

The use of stable isotope dendrochronology for environmental interpretations from tree-ring patterns in sub-fossil bog oaks

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Introduction

Across Northwest Europe over 200 sites have yielded sub-fossil bog oak material. Together, these trees have catalogued changes in their sub-optimal site conditions for thousands of years. High ground water levels characterised these conditions and the changing status of the environment, through for example inundation, impacted tree growth and population dynamics (Leuschner *et al.* 2002; Sass-Klaassen and Hanraets 2003). Environmental shifts, such as changes of hydrological status and climate, have been recorded in the tree-ring chronologies of material excavated from these sites. Thus these chronologies provide a valuable basis for climate reconstruction during the Holocene (e.g. Mayr *et al.* 2003).

Material and Methods

Characteristics of bog oaks

Dendrochronologically dated bog oaks excavated from Zwolle-Stadshagen (The Netherlands) were used to try to determine more fully those changes in the environment that resulted in the characteristic growth depressions seen in the ring patterns of bog oaks across Northwest Europe (Fig 1). The underlying hypothesis centres on the fact that the bog oaks originally grew and subsequently became preserved in wet environments. This implies that variations in tree growth were determined predominantly by changes of the environment to relatively wetter conditions (as evidenced by anoxic soil conditions), which would have limited annual growth rate of the trees and provided the trigger for these growth depressions (Kooistra 2003; Sass-Klaassen and Hanraets 2003; Kozłowski 1984; Crawford and Braendle 1996). Since no analogous sites with living oaks exist in Europe today (see Sass-Klaassen this issue) from which environmental comparisons could be drawn, stable isotope dendroclimatology was applied to this sub-fossil bog-oak material.

The stable isotope approach

Relative changes in environmental conditions underpin the use of stable carbon and oxygen isotope dendrochronology. Carbon and oxygen originate from different sources (i.e. carbon

dioxide and water respectively) thus the combination of these isotopes may provide a clearer understanding of the physiological factors affecting tree growth (e.g. Edwards *et al.* 2000). Water is often a growth-limiting factor and therefore water loss must be kept to a minimum. Water enters the plant through the roots, ascends to the leaves via the xylem and is expelled by the stomata on the leaves. Stomata help to minimize water loss through evapotranspiration where H_2^{16}O is preferentially lost from the plant. Too much water and permanently saturated soil result in oxygen deficiency lowering root-osmotic potential and hindering hydraulic conductivity, which affects the $\delta^{18}\text{O}$ signature (Everard and Drew 1987). Stomatal behaviour is also involved in carbon dioxide uptake from the atmosphere. Plants discriminate against the isotopically heavier ^{13}C which determines the stable carbon isotope value of the plant. Upon stomatal closure an increase in ^{13}C is used in photosynthesis and this in turn alters the $^{13}\text{C}/^{12}\text{C}$ ratio locked up within the organic entities (Farquhar *et al.* 1989). Relative shifts in stable isotope signatures and their relation to environmental change and manifesting in the normal *versus* depression growth are the focus of this study. It was hoped that this will form a sensitive additional technique for dendrochronological interpretations of bog-oaks.

Results and Discussion

Molecular composition

The wood of the individual oaks from Zwolle was analysed (c.f. van Bergen and Poole 2002, Poole and van Bergen 2002) to determine the molecular composition (for further details, see Sass-Klaassen *et al.* submitted) since inherent differences in molecular preservation can affect the isotope signature and hence any ecological interpretation based on those signatures (van Bergen and Poole 2002). Cellulose was the dominant component with only relatively small amounts of lignin present (for further details, see Sass-Klaassen *et al.* submitted). Thus, the bulk wood isotope signal is biased in favour of cellulose in all samples, which eliminates the need for further correction prior to interpretation.

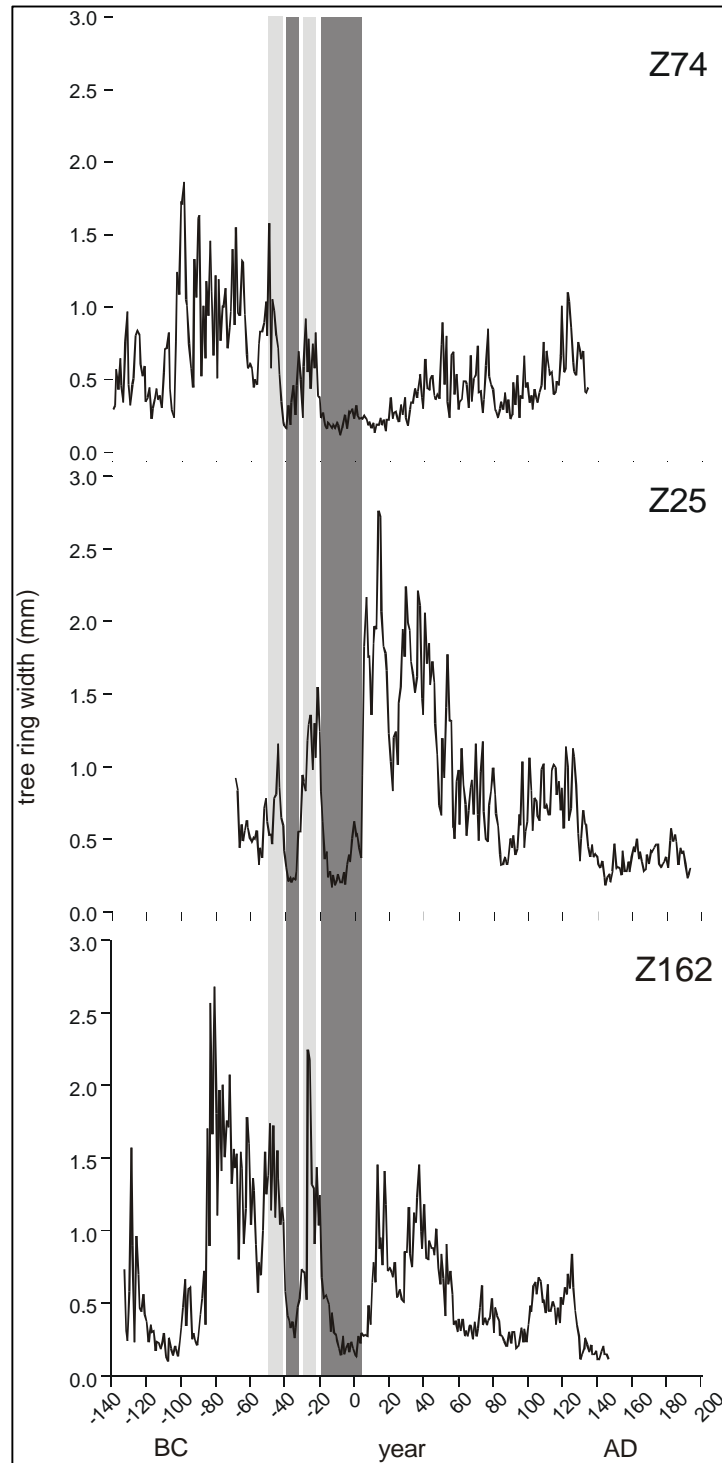


Figure 1: The relative positioning and duration of the depressed- (dark grey) and normal (light grey) growth years in the three trees (Z74, Z25, Z162) studied.

$\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ Stable isotope composition

No apparent directional trend was evident for either $\delta^{13}\text{C}_{\text{bulk}}$ or $\delta^{13}\text{C}_{\text{cellulose}}$ (data not shown) with depressed or normal growth in any of the trees. The shift in the $\delta^{13}\text{C}$ isotopic signature (i.e. $<2.4\text{‰}$) in values between the depression and normal growth phases is similar to that (1-3 ‰) documented for intra tree-ring variation (Schleser 1999; Leavitt 2002).

A similar scenario was noted for the $\delta^{18}\text{O}$ values (Fig 2) between depression and normal growth years with no obvious overriding directionality. However, there is a slight tendency towards depleted $\delta^{18}\text{O}$ values in the growth-depression samples. The maximum shift ($<2.5\text{‰}$ for the bulk wood and c. 1‰ for cellulose) in $\delta^{18}\text{O}$ is smaller than the difference (4 - 5 ‰) documented for intra tree-ring variation (Helle and Schleser 2003). These trends could be explained by the difference in relative amounts of early wood *versus* late wood in the samples measured obscuring any ecophysiological signal. Therefore the observed changes in isotopic shifts between periods of normal and depressed growth have to be interpreted with caution.

Unfortunately the underlying mechanisms of isotopic fractionation in the whole tree as well as the processes that finally result in a specific (intra-annual) pattern of isotopic composition in the wood are not yet fully understood. Ongoing investigations into the intra-annual pattern of isotopic composition in sub-fossil oak focusing on consecutive periods of normal and depressed growth will provide greater insight into this latter aspect. However, it is evident that the hydrological status of the environment, previously thought to result in the characteristic tree-ring pattern, appears not to be recorded in the isotopic composition. This may imply that changes in hydrology have not been severe enough to induce physiological stress, although it cannot be ruled out that changes in the hydrological status may have affected the length of growing season.

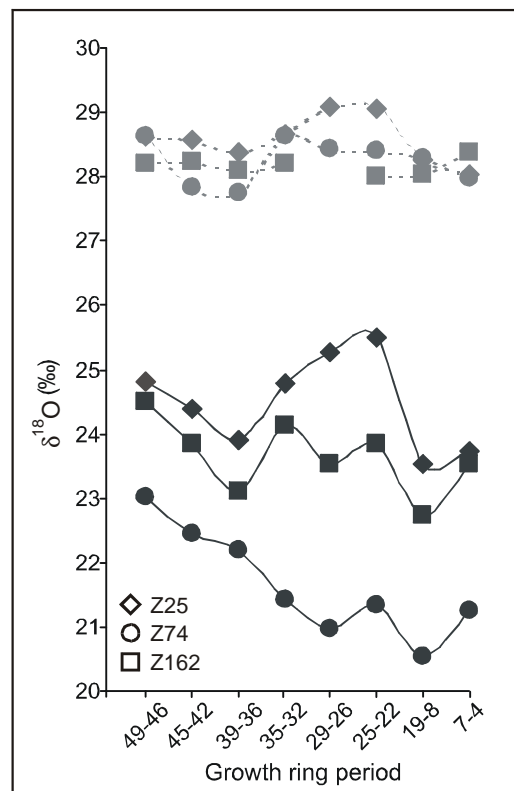


Figure 2: Shifts in the oxygen isotope signal with normal-growth (49 to 42 BC, 29 to 22 BC) versus depression-growth (39 –32 BC, 19 BC to AD 4) periods as determined from cellulose (grey symbols and broken line) and bulk wood (black symbols and solid line) for the trees Z74, Z25 and Z162.

Conclusions

The combined stable carbon- and oxygen isotope approach has successfully eliminated direct physiological stress on the leaves or roots as the cause of the characteristic growth patterns seen in the tree-ring series of the Zwolle bog oaks. However, shortening of the growing season through hydrological changes may have indirectly given rise to the characteristic tree-ring patterns observed. This would imply that in this study tree-ring widths provide a more sensitive monitor of the changing status of the external environment than shifts in stable carbon- or oxygen isotopes

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References

- van Bergen, P.F. & I. Poole (2002): Stable carbon isotopes of wood: a clue to palaeoclimate? *Palaeogeography, Palaeoclimatology, Palaeoecology* 182: 31-45
- Crawford, R.M.M. & R. Braendle (1996): Oxygen deprivation stress in a changing climate. *Journal of Experimental Botany* 47: 145-159
- Edwards, T.W.D., Graf, W., Triborn, P., Stichler, W., Lipp, J. & H.D. Payer (2000): $\delta^{13}\text{C}$ response surface resolves humidity and temperature signals in trees. *Geochimica et Cosmochimica Acta* 64(2): 161-67
- Everard, J.D. & M.C. Drew (1987): Mechanisms of inhibition of water movement in anaerobically treated roots of *Zea mays* L. *Journal of Experimental Botany* 38(II): 1154-1165
- Farquhar, G.D., Ehleringer, J.R. & K.T. Hubick (1989): Carbon isotope discrimination and photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology* 40: 503-537
- Helle, G. & G.H. Schleser (2003): Interpreting climate proxies from tree-rings. In: Fischer, H., Kumke, T., Lohmann, G., Flöser, G., Miller, H., von Storch, H. & Negendank, J.F.W.. *The KIHZ project: Towards a Synthesis of Holocene Proxy Data and Climate Models*. Springer, Berlin.
- Kooistra, M. (2003): Woodlands of the past: results of the excavation of Zwolle-Stadshagen (The Netherlands) II, Development of the paleo-landscape in its hydrological context. *Netherlands Journal of Geosciences*, submitted.
- Kozlowski, T.T. (1984): *Flooding and plant growth*. Academic Press, New York.
- Leavitt, S.W. (2002): Prospects for reconstruction of seasonal environment from tree-ring $\delta^{13}\text{C}$: baseline findings from the Great Lakes area, USA. *Chemical Geology* 192: 47-58
- Leuschner, H.H., Sass-Klaassen, U., Jansma, E., Baillie, M.G.L. & M. Spurk (2002): Subfossil European bog oaks: population dynamics and long-term growth depressions as indicators of changes in the Holocene hydro-regime and climate. *The Holocene* 12: 695-706

- Mayr, C., Frenzel, B., Friedrich, M., Spurk, M., Stichler, W. & P. Trimborn (2003): Stable carbon- and hydrogen-isotope ratios of subfossil oaks of southern Germany: methodology and application to a composite record for the Holocene. *The Holocene* 13: 393-402
- Poole, I. & P.F. van Bergen (2002): Carbon isotope ratio analysis of organic moieties from fossil mummified wood: Establishing optimum conditions for off-line pyrolysis extraction using GC/MS. *Rapid Communications in Mass Spectrometry* 16: 1-6
- Sass-Klaassen, U. & E. Hanraets (submitted). Woodlands of the past: results of the excavation of Zwolle- Stadshagen (The Netherlands) IV, Growth patterns and population dynamics of oak and ash. *Netherlands Journal of Geosciences*.
- Sass-Klaassen, U., Poole, I., Wils, T., Helle, G., Schleser, G. & P.F. van Bergen (submitted). The use of stable isotope dendrochronology for environmental interpretations from growth ring patterns in sub-fossil bog oaks. *IAWA Journal*.
- Schleser, G.H. (1999): $^{13}\text{C}/^{12}\text{C}$ in growth rings and leaves: carbon distribution in trees. In: T.P. Jones & N.P. Rowe, *Fossil plants and spores: modern techniques*. The Geological Society, London: 306-309