# How did bog oaks grow? Excavation of a past woodland at Zwolle-Stadshagen, The Netherlands

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## Introduction

The NW-European dendrochronological data set consists of tree-ring series of about 2600 sub-fossil 'bog' oaks from approximately 200 sites. Ultra-long bog oak chronologies were derived extending from 6069 BC to the tenth century AD (Jansma 1995; Pilcher *et al*. 1996; Spurk *et al*. 1998; Leuschner *et al*. 2002). These chronologies can be used as proxy data for climate. However, for this purpose it is necessary to assess the relationship between the growth of bog oaks and (changing) ecological site conditions, e.g. hydrology. By excavating an ancient woodland at Zwolle Stadshagen it was possible to investigate sub-fossil bog oaks and ash *in situ* and to collect additional information on vegetation and soil(hydrology) to explain the growth patterns of the oaks and ashes. Moreover it was evaluated whether local factors that influenced the growth of the bog oaks and ashes were triggered by large-scale regional factors, such as weather and climate.

## Material and Methods

At Zwolle-Stadshagen, an area of about 1270 $m^2$ was excavated. All wood remains were numbered, their morphology (i.e., stem, root, branch) was described and their position was recorded in three dimensions. Wood samples were taken for species determination in order to reconstruct the local tree vegetation and pollen profiles were analysed to provide additional information on the structure and development of the (surrounding) vegetation. Soil samples were studied by micromorphology to assess (changes in) site hydrology.

Out of 521 wood samples (215 ash, 103 oak) 60 % of the oaks and 15 % of the ashes were dendrochonologically dated and studied with respect to annual growth- and population dynamics. Tree-ring width was measured and tree-ring series were dated and analysed using standard dendrochronological methods (TSAP, Rinn 1996; COFECHA, Holmes 1983; Mean-age method (Leuschner *et al.* 2002).

## Results and discussion

Of 59 oaks and 36 ashes, the year of germination and dying-off as well as the growth pattern was established. The results show that the woodland at Zwolle Stadshagen existed at least for a period of 700 years, from ca. 150 BC to AD 586.

All dated oaks and ashes showed a characteristic growth pattern with alternating phases of normal and depressed growth (Fig. 1). Growth depressions occur with a frequency of between 20 and 40 years throughout the studied period of 700 years. The comparison between the oak and ash chronologies from Zwolle with an aggregated (NW German and Dutch) continental chronology (University of Goettingen, Ring Foundation, unpublished data) showed that almost all phases of normal and depressed growth in the Zwolle trees are synchronous with those in oaks from other wetland sites in the Netherlands and NW Germany (Fig. 1). This means that the striking changes in growth of oak and ash from Zwolle were not merely the result of *local* impacts but instead were triggered by *regional* factor(s), which are most likely related to climate (Sass-Klaassen & Hanraets 2003).

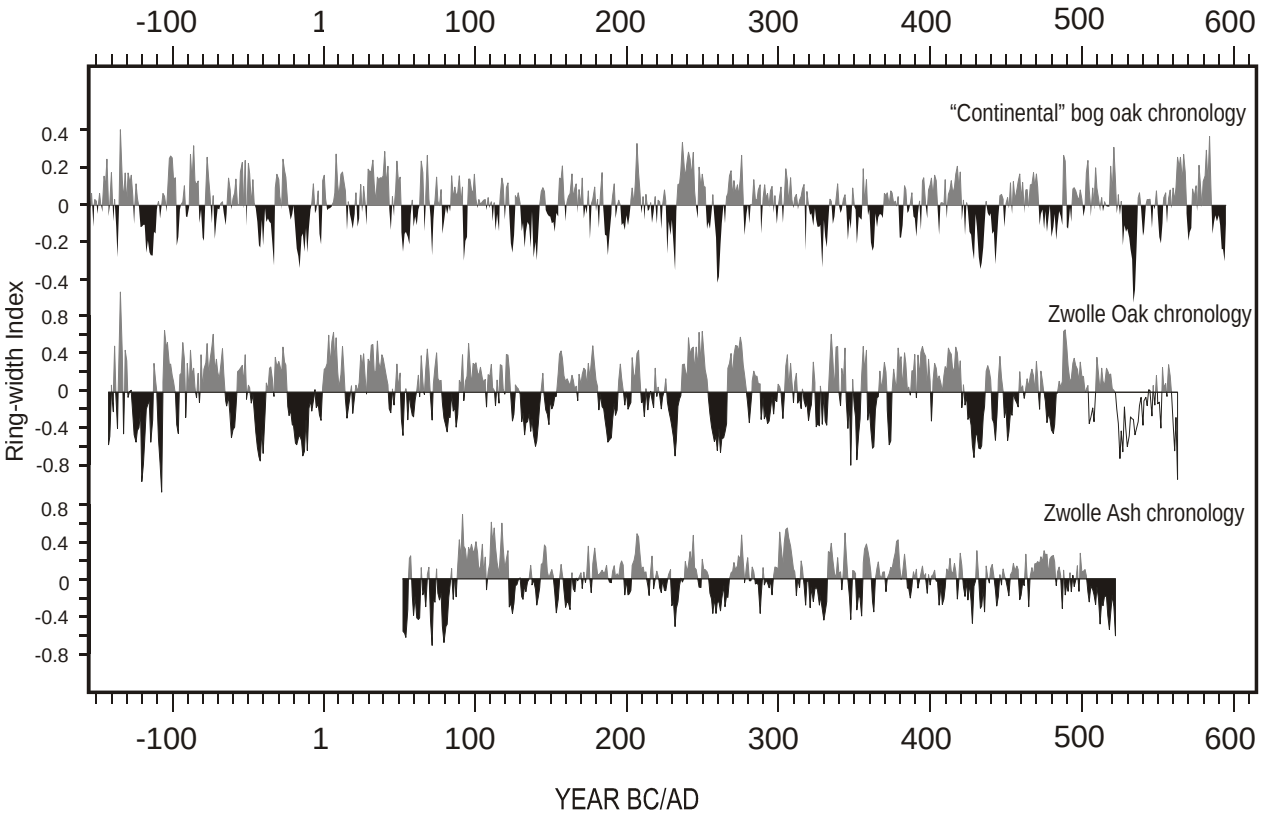


*Figure 1: Comparison between the Zwolle oak and ash chronologies and the continental (aggregated Dutch and German) bog-oak chronology*

The results of the micromorphological analysis indicate frequent changes in site hydrology that are most likely the dominant factor influencing the growth of oak and ash in Zwolle Stadshagen (Kooistra 2003). Peat formation started according to the general rise in sea level (=transgression) around AD 25. However, the soil archive documents that peat growth was not continuous but periodically interrupted by dryer periods with a lower ground-water level (Kooistra 2003). From AD 300 onwards, site hydrology changed and frequent flooding with

shallow water became an additional (growth-limiting) factor. The flooding frequency steadily increased, until after ca. AD 540 the woodland became completely inundated and changed into a huge freshwater lake (Kooistra *et al*. 2003). The site hydrology in Zwolle Stadshagen was complex. Two big river systems, the IJssel and the Vecht, had a major influence on the drainage and inundation of the woodland in the area (Kooistra 2003). Prolonged high ground-water levels during the first phase of the woodland (150 BC to 300 AD) and from AD 300 onwards in combination with frequent flooding caused anoxic soil conditions. Prolonged anoxic soil conditions may drastically reduce the radial growth activity of the trees due to a combination of root- and/or mycorrhiza damage as well as depletion of carbonhydrate reserves (Crawford *et al.* 2003). Isotopic studies on the Zwolle oaks suggest that periods of depressed growth can also be the result of a shorter growing season due to high ground-water level and/or flooding in winter and spring during relatively wetter periods (Poole *et al.,* this issue).

River run-off, ground-water level and precipitation were mutually connected at Zwolle Stadshagen. It is however remarkable that despite temporal and spatial (new river course from AD 300 onwards) changes in these three factors neither the general growth pattern nor the frequency of growth depressions in the oaks and ashes changed during the investigated period. This information together with the fact that growth depressions occur synchronous on different wetland sites in NW Europe supports the assumption that a large-scale climate-related factor triggered the (complex) hydrology at wetland sites in NW Europe. Current research including frequency analysis of the bog-oak time series and the comparison with tree-ring series of land-grown oak will provide more knowledge on the characteristics of the triggering factor.

## Conclusions

Changes in the growth patterns of the oaks and ashes from Zwolle Stadshagen are related to changes in site hydrology. Prolonged high ground-water levels during the first phase of the woodland and from AD 300 onwards in combination with frequent flooding caused anoxic soil conditions, which caused abrupt, long-term growth depressions in oaks and ashes. The fact that these growth depressions in the Zwolle trees are synchronous to the NW European records points to a large-scale climate-related factor as a trigger of site hydrology at wetland woods in NW Europe.

**Acknowledgements**

This research was made possible by funding from The Netherlands Organisation for Scientific Research (NWO/AWL 750.700.04). The municipality of Zwolle supported part of this project through the Foundation Promotion of Archaeology (Stichting Promotie Archeologie). Additional financial support for the poster was provided by Alterra, program no. 382.

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