately expressed in the *effective chronology signal*.

In view of conclusion (3), the values for *EPS* in Chapters 5 and 6 are derived from the between-tree signal only. Conclusion (1) was established too late during the analysis to be put into effect. The implication of conclusion (1) is that the values for *EPS* established throughout this study underestimate the actual strength of the signal in the chronologies (the resulting error is largest for the highest values for *EPS*). Conclusion (2) was also established too late. Once more tree-ring series have been added to the chronologies, i.e. the overlap between the series has improved, the chronologies should be analysed using other techniques for time-series analysis.

8.3 THE APPLICATION OF CHRONOLOGIES FROM DUTCH CONTEXTS

8.3.1 *Prehistory*

The prehistoric chronology *NLPre_ZH*, developed from bog oaks found in the province of Zuid-Holland, contains series of 36 trees and runs from the Late Neolithic/Early Bronze Age to the Early Iron Age (Chapter 4). The chronological position of this and all other chronologies is shown in Figure 8.1; further details are given in Table 8.1. We refer to these summaries in the sequel.

The signal contained in *NLPre_ZH*, as estimated by *EPS*, is insufficient over two-thirds of the interval. This indicates that more series should be added. Recently, the series from three bog oaks from Papendrecht (province of Zuid-Holland) and one from Wageningen (province of Gelderland) were dated against this chronology. The Papendrecht series cover the period between 1406 and 1035 BC, i.e., since its construction *NLPre_ZH* has been extended from 1141 to 1035 BC. Interestingly, a fourth bog oak series from Papendrecht matches well with archaeological series from Ede, Oss-Mettegeupel and

Spijkenisse (provinces of Gelderland, Noord-Brabant and Zuid-Holland) and with a single bog-oak series from Weesp (province of Noord-Holland; RING, unpublished data). The combined chronology of the five locations, which was matched against the North German bog oak chronology, runs from the eleventh to the seventh century BC; a gap of seven years (1034 - 1028 BC) separates it from the extended, as yet unpublished, *NLPre_ZH* chronology. These new results show that (1) *NLPre_ZH* is suitable as a reference for dating bog oak series and (2) the tree-ring patterns in bog oaks from the first 350 years of the first millennium BC do match with the patterns in timber from cultural contexts. This is especially important in view of the chronological gap in the Dutch chronologies between 1141 (currently 1035) and 325 BC.

FIGURE 8.1 - The chronological position of oak tree-ring chronologies for the Netherlands. *Chronologies 1* and *2* are described by Eckstein *et al.* 1975

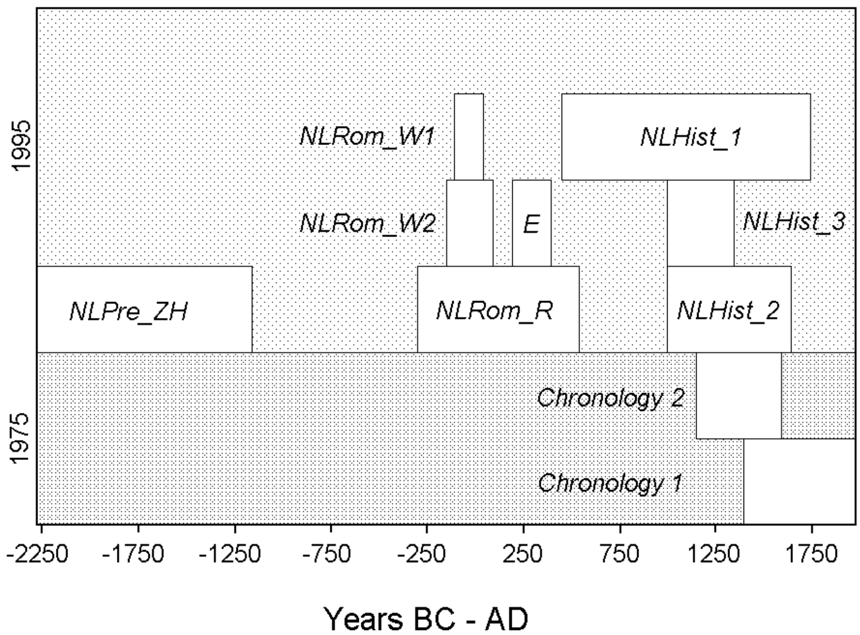


TABLE 8.1 - Overview of new tree-ring chronologies for the Netherlands

Chronology	First Year	Last Year	No. of trees	Context			Reference
				natural	archaeol.	historical	
NLPre_ZH	2258 BC	1141 BC	36	+	-	-	Chapter 4
NLRom_R	325 BC	AD 563	46	+	+	-	Chapter 5
NLRom_W2	140 BC	AD 87	42	-	+	-	Chapter 5
NLRom_W1	84 BC	AD 50	14	-	+	-	Chapter 5
NLRom_E	AD 190	AD 395	92	-	+	-	Chapter 5
NLHist_1	AD 427	AD 1752	259	-	+	+	Chapter 6
NLHist_2	AD 1023	AD 1666	195	-	+	+	Chapter 6
NLHist_3	AD 1041	AD 1346	30	+	+	-	Chapter 6

The first millennium BC is somewhat of an enigma in palaeodendrochronology. First, established oak chronologies that cover this period show minimal replication at various intervals between 800/700 and 400 BC (Schmidt and Gruhle 1988; Baillie 1993; Becker 1993). Second, during this period the similarity between the established chronologies is low (Schmidt and Gruhle 1988). Of course, these phenomena could be related, since the reliability of the signal in a chronology (in part expressed by the strength of the match with other chronologies) is, among other things, related to the number of samples. On the other hand, they could also be the expression of climatic factors, such as a sudden environmental change that caused (1) the death of oaks on low sites (fewer bog oaks) and (2) an increased local signal in surviving oaks (decreased correlations among established chronologies).

In view of the anomalous ^{14}C production during this interval (the 'Hallstatt Plateau'), Schmidt and Gruhle (1988) opt for the latter explanation and state that the climate in general became cooler and wetter. They argue that established chronologies do not match well during this period as a result of the increased *locality* of the signal in patterns of oak. The recently found match between series from Papendrecht, Weesp, Ede, Oss-Mettegeupel and Spijkenisse (and between their average chronology and the North German bog oak chronology) contradicts this line of reasoning, at least for the period between 1027 and 658 BC; it proves that oak series from this period, derived from different natural and archaeological sites, *can* be matched. In other words, oak series from the first 350 years of the first millennium BC contain a strong, and similar, environmental signal. This indicates that it is only a matter of time before *NLPre_ZH* can be linked to the newly dated series and extended into the first millennium BC. In the Netherlands no bog oaks have been found that lived from the mid-eighth century to the fourth century BC. This may indicate that oaks growing on sites at low elevations did not survive past the eighth century BC. Possible explanations are a raised water table, increased marine/fluvial activity at low sites, and increased development of bogs. However, the lack of bog oak samples in the Netherlands for this period may also, at least in part, be the result of sample bias.

Linking *NLPre_ZH* to the more recent chronology *NLRom_R* (325 BC - AD 563) is one of the current priorities in Dutch dendrochronology, because it will allow not only a closer look at the impact of the assumed environmental change on the distribution and growth characteristics of indigenous oak during this period, but also enhance the possibility of dating archaeological contexts from the first millennium BC. To this end two *floating* chronologies have already been established that contain oak tree-ring series from archaeological sites dated to the first millennium BC. The first chronology represents archaeological series from the Velserbroekpolder (province of Noord-Holland); the second chronology represents one archaeological series from Wommels (province of Friesland) and bog oak series from Papendrecht (province of Zuid-Holland) and Vriezenveen (province of Overijssel).

8.3.2 *The Iron Age/Roman period*

NLRom_R represents bog oaks and archaeological material from a variety of locations. Its signal was not analysed for different intervals. Initially, its use as a reference chronology for dating appeared to be limited; the first and last parts of *NLRom_R* (the segments before 100 BC and after AD 400) do not match well with established chronologies, and its use as a reference chronology did not result in any new dates for undated oak series for this period. Given that the first and last interval of *NLRom_R* consist of only a few series, more samples should be included. Nonetheless, the dendrochronological dates of about ten archaeological timbers from sites in Oss-Ussen and Valkenburg (provinces of Noord-Brabant and Zuid-Holland), which I established in the earliest phase of my research, were confirmed by matching with *NLRom_R* (Appendix A). And, more recently, two archaeological samples from Eme (Zutphen, province of Gelderland), which were undatable with any other chronology, could be dated to the sixth century by matching with *NLRom_R* (RING, unpublished data). This indicates that also in its current form *NLRom_R* is suitable as a reference chronology for dating.

No problem exists regarding the sample size of the three archaeological chronologies from this period. Only one timber, derived from Valkenburg (province of Zuid-Holland), has been dated so far by a match with *NLRom_W1*. *NLRom_W2* was recently used as a reference to date timbers from archaeological sites at Alphen aan de Rijn and Spijkenisse (province of Zuid-Holland; RING, unpublished data). In Chapter 5 it was argued that, in view of the match with established German chronologies, *NLRom_W2* represents trees that grew in the eastern Netherlands. The new dates established through this chronology, however, exclusively apply to archaeological sites in the province of Zuid-Holland. This indicates that the interpretation presented in Chapter 5 may be wrong and that *NLRom_W2* instead consists of series from Zuid-Holland, i.e. the western Netherlands. *NLRom_E* has been used as a reference to date timbers from archaeological sites at Bergeijk (province of Noord-Brabant) and, in an earlier version, Wehl (province of Gelderland). Given the distribution of the sites represented by *NLRom_E* (situated in the provinces of Limburg and Noord-Brabant) as well as that of the sites that can be dated by it, this chronology represents forests located in the southeastern Netherlands.

Linking the Iron Age/Roman period chronologies to the historical timber chronologies *NLHist_1, NLHist_2* and *NLHist_3* is a second priority in current Dutch dendrochronological research. Although *NLRom_R* overlaps with *NLHist_1* for more than a hundred years, the chronologies do not crossdate and cannot be combined. This could be related to differences in their geographical distribution; *NLRom_R* represents oak from low, wet locations in the central Netherlands, whereas *NLHist_1* represents oak from a broad geographical region that ranges from the Pleistocene soils in the southern Netherlands and Belgium to Central Germany. If *NLHist_1* can be linked to an earlier chronology, the most likely candidate is *NLRom_E*, which represents oak that grew in the southeastern Netherlands. *NLRom_E* runs no further than AD 395 (Table 8.1). Given that dendrochronological matching requires an overlap of 80 years or more, this chronology needs to be extended at least a hundred years before the link with *NLHist_1* can be established. It is, however, uncertain whether an extended version of *NLRom_E* will match with *NLHist_1*, because the size of the regions represented by both chronologies differs considerably.

8.3.3 *The Merovingian and Carolingian periods*

Given the geographical differences between the newly established historical chronologies and the fact that the more recent chronologies among them are either of insufficient quality before AD 1000 (*NLHist_1*) or do not even extend back this far (*NLHist_2* and *3*), more dendrochronological data are needed for the period between AD 400 and 1000. It has been shown that archaeology will profit greatly from precise dating for this particular interval (Chapter 1). Dendroclimatology provides additional reasons to focus on this period. In AD 536, either a volcano erupted or meteors struck. A cooling of the climate resulted that lasted at least a decade, and is recorded in tree-rings from Ireland and Germany (Baillie 1994). We cannot look at the environmental impact in the Netherlands, because this particular year occurs only in two bog oak series (*NLRom_R*) and one archaeological series (*NLHist_1*). The tenth century, also characterized by climatic anomalies (a cooling of the climate caused by an eruption of the Icelandic vulcano Eldgjá in about AD 940 (Zielinski *et al.* 1995); extreme drought in the Netherlands (Heidinga 1987)), is represented by about ten series (*NLHist_1*). Given their weak match (represented by a slight dip in the value for *EPS*; Chapter 6), more series should be added to this interval, both to strengthen the chronology signal and its quality for dating and to improve the quality of *NLHist_1* for climate studies. A recent success in this respect was the dating of four oak posts from Tiel (province of Gelderland) to the tenth century by matching their series with *NLHist_1* (RING, unpublished data).

8.3.4 *The Late Middle Ages*

NLHist_1 is the longest and best-replicated of the newly established Medieval chronologies. It has, however, resulted in only a few new dendrochronological dates after AD 1100. This is related to a tautology that was implicit in the research from the very beginning. The undertaking was to match samples from Dutch locations with established chronologies from neighbouring countries, and then to compile the dated series into new Dutch chronologies. In this way, a 'Dutch' chronology resulted that mirrors an established chronology abroad: *NLHist_1* strongly resembles, and possibly repeats, Hollstein's Central German oak chronology ($r = 0.62$; Chapter 6), and to a lesser extent resembles the chronology of eastern Belgium, which was produced from patterns *matched* with the Central German chronology (Hoffsummer 1989). In other words, the reason that the interval of *NLHist_1* after AD 1100 is not important in dendrochronological dating is because well-replicated chronologies for eastern Belgium and adjacent areas of Germany already exist for this period. Tree-ring series that can be matched with the established chronologies of eastern Belgium and Central Germany can also be matched with *NLHist_1*, and vice versa; hence the lack of unique dating results through the application of *NLHist_1*.

The historical chronology *NLHist_2* has proven to be the most useful of the new Medieval chronologies in recent dating research; quite a few tree-ring patterns that were undatable with established chronologies could be matched with *NLHist_2*. Although its Expressed Population Signal (*EPS*) between AD 1023 and 1300 is weak, this early interval is nevertheless suitable for dating oak from cultural contexts. This is illustrated by recent datings for the N.H. Kerk in Oudewater (province of Utrecht), a church with building phases in the fourteenth to sixteenth century. The oldest timbers in this church are in the roof of the tower and the nave. Their tree-ring series match well with *NLHist_2* and run back to AD 1182, i.e., well into the interval of *NLHist_2* that is characterized by low values for *EPS*.

In summary, it can be stated that the objectives as outlined in the introduction were well achieved. New oak chronologies have been produced from series derived from natural sites and archaeological and historical structures in the Netherlands. These chronologies allow excellent dating of archaeological and historical material for the periods 2258 - 1141 BC and 325 BC - AD 1752.

SAMENVATTING

In dit proefschrift komen diverse methoden en toepassingen van dendrochronologie aan de orde. Hieronder zijn de resultaten samengevat. Paragraaf A bevat een discussie over de gebruikte methoden, paragraaf B een discussie over de wijze waarop de nieuwe jaarringkalenders sinds hun vervaardiging worden toegepast.

A
METHODOLOGISCHE ASPECTEN: HET SCHATTEN VAN HET SIGNAAL IN JAARRINGKALENDERS

Hoofdstuk 1

In het midden van de 80er jaren was weinig bekend over de reactie van Nederlandse eiken op het klimaat. Gebleken was dat de groeipatronen van levende bomen, bouwhout en schilderijpanelen (alle eik) dateerbaar waren met Duitse kalenders; dit had geleid tot de samenstelling van *Chronologie 1* en *Chronologie 2* (Eckstein *et al.* 1975). *Chronologie 1* en *2* vertoonden echter geen onderlinge overeenkomst, wat erop leek te wijzen dat in Nederland in het verleden duidelijk onderscheiden bosbestanden bestonden, elk gekenmerkt door een ander klimaatsignaal (de variatie van ringbreedten die bomen op verschillende standplaatsen gemeen hebben), en dat deze bestanden ten dele zodanig werden geëxploiteerd dat ze later voorgoed verdwenen waren. Voorts was gebleken dat *Chronologie 1* en *2* niet goed bruikbaar waren als standaard ter datering van ongedateerd eikehout uit Nederlandse vindplaatsen en gebouwen. Dit leek erop te wijzen dat het signaal in Nederlandse eiken in het verleden gedomineerd werd door lokale groeisignalen (ringbreedtevariaties die alleen voorkomen in bomen op een enkele standplaats, of slechts in een enkele boom). Aan de andere kant was het mogelijk gebleken om de jaarringpatronen van veeneiken uit het West-Nederlandse kustgebied te correleren met de Centraal-Duitse eikkalender van Hollstein (Hollstein 1980; Jansma 1987); dit wees er juist op dat de groeipatronen van in Nederland gegroeide eiken wèl een algemeen klimaatsignaal kunnen bevatten, en zelfs een signaal dat overeenkomsten vertoont met het signaal in patronen van eiken uit regio's met een landklimaat.

Hoofdstuk 2

Om meer inzicht te verkrijgen in de soorten variabiliteit die aanwezig zijn in de jaarringpatronen van Nederlands eiken, analyseerde ik de 'Mean Sensitivity' (ζ) van eiken uit natuurlijke en antropogene contexten uit de IJzertijd/Romeinse Tijd. De beschrijvende parameter ζ werd door A.E. Douglass (1928) ontwikkeld als schatter van de variatie van ringbreedten van jaar tot jaar; deze variatie reflecteert tot op zekere hoogte de mate waarin boomgroei afhankelijk is van, en onderdrukt wordt door het klimaat (de sterkte van het klimaatsignaal). Hoge waarden voor ζ werden vooral verklaard in termen van stress die samenhangt met *continentale* klimatologische omstandigheden (Fritts 1976; Fürst 1963; Fürst 1978). Omdat de patronen van bomen die reageren op klimatologische stress vaak dateerbaar zijn, werd de waarde voor ζ daarnaast opgevat als een indicatie van het daterend potentieel van jaarringpatronen. Mijn belangrijkste bevinding was dat jaarringpatronen van eiken uit natuurlijke en antropogene vindplaatsen in West-Nederland gekenmerkt worden door even hoge waarden voor ζ als patronen uit gebieden met een landklimaat, zoals Centraal-Duitsland (Jansma, ongepubliceerde gegevens). De conclusies waren: (1) de waarde voor ζ weerspiegelt niet alleen continentale, maar ook oceanische omgevingsinvloeden; (2) indien de waarde voor ζ gerelateerd is aan stress kunnen de groeiomstandigheden voor eiken in regio's met een zeeklimaat even extreem zijn als in regio's met een landklimaat. Verder werd vastgesteld dat langdurige stress niet kan worden uitgedrukt in ζ, omdat langdurig onderdrukte groei resulteert in reeksen jaarringen die zeer smal zijn en daardoor weinig variatie vertonen van jaar tot jaar, dus in lage waarden voor ζ.

Dit onderzoek werd niet gepubliceerd; het gegevensbestand waarop de analyse was gebaseerd, bleek te klein te zijn en ζ bleek als parameter problematisch. In samenwerking met Prof. Dr. J. Strackee (Afd. Medische Fysica en Informatica, Universiteit van Amsterdam) werd vastgesteld dat een tijdreeks die een lognormale verdeling heeft, zoals een reeks geïndexeerde jaarringbreedten, een waarde voor ζ heeft die afhankelijk is van de standaarddeviatie en de eerste-orde autocorrelatie van de reeks. Er werd een model van deze relatie ontwikkeld en toegepast op bestaande jaarringseries. De belangrijkste conclusie was dat ζ volledig afhankelijk is van $\beta\sqrt{(1-r_1)}$, waarbij β de geschatte standaarddeviatie van de reeks is en r_1 de geschatte autocorrelatie. Dit houdt in dat de waarde voor ζ afgeleid kan worden uit de standaarddeviatie (σ) en de eerste-orde autocorrelatie (r_1) van een reeks (een hoge waarde voor ζ kan het resultaat zijn van een hoge waarde voor σ, een lage waarde voor r_1, of een combinatie van beide). Dit verklaart overigens waarom ζ slechts lage waarden bereikt voor jaarringpatronen die langdurige onderdrukte groei vertonen; reeksen smalle ringen (lage meetwaarden) worden gekenmerkt door lage waarden voor σ en hoge waarden voor r_1, hetgeen tot lage waarden voor ζ leidt.

Hoofdstuk 3

Omdat ζ problematisch was gebleken, richtte ik mij op dendroklimatologische methoden om het signaal in jaarringreeksen te schatten. ANOVA (variantieanalyse; Fritts 1976) en de 'Gemiddelde Correlatietechniek' (Wigley *et al.* 1984) worden in de dendroklimatologie gebruikt om het signaal te schatten in jaarringreeksen van levende bomen die tot hetzelfde bosbestand behoren. In tegenstelling tot ANOVA vereist de Gemiddelde Correlatietechniek niet dat alle jaarringreeksen volledig in de tijd overlappen; daarom is deze methode goed toepasbaar bij de analyse van lange kalenders die uit korte jaarringreeksen zijn opgebouwd, zoals kalenders van eik. Aanvankelijk werd de aangepaste correlatietechniek van Briffa en Jones (1990) gebruikt, waarbij het *in-de-boom* signaal (de gemiddelde correlatie tussen jaarringreeksen die dezelfde boom vertegenwoordigen) wordt onderscheiden van het *tussen-de-bomen* signaal (de gemiddelde correlatie tussen reeksen die verschillende bomen vertegenwoordigen). Uit deze beide wordt het *effectief chronologiesignaal* afgeleid, waaruit het 'Populatie Signaal' (*EPS*) wordt geschat. Omdat *EPS* in klimatologische studies 0.85 of hoger moet zijn (Wigley *et al.* 1984), werd tijdens alle analyses een drempelwaarde van 0.85 aangehouden, wat inhoudt dat (intervallen van) kalenders met lagere waarden voor *EPS* als onbetrouwbaar werden beschouwd.

Als eerste werd de bruikbaarheid getest van *EPS* als schatter van het signaal in Nederlandse jaarringreeksen. Hierbij werd een gegevensbestand gebruikt uit een beperkt geografisch en temporeel domein: bouwhout met veldata[1] tussen 1463 en 1465 n. Chr., dat in 's-Hertogenbosch (Noord-Brabant) was gebruikt om huizen te renoveren die in 1463 door brand waren verwoest. 's-Hertogenbosch ligt vlakbij de Maas. De Oostbelgische eikkalender, vervaardigd uit de

1. Veldatum: het jaar waarin een boom is geveld.

patronen in bouwhout uit de Maasvlakte, was zojuist beschikbaar gekomen (Hoffsummer 1989), en op verzoek werden ook de individuele metingen beschikbaar gesteld.

De historische informatie over de houthandel en het bosbeheer in de regio laat zien dat in 's-Hertogenbosch in de vijftiende eeuw zowel lokaal gegroeide eiken werden gebruikt, als eikehout dat van elders werd aangevoerd via de Rijn en Maas (Vink 1990; Vink 1993). Meer dan honderd stukken bouwhout werden geanalyseerd; de meeste hiervan vertegenwoordigden ondateerbare, jonge en snelgegroeide bomen uit de onmiddellijke omgeving van 's-Hertogenbosch. Binnen het bestand van 21 houtmonsters met veldata tussen 1463 en 1465 konden geen verschillende groepen worden onderscheiden; uit deze jaarringseries werd een 's-Hertogenbosch kalender vervaardigd.

De overeenkomst van de 's-Hertogenbosch kalender met bestaande kalenders uit de omringende landen geeft aan dat het bouwhout met veldata tussen 1463 en 1465 afkomstig was uit Oost-België en daarom waarschijnlijk via de Maas moet zijn aangevoerd. De 's-Hertogenbosch kalender heeft een hogere waarde voor *EPS* dan de Oost-België kalender. Dit zou ten dele veroorzaakt kunnen zijn door het grotere aantal jaarringpatronen in de 's-Hertogenbosch kalender. Wanneer de reeksen in beide kalenders worden gecombineerd, neemt de waarde voor *EPS* toe en wordt de overeenkomst met de overige kalenders sterker. Met andere woorden, in de gecombineerde 's-Hertogenbosch/België kalender zijn de door lokale invloeden veroorzaakte ringbreedtevariaties zwakker, en de door algemeen klimatologische invloeden veroorzaakte variaties sterker, dan in de afzonderlijke kalenders.

Enkele van de regionale kalenders die tijdens de analyse werden gebruikt, bleken een andere regio te vertegenwoordigen dan algemeen werd aangenomen. Het grootste probleem betrof de Neder-Rijn kalender, die ten dele bestaat uit patronen van hout uit Nederlandse vindplaatsen (Hollstein 1980). Tussen 1327 en 1465 n. Chr. heeft deze kalender een correlatie (r) van -0.60 met Hollstein's Ardennen-Eiffel kalender, en het interval tussen 1369 en 1465 n. Chr. is praktisch identiek aan Hollstein's meer noordelijke Westerwald-Sauerland kalender (r = 0.72). Dit houdt in dat de herkomst van het hout waarop de Neder-Rijn kalender is gebaseerd, in een ander gebied ligt dan Hollstein aannam. Ook komt het overeen met mijn ervaring dat deze kalender onbruikbaar is ter datering van eik uit Nederlandse vindplaatsen.

Deze bevindingen leidden tot de volgende conclusies: (1) gegeven beperkte en in geografisch en chronologisch opzicht goed gedefinieerde jaarringbestanden is het in Nederland mogelijk om jaarringkalenders te vervaardigen met een homogeen signaal; (2) de Gemiddelde Correlatietechniek kan inderdaad gebruikt worden om de kracht van het signaal te schatten in kalenders van hout uit Nederlandse vindplaatsen; (3) om de kwaliteit van een kalender te kunnen vaststellen, is toegang tot de individuele jaarringreeksen waaruit de kalender is opgebouwd onontbeerlijk; (4) Hollstein's regionale kalenders zijn ten dele onbruikbaar als standaard ter bepaling van de herkomst van eiken bouwhout; (5) veel van het in Nederland toegepaste bouwhout is van elders afkomstig en is daarom onbruikbaar als uitgangspunt voor Nederlandse jaarringkalenders.

Hoofdstuk 4

Het Subfossiele Bossenproject (RING/ROB) werd onder andere gestart om een gegevensbestand van inheems eiken te verzamelen. In methodologisch opzicht was het doel empirisch vast te stellen hoe sterk het omgevingssignaal, zoals geschat door *EPS*, is in patronen van inheemse eiken die tegelijk groeiden op dezelfde oceanische standplaats. Het grootste bestand werd verzameld in de provincie Zuid-Holland, op lokaties bij Alphen a/d Rijn, Zoeterwoude en Hazerswoude. Van de 55 bemonsterde stammen konden 36 onderling gedateerd worden, hetgeen resulteerde in een 1118 jaar lange kalender, *NLPre_ZH*, die loopt van 2258 tot 1141 v. Chr. *NLPre_ZH* kon absoluut gedateerd worden met behulp van de Noordduitse veeneikkalender (Leuschner and Delorme 1988).

Een van de belangrijkste bevindingen was dat *EPS* geschat dient te worden voor korte opeenvolgende intervallen van lange kalenders, niet voor het hele interval; in dat laatste geval overschat de waarde voor *EPS* het feitelijke signaal. In *NLPre_ZH* moeten intervallen van 100 jaar gerepresenteerd worden door minstens 10 à 15 jaarringpatronen, om waarden voor *EPS* te bereiken die hoger zijn dan 0.85. Dit in tegenstelling tot kalenders van naaldbomen op droge lokaties in het westen van de Verenigde Staten, die minimaal 4 patronen nodig hebben, en kalenders van eik in Engeland, die gerepresenteerd moeten worden door minstens 25 patronen (Briffa en Jones 1990). Voorts werd opgemerkt dat het *effectief chronologiesignaal* in de 'residu'-kalender van *NLPre_ZH* (de versie waaruit de autocorrelatie is gefilterd) lager is dan in de 'standaard'-kalender (waarin de autocorrelatie aanwezig is), terwijl zowel het *in-de-boom* signaal als het *tussen-de-bomen* signaal in de eerste sterker is dan in de tweede. Dit werd genegeerd, omdat het verschil tussen de waarden klein was.

NLPre_ZH komt goed overeen met de Noordduitse veeneikkalender. Zowel deze overeenkomst als de waarden voor *EPS* geven aan dat de groeipatronen van de Zuidhollandse veeneiken in sterke mate een door maritieme omgevingsinvloeden gestuurd signaal bevatten. Met andere woorden, in tegenstelling tot wat men eerder aannam werd de groei van eiken in West-Nederland niet gedomineerd door lokale, maar over grotere gebieden werkzame omgevingsinvloeden. Gegeven het feit dat deze eiken in (voormalige) venen worden aangetroffen, terwijl eik nu vooral groeit op de Pleistocene zandgronden, moeten de in venen gevonden eiken in relatief droge omstandigheden zijn ontkiemd, waarna ze in problemen kwamen door een verhoging van het grondwaterniveau (die eveneens resulteerde in een uitbreiding van de bestaande venen). Het grondwaterniveau is gerelateerd aan het klimaat, wat inhoudt dat de variatie van de ringbreedten in veeneiken een klimatologische component heeft. In tegenstelling tot de dendrochronologische bevindingen van de 60er en 70er jaren is de belangrijkste conclusie hieruit dat eiken uit Nederlandse vindplaatsen goed bruikbaar zijn voor de ontwikkeling van aan het klimaat gerelateerde kalenders.

Hoofdstuk 5

Bovenstaande conclusie werd geverifieerd met behulp van een heterogeen bestand van jaarringpatronen uit de IJzertijd/Romeinse Tijd, bestaande uit 195 patronen van zowel veeneiken als archeologisch materiaal uit zeer diverse vindplaatsen. Met behulp van correlatietechnieken en dendrochronologische dateringsmethoden konden in dit bestand vier groepen worden onderscheiden, die ieder tot een afzonderlijke kalender leidden. De kalender *NLRom_R* vertegenwoordigt 46 bomen uit zes natuurlijke en vier archeologische vindplaatsen en loopt van de Midden IJzertijd tot de vroeg-Merovingische periode (325 v. Chr. - 563 n. Chr.; *EPS* = 0.96). Gegeven het feit dat hier veeneiken in opgenomen zijn moet deze kalender inheemse eiken vertegenwoordigen. De overige drie kalenders vertegenwoordigen uitsluitend bouwhout dat in archeologische vindplaatsen is aangetroffen. De eerste archeologische kalender, *NLRom_W1* (84 v. Chr. - 50 n. Chr.), bestaat uit series uit Leidschendam en Velsen (14 totaal) en heeft een waarde voor *EPS* van 0.92. Gegeven de sterke overeenkomst met *NLRom_R* en het aandeel van jonge onbewerkte bomen in deze kalender vertegenwoordigt *NLRom_W1* waarschijnlijk eiken die in West-Nederland zijn gegroeid. De tweede archeologische kalender, *NLRom_W2* (140 v. Chr. - 87 n. Chr.), bestaat uit series uit Nieuwenhoorn en Velsen (42 totaal) en heeft een waarde voor *EPS* van 0.98. In Hoofdstuk 5 wordt beargumenteerd dat deze kalender eiken uit Oost-Nederland en aangrenzend Duitsland vertegenwoordigt, maar dit wordt tegengesproken door nieuwe gegevens (zie onder). De derde archeologische kalender, *NLRom_E* (190 - 395 n. Chr.; *EPS* = 0.98), bestaat uit series uit Cuyk, Gennep en Heeten (92 totaal). Gegeven de lokatie van de vindplaatsen en het aandeel van jonge onbewerkte bomen vertegenwoordigt deze kalender waarschijnlijk eiken die in Zuidoost Nederland groeiden, niet ver van hun archeologische vindplaatsen. De conclusie was dat in bestanden van jaarringseries uit Nederlandse antropogene vindplaatsen subgroepen kunnen worden onderscheiden die gekenmerkt worden door verschillende signalen. De regio waar de bomen in deze subgroepen groeiden kan worden afgeleid uit de geografische ligging van de vindplaatsen en aanvullende gegevens zoals de leeftijd van de bomen en de mate waarin eik in het betreffende gebied en dezelfde periode als bouwhout werd gebruikt.

Hoofdstuk 6

Vervolgens werd ruim 80% van de gedateerde jaarringreeksen uit middeleeuwse vindplaatsen in Nederland geclusterd naar aanleiding van de overeenkomst tussen de reeksen zoals deze tot uitdrukking komt in correlatie-coëfficiënten. Hieruit resulteerden drie historische kalenders: *NLHist_1* loopt van 427 tot 1752 n. Chr. (259 bomen), *NLHist_2* van 1023 tot 1666 n. Chr. (195 bomen) en *NLHist_3* van 1041 tot 1346 n. Chr. (30 bomen). Uit de waarden voor *EPS* blijkt dat *NLHist_1* en *NLHist_2* te weinig jaarringreeksen bevatten voor respectievelijk 1100 en 1300 n. Chr., en dat *NLHist_3* over zijn gehele lengte uit voldoende reeksen bestaat. Interessant is dat intervallen van *NLHist_1* die worden gekenmerkt door lage waarden voor *EPS*, synchroniseren met uit de calibratiecurve bekende perioden van afwijkende ^{14}C-produktie. Op basis van de overeenkomst met bestaande kalenders uit de omringende landen werden de volgende conclusies getrokken: (1) met uitzondering van de eerste en laatste honderd jaar komt de variatie van de jaarlijkse groeiwaarden in *NLHist_1* overeen met die in de bestaande kalenders; dit betekent dat *NLHist_1*, met uitzondering van het eerste en laatste deel, goed bruikbaar is als standaard voor dateren, zelfs indien geen nieuwe series worden toegevoegd; (2) het interval voor 1300 n. Chr. van *NLHist_2* correspondeert niet goed met de bestaande kalenders; met andere woorden, aan de eerste tweehonderd jaar van deze kalender dienen series te worden toegevoegd; (3) *NLHist_3* correspondeert slechts zwak met de bestaande kalenders en deze situatie zal niet verbeteren wanneer reeksen worden toegevoegd.

De herkomst van eikehout dat in de Middeleeuwen in Nederland werd gebruikt is divers, hetgeen geïllustreerd wordt door de interpretatieproblemen rond de herkomst van *Chronologie 1* en *2* (Eckstein *et al.* 1975). Om meer inzicht te krijgen in de herkomst van Nederlands bouwhout en om de kans te verkleinen dat kalenders van lokaal gegroeid eiken niet herkend zouden worden, werd een regionale analyse gemaakt van de nieuwe bouwhout-kalenders. Hierbij werd de classificatie van Wolff (1989) gebruikt, volgens welke Nederland opgedeeld wordt in 26 geogenetische groeigebieden. Hoewel deze analyse niet tot gedetailleerde nieuwe informatie leidde, werd toch duidelijk dat *NLHist_1* dominant is in Zuid-Nederland, *NLHist_2* in Centraal- en Noord-Nederland, en *NLHist_3* in de kustgebieden en een incidentele riviervallei. Hieruit blijkt dat het signaal in de jaarringpatronen van Middeleeuws eiken dat in Centraal- en Noord-Nederland werd toegepast, sterk verschilt van het signaal in eikehout dat zuidelijker werd gebruikt. Dit verschil kan op twee manieren verklaard worden: (1) in Centraal- en Noord-Nederland werd eikehout aangevoerd vanuit andere herkomstgebieden, en langs andere routes, dan in Zuid-Nederland; (2) de omgevingsfactoren die de groei van inheems eiken in Centraal- en Noord-Nederland beïnvloeden, zijn wezenlijk anders dan de omgevingsfactoren in Zuid-Nederland.

Zowel de vroege datering van *NLHist_3* als de zwakke overeenkomst met de bestaande kalenders (inclusief *NLHist_1* en *NLHist_2*) wijzen uit dat deze kalender mogelijk inheemse eiken vertegenwoordigt. Als dit zo is moet dendrochronologie in Nederland de verklaring van Eckstein *et al.* (1975) weer aanvaarden, volgens welke bepaalde bosbestanden in Nederland in het verleden zodanig zijn geëxploiteerd dat ze verdwenen zijn, waardoor kalenders van patronen uit deze bosbestanden niet overeenkomen met andere kalenders. Voordat deze verklaring wordt aanvaard, dient echter te worden nagegaan of *NLHist_3* wellicht bomen uit een van de andere Europese landen vertegenwoordigt.

***Hoofdstuk** 7*

Tot slot werd de vraag gesteld waarom de 'residu'-kalender van *NLPre_ZH* in vergelijking met de standaardkalender een hoger *in-de-boom* signaal en *tussen-de-bomen* signaal bevat, maar een lager *effectief chronologiesignaal* (en dus een lagere *EPS*; Hoofdstuk 7). Briffa en Jones (1990) introduceerden een hyperbolische relatie tussen het *in-de-boom* signaal en het *effectief chronologiesignaal* (naarmate het eerste sterker wordt, wordt het tweede zwakker). Dit is in tegenspraak met het gegeven dat ringbreedtevariaties veroorzaakt door endogene (voor een enkele boom geldende) omgevingsinvloeden de variaties verhullen die veroorzaakt zijn door meer algemene (exogene en/of klimatologische) invloeden. Als het *effectief chronologiesignaal* inderdaad hyperbolisch gerelateerd zou zijn aan het *in-de-boom* signaal, zou de toepassing van ruis-reducerende technieken op jaarringseries die dezelfde boom vertegenwoordigen, contraproduktief zijn. Uit de analyse van het domein van, en de relatie tussen, deze variabelen blijkt: (1) de wijze waarop het signaal wordt geschat door Wigley *et al.* (1984) en Briffa and Jones (1990) leidt tot een onderschatting van het feitelijk signaal, met name wanneer de correlatiecoëfficiënten de grenzen van het domein van *r* naderen [-1,1]; de coëfficiënten dienen getransformeerd te worden tot Fisher's *z*-scores voordat hun gemiddelde wordt bereken; (2) het *effectief chronologiesignaal* (Briffa en Jones 1990) wordt behandeld als een correlatiecoëfficiënt, maar is dit niet; (3) het *in-de-boom* signaal komt onvolledig tot uitdrukking in het *effectief chronologiesignaal*.

Gegeven conclusie (3) werden de waarden voor *EPS* in Hoofdstukken 5 en 6 afgeleid uit het *tussen-de-bomen* signaal, en bleef in deze hoofdstukken het *in-de-boom* signaal buiten beschouwing. Conclusie (1) werd te laat getrokken om nog in de berekeningen te worden opgenomen; de hier gepubliceerde waarden voor *EPS* onderschatten daarom het feitelijk signaal in de kalenders (de onderschatting is groter naarmate de waarden voor *EPS* hoger zijn). Ook conclusie (2) werd te laat getrokken. Gesteld dat meer jaarringreeksen aan de kalenders kunnen worden toegevoegd, waardoor de individuele reeksen beter overlappen, dienen de kalenders geanalyseerd te worden met behulp van andere technieken van tijdreeksanalyse dan de Gemiddelde Correlatietechniek.

B
DE TOEPASSING VAN KALENDERS UIT NEDERLANDSE VINDPLAATSEN

- ***Prehistorie***

NLPre_ZH is opgebouwd uit 36 veeneiken uit Zuid-Holland en loopt van 2258 tot 1141 v. Chr. Het signaal is onvoldoende in tweederde van de chronologie, wat betekent dat er meer jaarringpatronen in moeten worden opgenomen. Drie recent onderzochte veeneiken uit Papendrecht (Zuid-Holland) konden met *NLPre_ZH* gedateerd worden, waardoor de kalender met ruim honderd jaar kon worden verlengd tot 1035 v. Chr. Ook een veeneik uit Wageningen kon met *NLPre_ZH* worden gedateerd. Dit betekent dat *NLPre_ZH* goed bruikbaar is als standaard voor het dateren van in Nederland gegroeide eiken uit de betreffende periode.

Een vierde veeneik uit Papendrecht vertoont een sterke overeenkomst met archeologische series uit Ede, Oss-Mettegeupel en Spijkenisse (Gelderland, Noord-Brabant en Zuid-Holland) en een veeneik uit Weesp. Uit dit nieuwe materiaal is onlangs een kalender vervaardigd die met de Noordduitse veeneikkalender gedateerd kon worden en loopt van 1027 tot 658 v. Chr., wat betekent dat *NLPre_ZH* nog maar met enkele jaren verlengd hoeft te worden voordat koppeling met de nieuwe, jongere, kalender mogelijk is. Dit is vooral van belang gezien het feit dat in Noordwest-Europa voor het eerste millennium v. Chr maar weinig jaarringkalenders bestaan. Een van de prioriteiten van het huidige dendrochronologische onderzoek in Nederland is het koppelen van *NLPre_ZH*, via de nieuwe kalender, aan *NLRom_R*, waardoor (1) de mogelijkheid tot het dateren van archeologisch materiaal uit het eerste millennium v. Chr. toe zou nemen, en (2) jaarringonderzoek mogelijk wordt naar de veronderstelde klimaatverandering in het eerste millennium v. Chr. (Schmidt en Gruhle 1988).

- ***De IJzertijd/Romeinse Tijd***

NLRom_R vertegenwoordigt veeneiken en archeologisch materiaal uit zeer diverse vindplaatsen, en loopt van 325 v. Chr. tot 563 n. Chr. De intervallen voor 100 v. Chr. en na 400 n. Chr. worden door slechts enkele jaarringreeksen vertegenwoordigd en komen niet optimaal overeen met de bestaande kalenders; deze delen van *NLRom_R* dienen daarom verfijnd te worden met behulp van meer jaarringreeksen.

De dateringen van tien archeologische jaarringreeksen uit Oss-Ussen en Valkenburg (Noord-Brabant en Zuid-Holland) konden met behulp van deze kalender bevestigd worden (Appendix A). Onlangs konden twee archeologische houtmonsters uit Eme (Zutphen, Gelderland) met behulp van *NLRom_R* in de zesde eeuw worden gedateerd. De conclusie is dat *NLRom_R* bruikbaar is voor dateren, inclusief het laatste segment dat uit slechts enkele jaarringreeksen bestaat.

De drie archeologische kalenders uit deze periode bevatten voldoende jaarringseries. *NLRom_W1*, die uit 14 series bestaat en loopt van 84 v. Chr. tot 50 n. Chr., heeft tot dusver slechts een enkele nieuwe datering opgeleverd. *NLRom_W2* (42 series; 140 v. Chr. - 87 n. Chr.) is zeer bruikbaar gebleken ter datering van archeologisch materiaal uit Alphen a/d Rijn en Spijkenisse. In Hoofdstuk 5 werd beargumenteerd dat deze kalender een Oost-Nederlandse of zelf Duitse herkomst heeft. De nieuwe dateringen echter betreffen alle materiaal dat, evenals het in *NLRom_W2* opgenomen materiaal, afkomstig is uit vindplaatsen in Zuid-Holland. Een Zuid-Hollandse herkomst van het materiaal mag daarom niet uitgesloten worden. *NLRom_E*, die bestaat uit series uit Cuyk, Gennep en Heeten (92 totaal), loopt van 190 tot 395 n. Chr. en vertegenwoordigt eiken die in Zuidoost Nederland groeiden. Deze kalender heeft geleid tot dateringen van archeologisch materiaal uit Bergeijk en Wehl. Samenvattend zijn ook de archeologische kalenders *NLRom_W1*, *NLRom_W2* en *NLRom_E* goed bruikbaar als standaard bij het dateren van eikehout uit Nederlandse vindplaatsen.

- ***De Merovingische en Karolingische perioden***

NLRom_R loopt door tot 563 n. Chr. Slechts een van de drie historische kalenders, *NLHist_1*, bestrijkt het hierop volgende interval tussen 564 en 1000 n. Chr. Er zijn met andere woorden meer dendrochronologische gegevens nodig voor deze periode. Een recent succes in dit opzicht is de datering met behulp van *NLHist_1* van vier eiken palen uit Tiel in de 10e eeuw n. Chr.

- ***De Late Middeleeuwen***

NLHist_1 (427 - 1752; 259 bomen) is de langste van de historische kalenders en vertegenwoordigt de meeste bomen. Toch heeft deze kalender voor de periode na 1100 n. Chr. tot weinig nieuwe dateringen geleid. Dit komt door de herkomst van de jaarringpatronen die in *NLHist_1* opgenomen zijn. De betreffende eiken groeiden in Zuid-Nederland, Oost-België en aangrenzend Duitsland; globaal hetzelfde gebied als dat waar de kalenders van Centraal-Duitsland (Hollstein 1980) en Oost-België (Hoffsummer 1989) betrekking op hebben. Jaarringpatronen die gedateerd kunnen worden met de Belgische en Duitse kalenders, kunnen gedateerd worden met *NLHist_1*, en omgekeerd.

NLHist_2 (1023 - 1666 n. Chr.) is de meest bruikbare van de nieuwe historische kalenders; met deze kalender, die eiken vertegenwoordigt uit Centraal- en Noord-Nederland en aangrenzend Duitsland (Westfalen, Nedersaksen) zijn al vele nieuwe dateringen verricht. Het signaal in de eerste tweehonderd jaar (1023 - 1300) is zwak. Uit recente dateringen van bouwhout uit de N.H. Kerk in Oudewater (Utrecht) blijkt echter dat ook dit vroege interval geschikt is als standaard bij dateringen.

Samenvattend kan gesteld worden dat de onderzoeksdoeleinden die in de introductie (Hoofdstuk 1) werden omschreven, zijn bereikt. Nieuwe jaarring - kalenders zijn vervaardigd uit eikehout dat afkomstig is uit natuurlijke, archeologische en historische vindplaatsen in Nederland. Deze kalenders, die ruim 3000 kalenderjaren bestrijken, zijn goed bruikbaar als standaard voor het dateren van in Nederland aangetroffen eikehout dat stamt uit de perioden 2258 - 1141 v. Chr. en 325 v. Chr. - 1752 n. Chr.

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APPENDIX

A

ABSOLUTELY DATED TREE-RING SERIES OF OAK FROM ANTHROPOGENIC AND NATURAL SITES IN THE NETHERLANDS

The dates listed below were established between 1985 and 1995 at the Dutch Centre for Dendrochronology (RING Foundation/ROB) and the laboratories it replaced (IPP; ROB). About 50 series that were dated during the earliest stages of dendrochronological research (1985/1986) could not be retrieved. The research was performed for many organizations, including the ‘Albert Egges van Giffen’ Institute for Pre- and Protohistoric Archaeology (IPP/Univ. of Amsterdam), the State Service for the Preservation of Monuments and Historic Buildings (RDMZ, Zeist), the State Service for Archaeological Research (ROB, Amersfoort), the *Bouwhistorische Dienst* ’s-Hertogenbosch, and universities and municipal archaeological and historical organizations in the Netherlands.

The statistics that accompany the dates are not always identical to the information made available to the organization(s) and persons for which the research was conducted. As part of the EC-programme *Temperature Change over Northern Eurasia during the last 2500 Years* (Contract No. CV5V CT94 0500) all dates were verified in 1994 by the author and her co-workers P. van Rijn and E. Hanraets (RING). During this process chronologies that have become available in recent years were used as a reference; this has resulted in new values for *St* and *PV*. When these are listed instead of the original values, it is because they provide a better argument for a dendrochronological date.

For each archaeological/historical object and natural site the following details are given:

First line	location; type of object; institute for which the research was conducted; references;
Object	sample description (e.g., find number, construction element, assembly-mark); the terms used for construction elements in buildings were derived from Haslinghuis (1986). Ships’ elements have been named in consultation with Dr. J. H. G. Gawronski (IPP);
Filename	the name of the computer file at RING;
Dendro-code	the dendrochronological code of the sample; this code is based on the country (first two digits), ecological growth-region (third digit, after Wolff *et al.* 1989), site number (fourth and fifth digits) and sample number (last three digits);
No.	the number of rings that were measured on the sample;
Date	the calender date of the last, outer, ring that was measured; in most cases this date is earlier than the actual felling date of the tree, as a result of the fact that rings are missing on the outside of the sample.
Reference	the code of the chronology used to date the sample (see Appendix B for a description of the chronologies);
St	the *Student’s t-value* that accompanies the match with the reference chronology;
PV	the *Coefficient of Parallel Variation* that accompanies the match with the reference chronology;
NL	the name of the Dutch chronology into which the series has been incorporated;
Remarks	further details.

AALTEN — Castle of Bredevoort (Oudheidk. Werkgemeenschap Aalten)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Oak post	ABP00011	NLC02001	104	1417	DLWF	6.3	64.6	*NLHist_2*

ABCOUDE — Bog oaks (Hist. werkgemeenschap Abcoude; Sub-Fossil Forests Project (RING/ROB; Jansma 1987))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Trunk 1	ABC00011	NLR20001	179	-4	DLNO	6.2	59.3	*NLRom_R*	Date through avg. chronology
Trunk 2	ABC00021	NLR20002	227	7	DLNO	idem	idem	*NLRom_R*	
Trunk 3	ABC00030	NLR20003	13	-164	DLNO	idem	idem	*NLRom_R*	
Trunk 4	ABC00041	NLR20004	148	-68	DLNO	idem	idem	*NLRom_R*	
Trunk 6	ABC00060	NLR20005	162	30	DLNO	idem	idem	*NLRom_R*	
Trunk 7	ABC00071	NLR20006	123	-122	DLNO	idem	idem	*NLRom_R*	
Trunk 8	ABC00081	NLR20007	112	-149	DLNO	idem	idem	*NLRom_R*	
Trunk 11	ABC00110	NLR20008	150	-153	DLNO	idem	idem	*NLRom_R*	
Trunk 12	ABC00121	NLR20009	94	-64	DLNO	idem	idem	*NLRom_R*	
Trunk 13	ABC00301	NLR20010	187	-139	DLNO	idem	idem	*NLRom_R*	

AKKRUM — De Deelen, bog oaks (Sub-Fossil Forests Project (RING/ROB))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Trunk 1	DDF00010	Not coded yet	143	-5824	DLNO	5.9	65.1	Not clustered yet
Trunk 2	DDF00020	Not coded yet	140	-5733	DLNO	3.9	61.9	Not clustered yet
Trunk 3	DDF00030	Not coded yet	147	-5663	DLNO	3.2	60.6	Not clustered yet
Trunk 4	DDF00040	Not coded yet	114	-5495	DLNO	4.9	61.5	Not clustered yet
Trunk 5	DDF00050	Not coded yet	83	-5513	Intern	7.7	73.2	Not clustered yet
Trunk 7	DDF00070	Not coded yet	128	-5491	DLNO	6.0	72.0	Not clustered yet
Trunk 8	DDF00080	Not coded yet	151	-5508	DLNO	5.3	63.0	Not clustered yet
Trunk 9	DDF00090	Not coded yet	145	-5496	DLNO	7.8	67.7	Not clustered yet
Trunk 10	DDF00100	Not coded yet	97	-5673	Intern	9.8	76.6	Not clustered yet
Trunk 11	DDF00110	Not coded yet	115	-5492	DLNO	6.1	64.5	Not clustered yet
Trunk 13	DDF00130	Not coded yet	99	-5512	DLNO	4.2	66.3	Not clustered yet
Trunk 14	DDF00140	Not coded yet	115	-5470	DLNO	5.3	67.5	Not clustered yet
Trunk 15	DDF00150	Not coded yet	116	-5513	DLNO	4.4	63.5	Not clustered yet
Trunk 18	DDF00180	Not coded yet	131	-5467	DLNO	3.3	62.7	Not clustered yet

ALKMAAR — Barrel (Dr. Cordfunke)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Stave 1	IALK0011	NLV02001	128	1220	NLTF	5.3	65.2	*NLHist_3*	Date through avg. chronology
Stave 2	IALK0021	NLV02002	194	1239	NLTF	idem	idem	*NLHist_3*	
Stave 3	IALK0031	NLV02003	112	1237	NLTF	idem	idem	*NLHist_3*	
Stave 4	IALK0041	NLV02004	189	1229	NLTF	idem	idem	*NLHist_3*	
Stave 5	IALK0051	NLV02005	131	1213	NLTF	idem	idem	*NLHist_3*	
Stave 6	IALK0061	NLV02006	175	1233	NLTF	idem	idem	*NLHist_3*	
Stave 7	IALK0071	NLV02007	102	1236	NLTF	idem	idem	*NLHist_3*	

ALKMAAR — Magdalenastraat, barrel (Dr. Cordfunke)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Stave 1	IALM0011	NLV01001	125	1329	NLTF	5.6	65.7	-

ALKMAAR — Mient 31 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Roof, laid-on beam <<<<	AME0001A	NLV14001	174	1536	BMBA	8.8	74.7	-	Date through avg. chronology
Roof, laid-on beam ///	AME0002A	NLV14002	178	1544	BMBA	idem	idem	*NLHist_1*	
Roof, curved brace //// (left)	AME0003A	NLV14003	80	1525	BMBA	idem	idem	*NLHist_2*	
Roof, principal ///	AME0004A	NLV14004	53	1545	BMBA	idem	idem	*NLHist_2*	

ALPHEN A/D RIJN — Bog oaks (ARCHEON; Sub-Fossil Forests Project (RING/ROB))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Trunk 2	AFE00020	Not coded yet	140	-1210	DLNO	14.82	64.6	*NLPre_ZH*	Date through avg. chron. *NLPre_ZH*
Trunk 3	AFE00030	Not coded yet	218	-1890	DLNO	idem	idem	*NLPre_ZH*	
Trunk 4	AFE00040	Not coded yet	158	-1163	DLNO	idem	idem	*NLPre_ZH*	
Trunk 5	AFE00050	Not coded yet	70	-1932	DLNO	idem	idem	*NLPre_ZH*	
Trunk 6	AFE00060	Not coded yet	178	-1725	DLNO	idem	idem	*NLPre_ZH*	
Trunk 7	AFE00070	Not coded yet	72	-1910	DLNO	idem	idem	*NLPre_ZH*	
Trunk 8	AFE00080	Not coded yet	112	-1772	DLNO	idem	idem	*NLPre_ZH*	
Trunk 9	AFE00090	Not coded yet	109	-1771	DLNO	idem	idem	*NLPre_ZH*	
Trunk 10	AFE00100	Not coded yet	167	-1825	DLNO	idem	idem	*NLPre_ZH*	
Trunk 11	AFE00110	Not coded yet	257	-2002	DLNO	idem	idem	*NLPre_ZH*	
Trunk 12	AFE00120	Not coded yet	145	-1762	DLNO	idem	idem	*NLPre_ZH*	
Trunk 14	AFE00140	Not coded yet	168	-1215	DLNO	idem	idem	*NLPre_ZH*	
Trunk 16	AFE00160	Not coded yet	183	-2015	DLNO	idem	idem	*NLPre_ZH*	

ALPHEN A/D RIJN	Roman sheds (AWN)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
10.288.78 H2	C5A0102Z	NLR18001	70	76	*NLRom_W2*	5.7	73.2	-
10.290.80 H1	C5A0104A	NLR18002	181	79	*NLRom_W2*	5.5	71.9	-
11.587.157 H2	C5A0203B	NLR18003	164	72	*NLRom_W2*	6.7	69.0	-
12.234.14. H1	C5A0301Z	NLR18004	91	77	*NLRom_W2*	6.1	74.4	-
12.234.14	C5A0302B	NLR18005	118	113	*NLRom_W2*	5.0	74.2	-
12.236.12 H1	C5A0303Z	NLR18006	62	65	*NLRom_W2*	3.1	74.6	-
12.237.11 H4	C5A0307A	NLR18007	133	79	*NLRom_W2*	5.2	68.9	-
13.381 H1	C5A0404B	NLR18008	63	78	*NLRom_W2*	5.3	73.4	-
13.381.6 H3	C5A0405B	NLR18009	176	110	*NLRom_W2*	4.6	68.8	-
13.382 H1	C5A0406Z	NLR18010	128	63	*NLRom_W2*	6.6	66.1	-
13.382 H2	C5A0407Z	NLR18011	158	67	*NLRom_W2*	6.8	74.5	-

AMERSFOORT	Triptych, Johan van Oldenbarneveld estate (Flehite Museum, Amersfoort)								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Left and right panel (1 tree)	DRL12000	NLE06001	102	1461	NLPP	5.1	69.8	-	Date through avg. chronology
Central panel	DRL0003Z	NLE06002	208	1596	NLPP	idem	idem	-	

AMERSFOORT	Hof 11 (RDMZ))							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Sleeper beam 1	AHE00011	NLE04001	116	1548	DLWF	5.4	60.0	*NLHist_2*
Sleeper beam 3	AHE00031	NLE04002	99	1495	Intern	Visual date		*NLHist_2*

AMERSFOORT	Koppelpoort (RDMZ))								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Horizontal beam, southern post	AKP00011	NLE08001*	76	1439	*NLHist_2* (ev)	5.2	63.3	*NLHist_2*	ev = early version; * = new date
Curved brace, northern post	AKP00051	NLE08002*	41	1439	Intern	Visual date		*NLHist_2*	* = new date

AMERSFOORT	O.L.V. Toren (RDMZ; de Vries 1994)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Belfry, brace /	AOL00061	NLE03001	59	1293	DLCE	5.3	72.4	*NLHist_2*

AMERSFOORT	St. Joriskerk (RDMZ)								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Main choir, North, principal ///	AJK00061	NLE01001	119	1403	NLTF	10.2	71.2	*NLHist_2*	
Main choir, tie-beam <////	AJK00071	NLE01002	88	1398	NLTF	5.3	60.9	*NLHist_2*	
Main choir, ashlar-piece, truss <//	AJK00081	NLE01004	80	1422	NLTW	5.3	70.8	-	
Middle-aisle, principal O=	AJK00121	NLE01003	85	1434	NLTF	5.8	64.3	*NLHist_2*	
Northern bay, West, principal <<	AJK00141	NLE01005*	43	1469	*NLHist_2* (ev)	5.9	72.1	*NLHist_2*	ev = early version; * = new date

AMSTERDAM	Petronella Oortman doll's house (Rijksmuseum)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Kitchen ceiling	ARPSTD	NLR15001	235	1677	DLSO	10.0	67.7	-

AMSTERDAM	Castle "Kostverloren"								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
	AKK00020	NLR34001*	45	1425	*NLHist_2* (ev)	7.7	65.9	*NLHist_2*	* = new date

AMSTERDAM	Nieuwezijds Kolk, "Castle of the Lords of Amstel" (Inst. für Holzbiologie Hamburg; Jansma and Kars 1995)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M2	NZK0002M	NLR31001	127	1218	DLWB	5.0	69.4	-
M9	NZK0009M	NLR31002	113	1215	DLWB	idem	idem	*NLHist_1*
M6	NZK0006M	NLR32001	116	1272	DLCE	7.8	68.3	*NLHist_1*
M8	NZK0008M	NLR32002	92	1254	DLCE	6.0	68.7	*NLHist_1*

AMSTERDAM	Victoria Hotel (Afdeling Archeologie Amsterdam)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M165	IASD0031	NLR12001	91	1361	NLTF	5.8	67.2	*NLHist_2*

AMSTERDAM	Waalse Kerk (RDMZ)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Northern bay, centre, rafter //	IAWK0011	NLR05001	58	1488	NLTF	5.6	72.8	*NLHist_2*

AMSTERDAM	Ship "Het vliegend Hart" (Scheepvaartmuseum Amsterdam)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Unknown	IAVH0011	NLR13001	172	1601	DLCE	9.4	70.5	*NLHist_1*

APELDOORN — Foundation (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
5-1-25	APS00010	NLH02001	102	1339	DLNS	4.9	68.1	*NLHist_3*	Date through avg. chronology
5-1-23	APS00020	NLH02002	99	1346	idem	idem	idem	*NLHist_3*	
5-1-24	APS00030	NLH02003	101	1334	idem	idem	idem	*NLHist_3*	
4-1-13	APS00040	NLH02004	62	1346	idem	idem	idem	*NLHist_2*	
4-1-12	APS00050	NLH02005	136	1346	idem	idem	idem	-	Date through avg. chronology
4-1-12	APS00060	NLH02006	121	1342	idem	idem	idem	*NLHist_3*	

APPINGEDAM — Dijkstraat 30, cellar (ROB; Groenendijk 1994; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Oak beam	APW00010	NLV16001	96	1117	DLNS	6.1	67.4	*NLHist_1*

ASSENDELFT — Coffins (IPP)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
1618	ASS01618	NLR03001	89	985	DLCE	6.2	70.9	*NLHist_1*
1726	ASS01726	NLR03002	103	977	Intern	5.6	63.1	*NLHist_1*

BAARN — Bog oak (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Oak 1	C6C0104Z	NLR33001*	168	1228	*NLHist_3* (ev)	6.7	66.2	*NLHist_3*	ev = early version; * = new date

BANHOLT — Eijsden Stiegel 2 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M1	IBHE00011	not coded yet	56	1556	*NLHist_1*	7.2	82.7	Not clustered yet
M2	IBHE00021	not coded yet	45	1561	*NLHist_1*	6.8	73.9	Not clustered yet

BELTRUM — Farmhouse (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Truss beam >>>>	INOM0010	NLC01001	91	1528	NLTF	6.7	68.3	*NLHist_2*	
Curved brace >>>	INOM0020	NLC01002	62	1519	NLTF	5.8	62.4	-	Date through avg. chronology
Curved brace | <	INOM0030	NLC01003	86	1528	idem	idem	idem	*NLHist_2*	of C01002, C01003
Truss, curved brace [] [] [] []	INOM0050	NLC01004	82	1527	NLTF	8.4	74.1	*NLHist_2*	

BERGEIJK — Water well (IPP)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Plank 12	IBYK0011	NLJ01001	77	363	Intern	Visual date		Not clustered yet
Plank 28	IBYK0031	NLJ01002	67	367	Intern	6.8	73.5	Not clustered yet
Plank 31	IBYK0071	NLJ01003	96	390	Intern	6.3	70.0	Not clustered yet
Plank 37	IBYK0081	NLJ01004	109	396	*NLRom_E*	5.6	67.3	Not clustered yet
Plank 33	IBYK0091	NLJ01005	73	365	Intern	Visual date		Not clustered yet
293	IBYK0101	NLJ01006	83	386	Intern	Visual date		Not clustered yet
Plank 32	IBYK0111	NLJ01007	90	375	*NLRom_E*	6.4	62.9	Not clustered yet
Plank 27	IBYK0131	NLJ01008	52	366	Intern	Visual date		Not clustered yet
Plank 16	IBYK0151	NLJ01009	71	374	Intern	6.3	77.9	Not clustered yet

BREDA — Cingelstraat 1-3, Huis Brecht (RDMZ; de Vries 1990; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
W. wing, principal ((((	IHVB0010	NLJ03001	106	1532	DLCE	7.0	73.3	*NLHist_1*
W. wing, principal (	IHVB0020	NLJ03002	74	1527	DLCE	3.9	70.5	*NLHist_1*
N.E. wing, laid-on beam I	IHVB0030	NLJ03003	78	1538	DLCE	6.3	68.6	*NLHist_1*

BRIELLE — Nobelstraat 19 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
1st sleeper beam from façade	IBNO0011	NLW03001	162	1283	BMBA	6.9	73.5	*NLHist_1*
2nd sleeper beam from façade	IBNO0021	NLW03002	131	1299	BMBA	6.9	69.5	*NLHist_1*
Roof, laid-on beam (((	IBNO0031	NLW03003	118	1553	BMBA	6.8	70.3	*NLHist_1*
Roof, roof plate 21	IBNO0041	NLW03004	89	1523	DLWF	5.9	67.4	*NLHist_2*
Roof, laid-on beam ((	IBNO0061	NLW03005	70	1563	BMBA	4.5	78.3	*NLHist_2*

BUREN — Tower N. H. Kerk (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Post VII	BUT00011	NLQ28001	147	1637	DLNS	6.3	66.4	*NLHist_2*
Curved brace VII	BUT00021	NLQ28002	104	1662	DLNS	4.7	69.4	-
Curved brace ((((	BUT00041	NLQ28003	85	1649	DLSO	5.6	66.7	*NLHist_1*
Console under post VII	BUT00051	NLQ28004	83	1659	DLNS	6.5	72.2	*NLHist_2*

BUURMALSEN — N. H. Kerk (D. S. van Dorsser Keus)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Truss I	C6A0111Z	NLQ22001	128	1494	BMBA	5.7	67.3	*NLHist_1*

COLMSGATE — Water well (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
104-3-4	COW00010	NLH01001	217	251	DLNO	5.2	60.9	*NLRom_R*

CUYK — Roman bridge (AAOW/ROB; Goudzwaard 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
207	CUY00010	NLN10001	82	349	DLCE	6.0	66.2	*NLRom_E*	Date through avg. chronology
702	CUY00020	NLN10002	65	318	DLCE	idem	idem	*NLRom_E*	
703	CUY00041	NLN10003	44	296	DLCE	idem	idem	*NLRom_E*	
700	CUY00060	NLN10004	97	371	DLCE	idem	idem	*NLRom_E*	
200	CUY00070	NLN10005	71	326	DLCE	idem	idem	*NLRom_E*	
4000-1-89	CUY00181	NLN10006	50	352	DLCE	idem	idem	*NLRom_E*	
4000-22	CUY00201	NLN10007	54	336	DLCE	idem	idem	*NLRom_E*	
3000-84	CUY00211	NLN10008	47	307	DLCE	idem	idem	*NLRom_E*	
4000-31	CUY00221	NLN10009	89	344	DLCE	idem	idem	*NLRom_E*	
3000-36	CUY00231	NLN10010	43	317	DLCE	idem	idem	*NLRom_E*	
3000-47	CUY00240	NLN10011	72	325	DLCE	idem	idem	*NLRom_E*	
4000-52	CUY00251	NLN10012	52	347	DLCE	idem	idem	*NLRom_E*	
3000-38	CUY00261	NLN10013	33	298	DLCE	idem	idem	*NLRom_E*	
3000-91	CUY00271	NLN10014	43	317	DLCE	idem	idem	*NLRom_E*	
3000-7	CUY00281	NLN10015	60	317	DLCE	idem	idem	*NLRom_E*	
4000-48	CUY00291	NLN10016	50	347	DLCE	idem	idem	*NLRom_E*	
4000-56	CUY00300	NLN10017	118	367	DLCE	idem	idem	*NLRom_E*	
4000-44	CUY00310	NLN10018	111	367	DLCE	idem	idem	*NLRom_E*	
4000-32	CUY00320	NLN10019	39	368	DLCE	idem	idem	*NLRom_E*	
3000-44	CUY00331	NLN10020	80	354	DLCE	idem	idem	*NLRom_E*	
3000-20	CUY00340	NLN10021	66	349	DLCE	idem	idem	*NLRom_E*	
3000-LV92/9	CUY00351	NLN10022	67	353	DLCE	idem	idem	*NLRom_E*	
4000-1	CUY00361	NLN10023	70	348	DLCE	idem	idem	*NLRom_E*	
4000-3	CUY00370	NLN10024	77	339	DLCE	idem	idem	*NLRom_E*	
3000-5	CUY00381	NLN10025	97	372	DLCE	idem	idem	*NLRom_E*	
3000-1	CUY00391	NLN10026	64	338	DLCE	idem	idem	*NLRom_E*	
4000-50	CUY00400	NLN10027	92	345	DLCE	idem	idem	*NLRom_E*	
4000-LV92/10	CUY00411	NLN10028	94	367	DLCE	idem	idem	*NLRom_E*	
3000-43	CUY00421	NLN10029	65	323	DLCE	idem	idem	*NLRom_E*	
3000-46	CUY00431	NLN10030	74	387	DLCE	idem	idem	*NLRom_E*	
4000-53	CUY00441	NLN10031	95	356	DLCE	idem	idem	*NLRom_E*	
4000-48a	CUY00461	NLN10032	55	359	DLCE	idem	idem	*NLRom_E*	
4000-48b	CUY00471	NLN10033	76	343	DLCE	idem	idem	*NLRom_E*	
4000-55	CUY00481	NLN10034	54	352	DLCE	idem	idem	*NLRom_E*	
4000-25	CUY00491	NLN10035	65	356	DLCE	idem	idem	*NLRom_E*	
4000-26	CUY00501	NLN10036	49	352	DLCE	idem	idem	*NLRom_E*	
3000-49	CUY00510	NLN10037	73	374	DLCE	idem	idem	*NLRom_E*	
3000-97	CUY00520	NLN10038	54	327	DLCE	idem	idem	*NLRom_E*	
4000-64	CUY00541	NLN10039	64	352	DLCE	idem	idem	-	
3000-11	CUY00561	NLN10040	60	327	DLCE	idem	idem	*NLRom_E*	
3000-LV92/12	CUY00571	NLN10041	45	343	DLCE	idem	idem	*NLRom_E*	
3000-41	CUY00581	NLN10042	79	354	DLCE	idem	idem	*NLRom_E*	
3000-70	CUY00591	NLN10043	59	354	DLCE	idem	idem	*NLRom_E*	
3000-8	CUY00601	NLN10044	39	308	DLCE	idem	idem	*NLRom_E*	
3000-81	CUY00611	NLN10045	56	327	DLCE	idem	idem	*NLRom_E*	
3000-100	CUY00620	NLN10046	68	374	DLCE	idem	idem	*NLRom_E*	
3000-88	CUY00631	NLN10047	46	320	DLCE	idem	idem	*NLRom_E*	
3000-3	CUY00641	NLN10048	46	342	DLCE	idem	idem	*NLRom_E*	
4000-35	CUY00653	NLN10049	59	345	DLCE	idem	idem	*NLRom_E*	
LV92/4	CUY00661	NLN10050	52	351	DLCE	idem	idem	*NLRom_E*	
4000-16	CUY00671	NLN10051	44	345	DLCE	idem	idem	*NLRom_E*	
3000-82	CUY00681	NLN10052	73	352	DLCE	idem	idem	*NLRom_E*	
3000-6	CUY00691	NLN10053	37	321	DLCE	idem	idem	*NLRom_E*	
4000-1-89	CUY00701	NLN10054	48	349	DLCE	idem	idem	*NLRom_E*	
4000-57	CUY00711	NLN10055	66	366	DLCE	idem	idem	*NLRom_E*	
4000-10	CUY00721	NLN10056	53	346	DLCE	idem	idem	*NLRom_E*	
4000-13	CUY00731	NLN10057	37	350	DLCE	idem	idem	*NLRom_E*	
4000-LV92/8	CUY00761	NLN10058	78	368	DLCE	idem	idem	*NLRom_E*	
4000-2	CUY00771	NLN10059	49	347	DLCE	idem	idem	*NLRom_E*	
4000-8	CUY00781	NLN10060	59	347	DLCE	idem	idem	*NLRom_E*	
4000-66	CUY00800	NLN10061	74	331	DLCE	idem	idem	*NLRom_E*	
4000-33	CUY00811	NLN10062	60	342	DLCE	idem	idem	*NLRom_E*	
Landing	CUY00830	NLN10063	74	353	DLCE	idem	idem	*NLRom_E*	
2000-45	CUY00840	Not coded yet	90	346	DLCE	idem	idem	*NLRom_E*	

2000-119	CUY00086	Not coded yet	111	365	DLCE	idem	idem	*NLRom_E*
2000-80	CUY00880	Not coded yet	58	331	DLCE	idem	idem	*NLRom_E*
1500-133	CYT00890	Not coded yet	82	341	DLCE	idem	idem	*NLRom_E*
1800-308	CUY00900	Not coded yet	72	332	DLCE	idem	idem	*NLRom_E*
1800-301	CUY00910	Not coded yet	45	335	DLCE	idem	idem	*NLRom_E*
1800-303	CUY00920	Not coded yet	63	355	DLCE	idem	idem	*NLRom_E*
6000-17	CUY00930	Not coded yet	93	373	DLCE	idem	idem	*NLRom_E*
6000-48	CUY00950	Not coded yet	114	358	DLCE	idem	idem	*NLRom_E*
1500-188	CUY00960	Not coded yet	72	327	DLCE	idem	idem	*NLRom_E*
6000-47	CUY00970	Not coded yet	66	321	DLCE	idem	idem	*NLRom_E*
6000-10	CUY00980	Not coded yet	55	309	DLCE	idem	idem	*NLRom_E*

DEIL — Church (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Unknown	C6B0101X	NLQ24001	90	1525	NLSO	7.4	71.3	*NLHist_2*

DELFT — Rampart De Eland (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Sleeper beam I	DBE00011	NLR14001	96	1451	NLTF	6.4	66.8	*NLHist_2*

DE LIER — Castle Utelier (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Bridge, post B	C4B13400	NLW13001	234	1140	BMBA	10.0	69.1	*NLHist_1*
Bridge, post A	C4B25000	NLW13002	155	1101	BMBA	7.4	66.6	*NLHist_1*

DENEKAMP — Water well (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
A - H (1 tree)	D2A7000Z	NLF05001	117	40	*NLRom_R*	6.1	59.9	-

DEVENTER — Brink 23, Schimmelpennickhuis (RDMZ; de Vries 1990)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Beam (v)	IDBR0010	NLQ06001	149	1557	NLTF	7.5	75.0	*NLHist_2*
Curved brace V	IDBR0020	NLQ06002	148	1554	NLTF	6.2	63.9	*NLHist_2*
1st link-beam	IDBR0040	NLQ06003	88	1522	NLTF	7.0	66.1	*NLHist_2*

DEVENTER — Rivetments (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Rivetment I,1-499	DB100021	NLQ34001	111	1078	NLSO	5.4	67.7	*NLHist_1*	
Rivetment III, ship 2, D2 VB1	DS200010	NLQ33001	198	1021	DLCE	9.1	67.1	*NLHist_1*	Date through avg. chronology
Rivetment III, ship 2, D1 VB1	DS200021	NLQ33002	217	1006	DLCE	idem	idem	*NLHist_1*	of NLQ33001, NLQ33002,
Rivetment III, ship 2, D2 S8	DS200031	NLQ33003	106	1021	DLCE	idem	idem	*NLHist_1*	NLQ33003, NLQ33004,
Rivetment III, ship 2, D2 timber	DS200041	NLQ33004	114	1008	DLCE	idem	idem	*NLHist_1*	NLQ33005 and NLQ33006
Rivetment III, ship 2, D2 S2	DS200051	NLQ33005	83	1014	DLCE	idem	idem	*NLHist_1*	Idem
Rivetment III, ship 2, D2 S5	DS200071	NLQ33006	177	1014	DLCE	idem	idem	*NLHist_1*	Idem
Rivetment V, ship 1, D1 VB3	DS100011	NLQ32001	201	988	DLCE	7.1	62.9	*NLHist_1*	Date through avg. chronology
Rivetment V, ship 1, D1 VA3	DS100021	NLQ32002	139	989	DLCE	idem	Idem	*NLHist_1*	of NLQ32001, NLQ32002 and
Rivetment V, ship 1, D1 S7	DS100031	NLQ32003	97	987	DLCE	idem	Idem	*NLHist_1*	NL32003
Rivetment VII, ship 3, D3 VA1	DS300010	NLQ35001	120	893	DLCE	6.4	64.2	*NLHist_1*	

DEVENTER — Sandrasteeg 4 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Back-aisle, attic, laid-on beam 7	DSV00011	NLQ31001	96	1468	NLTF	7.8	71.1	*NLHist_2*
Back-aisle, attic, principal 4	DSV00021	NLQ31002	60	1473	Intern	Visual date		*NLHist_2*
Back-aisle, collar X	DSV00041	NLQ31003	70	1461	NLTF	6.9	62.3	*NLHist_2*

DOMBURG — Coffin (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Bottom and front	DRB2300Y	NLZ05001	201	824	DLCE	6.7	58.0	*NLHist_1*

DORDRECHT — Townhall (RDMZ; de Vries 1987)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Curved brace X	IDOR0010	NLW02001	111	1455	NLTF	8.2	65.9	*NLHist_2*

DORDRECHT — Drievriendenhof (ROB; Sarfatij 1991)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
58.2.19	C5D0102Z	NLW06001	58	1429	BMBA	5.6	73.7	*NLHist_1*
58.2.23	C5D0104Z	NLW06002	96	1529	NLTF	5.3	68.9	*NLHist_2*
58.2.24	C5D0105Z	NLW06003	110	1552	NLTW	5.8	69.3	*NLHist_2*
58.4.32	C5D0108D	NLW06004	185	1602	DLCE	9.2	73.6	*NLHist_1*
58.1.36	C5D0109Z	NLW06005	108	1484	BMBA	6.9	64.0	*NLHist_1*

DORDRECHT Farmhouse "Ruigten beneden de pereboom" (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
No number	C5C0101Z	NLW07001	61	1398	DLCE	5.7	69.2	*NLHist_1*

DORDRECHT De Waag (ROB; Sarfatij 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
63.7.21	DWA00010	NLW10001	71	1185	BMBA	5.8	75.5	*NLHist_1*	
63.8.22	DWA00020	NLW10002	64	1194	BMBA	4.8	73.8	*NLHist_1*	
63.3.10a	DWA00030	NLW10003	74	1243	Intern	Visual date		-	
63.3.10b	DWA00040	NLW10004	61	1230	BMBA	5.1	71.7	*NLHist_1*	
63.3.10c	DWA00050	NLW10005	47	1218	Intern	8.8	87.0	*NLHist_1*	
63.3.H	DWA00070	NLW10006	54	1240	Intern	Visual date		-	
63.3.23	DWA00080	NLW10007	58	1194	Intern	Visual date		-	
63.8.26	DWA00090	NLW10008	88	1154	Intern	Visual date		-	
63.8.24	DWA00100	NLW10009	65	1177	BMBA	4.6	78.9	-	
64.0.18	DWA00130	NLW10010	88	1258	BMBA	8.0	66.7	*NLHist_1*	
64.0.19	DWA00140	NLW10011	51	1243	BMBA	5.9	65.0	-	
64.0.20a	DWA00150	NLW10012	140	1279	Intern	Visual date		-	3-year periodicity (insects)
64.0.20b	DWA00160	NLW10013	124	1270	Intern	Visual date		-	3-year periodicity (insects)
64.0.21	DWA00170	NLW10014	87	1249	BMBA	7.0	70.9	*NLHist_1*	
64.2.12	DWA00180	NLW10015	58	1243	Intern	Visual date		*NLHist_1*	
60.3.9	DE010010	NLW12001	107	1264	BMBA	12.6	82.1	*NLHist_1*	

DORDRECHT Dubbeldam tree coffin (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
-	C5E00091	NLW09001	96	1043	DLCE	6.3	72.1	-

EDAM Achterhaven 105 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Truss plate, right (front)	EAH0002A	NLR23001	117	1503	DLWF	5.4	66.8	*NLHist_2*

EDAM Spui 2 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Curved brace 4 (left)	C2B0101Y	NLR26001	57	1501	DLWF	6.9	71.2	-	Date through avg. chronology
Sleeper beam 3	C2B0102Y	NLR26002	134	1484	DLWF	idem	idem	*NLHist_2*	
Sleeper beam 2	C2B0103Y	NLR26003	81	1516	DLWF	idem	idem	*NLHist_2*	
Post 4 (left)	C2B0105Y	NLR26004	61	1472	DLWF	idem	idem	*NLHist_2*	

EDAM Spui 6 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Truss plate (left)	C2A0102Y	NLR24001	90	1494	DLWF	5.7	67.4	*NLHist_2*

EDAM Spuistraat 31 (IPP)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Hall, post 1	EDS00010	NLR27001	84	1469	NLTF	5.4	72.3	*NLHist_2*
Hall, sole-plate 5	EDS00050	NLR27004	84	1465	NLTF	3.6	72.9	-
Hall, floor part 8	EDS00080	NLR27005	58	1481	NLTF	5.6	69.3	*NLHist_2*
Back-aisle, post 3	EDS00030	NLR27002	76	1430	Intern	6.7	77.1	-
Back-aisle, beam	EDS00040	NLR27003	66	1492	Intern	Visual date		*NLHist_2*

EDE Doesburger Mill (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Vertical beam	EDM00011	NLE02001	195	1613	DLCE	6.6	64.9	*NLHist_1*

EDE Water well (AWN)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Plank 1	WVE00010	Not coded yet	187	-656	DLNO	5.2	62.1	Not clustered yet

EINDHOVEN Water wells, staves (Dienst Maatsch. en Cult. Zaken, Afd. Kunst en Cultuur; Arts 1992; Arts 1994; Jansma 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
EHV-HE-89 WP 7, Sp 39, P3	IEHV3021	NLK01001	91	1346	DLCE	7.4	72.2	*NLHist_1*	
EHV-HE-89 WP 7, Sp 39, P3	IEHV3031	NLK01002	80	1348	DLCE	6.0	72.2	*NLHist_1*	
EHV-HE-89 WP 4, Sp180, P4	IEHV4021	NLK02001	93	1280	DLCE	7.2	78.8	*NLHist_1*	
EHV-HE-89 WP 4, Sp180, P4	IEHV4031	NLK02002	121	1288	DLCE	6.4	64.2	*NLHist_1*	
EHV-HE-89 WP 4, Sp180, P4	IEHV4051	NLK02003	89	1290	DLCE	6.8	65.9	*NLHist_1*	
EHV-HE-89 WP 8, Sp 23, P4	IEHV5011	NLK03001	148	1337	DLCE	4.6	61.2	-	
EHV-HE-89 WP 8, Sp 23, P4	IEHV5031	NLK03002	127	1325	DLSO	6.0	66.7	-	
EHV-HE-89 WP 8, Sp 23, P4	IEHV5041	NLK03003	131	1333	DLSO	7.4	63.5	*NLHist_1*	
P6, M1	IEHV6011	NLK04001	86	1310	DLSO	5.1	68.8	*NLHist_1*	Date through avg. chronology
P6, M2	IEHV6021	NLK04002	84	1312	idem	idem	idem	*NLHist_1*	of NLK04001 and NLK04002
EHV-HE-89 WP 4, Sp133, P7	IEHV7011	NLK05001	88	1274	DLCE	6.2	66.1	*NLHist_1*	
EHV-HE-89 WP 4, Sp133, P7	IEHV7021	NLK05002	136	1262	DLCE	6.0	70.7	*NLHist_1*	
EHV-HE-89 WP 4, Sp180, P8	IEHV8011	NLK06001	228	1326	DLCE	5.5	67.0	-	
3.51 B, M1	INMG0011	NLK07001	134	1398	DLSO	6.9	7.8	*NLHist_1*	
3.51 B, M2	INMG0021	NLK07002	142	1386	DLSO	7.5	68.8	*NLHist_1*	

3.51 B, M3	INMG0031	NLK07003	110	1389	DLSO	6.2	72.0	*NLHist_1*	
14.72, M1	INMK0011	NLK08001	104	1259	DLCE	8.4	69.9	*NLHist_1*	
14.72, M2	INMK0021	NLK08002	103	1268	DLCE	6.8	69.6	*NLHist_1*	
15.2	INMC0021	NLK09001	120	1344	DLCE	5.9	68.2	*NLHist_1*	
17.18	INMD0011	NLK10001	100	1242	DLSO	5.4	68.2	*NLHist_1*	
7.41, M1	INME0011	NLK11001	117	1413	BMBA	5.1	61.6	*NLHist_1*	
7.41, M2	INME0021	NLK11002	133	1423	BMBA	5.3	64.8	*NLHist_1*	
7.41, M3	INME0031	NLK11003	108	1422	Intern	9.0	72.4	*NLHist_1*	
15.1, M1	INMB0011	NLK12001	94	1350	DLCE	6.5	65.7	*NLHist_1*	Date through avg. chronology
15.1, M2	INMB0031	NLK12002	125	1353	DLCE	idem	idem	*NLHist_1*	of NLK12001 and NLK12002
14.15, M1	INMA0011	NLK13001	154	1376	DLCE	7.0	66.0	*NLHist_1*	
14.15, M2	INMA0031	NLK13002	108	1393	DLCE	4.7	66.8	*NLHist_1*	
EHV-TO-93, M1	EIT00011	NLK15001	129	1255	BMBA	7.0	73.8	*NLHist_1*	
EHV-TO-93, M2	EIT00021	NLK15002	50	1266	BMBA	4.7	83.7	*NLHist_1*	
EHV-TO-93, M3	EIT00031	NLK15003	158	1247	BMBA	6.1	66.9	*NLHist_1*	
EHV-TO-93, M4	EIT00071	NLK15004	115	1249	BMBA	5.1	65.8	*NLHist_1*	
EHV-TO-93, M5	EIT00061	NLK15005	73	1252	DLSO	5.5	70.8	*NLHist_1*	

EME — Water well (Gemeentelijke Archeologie Zutphen)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M1	EME00011	not coded yet	81	806	DLOF	4.9	76.9	-
M2	EME00021	not coded yet	88	805	DLOF	6.1	70.1	-

EMMELOORD — Bog oaks (Sub-Fossil Forests Project (RING/ROB))

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Trunk 1	EOF00010	Not coded yet	104	408	DLNO	4.6	61.9	*NLRom_R*	Date through avg. chronology
Trunk 2	EOF00020	Not coded yet	144	488	DLNO	idem	idem	*NLRom_R*	

EMPEL — Water wells (IPP; Hiddink 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
91/303 M4	EMP00041	NLQ26001	97	77	DLNO	6.9	63.3	*NLRom_R*	Date through avg. chronology
91/303 M5, 6 (1 tree)	EMP0506M	NLQ26002	132	75	DLNO	idem	idem	*NLRom_R*	
91/303 M7	EMP00071	NLQ26003	80	13	DLNO	idem	idem	*NLRom_R*	
91/303 M10	EMP00101	NLQ26004	55	84	DLNO	idem	idem	*NLRom_R*	
91/303 M11	EMP00111	NLQ26005	99	100	DLNO	idem	idem	*NLRom_R*	
91/303 M12	EMP00121	NLQ26006	106	106	DLNO	idem	idem	*NLRom_R*	
91/303 M13	EMP00131	NLQ26007	63	130	DLNO	idem	idem	*NLRom_R*	
91/303 M14	EMP00141	NLQ26008	60	127	DLNO	idem	idem	*NLRom_R*	
91/303 M15	EMP00151	NLQ26009	67	15	DLNO	idem	idem	*NLRom_R*	
91/303 M16	EMP00161	NLQ26010	83	31	DLNO	idem	idem	*NLRom_R*	

ENKHUIZEN — Westerstraat 76 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Sleeper beam ((((((	A5A0101Y	NLV13001	168	1524	DLWF	4.2	61.6	-	
Wallpost (((((	A5A0102Y	NLV13002	93	1489	DLWF	5.8	70.3	*NLHist_2*	
Wallpost ((((	A5A0103Y	NLV13003	85	1498	DLWF	6.8	66.1	*NLHist_2*	
Curved brace (((((	A5A0104Y	NLV13004	57	1530	DLWF	6.4	68.6	*NLHist_2*	Date through avg. chronology
Sleeper beam (((((	A5A0105Y	NLV13005	56	1534	DLWF	idem	idem	*NLHist_2*	NLV13004, NLV13005 and
Sole-plate ((((	A5A0106Y	NLV13006	48	1511	DLWF	idem	idem	*NLHist_2*	NLV13006

ERMELO — Village (IPP)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
301c	ERM0301C	NLX01001	69	1040	DLCE	7.0	69.9	*NLHist_1*
465a	ERM0465A	NLX01002	87	1101	DLCE	5.0	68.0	-
465b	ERM0465B	NLX01003	75	1108	DLCE	5.2	64.9	*NLHist_1*

FLEVOLAND — Bog oaks (Sub-Fossil Forests Project (RING/ROB))

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
NZ 108/109 (C49) Trunk 1	NKF00011	NLX02001	188	255	DLNO	4.3	61.8	*NLRom_R*	
NZ 108/109 (C49) Trunk 2	NKF00021	NLX02002	154	283	DLNO	6.4	69.0	*NLRom_R*	
NZ 108 (C49) Trunk 3	NLF00020	NLX03001	103	275	DLNO	5.0	68.6	*NLRom_R*	
NZ 108 (C49) Trunk 4	NLF00030	NLX03002	204	286	DLNO	4.0	60.0	*NLRom_R*	
NZ 108 (C49) Trunk 5	WJC00011	NLX05001	110	239	*NLRom_R* (ev)	6.0	72.0	*NLRom_R*	ev = early version
NZ 108 (C49) Trunk 6	WJC00021	NLX05002	113	200	*NLRom_R* (ev)	6.3	71.9	*NLRom_R*	ev = early version
NZ 108 (C49) Trunk 7	WJE00021	NLX05003	83	252	*NLRom_R* (ev)	6.3	70.1	*NLRom_R*	ev = early version
GZ 48 Trunk 1	FLE00010	NLX04001	204	477	DLNO	7.5	63.7	*NLRom_R*	
J 89 Trunk 1	FNF00010	Not coded yet	229	-4661	DLNO	6.7	65.1	Not clustered yet	
D 134 Trunk 1	FDF00010	Not coded yet	220	-3187	DLNO	4.0	67.6	Not clustered yet	
D 134 Trunk 2	FDF00020	Not coded yet	150	-3355	DLNO	5.0	62.1	Not clustered yet	
D 134 Trunk 3	FDF00030	Not coded yet	231	-3295	DLNO	5.2	61.1	Not clustered yet	
Urk D 14 Trunk 1	UFF00010	Not coded yet	129	-3100	DLNO	4.3	67.6	Not clustered yet	
Urk D 14 Trunk 2	UFF00020	Not coded yet	152	-3290	Intern	Visual date		Not clustered yet	

FLEVOLAND — Ships (Rijksmuseum voor Scheepsarcheologie Ketelhaven)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
KO 45/1	KKV00011	NLX07001	119	1610	NLTF	6.4	62.7	*NLHist_1*	
PZ 33/1 M1 knee of the head	KPD00010	NLX08001	138	1630	NLTF	6.4	68.2	-	
PZ 37/2 M3 knee of the head	KPZ00030	NLX09001	101	1571	NLTF	5.9	61.5	*NLHist_2*	
A 57 M6	KA500061	NLX10001	125	1237	POPO	6.9	64.3	-	Date through avg. chronology
A 57 M7 WB1/SB	KA500070	NLX10002	139	1247	POPO	idem	idem	-	
A 57 M8 outboard planking	KA500081	NLX10003	159	1249	POPO	idem	idem	-	
A 57 M24 GC1/BB	KA500240	NLX10004	197	1242	POPO	idem	idem	-	
OZ 36 M7 WD/SB	KKO00070	NLX11001	68	1305	NLH02	5.5	68.7	*NLHist_3*	Date through avg. chronology
OZ 36 M10 OO	KKO00100	NLX11002	77	1334	NLH02	idem	idem	*NLHist_3*	
OZ 36 M11 CL futtock	KKO00110	NLX11003	93	1312	NLH02	idem	idem	*NLHist_3*	
OZ 36 M14 WB/SB	KKO00140	NLX11004	135	1333	NLH02	idem	idem	*NLHist_3*	
OZ 36 M15	KKO00151	NLX11005	79	1325	NLH02	idem	idem	*NLHist_3*	
OZ 36 M16 N futtock	KKO00160	NLX11006	110	1311	NLH02	idem	idem	*NLHist_3*	
OZ 36 M17 M. floor timber	KKO00171	NLX11007	86	1318	NLH02	idem	idem	*NLHist_3*	
OZ 36 M18 QQ frame	KKO00180	NLX11008	150	1322	NLH02	idem	idem	*NLHist_3*	
OZ 36 M19 CT futtock	KKO00190	NLX11009	90	1325	NLH02	idem	idem	*NLHist_3*	
NZ 74/1 M1 knee of the head	KN100010	NLX12001	82	1524	NLTF	5.0	74.7	*NLHist_2*	
NZ 74/1 M2 keel	KN100020	NLX12002	88	1508	NLTF	6.6	71.3	*NLHist_2*	
NZ 74/1 M3 floor timber	KN100030	NLX12003	77	1520	NLTF	6.9	71.8	-	
NZ 74/2 M1 stern	KN200010	NLX13001	83	1524	NLTF	6.8	65.0	*NLHist_2*	Date through avg. chronology
NZ 74/2 M2 bow	KN200020	NLX13002	89	1516	NLTF	idem	idem	*NLHist_2*	
NZ 74/2 M3 stern 2	KN200030	NLX13003	76	1494	NLTF	idem	idem	*NLHist_2*	
NZ 74/2 M4 keel	KN200040	NLX13004	120	1500	NLTF	idem	idem	-	
OZ 71 M3 filling frame	KOZ00031	NLX14001	170	1634	DLNS	8.1	73.4	*NLHist_2*	
H 107 stealer VA/BB	KSH00041	NLX15001	208	1682	Intern	Visual date		-	
H 107 GF1/BB	KSH00061	NLX15002	153	1679	DLNS	7.9	67.1	-	
H 107 GA1/BB	KSH00071	NLX15003	148	1677	DLSO	7.0	66.7	-	
H 107 GA2/BB	KSH00081	NLX15004	177	1678	DLNS	5.6	61.9	-	
H 107 GA2/BB	KSH00101	NLX15005	197	1592	DLNS	5.8	63.8	-	
H 107 keel 2/HS	KSH00121	NLX15006	151	1666	DLSO	6.3	63.3	*NLHist_2*	
H 107 keel stern	KSH00141	NLX15007	154	1666	DLSO	4.6	60.8	-	
H 107 keel 1/HS	KSH00151	NLX15008	125	1666	Intern	8.7	71.4	*NLHist_2*	
H 107 keelson and stealer	KSH02011	NLX15009	241	1684	DLNS	9.4	71.3	-	
NZ 42/1 M1	KNZ00011	NLX16001	35	1525	DLWF	4.2	67.6	*NLHist_2*	
NZ 42/1 M3 keel	KNZ00030	NLX16002	75	1511	DLWF	4.2	62.8	*NLHist_2*	
NZ 42/1 M4	KNZ00040	NLX16003	72	1524	NLTF	5.6	65.5	*NLHist_2*	
AZ 87/2 M2 S7/BB	KAZ00021	NLX17001	136	1622	DLNS	6.4	70.0	-	
NZ 43 M15 G2C/BB	KN400151	NLX18001	112	1399	Intern	7.3	75.8	-	
NZ 43 M45 G10B/SB	KN400451	NLX18002	109	1354	NLTF	7.7	69.0	-	

GENNEP — 2 water wells (IPP; Heidinga and Offenberg 1992)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
4304.21	GEN11	NLN13001	71	351	DLNO	7.0	76.0	-	Date through avg. chronology 4304
4304.4	GEN12	NLN13002	117	364	DLNO	idem	idem	-	
4304.20	GEN13	NLN13003	89	349	DLNO	idem	idem	*NLRom_E*	
4304.19	GEN14	NLN13004	91	350	DLNO	idem	idem	-	
4304.15	GEN15	NLN13005	100	359	DLNO	idem	idem	*NLRom_E*	
4304.25	GEN17	NLN13006	110	373	DLNO	idem	idem	-	
4304.2	GEN19	NLN13007	83	353	DLNO	idem	idem	*NLRom_E*	
4304.3	GEN20	NLN13008	93	354	DLNO	idem	idem	*NLRom_E*	
4304.17	GEN21	NLN13009	73	368	DLNO	idem	idem	*NLRom_E*	
4304.18	GEN22	NLN13010	86	370	DLNO	idem	idem	*NLRom_E*	
4304.10	GEN23	NLN13011	64	338	DLNO	idem	idem	*NLRom_E*	
38 M7	GEP07	NLN13012	73	356	mc. 4304	6.0	73.0	*NLRom_E*	Date through avg. chronology sp. 38
38 M8	GEP08	NLN13013	48	361	mc. 4304	idem	idem	*NLRom_E*	
38 M28	GEP28	NLN13014	53	346	mc. 4304	idem	idem	*NLRom_E*	
38 M11	GEP11	NLN13015	99	393	mc. 4304	idem	idem	*NLRom_E*	
38 M1	GEP01	NLN13016	81	395	mc. 4304	idem	idem	*NLRom_E*	
38 M14	GEP14	NLN13017	67	392	mc. 4304	idem	idem	*NLRom_E*	

GOIRLE — Water well (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
2.1.36, 2.1.37 (1 tree)	F1B6000Z	NLJ04001	115	98	*NLRom_R*	6.7	67.1	-

'S-GRAVENHAGE — Binnenhof (Archeoplan)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M186	IDHB0010	NLZ02001	213	1602	DLCE	9.9	68.6	-
M183	DBH00011	NLZ03001	86	1239	DLCE	6.9	70.6	*NLHist_1*
M184	DBH00021	NLZ03002	85	1275	DLCE	5.5	72.0	*NLHist_1*

'S-GRAVENHAGE — Water wells, staves (Gem. 's-Gravenhage, Afd. Archeologie)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
3 M237 upper barrel	GRB00011	NLZ08001	163	1612	FRNO	4.9	65.2	-
3 M237 upper barrel	GRB00021	NLZ08002	136	1618	FREA	6.2	65.2	-
3 M238 lower barrel	GRB00031	NLZ08003	116	1625	Intern	5.0	63.4	-
4 M155 upper barrel	GRB00041	NLZ08004	111	1569	DLSM	5.4	67.3	-
4 M156 middle barrel	GRB00051	NLZ08005	176	1561	DLSM	5.2	58.6	-
4 M159 lower barrel	GRB00061	NLZ08006	117	1587	DLSO	4.8	70.7	-
3 M237 upper barrel	GRB00071	NLZ08007	143	1617	Intern	4.8	66.1	-
3 M238 lower barrel	GRB00081	NLZ08008	89	1610	FRNO	4.3	61.9	-
Hof 93 M217	GRH00010	NLZ09001	178	1593	DLCE	9.5	69.8	*NLHist_1*

GRONINGEN — Brugstraat 26, girder construction (RDMZ; de Vries 1990; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Curved brace (North), post (S.)	IGBR0011	NLV05001	120	1316	DLCE	4.4	66.4	-
Post (South)	IGBR0021	NLV05002	104	1319	Intern	8.9	74.5	*NLHist_2*

GRONINGEN — De Hunze, bridge (Gem. Groningen, afd. Part. Bezit en Monumenten; Kortekaas 1989; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Post 380	GDHB0010	NLV11001	138	1287	DLNS	7.3	70.8	*NLHist_2*	Date through avg. chronology
379 below	GDHB0021	NLV11002	72	1274	DLNS	idem	idem	*NLHist_2*	
379 below	GDHB0061	NLV11003	75	1277	DLNS	idem	idem	*NLHist_2*	

GRONINGEN — De Hunze, well (Gem. Groningen; Kortekaas 1989; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
366-E	GDHP0041	NLV12001	66	1197	DLOF	6.3	67.8	*NLHist_3*	Date through avg. chronology
366-B	GDHP0051	NLV12002	82	1233	DLOF	idem	idem	-	

GRONINGEN — Hoge ter A 14 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Roof plate (right)	GHV0001A	NLV19001	69	1510	DLWF	7.1	67.6	*NLHist_2*
Roof plate (left)	GHV0002A	NLV19002	124	1514	DLNS	8.0	76.0	*NLHist_2*

GRONINGEN — Oude Boteringestraat 16 (RDMZ; de Vries 1992; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
16.001	IGOB0101	NLV08001	109	1539	DLWF	7.4	72.2	*NLHist_2*
16.005	IGOB0131	NLV08002	133	1561	DLWF	7.6	72.7	*NLHist_2*

GRONINGEN — Oude Boteringestraat 24 (RDMZ; de Vries 1992; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Beam above ground floor 24.028	IGOB0011	NLV03001	71	1526	DLWF	7.2	77.1	*NLHist_2*
Beam above ground floor 24.029	IGOB0021	NLV03002	115	1534	DLWF	5.0	74.6	*NLHist_2*
Beam above ground floor 24.030	IGOB0031	NLV03003	77	1540	DLWF	7.2	75.0	*NLHist_2*
Beam above ground floor 24.031	IGOB0041	NLV03004	92	1525	DLWF	7.1	70.9	*NLHist_2*
Beam above ground floor 24.032	IGOB0051	NLV03005	83	1521	DLWF	6.7	76.2	*NLHist_2*

GRONINGEN — Heilige Geest- or Pelstergasthuis (RDMZ; de Vries 1990; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Collar IIII East	IGPEL010	NLV07001	85	1385	DLSO	5.5	78.0	*NLHist_2*	Date through avg. chronology
Spoor IIIII East	IGPEL050	NLV07002	72	1382	DLSO	idem	idem	*NLHist_2*	
Collar IIIII	IGPEL060	NLV07003	68	1384	DLSO	idem	idem	*NLHist_2*	

GRONINGEN — Pepergasthuis, left wing, Peperstraat (RDMZ; de Vries 1992; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Beam I above ground floor	IGPG0011	NLV06001	91	1551	HAM	4.2	73.9	*NLHist_2*

GRONINGEN — Ship (Scheepvaartmuseum Groningen, Glavimans Foundations)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Rudder	IGSM0010	NLV04001	165	1532	NLTF	7.1	61.9	-

GRONINGEN — Scheepvaartmuseum (Scheepvaartmuseum Groningen; Glavimans Foundations; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Floor, plank	IGSM0020	NLV09001	151	1500	NLTF	5.9	62.7	*NLHist_2*

GRONINGEN — Wolters Noordhof Complex (Gem. Groningen, Afd. Part. Bezit en Monumenten; Kortekaas 1991; Jansma 1995)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
VIII f (e) 986-1	GWN00011	NLV10001	149	1283	DLNS	9.0	71.8	*NLHist_2*	Date through avg. chronology
VIII f (e) 986-5	GWN00021	NLV10002	128	1280	DLNS	idem	idem	*NLHist_2*	
VIII f (e) 986-6	GWN00031	NLV10003	190	1281	DLNS	idem	idem	-	
VIII f (e) 960-1	GWN00061	NLV10004	62	1277	DLNS	idem	idem	*NLHist_2*	
VIII f (e) 928-1	GWN00071	NLV10005	239	1209	DLNS	idem	idem	-	
VIII b (c) 708-1	GWN00111	NLV10006	101	1260	DLNS	idem	idem	*NLHist_2*	
VIII b (c) 708-2	GWN00121	NLV10007	67	1267	DLNS	idem	idem	*NLHist_2*	
VIII b (c) 709-3	GWN00151	NLV10008	67	1267	DLNS	idem	idem	*NLHist_2*	
VIII c (u) 556-1	GWN00231	NLV10009	72	1233	DLNS	idem	idem	*NLHist_2*	

HAARLEM	Aelbertsberg, staves (IPP)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Stave 2	IAEL0021	NLR07001	123	1260	Intern	5.4	66.7	-
Stave 4	IAEL0041	NLR07002	71	1264	Intern	Visual date		*NLHist_1*
Stave 7	IAEL0071	NLR07003	86	1258	DLCE	5.4	68.7	*NLHist_1*
Stave 10	IAEL0101	NLR07004	77	1262	DLCE	idem	idem	*NLHist_1*

HAARLEM	Bog oaks (Sub-Fossil Forests Project (RING/ROB))							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Trunk 1	HAF00010	Not coded yet	164	-2128	DLNO	5.2	58.0	Not clustered yet
Trunk 2	HAF00020	Not coded yet	111	-2696	DLNO	4.7	70.0	Not clustered yet
Trunk 3	HAF00030	Not coded yet	107	-2700	DLNO	5.5	72.2	Not clustered yet
Trunk 5	HAF00050	Not coded yet	101	-2773	DLNO	4.5	65.5	Not clustered yet

HAARLEM	Spaarne 108 (RDMZ)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Roof, curved brace 1st truss	IHSH0011	Not coded yet	101	1376	*NLHist_2*	5.7	72.5	Not clustered yet

HAARLEM	Ursulastraat 16, Ursulinenklooster (RDMZ; de Vries 1990)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Roof plate North	IHUS0010	NLR11001	76	1463	DLWF	5.4	76.0	*NLHist_2*
Laid-on beam, truss IIII	IHUS0020	NLR11002	83	1445	NLTF	6.1	71.3	*NLHist_2*
Principal O IIII	IHUS0040	NLR11003	61	1448	Intern	Visual date		*NLHist_2*

HAZERSWOUDE	Bog oaks (Sub-Fossil Forests Project (RING/ROB))								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Trunk 2	HWF00020	Not coded yet	165	-1862	DLNO	14.85	64.6	*NLPre_ZH*	Date through avg. chron. *NLPre_ZH*
Trunk 3	HWF00030	Not coded yet	119	-1581	DLNO	idem	idem	*NLPre_ZH*	
Trunk 4	HWF00040	Not coded yet	123	-1581	DLNO	idem	idem	*NLPre_ZH*	
Trunk 5	HWF00050	Not coded yet	151	-1779	DLNO	idem	idem	*NLPre_ZH*	
Trunk 6	HWF00060	Not coded yet	82	-1255	DLNO	idem	idem	*NLPre_ZH*	
Trunk 7	HWF00070	Not coded yet	118	-1888	DLNO	idem	idem	*NLPre_ZH*	
Trunk 9	HWF00090	Not coded yet	154	-1240	DLNO	idem	idem	*NLPre_ZH*	
Trunk 11	HWF00110	Not coded yet	228	-1393	DLNO	idem	idem	*NLPre_ZH*	
Trunk 13	HWF00130	Not coded yet	208	-1413	DLNO	idem	idem	*NLPre_ZH*	
Trunk 14	HWF00140	Not coded yet	178	-1858	DLNO	idem	idem	*NLPre_ZH*	
Trunk 16	HWF00160	Not coded yet	135	-1798	DLNO	idem	idem	*NLPre_ZH*	
Trunk 17	HWF00170	Not coded yet	91	-1891	DLNO	idem	idem	*NLPre_ZH*	
Trunk 18	HWF00180	Not coded yet	110	-1425	DLNO	idem	idem	*NLPre_ZH*	
Trunk 20	HWF00200	Not coded yet	107	-1368	DLNO	idem	idem	*NLPre_ZH*	
Trunk 21	HWF00210	Not coded yet	185	-1799	DLNO	idem	idem	*NLPre_ZH*	
Rijndijk trunk 2	HRF00020	Not coded yet	123	-1141	DLNO	idem	idem	*NLPre_ZH*	
Rijndijk trunk 3	HRF00030	Not coded yet	213	-1490	DLNO	idem	idem	*NLPre_ZH*	

HEETEN/RAALTE	Water wells (ROB; Erdrich and Verlinde 1995)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
8-1-54, 8-1-55 (1 tree)	HRW12000	NLH03001	181	255	DLNO	6.2	67.8	*NLRom_E*
18 plank 1	HRW20010	NLH03002	116	315	DLNO	6.1	74.3	*NLRom_E*
18 plank 2	HRW20022	NLH03003	46	315	DLNO	3.3	72.2	*NLRom_E*
18 plank 3	HRW20030	NLH03004	110	310	DLNO	5.5	73.9	*NLRom_E*
18 plank 4	HRW20040	NLH03005	126	315	DLNO	4.6	69.2	*NLRom_E*
18 plank 5	HRW20051	NLH03006	57	286	DLNO	3.7	72.3	*NLRom_E*
19 plank 1	HRW30011	NLH03007	170	335	DLNO	4.5	61.5	*NLRom_R*
19 plank 2	HRW30021	NLH03008	121	304	DLNO	4.9	63.8	*NLRom_R*
19 plank 3	HRW30031	NLH03009	186	321	DLNO	4.1	63.2	*NLRom_R*
19 plank 4	HRW30041	NLH03010	124	275	DLNO	6.4	64.2	*NLRom_R*
23-1-68 planks 1, 2 and 4 (1 tree)	HRW41200	NLH03011	241	261	DLNO	8.1	68.0	-

HENGELO	Oldemeulen (RDMZ)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Foundation, plank	IHOMB011	NLF01001	88	1532	DLWF	7.5	70.1	*NLHist_2*
Unknown	IHOMA010	NLF04001	179	1626	DLCE	5.2	59.0	*NLHist_2*

'S-HERTOGENBOSCH	Water wells, staves (Gem. 's-Hertogenbosch, Sector Ruimtelijke Planning)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
VI-0-1819 M1	IDBV0011	NLK14001	72	1245	DLCE	8.3	70.4	*NLHist_1*
VI-0-1819 M2	IDBV0021	NLK14002	108	1257	DLCE	8.3	70.6	*NLHist_1*
VI-0-1819 M3	IDBV0031	NLK14003	86	1247	DLCE	7.7	72.4	*NLHist_1*
VI-0-1819 M5	IDBV0051	NLK14004	66	1251	BMBA	3.9	70.8	*NLHist_1*

'S-HERTOGENBOSCH — Historical buildings (Gem. 's-Hertogenbosch, BOAA; Boewijt 1993; van Drunen 1993; Vink 1993; de Vries 1994; van Drunen en Glaudem 1995)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Hinthamerstraat 4 M5	DBH550	NLK17001	171	1415	Intern	Visual date		*NLHist_1*
Hinthamerstraat 36 M3	DBH320	NLK18001	53	1419	BMBA	5.5	71.2	*NLHist_1*
Hinthamerstraat 85/87 M14	DBH040	NLK19001	158	1525	BMBA	6.5	67.2	*NLHist_1*
Hinthamerstraat 85/87 M27	DBH060	NLK19002	169	1550	BMBA	9.6	67.0	*NLHist_1*
Hinthamerstraat 85/87 M11	DBH091	NLK19003	84	1465	BMBA	6.1	74.7	*NLHist_1*
Hinthamerstraat 85/87 M14	DBH130	NLK19004	159	1526	BMBA	6.5	64.9	*NLHist_1*
Hinthamerstraat 85/87 M5	DBH142	NLK19005	71	1418	Intern	Visual date		*NLHist_1*
Hinthamerstraat 85/87 M26	DBH150	NLK19006	132	1565	BMBA	4.3	61.5	*NLHist_1*
Hinthamerstraat 85/87 M43	DBH510	NLK19007	120	1548	BMBA	7.6	68.9	*NLHist_1*
Hinthamerstraat 104 entersole	DBH591	NLK20001	148	1546	BMBA	5.1	69.4	*NLHist_1*
Hinthamerstraat 111 M18	DBH431	NLK21001	149	1468	BMBA	8.2	67.9	*NLHist_1*
Hinthamerstraat 111 M10	DBH440	NLK21002	74	1437	Intern	Vidual date		*NLHist_1*
Hinthamerstraat 111 M7	DBH450	NLK21003	77	1527	BMBA	7.9	72.4	*NLHist_1*
Hinthamerstraat 111 M2	DBH461	NLK21004	75	1383	BMBA	4.6	64.9	*NLHist_1*
Hinthamerstraat 111 M27	DBH571	NLK21005	119	1519	BMBA	5.1	66.1	*NLHist_1*
Hinthamerstraat 113 M23b	DBH491	NLK22001	70	1418	Intern	Visual date		*NLHist_1*
Hinthamerstraat 113 M12	DBH520	NLK22002	114	1463	BMBA	4.9	60.6	-
Hinthamerstraat 113 M14	DBH540	NLK22003	122	1443	BMBA	7.2	68.2	*NLHist_1*
Hinthamerstraat 113 M15	DBH611	NLK22004	92	1442	BMBA	9.7	67.0	*NLHist_1*
Hinthamerstraat 113 M13	DBH661	NLK22005	91	1451	BMBA	7.3	73.3	*NLHist_1*
Hinthamerstraat 134 M7	DBH020	NLK23001	129	1460	BMBA	6.2	66.5	*NLHist_1*
Hinthamerstraat 134 M5	DBH160	NLK23002	142	1473	BMBA	5.3	60.3	*NLHist_1*
Hinthamerstraat 209 M5	DBH601	NLK24001	95	1479	BMBA	6.3	69.7	*NLHist_1*
Hinthamerstraat 209 Unknown	DBH631	NLK24002	123	1458	BMBA	5.6	70.9	-
Korenbrugstraat 16, t	DBK010	NLK25001	106	1597	NLTF	5.2	72.9	-
Kruisstraat 16 M3	DBK040	NLK26001	100	1461	NLSO	5.6	65.2	*NLHist_1*
Mark 18 M6	DBM010	NLK27001	148	1270	BMBA	11.7	77.6	*NLHist_1*
Unknown context 2.1.J.1.3.c	DBJ011	NLK28001	101	1629	BMBA	5.6	71.5	*NLHist_1*
Unknown context 2.1.J.1.3.b	DBJ021	NLK28002	110	1615	BMBA	6.1	68.3	*NLHist_1*
Orthenstraat 23/25 M10	DBO010	NLK29001	152	1462	BMBA	7.2	62.9	*NLHist_1*
Orthenstraat 23/25 M8	DBO020	NLK29002	147	1462	BMBA	7.8	61.6	*NLHist_1*
Orthenstraat 23/25 M42	DBO070	NLK29003	150	1462	BMBA	8.3	64.4	*NLHist_1*
Orthenstraat 23/25 M3	DBO080	NLK29004	86	1439	BMBA	5.5	75.9	*NLHist_1*
Orthenstraat 23/25 M2	DBO092	NLK29005	86	1439	BMBA	4.6	72.4	*NLHist_1*
Orthenstraat 23/25 M8	DBO100	NLK29006	91	1441	Intern	Visual date		*NLHist_1*
Orthenstraat 23/25 Unknown	DBO110	NLK29007	110	1454	BMBA	5.5	62.4	*NLHist_1*
Orthenstraat 23/25 M40	DBO140	NLK29008	103	1450	DLWB	5.2	68.1	*NLHist_2*
Orthenstraat 23/25 M41	DBO180	NLK29009	166	1449	Intern	Visual date		-
Orthenstraat 41 M52	DBO030	NLK30001	109	1463	BMBA	5.2	63.4	*NLHist_1*
Orthenstraat 41 M19	DBO040	NLK30002	70	1451	BMBA	5.7	68.1	*NLHist_1*
Orthenstraat 41 M18	DBO061	NLK30003	70	1440	BMBA	6.6	71.0	*NLHist_1*
Orthenstraat 41 M138	DBO170	NLK30004	81	1440	BMBA	5.8	63.1	*NLHist_1*
Orthenstraat 41 M137	DBO191	NLK30005	13	1435	Intern	Visual date		*NLHist_1*
Postelstraat 29/31 M3	DBP061	NLK31001	11	1457	BMBA	Visual date		*NLHist_1*
Vuchterstraat 174 M2	DBV011	NLK32001	12	1544	BMBA	7.2	70.7	*NLHist_1*
Verwerstraat 78 Unknown	DBV032	NLK33001	77	1398	BMBA	6.8	65.8	*NLHist_1*
Visstraat 23 M8	DBV041	NLK34001	73	1458	BMBA	5.4	74.3	*NLHist_1*
Hinthamerstraat 89/91 M11	DBH030	NLK35001	128	1457	BMBA	7.5	67.3	*NLHist_1*
Hinthamerstraat 89/91 M8	DBH050	NLK35002	136	1462	BMBA	8.0	67.4	*NLHist_1*
Hinthamerstraat 89/91 M10	DBH070	NLK35003	143	1462	BMBA	7.3	65.5	*NLHist_1*
Hinthamerstraat 89/91 M14	DBH170	NLK35004	131	1440	BMBA	5.3	66.9	*NLHist_1*
Hinthamerstraat 89/91 M9	DBH180	NLK35005	145	1463	BMBA	7.6	66.0	*NLHist_1*
Hinthamerstraat 89/91 M27	DBH190	NLK35006	92	1501	BMBA	5.6	71.4	*NLHist_1*
Hinthamerstraat 89/91 M17	DBH230	NLK35007	65	1455	NLSO	5.6	77.3	*NLHist_1*
Hinthamerstraat 89/91 Feb. 88	DBH292	NLK35008	82	1408	Intern	Visual date		*NLHist_1*
Hinthamerstraat 89/91 M31	DBH671	NLK35009	80	1407	Intern	Vidual date		*NLHist_1*
Mariënhage (C) tie-beam	F1D0101Y	NLK36001	47	1439	BMBA	3.4	70.7	-
Mariënhage (B) tie-beam	F1D0102Y	NLK36002	126	1473	BMBA	5.4	66.0	*NLHist_1*
Mariënhage (A) tie-beam	F1D0103Y	NLK36003	148	1512	BMBA	11.4	76.5	*NLHist_1*
Mariënhage (C) tie-beam	F1D0104Y	NLK36004	61	1522	BMBA	5.8	75.8	*NLHist_1*
Mariënhage (D) principal South	F1D0105Y	NLK36005	65	1538	BMBA	7.0	76.6	*NLHist_1*
Mariënhage (D) principal North	F1D0107Y	NLK36006	53	1445	BMBA	4.1	65.4	*NLHist_1*

HILVARENBEEK — Tower (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
MV	IHILT051	NLJ02001	96	1544	DLNS	4.7	70.0	*NLHist_1*
M14	IHILT101	NLJ02002	64	1541	DLWF	6.5	73.8	*NLHist_2*

HINDELOOPEN — Ship (Rijksmuseum voor Scheepsarcheologie Ketelhaven)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Bottom planking	KHI00100	NLV18001	124	1544	POPO	5.4	65.0	-
Wood sheeting	KHI00131	NLV18002	170	1609	DLNS	7.5	68.6	*NLHist_2*

HOORN — Excavation "Bruintje 1990" (Westfries Museum)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
M57a	HBR00021	NLV17001	105	1279	DLNS	6.1	67.4	-	
M45	HBR00050	NLV17002	153	1308	DLOF	5.3	66.7	*NLHist_3*	Date through avg. chronology
M66	HBR00070	NLV17003	110	1296	DLOF	idem	idem	*NLHist_3*	of NLV07002, NLV07003,
M26	HBR00080	NLV17004	70	1310	DLOF	idem	idem	-	NLV07004 and NLV07006
M43	HBR00090	NLV17005	271	1398	POPO	6.9	64.1	-	
M57b	HBR00121	NLV17006	98	1284	DLOF	5.3	66.7	*NLHist_3*	Date through avg. chronology
m54	HBR00011	NLV17007*	87	1331	*NLHist_3* (ev)	5.5	68.0	*NLHist_3*	ev = early version; * = new date

HULST — Coffin (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Central plank	HBK00011	NLM01001	146	1051	BMBA	5.7	69.0	-

KAMPEN — Hofstraat, posts (Gem. Kampen, Afd. Monumentenzorg en Archaeologie)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Plank under post V	IKHB0041	NLR06001	82	1151	NLSO	7.1	67.3	-
Log under post IV	IKHB0051	NLR06002	82	1138	NLSO	7.4	77.2	*NLHist_1*
Lowest log under post IV	IKHB0121	NLR06003	97	1154	NLSO	6.2	70.3	-
2nd log under post paal V	IKHB0131	NLR06004	63	1148	NLSO	8.6	73.4	-
1st log under post V	IKHB0141	NLR06005	68	1148	NLSO	7.6	66.4	-

KAMPEN — Hofstraat, water well, staves (Gem. Kampen, Afd. Monumentenzorg en Archaeologie)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Stave 1	IKHT0011	NLR02001	119	1360	DLCE	5.6	69.5	*NLHist_1*
Stave 2	IKHT0021	NLR02002	106	1353	DLCE	9.4	73.3	-
Stave 3	IKHT0031	NLR02003	103	1357	DLSO	6.2	66.2	*NLHist_1*
Stave 4	IKHT0041	NLR02004	87	1366	DLSO	6.9	70.9	-

KAMPEN — Oudestraat 5 (RDMZ; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Attic, laid-on beam 8	IKOS0011	NLR09001	109	1497	NLTF	9.4	77.3	*NLHist_2*
Attic, curved brace < (North)	IKOS0021	NLR09002	95	1498	NLTF	5.3	71.8	*NLHist_2*
Attic, principal <	IKOS0031	NLR09003	91	1494	Intern	5.0	75.0	*NLHist_2*
Attic, laid-on beam 9	IKOS0042	NLR09004	84	1481	Intern	9.5	82.5	*NLHist_2*
Attic, laid-on beam /<	IKOS0051	NLR09005	55	1487	NLTF	6.3	70.4	*NLHist_2*
Attic, laid-on beam 5	IKOS0061	NLR09006	74	1497	NLTF	8.3	74.0	*NLHist_2*

KAMPEN — Oudestraat 7 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Hall, ground floor, curved brace	IKAO0011	not coded yet	74	1451	*NLHist_2*	5.4	66.4	Not clustered yet
Back aisle, ground floor, border joist	IKAO0051	not coded yet	70	1401	*NLHist_2*	6.2	76.8	Not clustered yet
Back aisle, ground floor, curved brace 3	IKAO0061	not coded yet	51	1385	Intern	3.6	78.0	Not clustered yet

KAMPEN — Oudestraat 9 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Back-aisle, sleeper beam 3	C3C0101	NLR29001	100	1506	DLWF	5.4	67.7	*NLHist_2*
Back-aisle, beam 4 A	C3C0102	NLR29002	90	1515	DLWF	5.8	68.0	*NLHist_2*

KAMPEN — Oudestraat 11 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Back-aisle, sleeper beam above ground floor	C3B0105	NLR28001	91	1486	DLCE	4.4	68.6	-
Back-aisle, sleeper beam 3	C3B0106	NLR28002	70	1462	DLWF	5.4	67.7	-

KAMPEN — Vloeddijk 1, plague house (RDMZ; de Vries 1990; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M1	KVD00011	NLR10001	49	1537	DLNS	6.4	77.1	*NLHist_2*
M2	KVD00021	NLR10002	45	1533	DLWF	5.1	75.0	*NLHist_2*

KAMPEN — Vloeddijk 76 (RDMZ; de Vries 1992; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Hall, attic, laid-on beam ///	IKVL0021	NLR01001	89	1458	DLWF	6.6	68.2	*NLHist_2*
Hall, border joist against back	IKVL0032	NLR01002	66	1457	NLTF	8.2	79.2	*NLHist_2*

Hall, ground floor, curved brace 2	IKVL0011	not coded yet	128	1469	*NLHist_2*	4.6	65.0	Not clustered yet	
Hall, 2nd sleeper beam from back	IKVL0051	NLR01003	54	1459	NLTF	6.5	70.8	*NLHist_2*	
Back-aisle, ground floor, sleeper beam	IKVL0111	NLR01006	55	1452	NLTF	4.8	66.7	*NLHist_2*	
Back-aisle, 1st floor, sleeper beam	IKVL0061	NLR01004	83	1470	NLTF	6.6	70.1	*NLHist_2*	
Back-aisle, 1st floor, border joist near back	IKVL0121	NLR01007	37	1462	NLTF	4.7	76.4	*NLHist_2*	
Back-aisle, attic, principal	IKVL0081	NLR01005	64	1469	Intern	5.6	79.3	*NLHist_2*	

KERKRADE — Abbey Rolduc (RDMZ; de Vries 1987)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Transepts, laid-on beam D III Λ	IKAR0030	NLB01001	85	1586	NLSO	4.9	78.6	*NLHist_1*	
Transepts, North, 5th truss	IKAR0040	NLB01002	56	1586	NLSO	6.1	67.3	*NLHist_1*	
Nave, laid-on beam X D	IKAR0060	NLB01003	68	1585	NLSO	5.5	70.9	*NLHist_1*	
Nave, M5 from Westwall tower	IKAR0080	NLB01004	47	1584	FFB	5.3	70.7	*NLHist_1*	
Transepts, laid-on beam Λ I D	IKAR0010	NLB01005	103	1586	DLCE	5.0	72.1	*NLHist_1*	
Transepts, laid-on beam X	IKAR0020	NLB01006	99	1586	DLCE	5.5	67.9	*NLHist_1*	
Nave, principal <| III V	IKAR0050	NLB01007	79	1585	NLSO	6.3	71.2	*NLHist_1*	Date through avg. chronology
Nave, principal III V	IKAR0070	NLB01008	67	1585	idem	idem	idem	*NLHist_1*	of NLB01007 and NLB01008

KRABBENDIJKE — Ship (Rijksmuseum voor Scheepsarcheologie Ketelhaven)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M8 GC3/BB	KKR00081	NLW15001	61	1495	DLWF	7.0	72.5	*NLHist_2*
M10 keel 2	KKR00100	NLW15002	75	1521	DLWF	7.2	76.4	*NLHist_2*
M11 keel 3	KKR00110	NLW15003	113	1488	Intern	Vidual date		-
M14 frame 7	KKR00140	NLW15004	78	1525	Intern	Visual date		*NLHist_2*

LEEUWARDEN — Over de Kelders 11 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
1st floor, wallpost	ILEW0011	NLU01001	180	1507	DLWF	7.5	59.5	*NLHist_2*

LEIDSCHENDAM — Canal of Corbulo (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
RH01	LRC00017	NLR17001	89	49	*NLRom_R*	4.2	67.3	*NLRom_W1*	Date through avg. chronology
RH06	LRC00061	NLR17003	101	49	*NLRom_R*	idem	idem	*NLRom_W1*	
RH09	LRC00092	NLR17004	119	49	*NLRom_R*	idem	idem	*NLRom_W1*	
RH03	LRC00135	NLR17007	94	49	*NLRom_R*	idem	idem	*NLRom_W1*	
RH14	LRC00145	NLR17008	114	49	*NLRom_R*	idem	idem	*NLRom_W1*	
RH17	LRC00175	NLR17009	99	50	*NLRom_R*	idem	idem	*NLRom_W1*	
RH18	LRC00186	not coded yet	93	46	*NLRom_R*	idem	idem	*NLRom_W1*	
RH21	LRC00210	not coded yet	132	48	*NLRom_R*	idem	idem	*NLRom_W1*	

LENT — Ship (Rijksmuseum voor Scheepsarcheologie Ketelhaven)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Inner planking M1, M5 (1 tree)	KLE0105M	NLE05001	155	1557	POPO	6.2	66.9	-

MAASTRICHT — Brugstraat 18 (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Roof M3	IMBR0031	NLN05001	47	1562	BMBA	6.5	77.1	*NLHist_1*	Date through avg. chronology
Roof M4	IMBR0041	NLN05002	58	1560	BMBA	Idem	Idem	*NLHist_1*	of NLN05001 and NLN05002

MAASTRICHT — Dominicanenkerk (RDMZ)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Western nave, 2nd principal, back	MDK00020	NLN12001	80	1388	BMBA	5.7	66.5	*NLHist_1*
Western nave, North, principal //	MDK00031	NLN12002	77	1388	BMBA	3.7	64.5	-
Western nave, North, rafter in compartment 2	MDK00040	NLN12003	66	1392	BMBA	4.3	73.1	*NLHist_1*
Western nave, South, ashlar-piece in compartment 1	MDK00050	NLN12004	51	1380	BMBA	6.7	65.0	*NLHist_1*
Chevet, tie-beam	MDK00061	NLN12005	159	1262	BMBA	5.3	63.9	*NLHist_1*
Chevet, principal 1	MDK00071	NLN12006	145	1276	BMBA	9.3	74.0	*NLHist_1*
Chevet, principal 3	MDK00081	NLN12007	86	1275	BMBA	5.3	65.9	*NLHist_1*
Chevet, principal 4	MDK00091	NLN12008	83	1270	BMBA	5.1	64.0	*NLHist_1*
Chevet, principal 2	MDK00101	NLN12009	80	1266	BMBA	8.4	70.9	*NLHist_1*
Western choir, Southwest brace, rood-turret	MDK00111	NLN12010	130	1275	BMBA	8.4	70.5	*NLHist_1*
Western choir, North, rafter 21	MDK00121	NLN12011	99	1262	BMBA	9.4	65.3	*NLHist_1*
Western choir, Northwest brace, rood-turret	MDK00131	NLN12012	91	1249	BMBA	6.2	62.8	*NLHist_1*
Western choir, North, rafter 20	MDK00151	NLN12013	89	1260	BMBA	8.1	68.2	*NLHist_1*
Western choir, truss 19	MDK00161	NLN12014	76	1266	BMBA	5.2	70.7	*NLHist_1*

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Western choir, Northeast brace, rood-turret	MDK00171	NLN12015	57	1270	BMBA	7.2	72.3	*NLHist_1*

MAASTRICHT Fransiscanenkerk (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Choir, chevet, south principal	IMFK0101	Not coded yet	105	1293	BMBA	7.7	69.2	Not clustered yet
Choir, ashlar-piece, rafter near truss II north	IMFK0091	Not coded yet	106	1296	*NLHist_1*	9.2	76.2	Not clustered yet
Choir, chevet, ashlar-piece	IMFK0071	Not coded yet	150	1297	BMBA	9.5	67.4	Not clustered yet
Choir, principal X/ north	IMKF0061	Not coded yet	152	1288	BMBA	6.9	65.2	Not clustered yet
Nave, ashlar-piece /// south	IMKF0031	Not coded yet	113	1380	DLCE	5.5	71.4	Not clustered yet
Nave, principal ///V north	IMKF0031	Not coded yet	117	1390	Intern	4.7	69.0	Not clustered yet
Nave, ashlar-piece /// south	IMKF0011	Not coded yet	173	1387	DLCE	5.4	61.0	Not clustered yet

MAASTRICHT St. Janskerk (RDMZ; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Choir, trimmer between V and V/	MJK00021	NLN07001	87	1395	DLCE	5.3	64.0	-
Choir, principal ///V	MJK00031	NLN07002	65	1399	Intern	5.6	74.0	-
Choir, principal ////	MJK00041	NLN07003	55	1389	Intern	Visual date		-
Choir, tie-beam ////	MJK00051	NLN07004	51	1394	Intern	4.7	68.0	-
Nave, kingpost 3	MJK00081	NLN07005	89	1390	Intern	6.2	72.8	*NLHist_1*
Nave, principal <	MJK00091	NLN07006	73	1405	Intern	6.2	70.6	*NLHist_1*
Nave, laid-on beam //	MJK00101	NLN07007	74	1408	Intern	Visual date		*NLHist_1*
Nave, laid-on beam ///	MJK00111	NLN07008	211	1401	DLCE	5.9	63.6	*NLHist_1*
Tower, belfry, strut	MJK00121	NLN07009	103	1443	BMBA	5.1	65.2	*NLHist_1*
Tower, belfry, brace //	MJK00131	NLN07010	83	1453	Intern	Visual date		*NLHist_1*
Tower, belfry, brace ///	MJK00141	NLN07011	68	1457	BMBA	3.1	73.1	*NLHist_1*
Tower, belfry, brace V///	MJK00151	NLN07012	76	1453	BMBA	6.3	67.3	*NLHist_1*
Spire, eastern staircase tower, curved brace 2	MJK00171	NLN07013	91	1455	DLCE	4.4	68.3	*NLHist_1*

MAASTRICHT Kleinestraat 3 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M3	IMKL0031	NLN01001	52	1473	BMBA	4.5	74.5	*NLHist_1*
M4	IMKL0041	NLN01002	62	1468	BMBA	5.8	68.9	*NLHist_1*

MAASTRICHT Markt 55 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Gatehouse, attic, beam 2	IMMA0011	NLN04001	118	1750	BMBA	5.8	68.4	*NLHist_1*
Gatehouse, beam 1	IMMA0021	NLN04002	101	1752	Intern	10.3	69.4	*NLHist_1*
Corner estate, beam 1	IMMA0031	NLN04003	108	1570	Intern	5.2	69.1	*NLHist_1*
Corner estate, attic, beam IIII /|\	IMMA0041	NLN04004	69	1553	BMBA	6.3	70.6	*NLHist_1*

MAASTRICHT Matthiaskerk (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Chevet, tie-beam ///<	MMK00011	NLN08001	120	1491	DLCE	5.3	69.3	*NLHist_1*
Chevet, ashlar-piece 5	MMK00021	NLN08002	118	1492	DLCE	5.4	67.1	*NLHist_1*
Chevet, principal ///<	MMK00031	NLN08003	102	1494	DLCE	5.8	70.3	*NLHist_1*
Nave, principal /<	MMK00051	NLN08004	144	1519	BMBA	5.4	65.7	*NLHist_1*
Nave, principal 5	MMK00061	NLN08005	114	1502	BMBA	4.7	66.4	*NLHist_1*
Nave, principal 4 North	MMK00071	NLN08006	93	1506	BMBA	4.6	72.8	*NLHist_1*
Nave, ashlar-piece, truss 4 North	MMK00081	NLN08007	80	1449	BMBA	5.7	69.0	-
Nave, principal /< North	MMK00091	NLN08008	65	1518	DLCE	4.7	77.3	*NLHist_1*
Sacristy, curved brace /<	MMK00101	NLN08009	100	1474	BMBA	7.3	67.2	*NLHist_1*
Sacristy, purlin near truss ///	MMK00111	NLN08010	80	1467	Intern	5.2	63.9	*NLHist_1*
Sacristy, ashlar-piece ///	MMK00121	NLN08011	60	1492	Intern	5.4	66.1	*NLHist_1*

MAASTRICHT O.L.V. Kerk (RDMZ; de Vries 1990; de Vries 1992; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Choir, ring-anchor	IMOV0031	NLN03001	75	1063	DLCE	5.5	73.0	*NLHist_1*
Northern transepts, laid-on beam (sec.)	IMOV0041	NLN03002	81	1203	DLCE	7.2	79.4	*NLHist_1*
Ambulatory, ashlar-piece	IMOV0061	NLN03003	110	1417	DLSO	5.4	68.3	*NLHist_1*
Ambulatory, post IIII	IMOV0071	NLN03004	101	1416	Intern	5.0	61.0	-
Level 1, West, curved brace (North)	OLV00221	NLN06001	105	1338	Intern	5.2	64.9	-
Level 1, West, curved brace (South)	OLV00231	NLN06002	100	1347	Intern	5.2	72.2	-
Level 1, East, brace	OLV00241	NLN06003	67	1349	Intern	5.1	70.5	*NLHist_1*
Level 2, centre/South, post	OLV00261	NLN06004	120	1342	DLCE	6.8	65.5	*NLHist_1*
Level 2, West, brace	OLV00271	NLN06005	75	1349	DLCE	6.7	65.5	*NLHist_1*
Level 3/4, Southeast, post	OLV00291	NLN06006	106	1349	DLCE	6.0	69.5	*NLHist_1*
Level 3/4, Northwest, post	OLV00301	NLN06007	102	1347	Intern	Visual date		*NLHist_1*

Level 3/4, East, brace	OLV00311	NLN06008	100	1351	Intern	7.8	68.3	*NLHist_1*
Level 3/4, North, post	OLV00321	NLN06009	80	1350	Intern	5.5	66.5	-

MAASTRICHT — St. Servaas (RDMZ; de Vries 1987; de Vries 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Bergkapel, Curved brace -|-|-|-	MSS00011	NLN02001	113	1593	BMBA	5.7	69.2	*NLHist_1*	
Bergkapel, Vertical post X\	MSS00021	NLN02002	103	1592	Intern	Visual date		-	
Bergkapel, Purlin \	MSS00031	NLN02003	93	1569	BMBA	9.4	78.3	*NLHist_1*	
Bergkapel, Principal X\	MSS00041	NLN02004	80	1549	BMBA	7.0	72.2	*NLHist_1*	
Bergkapel, Brace in principal X\	MSS00051	NLN02005	78	1552	BMBA	7.8	70.1	*NLHist_1*	
Bergkapel, Ashlar-piece -/-/-/- SW	MSS00061	NLN02006	54	1560	BMBA	7.0	79.2	*NLHist_1*	
Northern tower, highest floor level, beam A	IMSS0201	Not coded yet	124	1539	*NLHist_1* ev	7.3	69.9	Not clustered yet	ev = early version
Northern tower, level above 'Keizerzaal', stairway	IMSS0211	Not coded yet	108	1192	BMBA	10.1	76.6	Not clustered yet	
Northern tower, highest floor level, unknown	IMSS0231	Not coded yet	76	1289	*NLHist_1*	6.9	70.7	Not clustered yet	
Northern tower, crowning, wooden spire, beam	IMSS0281	Not coded yet	113	1757	*NLHist_1*	5.2	67.3	Not clustered yet	
Northern tower, crowning, wooden spire, brace I	IMSS0291	Not coded yet	83	1767	*NLHist_1*	4.1	69.5	Not clustered yet	
Northern tower, crowning, wooden spire, brace III	IMSS0301	Not coded yet	79	1766	Intern	9.4	84.0	Not clustered yet	
Southern tower M2	IMSS0261	Not coded yet	80	1230	DLCE	6.8	70.3	Not clustered yet	

MARIENBERG — Bog oak (Sub-Fossil Forests Project (RING/ROB))

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Trunk 1	FMB00010	NLP01001	149	563	DLNO	5.9	63.5	*NLRom_R*

MIDDELBURG — Kousteensedijk (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
City wall, foundation	MKD00010	NLW17001	121	1597	DLCE	8.6	69.6	*NLHist_1*

MIERLO — Neerakkers (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Find without context	F2A0101X	NLK16001	159	-44	DLNO	6.7	65.2	-

MIERLO — Roman house (ROB; Verwers 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
7NE-205	MLO00011	NLK37001	78	13	*NLRom_W2*	5.4	63.6	-

MOLENGAT — Ship (AAOW/ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
SO1 AE HS/A1	SAM0002Y	NLS01001	147	1530	DLWB	5.6	65.2	*NLHist_2*
SO1 AE/keel	SAM0004Y	NLS01002	99	1575	DLNS	5.3	68.4	*NLHist_2*
SO1 VE WH2/SB	SAM0007A	NLS01003	154	1557	DLWF	6.7	68.0	*NLHist_2*
SO1 VE WF2/BB/a	SAM0008A	NLS01004	80	1513	Intern	10.0	73.1	*NLHist_2*
SO1 VE WF2/BB/b	SAM0009Y	NLS01005	124	1551	NLDT	5.4	63.4	*NLHist_2*
SO1 AE GB1/SB	SAM0011A	NLS01006	112	1557	Intern	6.9	63.5	*NLHist_2*
SO1 AE GA1/SB	SAM0012A	NLS01007	128	1526	Intern	9.3	73.0	-
SO1 VE GA1/BB	SAM0014A	NLS01008	147	1555	Intern	7.3	72.9	-
SO1 AE 437	SAM0015A	NLS01009	78	1560	DLWF	4.9	62.1	*NLHist_2*
SO1 AE A4/HS	SAM0016A	NLS01010	155	1540	Intern	8.1	70.9	-

MOLENGAT — Ship (AAOW/ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Keel	A3A0101Y	NLS02001	148	1612	DLWF	7.4	67.3	*NLHist_2*

NIEUWENHOORN — Farmhouse 09-89 (BOOR; van Trierum 1992)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
1569	NWH011	NLW14001	130	-1	DLCE	8.26	64.6	*NLRom_W2*	Date through avg. chronology
1240	NWH021	NLW14002	96	83	DLCE	idem	idem	*NLRom_W2*	
1384	NWH031	NLW14003	101	87	DLCE	idem	idem	*NLRom_W2*	
1271	NWH041	NLW14004	111	87	DLCE	idem	idem	*NLRom_W2*	
970	NWH051	NLW14005	146	26	DLCE	idem	idem	*NLRom_W2*	
1313	NWH061	NLW14006	174	58	DLCE	idem	idem	*NLRom_W2*	
1290	NWH071	NLW14007	95	59	DLCE	idem	idem	*NLRom_W2*	
1009	NWH081	NLW14008	96	64	DLCE	idem	idem	*NLRom_W2*	
1402	NWH091	NLW14009	64	64	DLCE	idem	idem	*NLRom_W2*	
1642	NWH101	NLW14010	73	38	DLCE	idem	idem	*NLRom_W2*	
451	NWH111	NLW14011	65	44	DLCE	idem	idem	*NLRom_W2*	
626	NWH121	NLW14012	110	51	DLCE	idem	idem	*NLRom_W2*	
1300	NWH131	NLW14013	149	51	DLCE	idem	idem	*NLRom_W2*	
1570	NWH141	NLW14014	82	26	DLCE	idem	idem	*NLRom_W2*	

Unknown	NWH181	NLW14015	102	42	DLCE	idem	idem	*NLRom_W2*	
1545	NWH191	NLW14016	110	48	DLCE	idem	idem	*NLRom_W2*	
1322	NWH201	NLW14017	76	43	DLCE	idem	idem	*NLRom_W2*	
544	NWH211	NLW14018	72	75	DLCE	idem	idem	*NLRom_W2*	
22	NWH231	NLW14019	82	62	DLCE	idem	idem	*NLRom_W2*	
1493	NWH241	NLW14020	128	-13	DLCE	idem	idem	*NLRom_W2*	
1366	NWH251	NLW14021	70	85	DLCE	idem	idem	*NLRom_W2*	
446	NWH261	NLW14022	84	61	DLCE	idem	idem	*NLRom_W2*	
1364	NWH271	NLW14023	104	29	DLCE	idem	idem	*NLRom_W2*	
1037	NWH281	NLW14024	129	48	DLCE	idem	idem	*NLRom_W2*	
1310	NWH291	NLW14025	72	79	DLCE	idem	idem	*NLRom_W2*	
1608	NWH301	NLW14026	172	59	DLCE	idem	idem	*NLRom_W2*	
725	NWH311	NLW14027	96	56	DLCE	idem	idem	*NLRom_W2*	
573	NWH321	NLW14028	74	84	DLCE	idem	idem	*NLRom_W2*	
34	NWH331	NLW14029	60	86	DLCE	idem	idem	*NLRom_W2*	
1363	NWH341	NLW14030	106	85	DLCE	idem	idem	*NLRom_W2*	
1796	NWH351	NLW14031	124	61	DLCE	idem	idem	*NLRom_W2*	
1249	NWH361	NLW14032	116	84	DLCE	idem	idem	*NLRom_W2*	
1456	NWH381	NLW14033	76	86	DLCE	idem	idem	*NLRom_W2*	
1556	NWH391	NLW14034	139	38	DLCE	idem	idem	*NLRom_W2*	
608	NWH401	NLW14035	63	86	DLCE	idem	idem	*NLRom_W2*	
1293	NWH411	NLW14036	70	43	DLCE	idem	idem	*NLRom_W2*	
708	NWH421	NLW14037	171	48	DLCE	idem	idem	*NLRom_W2*	
551	NWH431	NLW14038	74	75	DLCE	idem	idem	*NLRom_W2*	
1283	NWH441	NLW14039	64	40	DLCE	idem	idem	*NLRom_W2*	

OEGSTGEEST — Huis Endegeest (RDMZ; de Vries 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Eastern tower, crowning, rafter 2	OHE00041	NLR25001	109	1648	DLNS	7.5	63.6	*NLHist_1*	Date through avg. chronology
Eastern tower, crowning, rafter 3	OHE00051	NLR25002	76	1650	DLNS	idem	idem	*NLHist_1*	
Western tower, wooden vault, wallpost I	OHE00061	NLR25003	79	1629	DLNS	idem	idem	*NLHist_2*	
Western tower, wooden vault, wallpost III	OHE00071	NLR25004	78	1592	DLNS	idem	idem	*NLHist_1*	
Western tower, wooden vault, wallpost IIII	OHE00081	NLR25005	55	1601	DLNS	idem	idem	*NLHist_1*	
Ground floor, room front (left), chimney trimming	OHE00091	NLR25006	174	1630	DLNS	idem	idem	*NLHist_2*	
Ground floor, room front (left), fireplace, trimmer	OHE00111	NLR25008	91	1646	DLNS	idem	idem	*NLHist_2*	
Ground floor, room front (left), chimney, border joist	OHE00121	NLR25009	103	1637	DLNS	idem	idem	-	
1st floor, sleeper beam	OHE00101	NLR25007	173	1627	DLNS	idem	idem	*NLHist_2*	

OLST — Bog oaks (Sub-Fossil Forests Project (RING/ROB))

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Trunk 5	OLF00050	NLQ23001	115	538	*NLRom_R* (ev)	5.3	64.7	*NLRom_R*	Date through avg. chronology
Trunk 6	OLF00061	NLQ23002	95	540	*NLRom_R* (ev)	idem	idem	*NLRom_R*	ev = early version

OSS-USSEN — Wooden box 6816 (IPL)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
plank a	OSP00011	NLL01001	133	138	Intern	Visual date		-
plank b	OSP00021	NLL01002	85	133	Intern	Visual date		-
plank c	OSP00031	NLL01003	134	121	DLCE	5.8	61.2	-
plank d	OSP00051	NLL01004	157	134	Intern	Visual date		-
plank e	OSP00061	NLL01005	140	121	DLCE	5.1	60.8	-
plank f	OSP00071	NLL01006	170	145	Intern	Vidual date		-
plank g	OSP00081	NLL01007	112	143	DLCE	5.5	62.2	-
plank h	OSP00091	NLL01008	96	71	Intern	Visual date		-
plank i	OSP41000	NLL01009	159	134	Intern	Visual date		-

OSS-USSEN — Iron-Age village (IPL; van der Sanden 1987)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
5899 plank 10	OSN011	NLL02001	113	72	*NLRom_R*	5.2	64.3	-
8644 central post	OSN021	NLL02002	68	53	Intern	7.4	71.9	-
9060 central post	OSN031	NLL02003	88	-12	DLCE	6.6	72.4	-
9668	OSN041	NLL02004	91	79	*NLRom_R*	Visual date		-
451	OSN051	NLL02005	143	50	Intern	6.2	69.0	-
10.455b post horreum	OSN061	NLL02006	146	52	Intern	4.3	67.1	-

OSS-USSEN	Water well (IPL)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
5021	OSDBOOM1	NLL03001	157	88	*NLRom_R*	6.8	67.2	-
5021	OSDBOOM2	NLL03002	124	74	Intern	6.0	67.1	-
5021	OSD00091	NLL03003	204	78	*NLRom_R*	5.3	64.0	-
5021	OSD00141	NLL03004	94	69	*NLRom_R*	Visual date		-
5021	OSD00151	NLL03005	114	56	*NLRom_R*	Visual date		-
5021	OSD00171	NLL03006	84	3	*NLRom_R*	5.2	64.0	-

OUDDORP	Bosweg 2, 't Blaeuwe Huus (RDMZ)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
1st anchor, border joist	IOUD0021	NLZ01001	63	1469	Intern	5.7	79.8	*NLHist_1*
2nd tie-beam	IOUD0031	NLZ01002	62	1454	BMBA	5.8	71.1	*NLHist_1*

OUDERKERK A/D IJSSEL	Bog oak (Sub-Fossil Forests Project (RING/ROB))								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Trunk 2	OKF00020	Not coded yet	243	324	DLNO	6.4	65.0	*NLRom_R*	Date through avg. chronology
Trunk 3	OKF00030	Not coded yet	232	312	DLNO	idem	idem	*NLRom_R*	

PAPENDRECHT	Bog oak (Sub-Fossil Forests Project (RING/ROB))							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Trunk 1	PAF00010	Not coded yet	174	-1158	*NLPre_ZH*	5.0	63.7	Not clustered yet
Trunk 2	PAF00020	Not coded yet	196	-832	DLNO	4.6	64.2	Not clustered yet
Trunk 4	PAF00040	Not coded yet	270	-1366	*NLPre_ZH*	6.2	59.3	Not clustered yet
Trunk 7	PAF00070	Not coded yet	255	-1152	*NLPre_ZH*	6.5	62.1	Not clustered yet
Trunk 8	PAF00080	Not coded yet	319	-1035	DLNO	6.2	58.2	Not clustered yet

ROCKANJE	N. H. Kerk (RDMZ; de Vries 1992)								
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
Roof, laid-on beam	RK000021	NLW01001	62	1447	*NLHist_1* (ev)	6.6	67.2	*NLHist_1*	ev = early version

ROTTERDAM	City wall, foundation (IPL)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
13.28.259	C4F0101Z	NLW11001	55	1497	NLTF	5.5	77.8	*NLHist_2*
13.28.542	C4F0102Z	NLW11002	123	1495	BMBA	5.9	61.5	*NLHist_1*
13.28.553	C4F0105Z	NLW11003	90	1464	BMBA	6.7	65.7	*NLHist_1*
13.28.562	C4F0106Z	NLW11004	127	1465	BMBA	5.6	71.0	-
13.28.441	C4F0107Z	NLW11005	122	1482	BMBA	7.5	78.1	*NLHist_1*
13.28.394	C4F0108Z	NLW11006	142	1494	NLSO	11.6	74.1	*NLHist_1*
13.28.577	C4F0109Z	NLW11007	112	1455	BMBA	5.9	63.1	*NLHist_1*
13.28.418	C4F0113Z	NLW11008	99	1486	BMBA	7.3	74.5	*NLHist_1*
13.28.434	C4F0115Z	NLW11009	99	1484	NLTF	7.2	77.6	*NLHist_2*
13.28.389	C4F0117Z	NLW11010	98	1461	BMBA	6.1	68.0	*NLHist_1*
13.28.563	C4F0119Z	NLW11011	113	1493	NLSO	9.3	78.1	*NLHist_1*
13.28.435	C4F0121Z	NLW11012	85	1482	NLTF	5.4	70.2	*NLHist_2*
13.28.456	C4F0125Z	NLW11013	74	1441	NLSO	4.6	69.8	*NLHist_1*
Unknown	C4F0126Z	NLW11014	87	1448	Intern	Visual date		*NLHist_1*
13.28.428	C4F0127A	NLW11015	115	1474	BMBA	7.3	75.0	*NLHist_1*
13.28.414	C4F0128Z	NLW11016	97	1482	NLTF	8.5	69.3	*NLHist_2*
13.28.409	C4F0129A	NLW11017	108	1436	BMBA	5.4	63.1	*NLHist_1*
13.28.545	C4F0131C	NLW11018	84	1481	BMBA	5.4	67.5	*NLHist_1*

ROTTERDAM	Ship (Rijksmuseum voor Scheepsarcheologie Ketelhaven)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Ship 1 M1 GE 1/SB	KSR00010	NLW16001	143	1220	POPO	5.6	60.9	-
Ship 1 M3 GE1 + 2/SB	KSR00031	NLW16002	138	1230	DLNS	6.3	65.0	*NLHist_3*
Ship 1 M5 GB 1/BB	KSR00051	NLW16003	267	1251	DLNS	6.7	64.3	-
Ship 1 M7 GD 1/BB	KSR00071	NLW16004	251	1240	DLNS	7.3	59.8	-
Ship 1 M12 GA 2/SB	KSR00121	NLW16005	277	1230	DLNS	4.9	61.2	-
Ship 1 M18 LH-2	KSR00180	NLW16006	94	1227	DLNS	5.1	65.6	*NLHist_3*
Ship 1 M21 WH 1/BB	KSR00211	NLW16007	196	1218	DLNS	5.4	68.7	*NLHist_2*
Ship 1 M22 WG 1/BB	KSR00221	NLW16008	233	1187	DLNS	4.9	63.1	-

SCHIPLUIDEN	Castle Schipluiden (ROB)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
21.52	C4G0105A	NLR16001	50	1451	NLTF	7.2	78.6	*NLHist_2*
14.4.75	C4G0108A	NLR16002	234	1590	NLSO	7.5	64.8	*NLHist_1*
14.4.74	C4G0109B	NLR16003	102	1384	NLTF	6.9	70.3	*NLHist_2*
23.2.7	C4G0116Z	NLR16004	146	1581	NLTF	8.5	65.2	*NLHist_2*

SUSTEREN	Cloister Salvatorplein (ROB)							
Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
8.6.257	SSK00010	NLN11001	144	1307	BMBA	10.1	73.1	*NLHist_1*
8.6.291	SSK00050	NLN11002	201	1351	DLCE	7.8	68.8	*NLHist_1*

TERNEUZEN: Unknown (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Unknown	E5A0101Z	NLW08001	122	1074	BMBA	6.4	67.4	*NLHist_1*

TUBBERGEN: Manderveenseweg 29 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Rafter XX||, 7th from back	ITUB0030	NLF03001	134	1598	DLCE	5.3	67.7	*NLHist_2*
Rafter, 5th from back (right)	ITUB0040	NLF03002	125	1575	NLTF	6.8	69.8	*NLHist_2*
Post 9, OOO (right)	ITUB0070	NLF03003	124	1595	NLTF	10.1	67.1	*NLHist_2*
Post 7, OOOOOO (right)	ITUB0051	NLF03004	64	1598	NLTW	5.6	72.2	*NLHist_2*
M6	ITUB0061	NLF03005	81	1596	NLTW	6.2	65.6	*NLHist_2*
Post 8 (right)	ITUB0081	NLF03006	103	1597	NLTF	6.9	68.6	*NLHist_2*
Wind brace OOOOO, near post 8	ITUB0101	NLF03007	80	1596	NLTW	5.5	69.0	*NLHist_2*

UTRECHT: Achter Clarenburg 2 (RDMZ; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Ground floor, E. room, East, sleeper beam	UAC00051	NLQ37001	94	1378	Intern	Visual date		-
Ground floor, E. room, West, sleeper beam	UAC00061	NLQ37002	87	1378	NLTF	5.8	64.0	*NLHist_2*
1st floor, W. façade, niche, I	UAC00071	NLQ37003	127	1282	POPO	8.8	73.8	*NLHist_2*
1st floor, W. façade, niche, II	UAC00081	NLQ37004	103	1293	DLNS	4.9	64.2	-
1st floor, W. façade, niche, III	UAC00091	NLQ37005	99	1298	DLNS	4.8	64.8	-

UTRECHT: Boterstraat 20 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
First truss, right post	IUBS0011	NLQ05001	113	1533	DLWF	3.4	66.5	-
Last truss, laid-on beam	IUBS0041	NLQ05002	157	1531	BMBA	7.4	68.6	*NLHist_1*
Last principal (truss)	IUBS0051	NLQ05003	110	1540	Intern	6.5	77.0	-

UTRECHT: Duitse huis, Springweg (RDMZ; De Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Main building, east wing, sleeper beam above ground floor	IUDH0011	Not coded yet	193	1346	NLTF	5.9	64.6	Not clustered yet
Main building, roof (west), collar	IUDH9921	Not coded yet	132	1345	NLTF	7.6	68.7	Not clustered yetMain building, roof (west), collar 35
	IUDH0031	Not coded yet	123	1339	NLTF	4.4	62.7	Not clustered yet
Main building, roof (west), rafter	IUDH0041	Not coded yet	99	1344	NLTF	4.2	70.4	Not clustered yet
Annex (south), curved brace	IUDH0071	Not coded yet	148	1556	*NLHist_2*	6.4	65.6	Not clustered yet
Annex (south), principal	IUDH0081	Not coded yet	129	1556	*NLHist_2*	5.5	62.9	Not clustered yet
Annex (south), curved brace II	IUDH0091	Not coded yet	138	1551	*NLHist_2*	5.9	60.9	Not clustered yet
Annex (south), attic, principal II	IUDH0101	Not coded yet	134	1550	*NLHist_2*	4.6	62.0	Not clustered yet
Commandeurswoning I, garret A, truss ////	IUDH0161	Not coded yet	112	1336	Intern	7.0	70.3	Not clustered yet
Commandeurswoning II, curved brace)))))	IUDH0111	Not coded yet	111	1473	*NLHist_2*	5.2	64.5	Not clustered yet

UTRECHT: Geertestraat 14 - 16 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Ground floor, beam VII	IUG14011	NLQ11001	105	1333	DLCE	5.1	64.4	*NLHist_1*
Sleeper beam	UGS00021	NLQ09001	81	1534	DLWB	5.1	65.6	*NLHist_2*

UTRECHT: Jacobijnenstraat 2 (Oudegracht 50) (RDMZ; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M2	IUJAC011	NLQ13001	77	1506	DLWF	4.9	65.1	*NLHist_2*
M3	IUJAC031	NLQ13002	53	1495	DLWF	5.7	75.0	*NLHist_2*

UTRECHT: Jeruzalemstraat 8-10 (RDMZ; de Vries 1990; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Floor plank	IUJS0010	NLQ14001	170	1551	DLCE	6.5	68.0	-

UTRECHT: Mariaplaats 22 (RDMZ)

Vice, step A	IUMP0021	NLQ21001	83	1519	DLWF	4.6	64.6	*NLHist_2*
Vice, step B	IUMP0031	NLQ21002	51	1482	DLWF	4.3	67.0	*NLHist_2*
Former stair passage, lintel	IUMP0051	NLQ21003	75	1501	DLWF	6.0	71.6	*NLHist_2*

UTRECHT: Oudegracht 55 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
M1	IUOG5011	NLQ16001	81	1655	DLSO	5.8	70.2	-	Date through avg. chronology
M2	IUOG5021	NLQ16002	122	1655	DLSO	idem	idem	-	
M3	IUOG5031	NLQ16003	116	1649	DLSO	idem	idem	-	
M4	IUOG5041	NLQ16004	96	1653	DLSO	5.3	74.7	-	
M5	IUOG5051	NLQ16005	84	1658	DLSO	5.8	70.2	-	Date through avg. chronology
M6	IUOG5061	NLQ16006	73	1639	DLSO	5.0	72.2	*NLHist_1*	

UTRECHT — Oudegracht 67 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Wooden lower front, post	IUOG6020	NLQ15001	90	1512	NLTF	6.0	68.5	-	Date through avg. chronology
Wooden lower front, side post	IUOG6040	NLQ15002	84	1489	NLTF	idem	idem	-	of NLQ15001, NLQ15002
Wooden lower front	IUOG6050	NLQ15003	82	1525	NLTF	idem	idem	*NLHist_2*	and NLQ15003

UTRECHT — Oudegracht 99, Huis Oudaen (RDMZ; de Vries 1987)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Step	UOA00011	NLQ03001	179	1227	NLSO	5.5	66.8	*NLHist_1*	Date through avg. chronology
Step	UOA00021	NLQ03002	144	1181	NLSO	idem	idem	*NLHist_1*	of NLQ03001, NLQ03002 and
Step	UOA00041	NLQ03003	111	1230	NLSO	idem	idem	*NLHist_1*	NLQ03003
Ground floor, sleeper beam	IUHO0010	NLQ04001	100	1493	DLNS	6.4	65.2	*NLHist_2*	
Ground floor, sleeper beam	IUHO0020	NLQ04002	74	1477	Intern	Visual	date	-	
3rd sleeper beam from back	IUOUC011	NLQ17001	156	1578	DLCE	6.1	66.5	*NLHist_1*	

UTRECHT — Oudegracht 240 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Groundfloor, sleeper beam	IUOG2031	NLQ18001	97	1490	DLWF	6.6	74.5	*NLHist_2*

UTRECHT — Unknown (excavation H. de Groot, Utrecht)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M12	IUSK00012	not coded yet	102	1011	*NLHist_1*	4.7	60.4	Not clustered yet
M47	IUSK00047	not coded yet	139	978	*NLHist_1*	4.7	64.1	Not clustered yet
M56	IUSK00056	not coded yet	176	1005	intern	4.4	68.8	Not clustered yet
M67	IUSK00067	not coded yet	131	971	intern	3.2	68.5	Not clustered yet
M79	IUSK00079	not coded yet	165	1066	*NLHist_1*	6.0	64.1	Not clustered yet

UTRECHT — Visscherssteeg 11/13 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Hall, roof, curved brace	IUVS0030	NLQ12001	83	1472	NLTF	7.5	81.1	*NLHist_2*
Hall, principal	IUVS0040	NLQ12002	73	1470	NLTF	5.8	66.7	*NLHist_2*
Back-aisle, East, roof plate	IUVS0050	NLQ12003	68	1471	NLTF	6.2	71.6	*NLHist_2*

VALKENBURG (ZH) — De Woerd, Stave (IPP)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
WP 510 sp. 82 Stave 1	IVAW0081	NLR30001	151	750	DLCE	6.7	72.0	-

VALKENBURG (L.) — Kasteel Genhoes (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
N. wing, West, principal XI	VKG00052	NLA01001	117	1748	NLDT	6.0	63.4	-
N. wing, staircase tower, principal	VKG00061	NLA01002	104	1748	BMBA	6.5	69.9	*NLHist_1*
N. wing, East, principal	VKG00071	NLA01003	76	1749	NLDT	3.6	69.3	-

VALKENBURG (ZH) — Marktveld (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
31.408 H8	VAL00111	NLR04001	120	23	*NLRom_W1*	5.3	67.6	-
41.865	VAL00251	NLR04002	114	51	DLCE	8.4	75.7	-
67.257 H124 (stave)	VAL00290	NLR04003	114	199	DLWS	4.3	71.2	-
67.257 H113	VAL00301	NLR04004	195	201	DLCE	7.1	67.5	-
67.257 H118	VAL00311	NLR04005	136	196	DLCE	7.5	62.6	-
67.257 H176	VAL00331	NLR04006	137	196	DLCE	9.5	69.5	-
41.404 H51	VAL00401	NLR04007	80	137	DLWS	5.0	70.3	-

VALKENBURG (L.): — Nicolaas en Barbara Kerk (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Choir, tie-beam /	VNB00021	NLA02001	83	1425	DLCE	6.3	70.7	*NLHist_1*
Choir, North, rafter in compartment ///-////	VNB00031	NLA02002	84	1435	NLSO	5.2	69.3	*NLHist_1*
Choir, South, rafter in compartment //-////	VNB00041	NLA02003	60	1424	NLSO	5.4	67.8	*NLHist_1*
Choir, North, trimmer in compartment /-///	VNB00061	NLA02004	41	1435	BMBA	5.1	72.5	*NLHist_1*
Transept, tie-beam //	VNB00071	NLA02005	72	1478	Intern	Visual date		-
Transept, tie-beam ///	VNB00111	NLA02006	43	1463	Intern	Visu al date		*NLHist_1*
Spire, hip-rafter //	VNB00121	NLA02007	55	1456	Intern	Visu al date		*NLHist_1*

VALKENBURG (ZH) — Roman road (IPP; van Rijn 1987)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
H41	VNW00011	NLR08001	198	94	DLCE	8.5	67.3	-	
47-164 H23	VNW00021	NLR08002	208	123	DLCE	7.3	64.5	-	
47-165 H27	VNW00031	NLR08003	163	123	*NLRom_R*	6.3	66.7	-	
40-114 H38	VNW00041	NLR08004	215	123	DLCE	5.9	59.6	-	
40-057 H25	VNW00051	NLR08005	91	123	*NLRom_R*	4.6	71.7	-	
40-127 H 51	VNW00061	NLR08006	77	123	*NLRom_R*	3.6	69.7	-	

103 1.4.86	VRW00012	NLR21001	53	120	NLR08 (mc)	6.0	70.0	-	Date through avg. chronology, against mean chronology of NLR08
103 1.4.85	VRW00021	NLR21002	94	124	NLR08 (mc)	idem	idem	-	
103 1.4.88	VRW00030	NLR21003	33	124	NLR08 (mc)	idem	idem	-	
103 1.4.87	VRW00051	NLR21004	44	122	NLR08 (mc)	idem	idem	-	

VELSEN — Roman fortress Velsen I, foundation watchtower (IPP)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
221 M524	VEL00050	NLZ07001	65	37	DLNO	5.8	69.5	*NLRom_W1*	Date through avg. chronology
221 M518	VEL00060	NLZ07002	44	36	DLNO	idem	idem	*NLRom_W1*	
221 M555	VEL00070	NLZ07003	62	36	DLNO	idem	idem	*NLRom_W1*	
221 M525	VEL00080	NLZ07004	40	36	DLNO	idem	idem	*NLRom_W1*	
221 M537	VEL00090	NLZ07005	52	35	DLNO	idem	idem	*NLRom_W1*	
221 M559	VEL00100	NLZ07006	37	36	DLNO	idem	idem	*NLRom_W1*	

VELSEN — Roman fortress Velsen I, harbour, western jetty (IPP; Jansma 1985; Morel 1988)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
5269	VL5269	NLZ04001	61	15	NLR20 (mc)	5.1	68.8	*NLRom_R*	Date through avg. chronology
5271	VL5271	NLZ04002	75	21	NLR20 (mc)	idem	idem	*NLRom_R*	mc = mean chronology
5288	VL5288	NLZ04003	80	21	NLR20 (mc)	idem	idem	*NLRom_R*	
5289	VL5289	NLZ04004	109	21	NLR20 (mc)	idem	idem	*NLRom_R*	
5291	VL5291	NLZ04005	106	21	NLR20 (mc)	idem	idem	*NLRom_R*	
5292	VL5292	NLZ04006	74	21	NLR20 (mc)	idem	idem	*NLRom_R*	
5293	VL5293	NLZ04007	73	21	NLR20 (mc)	idem	idem	*NLRom_R*	

VELSEN — Roman fortress Velsen I, ships' timber (IPP)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**	**Remarks**
M33	VEL00020	NLZ06001	115	26	DLCE	6.2	67.1	*NLRom_W2*	Date through avg. chronology
M32	VEL00030	NLZ06002	108	15	DLCE	idem	idem	*NLRom_W2*	
M31	VEL00041	NLZ06003	116	28	DLCE	idem	idem	*NLRom_W2*	

VENLO — Heiershoeve (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Inner West	VEN00012	NLN09001	166	73	DLCE	4.8	66.7	Not clustered yet
Inner North	VEN00041	NLN09002	137	69	DLCE	5.4	62.9	Not clustered yet
East 2	VEN00061	NLN09003	189	93	Intern	5.6	63.0	Not clustered yet
Z1, North and South (1 tree)	VEN0709M	NLN09004	188	89	DLCE	8.8	70.1	Not clustered yet
North and South (1 tree)	VEN810MM	NLN09005	174	87	DLCE	9.1	71.4	Not clustered yet

VIANEN — Voorstraat 30, town hall (RDMZ; de Vries 1990; de Vries 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Principal < (back)	VSH00011	NLQ08001	82	1471	NLTF	5.9	71.6	*NLHist_1*
Curved brace I, 1st truss (back)	VSH00041	NLQ08002	64	1470	NLTF	6.5	77.0	*NLHist_2*
Laid-on beam < (back)	VSH00051	NLQ08003	58	1456	NLTF	4.1	71.9	*NLHist_2*
Principal < (back)	VSH00061	NLQ08004	75	1470	NLTF	5.5	73.6	*NLHist_2*

VOORBURG — Water well (ROB)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
1.4.105	VBP00021	NLR22001	171	116	DLCE	8.6	66.7	-
1.4.96	VBP00031	NLR22002	42	65	Intern	Visual date		-
1.4.87	VBP00091	NLR22003	216	201	DLCE	9.7	67.4	-
1.4.89	VBP00171	NLR22004	243	188	Intern	Visual date		-
1.4.88	VBP00251	NLR22005	247	205	DLCE	12.4	72.1	-

WAGENINGEN — Bog oak (Sub-Fossil Forests Project (RING/ROB))

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Trunk 1	WVE00010	Not coded yet	187	-1160	*NLPre_ZH*	5.7	67.5	Not clustered yet

WARFFUM — Pastorieweg 24, former refectory (RDMZ; de Vries 1990; de Vries 1994)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
Floor, beam under truss Λ	IWPA0060	NLF02005	81	1614	NLTF	6.0	70.0	*NLHist_2*
Floor, beam between truss V, IIII	IWPA0050	NLF02009	99	1626	NLTF	4.7	65.8	-
Mezzanine, room, beam 1	IWPA0010	NLF02001	80	1466	DLOF	5.4	74.1	-
Mezzanine, room, beam 2	IWPA0020	NLF02002	72	1475	DLOF	5.0	74.6	*NLHist_2*
Mezzanine, room, principal	IWPA0120	NLF02004	79	1449	NLTF	7.4	64.1	*NLHist_2*
Roof, rafter XXþII	IWPA0130	NLF02010	55	1632	NLTF	5.6	66.7	*NLHist_2*
Cupboard	IWPA0040	NLF02003	39	1467	NLTF	5.6	80.3	*NLHist_2*
Rafter VI	IWPA0080	NLF02006	107	1620	NLTF	5.7	67.9	*NLHist_1*
Rafter XVII	IWPA0090	NLF02007	102	1632	NLTF	5.0	61.9	-
Rafter XIX	IWPA0100	NLF02008	92	1632	Intern	7.1	73.1	-

WEDDE — Wedder borg, castle (ROB; Jansma 1995)

Object	**Filename**	**Dendro-code**	**No.**	**Date**	**Reference**	***St***	***PV***	**NL**
M30	WED00030	NLD01001	95	1520	NLTF	7.7	72.3	*NLHist_2*
M36	WED00040	NLD01002	67	1503	NLTF	5.5	71.2	*NLHist_2*
M38	WED00050	NLD01003	81	1512	NLTF	5.0	73.1	*NLHist_2*

M15	WED00060	NLD01004	75	1524	NLTF	5.2	71.7	*NLHist_2*
M19	WED00070	NLD01005	118	1529	NLTF	5.3	64.1	*NLHist_2*
M24	WED00090	NLD01006	70	1529	NLTF	3.9	68.1	*NLHist_2*
M17	WED00110	NLD01007	87	1529	NLTF	4.7	66.5	*NLHist_2*
M27	WED00120	NLD01008	79	1529	NLTF	4.8	63.5	*NLHist_2*
M2	WED00130	NLD01009	70	1529	Intern	5.8	70.3	*NLHist_2*
M7, M8 (1 tree)	WED08010	NLD01010	73	1531	Intern	Visual date		*NLHist_2*

WEERSELO Huneborg moat (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
4.1.1b	WHG00012	NLF06001	144	1141	DLOF	6.1	71.0	-
4.1.1a	WHG00021	NLF06002	133	1140	DLOF	4.1	63.3	-

WEESP Bog oaks (Sub-Fossil Forests Project (RING/ROB))

Trunk 1	WEF00010	Not coded yet	202	-739	DLNO	5.3	64.2	Not clustered yet

WEHL Water well (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M1	WHN00040	NLE07001	97	312	*NLRom_E*	5.0	72.7	-
M2	WHN00050	NLE07002	55	312	*NLRom_E*	4.8	68.5	-
M3	WHN00060	NLE07003	46	302	*NLRom_E*	5.5	76.1	-

WILDERVANCK (G) Bog oaks (Veenkoloniaal Museum; Sub-Fossil Forests Project (RING/ROB))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Trunk 1	WZF00010	Not coded yet	81	-5729	DLNO	5.5	68.1	Not clustered yet
Trunk 10	WZF00100	Not coded yet	72	-4988	DLNO	3.9	62.7	Not clustered yet
Trunk 11	WZF00110	Not coded yet	114	-4940	DLNO	6.5	68.6	Not clustered yet
Trunk 12	WZF00120	Not coded yet	67	-5733	DLNO	4.7	65.2	Not clustered yet
Trunk 19	WZF00190	Not coded yet	78	-4968	DLNO	3.8	66.9	Not clustered yet
Trunk 22	WZF00220	Not coded yet	69	-4969	DLNO	5.1	66.2	Not clustered yet
Trunk 23	WZF00230	Not coded yet	116	-4967	DLNO	4.4	69.6	Not clustered yet

WOERDEN: Canoo (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Ship 4, mast beam/floor timber	WS400011	NLQ30001	132	199	DLCE	5.9	67.9	Not clustered yet

WOERDEN Castle Woerden (RDMZ; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Sleeper beam	IWOK0041	NLQ20001	101	1519	DLNS	5.9	68.0	*NLHist_2*

WOERDEN Ship (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Ship 3, planks 1 and 2 (1 tree)	WS30123Z	NLQ29001	144	164	DLSM	6.5	66.1	Not clustered yet

WORKUM Ship (Rijksmuseum voor Scheepsarcheologie Ketelhaven)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M3 keel part 2	WNS00011	NLV15001	91	1535	DLWF	5.6	71.1	*NLHist_2*
M17 GD1/BB	WNS00021	NLV15002	126	1528	DLWF	6.5	60.8	*NLHist_2*
M9 GB2/SB	WNS00031	NLV15003	77	1532	DLWF	6.2	71.1	*NLHist_2*
M6 keel	WNS00041	NLV15004	139	1531	DLWF	7.1	66.3	*NLHist_2*
M19 GC2/BB	WNS00051	NLV15005	103	1539	DLWF	12.6	85.3	*NLHist_2*
M16 GC2/SB	WNS00061	NLV15006	95	1534	DLWF	11.6	75.5	*NLHist_2*
M13 GC1/SB	WNS00071	NLV15007	51	1536	DLWF	5.2	75.0	*NLHist_2*

WOLLINGHUIZEN (G) Westerwolde, bog oak (Sub-Fossil Forests Project (RING/ROB))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Trunk 1	WOF00010	Not coded yet	250	-2101	DLNO	7.0	64.1	Not clustered yet

WOUDENBERG Castle Gerestein (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Back-aisle, roof, garret, laid-on beam V	WBG011	NLI01001	128	1555	DLNS	7.7	69.3	*NLHist_2*
Back-aisle, roof, garret, laid-on beam I	WBG021	NLI01002	125	1557	DLNS	7.5	68.1	*NLHist_2*
Back-aisle, roof, curved brace i	WBG031	NLI01003	111	1540	DLNS	6.0	63.2	*NLHist_2*
Back-aisle, roof, curved brace I	WBG041	NLI01004	74	1533	DLNS	7.1	73.3	*NLHist_2*

WIJK BIJ DUURSTEDE Markt 11 (RDMZ; de Vries 1990)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
2e truss brace near truss ///\	IWYM0010	NLQ02001	77	1468	NLTF	5.7	67.1	*NLHist_2*	
Curved brace //	IWYM0020	NLQ02002	69	1473	NLTW	5.1	62.5	*NLHist_2*	Date through avg. chronology
Curved brace //\	IWYM0030	NLQ02003	50	1473	NLTW	idem	idem	*NLHist_2*	of NLQ02002 and NLQ02003

WIJK BIJ DUURSTEDE — Water well (ROB)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
767.3.60;61;64;66;79;82;84	C6D02800	NLQ25001	286	712	DLCE	10.6	69.1	*NLHist_1*	7 planks are 1 tree
772.5.32;33;43;44;45;48;49	C6D04700	NLQ25002	236	734	DLCE	9.0	67.0	*NLHist_1*	7 planks are 1 tree

YERSEKE — Castle (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Post 7	YKB00010	NLW18001	75	1420	NLDT	6.4	68.9	*NLHist_1*
Post 6	YKB00021	NLW18002	67	1411	NLDT	6.0	72.0	*NLHist_1*

ZALTBOMMEL — Bloemendaal 5-9 (RDMZ; de Vries 1992; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Window lintel (East)	ZBB00011	NLQ10001	85	1534	BMBA	6.2	71.4	*NLHist_1*
Border joist (East)	ZBB00041	NLQ10002	75	1469	DLCE	7.0	74.3	*NLHist_1*

ZALTBOMMEL — Gasthuistoren (Company Mazzola Partners)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Balk	ZGT0001Y	NLQ27001	89	1634	DLNS	5.1	72.7	-

ZOETERWOUDE — Bog oaks (Sub-Fossil Forests Project (RING/ROB))

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL	Remarks
Trunk 1	ZWF00010	Not coded yet	154	-1358	DLNO	14.85	64.6	NLPre-ZH	Date through avg. chron. *NLPre_ZH*
Trunk 4	ZWF00040	Not coded yet	156	-1572	DLNO	idem	idem	*NLPre_ZH*	
Trunk 5	ZWF00050	Not coded yet	159	-1690	DLNO	idem	idem	*NLPre_ZH*	
Trunk 7	ZWF00070	Not coded yet	95	-1787	DLNO	idem	idem	*NLPre_ZH*	
Village, trunk 4	ZDF00040	Not coded yet	104	-1589	DLNO	idem	idem	*NLPre_ZH*	
Village, trunk 7	ZDF00070	Not coded yet	123	-1567	DLNO	idem	idem	*NLPre_ZH*	

ZWOLLE — Broerenkerk (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M2	IBRK0021	NLQ38001	72	1476	NLTF	5.6	65.5	*NLHist_2*

ZWOLLE — Kamperstraat 14 (RDMZ; de Vries 1988; de Vries 1994)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Border joist 1	IZKS0010	NLQ01001	212	1374	DLWF	5.1	66.7	-

ZWOLLE — Melkmarkt 53 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
Part A, common rafter roof, rafter xiii	ZMV00011	NLQ36001	69	1346	DLNS	5.0	66.9	*NLHist_2*
Part A, common rafter roof, collar yiiii	ZMV00021	NLQ36002	51	1351	Intern	4.1	66.0	-
Part A, common rafter roof, rafter yiii	ZMV00041	NLQ36003	33	1340	DLNS	4.9	75.0	*NLHist_3*
Part A, laid-on beam iii<	ZMV00071	NLQ36004	71	1403	NLTF	6.9	72.9	*NLHist_2*
Part C, curved brace //	ZMV00121	NLQ36005	75	1463	NLTW	4.2	68.2	-
Part C, principal </	ZMV00131	NLQ36006	76	1464	NLTF	5.1	68.0	-
Part C, East, roof plate	ZMV00141	NLQ36007	36	1464	NLTF	4.6	75.7	*NLHist_1*
Part C, wind brace against //<	ZMV00151	NLQ36008	36	1464	NLTF	7.2	71.1	*NLHist_2*
Part E, principal ///	ZMV00161	NLQ36009	160	1485	NLTF	5.8	59.0	-
Part E, laid-on beam ///<	ZMV00170	NLQ36010	99	1486	NLTW	4.3	63.3	-
Part E, laid-on beam //	ZMV00181	NLQ36011	79	1483	NLTF	5.1	67.9	*NLHist_2*
Part E, East, roof plate	ZMV00190	NLQ36012	59	1474	NLTF	4.1	69.8	*NLHist_2*

ZWOLLE — Walstraat 52 (RDMZ)

Object	Filename	Dendro-code	No.	Date	Reference	*St*	*PV*	NL
M1	ZWS00011	NLQ19001	83	1513	DLWF	7.9	70.7	*NLHist_2*

APPENDIX B

TREE-RING CHRONOLOGIES OF OAK USED FOR DATING

Belgium

Region	First Year	Last Year	Author(s)	Code
Meuse Basin	AD 672	AD 1986	Hoffsummer 1989	BMBA

England

Region	First Year	Last Year	Author(s)	Code
Baltic timber	AD 1156	AD 1597	Hillam & Tyers 1995	GBB1
Baltic timber	AD 1257	AD 1615	Hillam & Tyers 1995	GBB2
British Isles	AD 401	AD 1981	Baillie & Pilcher 1982	GBBI
Isle of Wight	3463 BC	2694 BC	Hillam u.d.[1] (1994)	GBIW
London	AD 413	AD 1728	Tyers, Hillam & Groves u.d. (1994)	GBLO
Northern England/Wales	AD 440	AD 1742	Hillam & Groves u.d. (1994)	GBNW
Northern England	434 BC	AD 119	Hillam & Groves u.d. (1994)	GBNO

France

Region	First Year	Last Year	Author(s)	Code
Bourgogne	AD 681	AD 1991	Lambert, Lavier & Bernard u.d. (1994)	FRBO
Eastern France	AD 582	AD 1991	Lambert & Lavier u.d. (1992)	FREA
Flemish painters	AD 1169	AD 1518	Lambert & Lavier u.d. (1993)	FRFP
Fontainebleau	AD 1531	AD 1979	Pilcher (ITRDB)	FRFO
Paris Basin	81 BC AD 279 AD 689 AD 848 AD 1618	AD 140 AD 653 AD 834 AD 1597 AD 1984	Lambert, Lavier & Bernard u.d. (1994)	FRPB
Western France	AD 913 AD 1077	AD 1064 AD 1912	Lambert, Lavier & Doucerain u.d. (1994)	FRWE

1 u.d. = unpublished data

Germany

Region	First Year	Last Year	Author(s)	Code
Aare region	545 BC AD 768	AD 129 AD 868	Hollstein 1980	DLAR
Ardennes-Eiffel region	154 BC AD 94 AD 1906	AD 63 AD 1756 AD 1965	Hollstein 1980	DLAE
Central Germany	690 BC	AD 1975	Hollstein 1980	DLCE
Ems-Weser region	241 BC AD 663 AD 1314 AD 1810	AD 66 AD 1288 AD 1617 AD 1958	Hollstein 1980	DLEW
Lower Rhine region	117 BC AD 114 AD 847 AD 1327 AD 1770	AD 61 AD 511 AD 1311 AD 1631 AD 1968	Hollstein 1980	DLLR
Neckar-Domau region	637 BC 71 BC AD 384 AD 890 AD 1099 AD 1921	551 BC AD 152 AD 643 AD 1029 AD 1808 AD 1970	Hollstein 1980	DLND

Ostfriesland	441 BC	AD 1992	Leuschner u.d.	DLOF
Rhein-Main region	502 BC AD 440	AD 259 AD 1787	Hollstein 1980	DLRM
Saar-Mosel region	690 BC 339 BC AD 443 AD 730	442 BC AD 316 AD 577 AD 1975	Hollstein 1980	DLSM
Schleswig-Holstein	AD 436	AD 1968	Eckstein *et al.* 1970	DLSH
Southern Germany	AD 631	AD 1950	Hollstein 1965; Hollstein u.d.	DLSO
Weserbergland	AD 1004	AD 1970	Delorme 1972	DLWB
Westerwald-Sauerland region	483 BC 109 BC AD 739 AD 960 AD 1369 AD 1847	420 BC AD 203 AD 897 AD 1338 AD 1773 AD 1967	Hollstein 1980	DLWS
Westphalia	AD 1040	AD 1972	Tisje u.d.	DLWF

The Netherlands

Region	First Year	Last Year	Author(s)	Code
Dutch timber	AD 1036	AD 1972	Eckstein, Brongers & Bauch 1975	NLDT
Panel paintings	AD 1115	AD 1643	Bauch, Eckstein & Meier-Siem 1972 Eckstein, Brongers & Bauch 1975	NLPP
Twente	AD 1357	AD 1724	Tisje u.d.	NLTW
Twente/Westphalia	AD 1040	AD 1972	Tisje u.d.	NLTF
Southern Netherlands/ Belgium/Germany	AD 624	AD 1749	Jansma u.d. (1993)	NLSO

Poland

Region	First Year	Last Year	Author(s)	Code
East Pomerania	AD 996	AD 1985	Wazny (1990)	POPO
Wolin	AD 1554	AD 1986	Wazny (1990)	POWO

APPENDIX C

AVERAGE GROWTH-INDEX VALUES OF SOME DUTCH CHRONOLOGIES (2258 - 1141 BC AND 325 BC - AD 563)

NLPre_ZH (2258 - 1141 BC; Chapter 4)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-2260			70	70	59	98	110	73	105	127			1	1	2	2	2	2	2	2
-2250	105	24	92	110	114	132	118	99	125	103	2	2	2	2	2	2	2	2	2	2
-2240	88	145	131	105	70	120	121	158	95	99	2	2	2	2	2	2	2	2	2	2
-2230	60	49	78	106	69	69	112	120	126	118	2	2	2	2	2	2	2	2	2	2
-2220	172	134	157	150	139	137	93	99	87	57	2	2	2	2	2	2	2	2	2	2
-2210	44	46	54	51	106	130	58	56	74	34	2	2	2	2	2	2	2	2	2	2
-2200	142	114	67	69	102	166	89	119	100	92	2	2	2	3	4	4	4	4	4	4
-2190	40	41	76	88	98	99	106	124	128	139	4	4	5	5	5	5	5	5	5	5
-2180	178	168	87	43	41	30	132	150	77	51	5	5	5	5	5	5	5	5	5	5
-2170	122	106	98	148	158	127	135	105	95	100	5	5	5	5	4	4	4	4	4	4
-2160	104	71	76	115	124	102	58	76	85	44	4	4	4	4	4	4	4	4	4	4
-2150	71	45	49	67	105	181	225	89	59	148	4	4	4	4	4	4	4	4	4	4
-2140	105	83	76	118	115	106	125	148	141	145	4	4	4	4	4	4	4	4	4	4
-2130	82	98	77	61	144	146	70	89	59	90	4	4	4	4	4	4	4	4	4	4
-2120	72	85	100	138	124	130	68	96	60	61	4	4	4	4	4	4	4	4	4	4
-2110	66	56	55	74	99	127	98	122	158	153	4	4	4	6	6	6	6	6	6	6
-2100	108	111	74	96	81	67	72	82	110	94	6	6	6	6	6	6	7	7	7	7
-2090	81	109	122	155	127	99	80	69	88	97	7	7	7	7	7	7	7	7	7	7
-2080	99	123	110	170	78	51	59	116	129	134	7	7	7	7	7	7	7	7	7	7
-2070	81	72	90	72	57	55	82	75	129	138	7	7	7	7	7	7	7	7	7	7
-2060	166	148	114	78	128	143	151	150	132	134	7	7	7	7	7	7	7	7	7	7
-2050	100	61	53	88	80	69	82	89	61	66	7	7	7	7	7	7	7	7	7	7
-2040	67	79	80	95	112	112	113	110	99	102	7	7	7	7	7	8	8	8	8	8
-2030	130	105	101	141	83	71	54	116	138	153	8	8	8	8	9	10	10	10	10	10
-2020	122	131	80	86	106	87	88	87	99	83	10	10	9	9	9	9	8	8	8	8
-2010	101	87	60	61	68	95	89	87	74	112	8	8	8	8	8	8	8	8	8	9
-2000	161	211	175	115	69	60	57	96	94	145	9	9	9	9	9	9	9	9	9	10
-1990	147	152	79	100	97	91	90	98	70	88	10	10	10	10	12	12	12	14	14	16
-1980	75	61	45	60	98	104	99	101	110	117	16	17	17	17	17	17	17	17	17	17
-1970	61	73	84	150	123	124	130	102	131	93	17	17	17	17	17	17	17	17	17	17
-1960	103	105	112	106	89	99	112	118	133	104	17	17	17	17	17	17	17	17	17	17
-1950	95	85	72	89	84	89	92	101	93	64	16	16	16	16	16	16	16	16	16	16
-1940	86	70	95	110	161	142	118	175	153	158	16	16	16	16	16	16	16	15	17	15
-1930	129	103	79	83	83	60	62	81	70	71	15	16	16	16	16	16	16	16	16	16
-1920	74	81	87	109	123	114	126	123	111	73	16	16	16	16	17	17	17	17	17	17
-1910	87	61	95	89	99	115	130	108	83	98	17	16	15	15	16	16	17	17	19	19
-1900	84	76	86	104	123	117	133	105	91	115	20	20	20	20	20	20	20	20	20	20
-1890	95	89	92	125	104	83	101	126	95	96	19	17	17	16	16	17	17	20	20	20
-1880	104	116	96	128	106	116	140	116	133	116	21	22	22	22	23	23	23	23	23	23
-1870	91	73	141	93	69	46	71	83	56	67	23	23	23	23	23	23	23	23	23	22
-1860	68	75	97	87	97	65	73	79	71	81	22	22	22	21	21	21	21	21	21	21
-1850	102	141	193	130	101	130	128	166	165	111	21	20	21	21	21	20	20	21	21	21
-1840	113	108	121	122	95	78	72	39	57	73	21	21	21	21	21	20	20	20	20	20
-1830	94	69	84	91	109	96	42	56	63	154	20	20	20	20	20	20	19	19	19	19
-1820	151	145	84	83	99	134	143	172	133	109	19	19	19	19	19	19	18	18	17	17
-1810	105	81	79	91	81	71	62	57	93	116	17	17	17	17	17	17	17	17	17	17
-1800	111	84	144	116	107	114	129	117	119	89	17	17	16	15	15	14	14	14	14	14
-1790	98	95	78	83	67	68	73	83	66	54	14	14	14	14	13	13	13	13	13	13

continued

NLPre_ZH (continued)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-1780	90	94	97	150	153	124	131	140	122	143	13	13	12	12	12	12	12	11	9	8
-1770	68	69	84	102	112	114	100	103	150	144	7	7	7	7	7	7	7	6	5	3
-1760	150	95	85	72	92	100	80	99	81	79	3	3	3	3	3	3	3	3	3	3
-1750	92	124	120	100	102	116	90	66	50	89	3	3	3	3	3	3	3	3	3	3
-1740	134	118	138	89	76	62	89	95	87	78	3	3	3	3	3	3	3	3	3	3
-1730	77	109	122	139	119	98	212	136	125	90	3	3	3	3	3	3	2	2	2	2
-1720	85	59	69	110	120	88	113	125	74	64	2	2	2	2	2	2	2	2	2	2
-1710	41	44	76	59	83	104	116	155	145	96	2	3	3	3	3	3	3	4	5	5
-1700	105	129	115	94	89	81	94	110	121	92	5	6	6	6	6	6	6	7	8	8
-1690	103	130	118	88	79	89	103	93	76	48	8	8	8	8	8	8	8	9	9	9
-1680	78	90	79	87	73	98	106	161	146	126	9	9	9	9	9	9	9	9	9	10
-1670	94	122	94	82	66	91	117	117	99	86	10	10	10	10	10	11	11	11	11	11
-1660	140	119	90	96	105	113	94	77	89	95	11	11	11	11	11	11	11	11	11	11
-1650	91	95	92	133	103	101	110	118	94	97	11	11	11	11	11	11	11	11	11	11
-1640	96	99	146	116	113	116	120	99	122	115	11	11	11	11	11	11	11	11	11	11
-1630	111	66	50	50	57	71	87	99	130	109	11	11	11	11	11	11	11	10	10	10
-1620	92	112	102	85	102	77	86	166	138	105	12	13	13	13	13	13	13	13	13	13
-1610	121	116	94	73	48	83	118	132	103	70	13	13	13	13	13	13	13	13	13	13
-1600	70	102	98	128	136	127	101	54	66	95	13	12	12	12	12	12	12	12	12	12
-1590	94	94	104	98	122	52	44	59	110	122	12	11	10	10	10	9	9	9	9	9
-1580	124	113	148	105	124	149	144	123	116	126	7	7	7	7	7	7	7	7	7	6
-1570	114	71	123	102	77	101	115	95	71	62	6	6	6	6	5	5	5	5	5	5
-1560	59	90	105	131	145	145	117	131	175	155	5	5	5	5	5	5	5	5	5	5
-1550	140	92	58	47	68	87	63	55	57	84	5	5	5	5	5	5	5	5	5	5
-1540	67	82	174	127	75	69	123	101	109	88	5	5	5	5	5	5	6	6	6	5
-1530	92	59	49	47	57	51	57	111	144	178	5	5	5	5	5	5	5	5	6	6
-1520	197	144	111	85	95	122	124	64	48	32	6	6	6	6	6	6	6	6	6	7
-1510	39	81	86	130	86	63	62	73	105	111	7	7	8	8	8	8	8	8	8	8
-1500	126	110	108	156	176	115	90	69	74	89	8	8	8	8	8	8	8	8	8	8
-1490	118	163	163	185	163	134	87	105	131	140	8	7	7	7	7	7	7	7	7	7
-1480	113	104	110	138	94	96	79	72	49	62	7	7	7	7	7	7	8	8	8	8
-1470	50	59	74	88	88	88	63	52	44	39	8	8	8	8	8	8	8	8	8	8
-1460	54	54	64	71	112	87	94	73	74	86	8	8	8	8	8	8	8	8	8	8
-1450	111	87	103	126	105	151	198	175	200	169	8	8	8	8	8	8	8	8	8	8
-1440	135	133	137	98	107	96	68	76	85	90	8	8	8	8	8	8	8	8	8	8
-1430	63	104	82	91	80	119	153	102	89	106	8	8	8	8	8	7	6	6	6	6
-1420	98	99	117	129	114	80	69	78	66	92	6	6	6	6	6	6	6	6	4	4
-1410	105	90	88	91	63	87	85	111	99	62	4	4	4	4	4	4	4	4	4	4
-1400	84	83	195	161	119	147	127	113	121	84	4	4	4	4	4	4	4	5	4	4
-1390	94	120	96	91	109	78	80	92	73	70	4	4	4	4	4	4	4	4	5	5
-1380	84	84	106	90	82	89	109	126	113	86	6	6	6	6	6	6	6	6	5	5
-1370	92	84	154	124	93	145	92	116	98	129	5	5	5	4	4	4	4	5	5	5
-1360	81	151	95	72	61	188	113	103	82	104	5	5	5	4	4	4	4	4	4	4
-1350	135	81	40	44	96	109	79	64	56	63	4	6	6	6	6	6	6	6	6	6
-1340	84	86	89	134	85	107	182	152	99	73	6	6	6	6	7	7	7	7	7	7
-1330	49	91	95	148	164	128	108	108	119	143	7	7	7	7	7	7	7	7	7	7
-1320	139	128	155	100	60	74	87	81	97	106	9	9	9	10	10	10	10	10	10	10
-1310	116	130	72	59	58	55	69	86	70	104	10	10	10	10	10	10	10	10	10	10

continued

NLPre_ZH (continued)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-1300	116	162	126	147	138	90	100	46	53	61	10	10	10	10	10	10	10	10	10	10
-1290	61	93	81	96	105	59	68	109	109	96	10	10	10	10	10	10	10	10	10	10
-1280	82	132	178	217	171	141	138	123	66	68	10	10	10	10	10	10	9	9	9	9
-1270	68	87	81	74	77	73	96	117	111	85	9	9	9	9	9	9	9	10	10	10
-1260	81	81	74	86	83	126	97	91	83	116	10	10	10	10	9	9	8	8	8	8
-1250	149	155	175	98	95	105	128	115	75	56	8	8	8	8	8	8	8	8	8	8
-1240	57	76	74	83	107	158	102	129	117	92	7	6	6	6	6	6	6	6	6	6
-1230	128	114	121	117	100	80	102	88	82	73	6	6	6	6	6	6	6	6	6	6
-1220	102	60	85	97	116	153	127	91	87	92	6	6	6	6	6	6	5	5	5	5
-1210	74	55	64	48	84	101	104	117	97	127	5	3	3	3	3	3	3	3	3	3
-1200	114	63	40	47	46	66	109	118	84	121	3	3	3	3	3	3	3	3	3	3
-1190	134	103	90	65	76	93	96	189	143	138	3	3	3	3	3	3	3	3	3	3
-1180	200	200	334	166	95	126	103	82	63	55	3	3	3	3	3	3	3	3	3	3
-1170	54	44	55	75	59	69	54	75	87	63	3	3	3	3	3	3	3	2	1	1
-1160	83	72	69	66	81	92	82	73	88	82	1	1	1	1	1	1	1	1	1	1
-1150	96	101	74	101	107	124	157	180	134	108	1	1	1	1	1	1	1	1	1	1

NLRom_E (AD 190 - 395; Chapter 5)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
190	91	44	72	65	113	108	131	116	132	127	2	2	2	2	2	2	2	2	2	2
200	118	105	83	70	92	107	94	124	114	134	4	6	6	6	6	6	6	6	6	6
210	96	82	112	131	86	68	91	64	106	76	6	6	6	6	6	6	6	6	6	6
220	94	138	96	134	164	96	128	85	80	82	6	6	6	6	6	6	6	6	6	6
230	107	101	75	109	79	112	92	109	146	156	7	7	7	7	7	7	7	7	7	7
240	125	155	148	103	76	41	53	71	77	94	7	7	7	7	7	8	8	8	8	8
250	62	67	80	119	108	100	93	84	108	130	10	10	10	11	15	17	21	27	33	36
260	109	110	109	75	60	69	90	108	103	117	39	43	45	47	48	48	49	49	52	53
270	101	131	83	97	141	121	131	109	103	72	55	57	59	59	62	70	73	73	73	74
280	81	121	90	62	94	100	87	78	89	117	76	77	78	81	83	85	85	87	87	88
290	85	100	107	123	71	90	89	75	61	91	88	90	91	92	94	95	98	98	99	101
300	96	103	69	120	74	72	149	130	76	97	102	103	106	106	107	108	108	109	109	108
310	130	117	118	111	71	63	61	117	119	89	107	105	104	104	107	108	103	103	99	97
320	109	115	98	67	115	119	112	143	139	111	97	95	92	92	90	90	88	85	80	80
330	111	107	89	70	55	81	67	58	71	110	82	82	80	79	79	79	78	75	75	73
340	92	103	89	91	147	131	134	114	127	127	72	72	71	69	67	64	61	57	53	51
350	123	91	106	108	131	133	121	120	89	83	47	46	45	41	38	34	33	30	30	28
360	48	114	81	78	100	90	67	63	100	133	25	25	24	24	24	24	23	22	16	13
370	163	115	102	113	142	97	112	119	81	95	13	12	10	9	6	4	4	4	4	4
380	97	107	96	61	63	68	105	83	152	132	4	4	4	4	4	4	4	4	3	3
390	89	101	148	86	47	87					3	3	3	2	1	1				

NLRom_W1 (84 BC - AD 50; Chapter 5)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-91								63	126	91								1	1	2
-81	59	128	110	135	68	118	108	145	109	167	2	2	2	2	2	2	2	2	2	2
-71	117	56	59	94	85	82	103	127	115	140	2	3	3	3	3	3	4	4	4	4
-61	113	92	97	96	92	61	63	65	70	82	4	4	4	4	4	5	5	5	5	6
-51	107	141	110	147	110	91	86	101	90	117	6	6	7	7	7	7	9	9	9	9
-41	89	123	127	97	94	64	64	83	91	86	9	10	10	10	10	10	10	10	10	10
-31	101	94	52	70	92	118	140	98	122	154	10	10	10	11	11	12	12	12	12	12
-21	106	128	103	120	85	102	70	124	100	63	12	13	13	13	14	15	15	16	16	16
-11	79	101	108	86	141	95	118	117	120	148	16	16	16	17	18	18	18	20	20	20
-1	152	150	124	86	60	82	78	105	112	104	20	20	20	20	20	20	20	20	20	20
10	68	59	55	59	79	89	104	133	105	102	20	20	20	20	20	20	20	20	20	20
20	101	78	98	89	91	71	56	85	66	75	20	20	20	20	20	20	20	20	19	19
30	97	94	121	119	91	126	125	76	72	86	19	19	19	18	18	18	17	10	9	9
40	78	103	86	90	151	160	177	132	123	84	9	9	9	9	9	9	8	8	8	6
50	82										1									

NLRom_W2 (140 BC - AD 87; Chapter 5)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-141		153	91	81	95	86	59	56	107	142		1	1	1	1	1	1	1	1	1
-131	66	140	179	105	42	69	40	96	123	114	1	2	2	2	2	2	2	2	3	3
-121	123	152	149	78	91	105	81	69	74	46	3	4	4	4	4	5	5	5	6	6
-111	66	84	81	58	79	92	88	84	75	71	6	6	6	6	6	6	6	6	6	6
-101	81	115	169	95	123	118	93	102	146	104	7	7	7	8	8	8	8	8	10	10
-91	143	185	180	41	93	111	134	125	157	116	10	10	10	11	11	12	12	12	12	12
-81	107	109	64	89	63	88	56	62	94	135	13	13	13	13	13	13	14	14	14	14
-71	127	104	94	119	117	96	83	93	72	87	15	15	15	15	15	15	15	15	16	17
-61	98	117	104	105	78	57	44	70	115	110	17	18	19	19	19	20	20	20	20	20
-51	121	172	178	113	157	68	121	106	92	115	20	20	20	20	20	20	20	20	20	20
-41	87	57	58	49	63	65	55	72	95	101	20	21	21	21	21	22	23	23	24	26
-31	103	92	59	59	118	159	159	105	109	197	26	26	26	26	27	27	27	29	30	30
-21	144	104	90	113	95	103	98	86	85	92	32	33	33	33	33	33	33	34	35	34
-11	89	101	113	84	127	28	51	59	101	121	34	34	34	34	34	34	34	34	34	34
-1	132	98	121	112	104	136	132	131	81	60	34	34	35	35	36	36	36	35	36	36
10	84	96	118	131	170	168	73	69	51	57	36	38	38	38	38	38	38	38	38	38
20	100	79	76	96	98	81	122	137	120	54	38	38	38	38	39	39	38	36	36	35
30	51	71	77	74	94	96	139	140	215	148	34	34	34	34	34	34	34	34	34	32
40	92	176	141	176	87	51	68	65	87	78	32	31	31	30	28	27	27	27	27	24
50	51	64	69	61	97	81	87	71	57	60	24	24	22	22	22	22	22	21	21	20
60	89	72	101	149	128	109	91	86	103	120	18	18	16	15	15	13	13	13	13	13
70	226	194	157	102	126	110	100	67	69	88	13	13	13	13	13	13	11	11	11	11
80	109	100	90	92	83	81	75	107			10	10	10	10	9	7	5	2		

NLRom_R (325 BC - AD 563; Chapter 5)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
-331							107	79	79	67							1	1	1	1
-321	137	87	109	75	109	109	104	157	142	95	1	1	1	1	1	1	1	1	1	1
-311	84	69	128	147	141	145	108	83	81	112	1	1	1	1	1	1	1	1	1	3
-301	122	111	99	101	104	112	115	114	113	94	3	3	3	4	5	5	5	5	6	6
-291	83	72	61	57	58	68	70	87	83	87	6	6	6	6	6	6	6	6	6	6
-281	105	106	95	133	99	109	107	105	117	108	6	6	6	6	6	6	6	6	6	6
-271	99	131	106	107	135	131	121	108	97	79	6	6	6	6	6	6	6	6	6	6
-261	107	110	120	127	151	130	101	81	81	88	6	7	7	7	7	7	7	7	7	7
-251	84	73	67	102	110	117	131	124	120	88	7	7	7	7	7	7	7	8	8	8
-241	117	95	85	62	59	52	62	62	92	97	8	8	8	8	8	8	8	8	8	8
-231	108	89	85	82	107	145	125	119	116	115	8	8	8	8	8	8	8	8	8	8
-221	104	113	88	84	114	89	89	95	56	63	8	9	9	9	9	9	10	10	10	10
-211	77	104	117	115	104	103	119	103	95	117	10	10	10	10	10	10	10	10	10	10
-201	127	140	122	125	113	136	107	96	135	139	10	10	10	10	10	10	10	10	10	10
-191	151	118	105	84	69	70	75	78	85	73	10	10	9	9	9	9	9	9	9	10
-181	85	104	68	67	73	54	44	50	71	71	10	10	10	10	10	10	10	10	10	10
-171	96	103	99	98	120	125	99	135	159	125	10	10	9	9	9	9	9	9	8	8
-161	117	115	113	74	66	62	94	113	115	120	8	7	7	7	8	8	8	8	8	7
-151	143	113	93	106	87	101	90	93	91	91	7	7	7	6	6	6	6	6	6	6
-141	85	130	123	129	87	92	132	101	105	116	6	6	6	5	5	5	5	5	5	6
-131	82	94	155	94	103	117	104	133	120	122	6	6	6	6	6	6	6	6	6	6
-121	118	94	97	88	82	69	62	78	74	57	5	5	5	5	5	5	5	5	5	5
-111	61	72	64	82	77	109	109	88	94	87	5	5	5	5	5	5	5	6	6	6
-101	108	114	103	90	134	139	142	130	134	101	6	6	6	6	6	6	6	6	6	6
-91	75	82	98	114	116	89	92	104	117	115	6	6	6	7	7	7	8	8	8	8
-81	96	94	78	73	60	65	52	70	99	129	8	8	8	8	8	8	8	8	8	8
-71	134	116	113	106	76	89	95	96	105	100	8	8	8	8	8	8	8	8	7	7
-61	115	105	139	114	92	60	73	79	99	91	7	7	8	8	9	10	10	11	12	15
-51	113	158	120	78	109	87	133	120	86	104	15	15	15	15	15	16	16	16	16	16
-41	87	80	81	59	63	90	99	148	132	138	16	16	16	16	16	16	16	16	16	16
-31	142	104	75	77	119	130	101	91	93	152	16	16	16	16	16	16	16	16	16	16
-21	124	109	106	76	63	73	70	73	67	84	16	17	17	17	17	17	17	17	17	17
-11	97	123	117	93	133	107	116	110	87	72	17	17	17	17	17	17	17	17	16	16
-1	75	78	118	72	74	115	113	133	84	89	16	16	17	17	17	17	17	17	16	16
10	86	79	103	109	138	128	106	132	106	101	16	16	16	16	15	15	13	13	13	13
20	96	65	75	102	95	85	63	99	55	59	13	13	7	7	7	7	7	7	7	7
30	105	117	121	127	111	110	84	92	126	107	8	7	6	6	6	7	7	7	7	7
40	97	125	92	103	142	127	153	132	110	106	7	7	7	7	7	7	7	7	7	7
50	58	70	99	105	129	109	104	76	77	80	7	7	7	7	7	7	7	7	7	7
60	74	87	60	74	52	82	95	91	87	103	7	7	7	7	8	8	8	8	9	9
70	134	148	97	105	153	118	113	66	83	116	9	9	9	9	9	8	7	7	6	6
80	126	92	79	78	71	106	89	80	71	71	6	7	8	9	9	8	9	9	10	10
90	104	113	94	103	97	131	113	155	109	122	10	10	10	10	10	10	10	10	11	11
100	133	157	136	86	107	122	92	70	99	91	11	10	10	10	10	10	11	10	10	10
110	74	82	87	69	82	79	92	66	87	92	10	10	10	10	10	10	10	10	10	10
120	97	83	103	113	105	78	101	110	88	91	10	10	11	11	11	11	11	11	11	11
130	127	124	144	144	126	129	109	108	87	97	13	13	13	13	13	13	14	14	14	14
140	84	64	56	77	52	76	49	102	116	86	14	14	14	14	14	14	14	14	14	14

continued

NLRom_R (continued)

	Tree-Ring Indices										Number of Measurement Series									
Year	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
150	99	109	85	86	94	82	82	80	74	63	14	14	15	15	15	15	15	15	14	14
160	80	132	145	165	142	125	158	120	121	133	14	14	14	14	14	14	15	15	15	15
170	113	123	107	82	117	97	119	82	99	100	16	16	16	17	17	17	17	17	17	17
180	97	75	94	111	127	107	104	85	106	118	17	17	17	17	18	19	19	19	19	19
190	66	67	89	65	77	85	96	96	89	89	19	19	19	19	19	19	19	19	19	19
200	100	114	76	90	73	118	75	84	79	112	19	18	18	18	18	18	18	18	18	18
210	116	125	190	133	138	99	92	91	116	99	18	18	18	18	18	18	18	18	18	18
220	109	109	89	96	115	87	102	89	72	84	18	18	18	18	18	18	18	18	18	18
230	99	88	65	94	65	80	63	47	90	108	18	18	18	18	18	18	18	18	18	18
240	109	148	157	113	105	109	142	122	117	135	17	17	17	17	17	17	16	16	16	16
250	95	94	84	132	99	85	88	84	109	85	16	16	15	14	14	14	13	13	13	13
260	88	88	81	81	76	55	65	75	93	109	13	13	13	13	13	13	13	13	13	13
270	87	131	137	128	114	94	129	114	112	94	13	13	13	12	13	12	10	10	10	10
280	141	138	104	98	119	108	76	110	126	133	10	10	9	9	8	8	8	7	7	7
290	110	101	68	83	54	102	89	102	93	112	8	8	8	8	8	8	8	8	8	8
300	95	90	71	50	72	77	103	86	56	79	8	8	8	8	8	8	8	7	8	8
310	109	146	81	75	90	96	142	114	101	115	8	8	8	7	7	7	7	7	7	7
320	144	141	153	107	162	104	93	115	112	87	7	7	6	6	6	5	5	5	5	5
330	94	82	85	75	52	91	82	82	117	108	5	5	5	5	5	5	4	4	4	4
340	112	129	100	113	135	90	66	90	100	89	4	4	4	4	4	4	4	4	4	4
350	103	116	115	111	114	78	73	57	67	87	4	4	4	4	4	4	4	4	4	4
360	63	149	104	189	94	87	59	96	100	107	4	4	4	4	4	4	4	4	4	4
370	132	97	91	87	73	94	139	109	110	153	4	4	4	4	4	4	4	4	4	4
380	119	115	97	72	81	61	106	75	115	75	4	4	4	4	4	4	4	4	4	4
390	71	75	82	79	67	99	70	99	94	91	4	4	4	4	4	4	4	4	4	4
400	161	181	142	124	119	105	111	107	100	109	4	4	4	4	4	4	4	4	4	3
410	85	82	98	86	95	90	104	97	117	79	3	3	3	3	3	4	4	4	4	4
420	97	96	117	156	99	115	77	128	119	113	4	4	4	4	5	6	6	7	7	7
430	113	80	71	61	51	103	107	59	80	82	7	7	7	7	7	7	7	7	7	7
440	96	106	123	124	127	127	98	98	80	85	7	7	7	7	7	7	8	8	8	7
450	126	149	131	115	75	56	91	80	110	122	7	7	7	6	6	6	6	6	6	6
460	119	103	92	71	98	72	83	88	99	111	6	6	6	6	6	6	6	6	6	6
470	91	93	96	103	125	141	119	74	95	101	6	6	6	6	6	6	6	6	5	5
480	95	76	57	99	116	71	66	81	77	86	5	5	5	5	5	5	5	5	5	5
490	115	83	93	163	203	94	68	76	62	80	5	5	5	5	5	5	5	5	5	5
500	129	111	91	83	82	82	80	121	169	178	5	5	5	5	5	5	5	5	5	5
510	128	102	116	91	133	94	98	82	93	114	5	5	5	5	5	5	5	5	5	5
520	99	89	85	78	100	102	114	104	71	87	5	5	5	5	4	3	3	3	3	3
530	108	112	87	93	81	93	84	79	90	78	3	3	3	3	3	3	3	3	3	2
540	94	72	132	136	108	105	94	104	99	119	2	1	1	1	1	1	1	1	1	1
550	125	135	164	120	173	90	72	81	99	87	1	1	1	1	1	1	1	1	1	1
560	112	74	77	78							1	1	1	1						

This book consists of a collection of articles on dendrochronology, a method of dating the growth rings in oak-wood to the nearest year. Dendrochronology is used to date oak from geological deposits, archaeological sites, historical buildings and works of art. Tree-ring dating is based on the comparison of undated tree-ring patterns with the absolute dates of 'standard chronologies': the average annual growth values of many oaks from large regions. The Dutch standard chronologies presented and justified in this book cover more than 3,000 years and run from 2258 to 1141 BC and from 325 BC to AD 1752. Approximately 700 oak tree-ring patterns are included in the chronologies; they mainly represent timber from Dutch archaeological and historical structures, but also parts of tree-trunks which have been preserved in (former) peat bogs, as well as works of art that contain oak. The chronologies include both native and imported oak-wood whose geographical origin can roughly be traced in the majority of cases. The book also contains a discussion on the statistical methods used to determine the quality of the chronologies for dating and other purposes, an extensive documentation of the datings on which the new chronologies are based and an overview of the chronologies available from neighbouring countries.

The author studied ecological archaeology at the 'Albert Egges Van Giffen' Institute for Pre and Protohistory (IPP/University of Amsterdam) where she set up a dendrochronological laboratory in 1985. She also trained at dendrochronological laboratories in Germany and Switzerland and spent the 1989/1990 academic year as a guest researcher at the Laboratory of Tree-Ring Research (University of Arizona [US]) as part of her research project for the Netherlands Organisation for Scientific Research (NWO). In 1991 she was appointed as dendrochronologist by the State Service for Archaeological Investigations in the Netherlands (ROB). In addition, she has been the scientific director of the Netherlands Centre for Dendrochronology (RING Foundation; ROB) since 1992. The author is a member of the advisory board of the International Tree-Ring Data Bank (ITRDB; NOAA Palaeoclimatology Program/World Data Centre A; Boulder, Colorado [US]).