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Population dynamics and long-term growth depressions in European bog oaks as indicators of climate changes in the Holocene

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Abstract

The dendrochronological data set of absolutely dated sub-fossil oak trunks from Irish, Dutch and German bogs consists of some 2600 series. They cover the period from 6000 BC to AD 1700. The distribution of the trees in time shows distinct changes in the frequency, germination and dying-off. One way to graphically represent germination and dying-off phases is to calculate the 'mean age' of all trees at every calendar year. Where trees are uniformly ageing the mean age chronology rises; recruitment of juvenile trees and dying-off of old trees causes the chronology to drop. The GDO-events (sudden drop) coincide with growth depressions in the regional ring-width chronologies. Regional mean-age chronologies of the bog oaks contain similar elements, sometimes over long periods. This observation indicates common large-scale climate forcing.

Introduction

From 1970 onwards, European tree-ring laboratories have studied oak trunks preserved in bogs, river gravels and marine/brackish sediments. Tree-ring series of these trees have been used to compile ultra-long absolutely dated tree-ring chronologies which extend back to 8400 BC (Pilcher et al. 1984 Leuschner 1992; Jansma 1996; Spurk et al. 1998). This paper considers the 'bog oaks' that grew under marginal ecological conditions on the surface and margins of the peat. Fluctuations of the generally high ground-water table – partly triggered by climate - are assumed to have a major impact on population dynamics and tree growth on these sites. However, by looking at the diversity of bog sites it is not clear to which extent changes in oak vitality have to be considered as local or regional. Leuschner et al. (1987) studied bog oaks from ten different sites in North Germany and found simultaneous phases of dying-off that were related to an increasing wetness of the climate. More evidence for wet climatic conditions as triggering factor is the temporal coincidence that was found between phases of dying-off and germination (=GDO) and periods of long-term growth depressions in

German bog oaks from different sites (Leuschner 1992). However, this picture became blurred when bog oaks from more sites were included.

Yet, we assume that at least major large-scale regional changes in climate towards wetter conditions are reflected in the population dynamics and the tree-ring pattern of oaks from different bog sites in Europe. Therefore comparisons are undertaken on a bigger scale; hence the comparisons between German, Dutch and Irish bog oaks. The new parameter 'mean age' is introduced, that describes variation in tree age through time and is used to detect common abrupt changes in population dynamics (germination and dying-off) of bog oaks from different European regions. Regional tree-ring chronologies are used to detect (contemporary) changes in growth activity. This paper provides a general outline of the results; a detailed description can be found in Leuschner et al. 2002.

Material and Methods

This study is based on 2.600 tree-ring series from North European bog-oak sites in Germany, the Netherlands and Ireland.

Compilation of regional bog-oak chronologies

We compiled four regional tree-ring chronologies for (1) North Germany, (2) The Netherlands, (3) Ireland, and (4) a so-called 'continental' chronology, as a combination of all German and Dutch bog-oak series. The chronologies span the interval from 6000 BC to AD 1000 and were calculated as the arithmetic mean of the single filtered tree-ring series from each area. We applied the following approach in order to remove the age trends and to maximise the common long-term variation: (1) logarithmical transformation of the series, (2) use of a weighted moving average as a high pass filter. The length of the moving average varies according to the variance of the ring width series. On average the filter-width was defined as 140 years (variable Kern-Filter, Riemer, 1994). A (parabolical) weighted running mean of 15 years (Riemer 1994) was applied to the chronologies to enable visualisation of the long-term variability of the average annual growth rates.

Assessment of population dynamics

Mean-age (MA) chronologies were compiled for the three regions (Germany, the Netherlands, Ireland) by calculating the arithmetic mean of the age of all single trees in each given year. The course of the MA chronology reflects phases of germination- and dying-off as well as the duration of undisturbed tree growth. An abrupt decrease in a MA chronology reflects a major GDO-phase while an increase of the curve points to relatively undisturbed growth. Minor wiggles and changes in slope reflect small-scale or local population dynamics. The height of the maxima in the MA chronology is related to the duration of undisturbed phases and the number of dominating old trees within a given population of trees. To detect major changes in population dynamics and to compare population dynamics with long term changes in tree-ring width we calculated the first differences of the smoothed (15-year parabolically weighted running mean) MA chronologies. Negative peaks in the first differences reflect abrupt drops in the mean-age chronologies and mark major GDO-phases in the bog oaks.

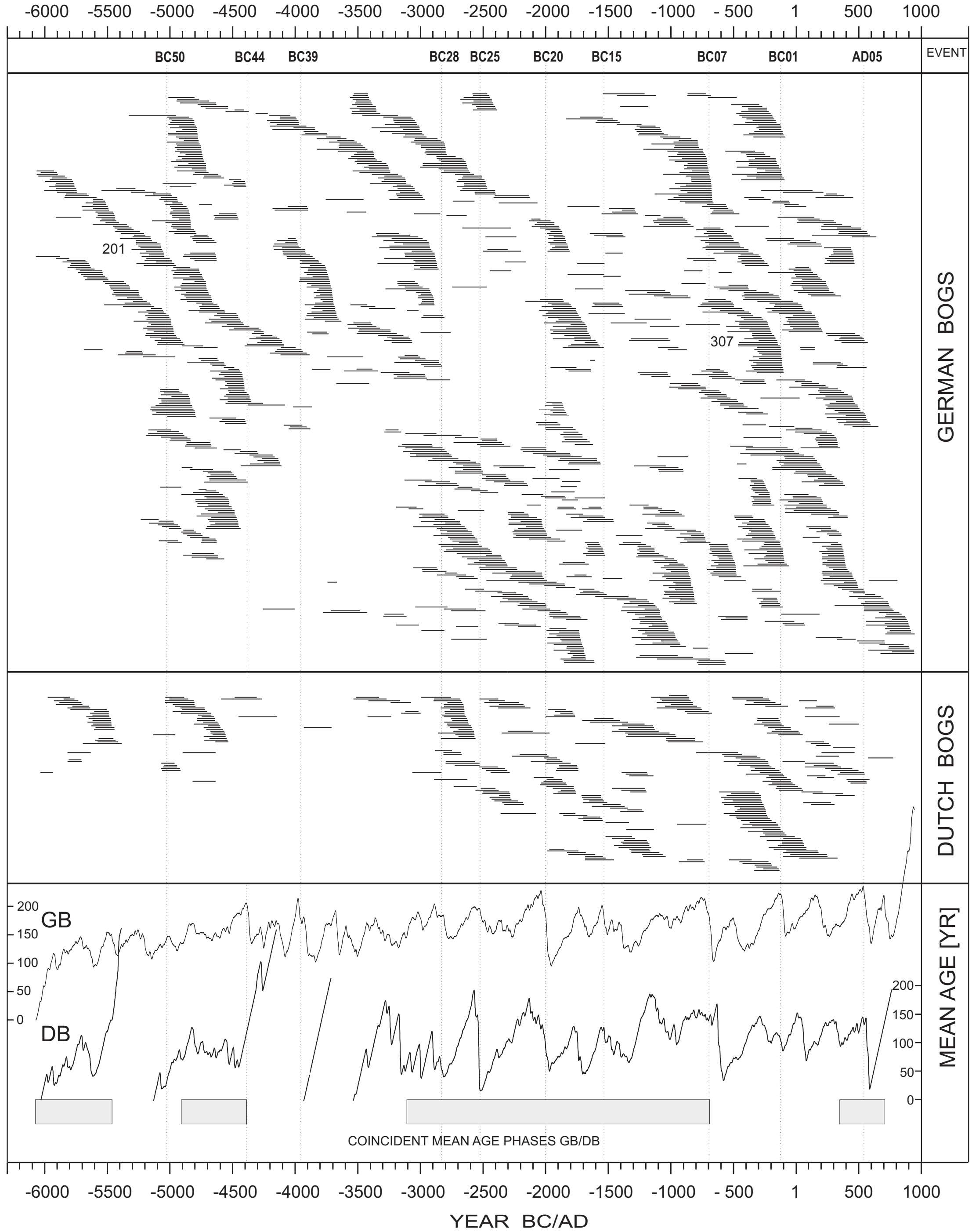

Figure 1: The life spans of bog oaks from Germany (GB, n = 1561, 101 sites) and the Netherlands (DB, n = 301, 43 sites) clustered according to their site provenance. The lower curves represent the mean ages of the trees in the two regions through time. For reference, decreases in the mean age (determined optically) are marked by dotted lines and labelled in two digits according to their date (e.g., B50 = 5000 BC; A05 = AD 500). Episodes of notable similarity are marked with bars.

Results and Discussions

The temporal distribution of the life spans of the North German and Dutch bog oaks is shown in figure 1. It is obvious that germination as well as dying-off phases on bog oak sites occur gradual instead of abrupt from one year to the other. That makes it difficult to define clear dying-off and germination (GDO) phases in the two data sets. However, the MA chronolgies of the two regional data sets clearly mirror common changes in population dynamics at the different sites of one region. Even less distinct GDO phases mostly fit to the steep part of a dropping MA curve. Striking changes in population dynamics, reflected by a sudden drop of the mean-age values in both the German and Dutch mean-age chronologies occurred around 5040 BC, 4350 BC, 3970 BC, 2820 BC, 2550 BC, 2000 BC, 1550 BC, 150 BC and AD 540

A large scale comparison is undertaken in Figure 2 by comparing the MA chronologies of the continental (German and Dutch) and the Irish bog oaks. Despite a distance of about 800 km between the sources of material we observe a remarkable agreement especially in the period from c.5500 BC to c.2000 BC. After 2000 BC, and especially between 2000 and 1000 BC there are only episodic periods of agreement which may be no more than random. This lack in agreement may be either notable climate change or increased human influence.

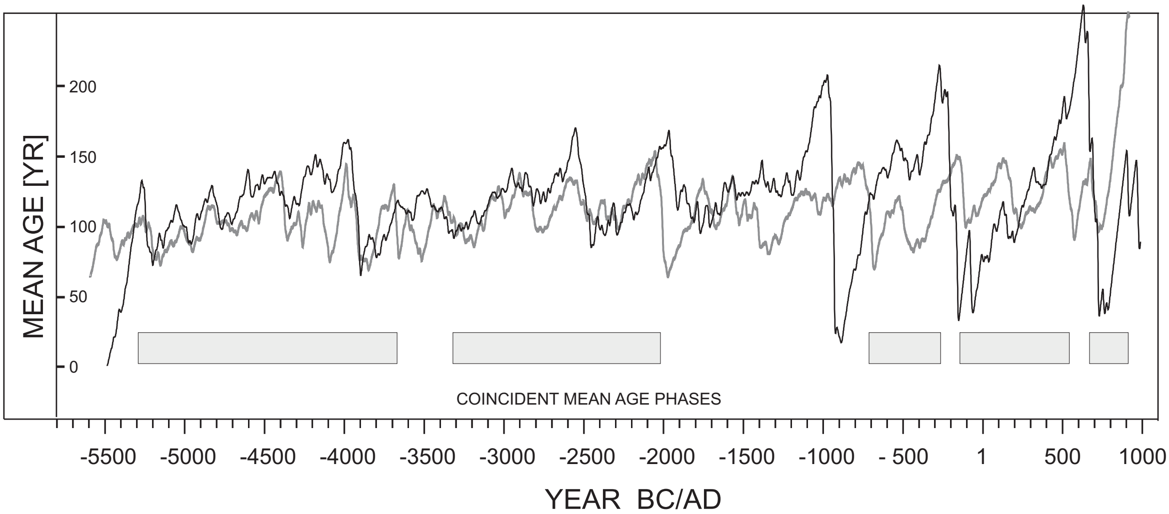

Figure 2: Comparison of macro-scale mean-age chronologies in common periods between continental (all German and Dutch) (grey) and Irish bog oaks. Phases of good agreement are marked by grey boxes.

Major common changes in population dynamics between the continental and the Irish oaks can be found between 4000 and 3900 BC around 2500 BC, and at 2000 BC. A good agreement can also be seen in much of the fine detail information of the two mean-age chronologies. We assume that phases of low mean age are the result of wetter than normal growth conditions (Baillie 1995), which may lead to the death of older trees and subsequently favor the germination of a new oak generation. Intervals of increasing mean age point to relatively dry conditions on bog sites allowing the oaks to get older; germination will eventually be reduced due to a lack of light.

Common abrupt changes in population dynamics on bog oak sites all through Europe in c. 4000 BC and 2500 BC and 2000 BC point to major changes in European climate around these periods. In this context it is interesting that there is a widespread interest in climate change in the later third millennium BC (Dalfes et al. 1997).

The question arises if significant changes in population dynamics as indicated by the first differences of the mean-age chronology correspond with contemporary changes in tree-ring width.

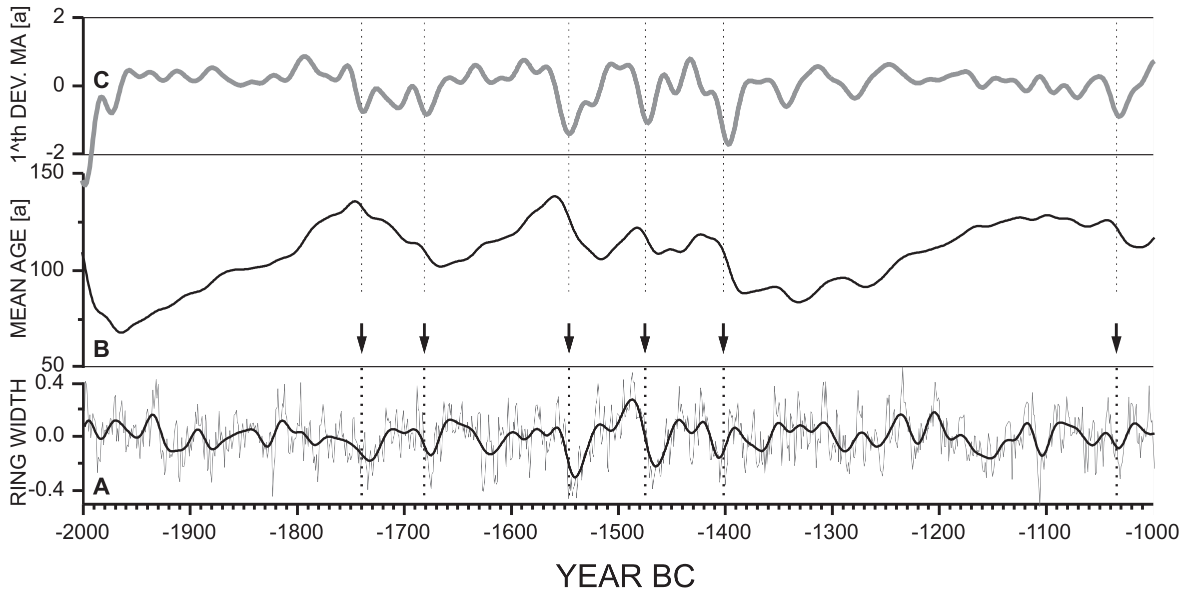

Figure 3: Example period (2000-1000 BC) for the continental (combined German and Dutch material) oaks showing comparison between the smoothed tree-ring chronology, the mean-age chronology and the chronology of first differences derived from the mean-age chronology.

A: tree-ring chronology with 15-year running mean superimposed, B: mean-age chronology, 15-year running mean C: chronology of first differences of "B". Arrows mark depression phases in the tree-ring chronology, which coincide with abrupt changes in the slope in the mean-age chronology, expressed by minimum peaks in the chronology of first differences.

Figure 3 shows a comparison of the two independent chronologies. There is clear evidence for the coincidence of the majority of GDO events with long-term ring width depressions in the Continental and the Irish data set (fig. 4) The comparison between the continental and the Irish tree-ring chronologies proves a high agreement and suggests a common forcing by climate. In this way tree-ring widths chronologies and mean-age chronologies may complement each other very well.

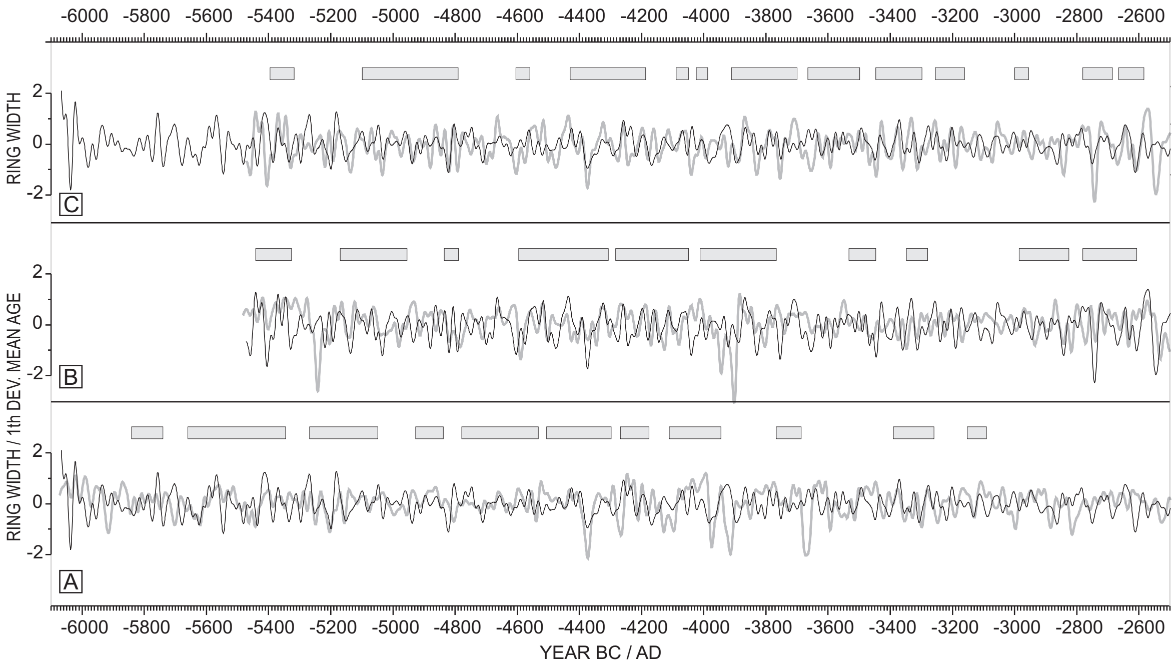

Figure 4: Comparison of regional and macro-scale population dynamics (derived from mean age curves) and changes in the tree-ring chronology in the period from 6100 BC to 2500 BC.

A: Running mean of the continental (German and Dutch) bog oak tree-ring chronology in comparison to the chronology of first differences of the mean-age chronology (15-year running mean). B: Running mean of the Irish bog oak tree-ring chronology in comparison to the chronology of first differences of the mean-age chronology (15-year running mean). C: Running mean of the continental and the Irish tree-ring chronologies. Phases of good agreement are marked by grey boxes at the top. The tree-ring chronologies were derived from the raw tree-ring measurements after logarithmic transformation and by applying a 141-year high-pass filter.

Conclusions

The analysis of large dendrochronological data sets in terms of mean age produces clear data about changes in population dynamics on bog sites in Europe. Abrupt changes in population dynamics indicate climatic change in regions of varying size. Given the scale of these events in the extended period 5400 BC to 2000 BC and – less clear – 2000 BC to 1000 AD, it is highly unlikely that they resulted from human intervention. Instead this must have been the result of a strong forcing by macro-scale environmental influence probably expressed as hydrological changes.

Acknowledgements

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