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Short Communication

Effects of wood degradation on tree-ring stable isotopes used in climate reconstructions

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ABSTRACT

Tree-ring stable isotopes from relict wood samples play an important role in climate reconstructions, but fire exposure, waterlogging, and post-excavation storage may bias the isotopic signal. Here, we test how thermal alteration and storage conditions affect holocellulose $\delta^{13}C$ and $\delta^{18}O$ values in archaeological oak (*Quercus* spp.) samples from southern Germany, focusing on the 1430–1444 CE period and considering a range of preservation states. We differentiate (i) dry-stored wood across four thermal-alteration categories (unaffected, intact, moderately charred, fully charred) and (ii) waterlogged wood kept wet after excavation, sampled at the outer surface and in the interior.

We found no significant differences in holocellulose $\delta^{13}C$ and $\delta^{18}O$ values among unaffected, intact and moderately charred rings. Fully charred rings yielded no extractable holocellulose; however, their bulk-wood $\delta^{13}C$ values were systematically shifted to lower values while preserving the interannual variability. In waterlogged wood, surface holocellulose $\delta^{18}O$ values were lower and showed weaker coherency with the interior series, whereas holocellulose $\delta^{13}C$ showed no meaningful change.

We conclude that moderate charring and waterlogging have limited effects on holocellulose-based tree-ring isotope signals in archaeological wood. For $\delta^{18}O$ in waterlogged wood, shallow surface samples should be avoided where possible, or a correction should be applied based on the mean offset across overlapping years. Our results support the inclusion of partially degraded archaeological and subfossil oak wood in isotope-based dating and paleoclimate reconstructions.

1. Introduction

Cellulose-derived stable isotopes from annually resolved tree rings can be reliable indicators of past climate and environmental conditions (McCarroll and Loader, 2004). However, fire, prolonged waterlogging, and post-excavation storage may affect signal integrity. Carbon isotope ratios ($\delta^{13}C$) primarily reflect photosynthetic ^{13}C discrimination, which is driven by the balance between assimilation rate and stomatal conductance. However, absolute $\delta^{13}C$ values are also influenced by atmospheric CO_2 concentration and its carbon isotopic composition. Oxygen isotope ratios ($\delta^{18}O$) typically integrate the isotopic composition of source water together with the evaporative ^{18}O enrichment of leaf water (Siegwolf et al., 2023). The combination of tree-ring stable isotopes (TRSI) with classical dendrochronological parameters, such as tree-ring width (TRW) and maximum latewood density (MXD), can provide valuable information for hydroclimate reconstructions and physiological investigations (Gessler et al., 2014; Römer et al., 2025).

Long isotope-based hydroclimate reconstructions often rely on

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archaeological and subfossil wood remains (Arosio et al., 2025; Büntgen et al., 2021), yet this material can be affected by thermal charring (Braadbaart and Poole, 2008), microbial decay (Blanchette, 2000), prolonged waterlogging in anoxic sediments (Björdal, 2012), and other chemical changes to organic components (Nagavciuc et al., 2018; Spiker and Hatcher, 1987). Post-excavation handling, including wet storage in sealed bags that retain moisture or dry storage in air storage, may further challenge interpretation. How these processes and storage conditions affect interannual patterns and absolute TRSI values remains only partly quantified for archaeological oak—an issue that is especially important in periods and contexts where perfectly preserved wood is not available.

Here, we analyse holocellulose $\delta^{13}C$ and $\delta^{18}O$ values from absolutely dated archaeological oak (*Quercus* spp.) in two sample sets: (1) dry-stored wood representing different thermal-alteration states (Unaffected, Intact, Moderately charred, Fully charred), and (2) waterlogged, wet-stored wood sampled at two radial positions (outer surface vs centre). We evaluate both year-to-year coherence and absolute offsets to determine whether partially degraded archaeological material retains isotopic information suitable for paleoclimate reconstructions and absolute dating.

2. Material and methods

This study utilises absolutely dated archaeological oak wood from two sites in Nuremberg, southern Germany (Fig. 1). The underlying tree-ring width (TRW) series from the Imperial Castle deep well span 1395–1495 CE, whereas the Augustinerhof latrine timbers preserve waney edge with a last ring of 1517 CE (Table 1; see Supplementary Material S1 for site and handling details). For stable isotope analyses, we extracted the common 15-year interval spanning 1430–1444 CE from the securely cross-dated series.

Nuremberg Imperial Castle, deep well. The ~53 m shaft through Keuper sandstone reaches the Pegnitz floodplain and is documented from the 13th century. Superstructures built in 1563/1564 were destroyed by bombing on 2 January 1945; fire debris fell into the well, absorbed water, and sank, becoming waterlogged *in situ*. In 2012, underwater archaeology recovered ~180 pieces; discs were sawn from the charred timbers, and subsequently air-dried (~8% moisture content) and archived dry at room temperature. This dry-stored material forms the thermally altered set (Unaffected, Intact, Moderately charred, Fully charred).

Augustinerhof, Nuremberg, latrine. Large excavations in 2008 on the Pegnitz floodplain yielded well-preserved waterlogged oak boards. Three oak boards from feature 1214 (latrine), cross-dated with waney edge to 1517 CE, were selected for this study. After examination, the material was cleaned in deionized water and kept wet-stored at 6–8 °C, later vacuum-sealed under N_2 in transparent PE/LDPE bags (see Supplementary Material S1). This wet-stored material forms the waterlogged set, sampled at outer surface and centre.

To assess the effects of thermal alteration, dry-stored tree-ring samples were categorised into four groups: Unaffected (Un; rings with no exposure to fire), Intact (In; no visible charring), Moderately charred (Mc; visible charring with partial loss of cell structure), and Fully charred (Fc; heavily charred rings with minimal original structure). To assess the effects of waterlogging, we analysed samples excavated from water-saturated, low-oxygen deposits and then kept wet after excavation without drying. From this material, two radial positions were analysed: outer surface (~0–1 mm) and centre (>20 mm from surface). For each calendar year (1430–1444 CE), three independent tree replicates

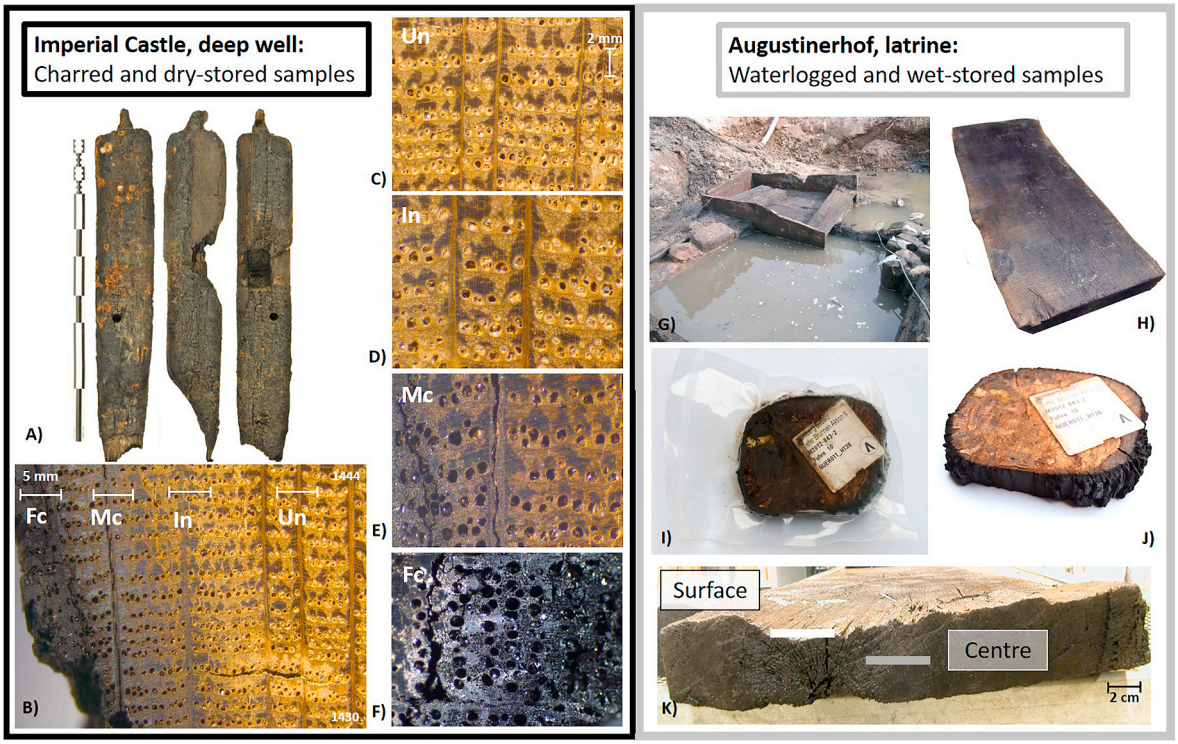

Fig. 1. Archaeological oak (*Quercus* spp.) from two sites in Nuremberg, southern Germany, illustrating the wood material analysed for stable isotope measurements covering the period 1430–1444 CE. **Imperial Castle, deep well** – thermally altered and dry-stored wood, black frame: (A) charred oak beam fragments recovered from the well; (**B**) transverse section showing the analysed tree-ring sequence and preservation gradient from unaffected (Un), through intact (In) and moderately charred (Mc) to fully charred (Fc) wood; (**C–F**) representative microscopic transverse sections of unaffected (Un), intact (In), moderately charred (Mc), and fully charred (Fc) wood, respectively. **Augustinerhof, latrine** – waterlogged and wet-stored wood, grey frame: (**G**) waterlogged oak wood at the excavation site; (**H**) example of a recovered waterlogged oak board; (**I–J**) oak discs stored in sealed, humid conditions prior to sampling; and (**K**) radial sampling positions at the outer surface layer (~0–1 mm) and centre (>20 mm from the surface). For further details on site context, wood samples, and post-excavation handling, see Supplementary Material S1.

Table 1
Site and sample information.

Site name Coordinates	Context	Material description	Post-excavation storage	Analytical focus	Ring span (full; AD)	Sample ID
Nuremberg, Imperial Castle						
49.457846° N, 11.076098° E	Deep well	Surface charred	Dry-stored, room temp.; open PE bags	Thermal alteration	1396–1495	NUER011_H054
49.457846° N, 11.076098° E	Deep well	Surface charred	Dry-stored, room temp.; open PE bags	Thermal alteration	1404–1476	NUER011_H114
49.457846° N, 11.076098° E	Deep well	Surface charred	Dry-stored, room temp.; open PE bags	Thermal alteration	1395–1454	NUER011_H089
Nuremberg, Augustinerhof						
49.453604° N, 11.075386° E	Latrine	Not charred; waterlogged	Wet-stored 6–8 °C; sealed LDPE bags	Radial positions	1412–1513	N08_L0004
49.453604° N, 11.075386° E	Latrine	Not charred; waterlogged	Wet-stored 6–8 °C; sealed LDPE bags	Radial positions	1423–1516	N08_L0007
49.453604° N, 11.075386° E	Latrine	Not charred; waterlogged	Wet-stored 6–8 °C; sealed LDPE bags	Radial positions	1428–1517	N08_L0006

Notes: (1) Isotope window used: All isotopic analyses employ the common interval 1430–1444 CE extracted from the absolutely dated series listed above; (2) Coordinates: WGS84 decimal degrees. Source UTM32 values are provided in Supplementary Material S1.; (3) Storage conditions: Dry-stored = air-dry archive at room temperature in open PE bags; Wet-stored = sealed under moisture at 6–8 °C (later vacuum-sealed, N_2 flush).

(Tree1–Tree3) were analysed per thermal category (Un, In, Mc, Fc) and per waterlogged radial position (Surface, Centre), yielding 270 individual tree-ring samples in total (15 years × 3 trees × 6 groups = 270; 45 per group).

We used tree-ring width (TRW) series to benchmark potential effects of sample conditions on the isotope data. The mean pairwise interseries correlation was 0.65 (range 0.62–0.67) among the three dry-stored, thermally altered samples, and 0.70 (range 0.57–0.81) among the three waterlogged, wet-stored samples. Between the dry and wet sets, the mean pairwise correlation was lower (0.52; range 0.24–0.73), consistent with their likely different localities of origin. The TRW series are provided in the Supplementary Material S2.

For stable-isotope analysis, annual rings were first dissected under a stereomicroscope. Holocellulose was isolated in F57 Teflon filter bags (Ankom Technology, USA) using a modified Jayme–Wise protocol (Boettger et al., 2007): treatment with 5% NaOH (2 × 2 h, 60 °C), followed by 7% $NaClO_2$ (30 h, 60 °C) buffered with acetic acid (pH 4–5). Repeated rinsing with hot distilled water (90 °C) was followed by drying (50 °C, 24 h). For Fc samples, cellulose could not be obtained; therefore, bulk-wood carbon was analysed for $\delta^{13}C$.

Following extraction, approximately 1 mg of holocellulose was sealed in Ag capsules for $\delta^{18}O$ and pyrolyzed to CO in a varioPYRO cube elemental analyser (Elementar, Germany) coupled with a continuous-flow ISOPRIME100 IRMS (Isoprime, UK). For $\delta^{13}C$, ~1 mg of holocellulose, or powdered bulk wood from Fc samples, was weighed into Sn capsules and combusted to CO_2 on the same system. Isotope compositions are expressed in delta notation as $\delta^{n}X = R_{sample}/R_{standard} - 1$ (Coplen, 2011), where R is $^{13}C/^{12}C$ or $^{18}O/^{16}O$. Numerical values are reported in per mil (‰), after multiplying $\delta^{n}X$ by 1000, relative to VPDB for $\delta^{13}C$ and VSMOW for $\delta^{18}O$. Measurement results were normalised and referenced to the international isotope scales using two-point scale normalisation with international reference materials, namely IAEA-600 (caffeine) and USGS24 (graphite) for $\delta^{13}C$, and IAEA-601 and IAEA-602 (benzoic acids) for $\delta^{18}O$. Routine QA/QC included reference-gas stability, linearity across the working ion-current range, internal laboratory standards (cellulose, wood), and replicate ring measurements; typical precision (1σ) was ≤0.07‰ ($\delta^{13}C$) and ≤0.64‰ ($\delta^{18}O$). For details see Supplementary Material S3.

Interannual coherence of the raw, non-detrended TRSI time series (Büntgen et al., 2020) was assessed using two-tailed Pearson's correlation coefficients and the Gleichläufigkeit (GLK). GLK is defined as the proportion of years in which first differences share the same sign, with ties excluded; significance was evaluated with a one-sided binomial test versus 50%. Mean isotope offsets were denoted as $^{13}\Delta$ and $^{18}\Delta$ for carbon and oxygen, respectively, and calculated as $\delta^{n}X_{test} - \delta^{n}X_{reference}$, where the reference was Unaffected for the thermal-alteration set and Centre for the waterlogged set. Offsets were estimated in two ways. First, linear mixed-effects models were fitted at the replicate level with Year as a random intercept and Unaffected or Centre as the reference group: $y_{ij} = \mu + \beta_{Group(i)} + u_{Year(j)} + \varepsilon_{ij}$. We report fixed-effect contrasts ($^{13}\Delta$ or $^{18}\Delta$) ± 95% CI and p-values. Second, year-wise paired differences, for example Category − Unaffected; Surface – Centre, were tested against zero using a one-sample t-test with t-based 95% CIs. All hypothesis tests were two-tailed unless a directional effect was pre-specified. For waterlogged $\delta^{18}O$ (Surface – Centre), we additionally report a one-tailed p-value for the *a priori* expectation of lower surface $\delta^{18}O$ values.

3. Results and discussion

3.1. Thermal alteration (dry-stored wood)

Across all thermally altered categories, mean $\delta^{13}C$ values ranged between −24‰ and −27‰ (Fig. 2A–D). Cellulose time-series for Intact and Moderately charred wood were highly coherent with Unaffected (r = 0.87/0.93; GLK = 93%/100%). Mixed-effects modelling and paired year-wise tests indicated a negligible mean offset for Intact ($^{13}\Delta = -0.05$‰, n.s.) and a small but significant shift to lower values for Moderately charred ($^{13}\Delta = -0.21$‰, $p = 0.02$; 95% CI −0.30 to −0.13). Bulk-wood $\delta^{13}C$ values from Fully charred rings retained a recognisable interannual pattern ($r = 0.81$; GLK = 71%) but showed a clear shift to lower mean values ($^{13}\Delta = -1.31$‰, $p < 0.001$).

These results demonstrate that moderate charring has a negligible effect on cellulose $\delta^{13}C$ values, whereas severe charring causes a substantial shift to lower $\delta^{13}C$ values in bulk wood. The mechanisms responsible for carbon isotope changes during burning and carbonisation depend on plant material, oxygen availability, temperature, heating duration, and the relative proportions of cellulose, hemicellulose, lignin, and volatile compounds (Benner et al., 1987; Czimczik et al., 2002; Loader et al., 2003; Turney et al., 2006). Our Fully charred material most likely represents incomplete, oxygen-limited charring, which is common in archaeological contexts where wood is rapidly buried, covered by debris, or exposed to restricted air supply after burning. Under such conditions, thermally labile carbohydrate-rich fractions, particularly hemicelluloses and cellulose, are preferentially degraded, producing volatile compounds such as wood gases, organic acids, and other oxygenated pyrolysis products, while more refractory lignin- and char-derived residues become relatively more important (Braadbaart and Poole, 2008; Czimczik et al., 2002). Because cellulose and other carbohydrate fractions are generally enriched in ^{13}C relative to lignin, their preferential loss leaves a residue with a greater proportion of ^{13}C-depleted lignin-derived material, resulting in lower bulk-wood $\delta^{13}C$ values (Benner et al., 1987; Loader et al., 2003; Spiker and Hatcher, 1987; Turney et al., 2006). This interpretation is consistent with experimental evidence showing that $\delta^{13}C$ values of charred wood may change only slightly at low temperatures (150–200 °C), where preferential loss of ^{13}C-depleted lipids can produce a small shift to higher values. With stronger carbonisation, however, $\delta^{13}C$ values tend to shift to lower values as degradation of cellulose and hemicelluloses becomes dominant (Czimczik et al., 2002; Turney et al., 2006). Similar shifts to lower $\delta^{13}C$ values (≈0.3–1.3‰) have been reported for burnt or carbonised wood (Hall et al., 2008; Schleser et al., 1999; Turney et al., 2006), while interannual patterns may remain preserved (Hall et al.,

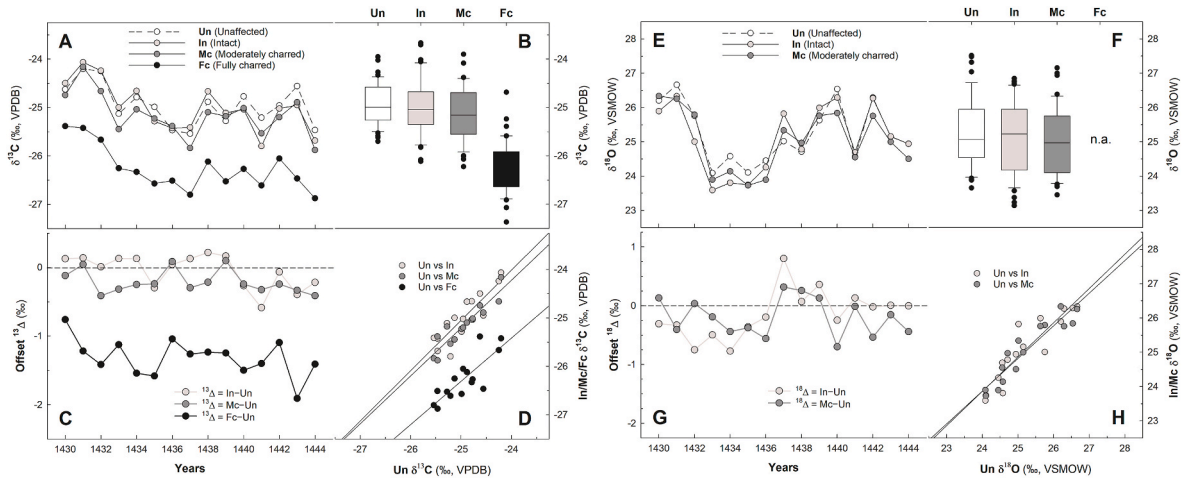

Fig. 2. Tree-ring stable isotope ratios of carbon ($\delta^{13}C$; **A–D**) and oxygen ($\delta^{18}O$; **E–H**) in dry-stored oak wood across thermal-alteration states (Un, In, Mc, Fc). Top panels show annual means of three trees for each category and box-whisker plots summarising all measured values (full dataset in Supplementary Material S2). Bottom panels show year-by-year offsets of category means relative to Unaffected samples (Un), expressed as $^{13}\Delta$ or $^{18}\Delta$ = category − Un, and Pearson correlations (r) between each category and Unaffected (values listed in Supplementary Material S2). $\delta^{18}O$ is shown for cellulose only; Fc is excluded because cellulose could not be isolated.

2008). This progressive loss of carbohydrate-rich material is also consistent with the absence of extractable cellulose in Fully charred rings, indicating destruction of the holocellulose fraction at high temperature; analogous extraction failures are known from extremely degraded or mummified wood material (Hook et al., 2015).

Mean $\delta^{18}O$ values ranged between 23‰ and 27‰ (Fig. 2E–H). As with $\delta^{13}C$, cellulose $\delta^{18}O$ time-series for Intact and Moderately charred categories were strongly coherent with Unaffected (r = 0.91/0.93; GLK = 100%/92.9%). Year-wise paired differences showed a negligible mean offset for Intact ($^{18}\Delta = -0.14$‰, 95% CI −0.35 to 0.07; n.s.) and a slightly lower $\delta^{18}O$ values for Moderately charred rings ($^{18}\Delta = -0.20$‰, 95% CI −0.36 to −0.03; p = 0.034). These small shifts agree with evidence that cellulose $\delta^{18}O$ values remain stable under moderate (~250 °C) hydrothermal conditions (Ren et al., 2025), consistent with the relative stability of C–O bonds in the polysaccharide matrix. Controlled heating of bulk oak wood, i.e. whole wood rather than isolated cellulose, further revealed a two-step $\delta^{18}O$ response (du Boisgueheneuc et al., 2023): slightly higher $\delta^{18}O$ values below ~300 °C (up to +1.6‰), followed by large decreases in $\delta^{18}O$ values (up to −20 to −30‰) at ~700–1000 °C due to cellulose and lignin degradation. These decreases are larger under oxidative combustion than under oxygen-limited pyrolysis at the same temperature. Together, our data and these experiments indicate that cellulose $\delta^{18}O$ is resilient to moderate charring, whereas bulk-wood $\delta^{18}O$ at higher temperatures becomes chemistry- and atmosphere-dependent, with potentially large, non-linear shifts.

3.2. *Waterlogging (wet-stored wood)*

Tree rings from the same year across surface and centre positions had almost identical year-to-year $\delta^{13}C$ values ($r \approx 0.98$; GLK = 100%) (Fig. 3A–D). The mean Surface − Centre offset was +0.09‰, indicating slightly higher surface $\delta^{13}C$ values, but this difference was not significant on a two-tailed test. This confirms reports that prolonged

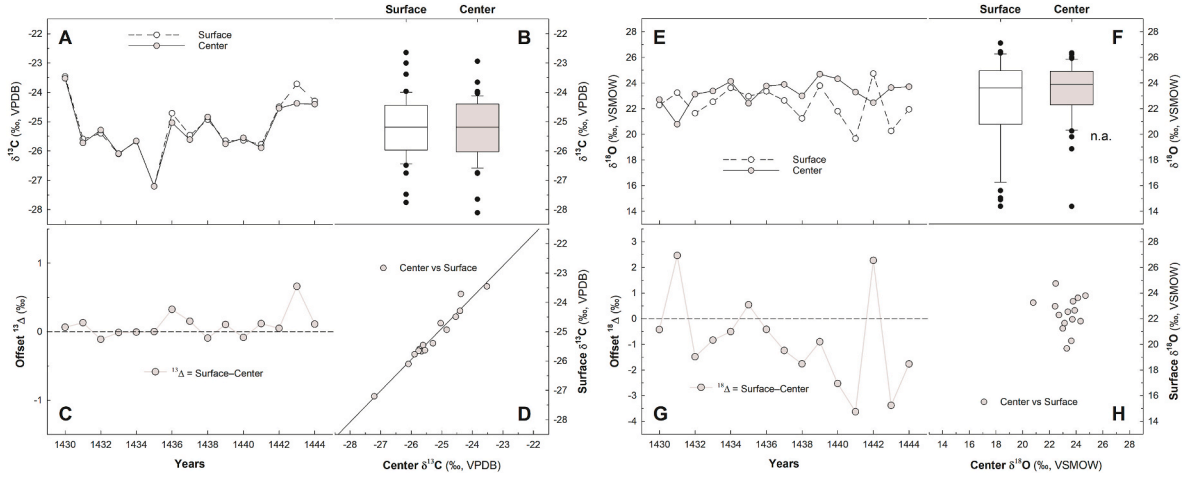

Fig. 3. Tree-ring stable isotope ratios of carbon ($\delta^{13}C$; **A–D**) and oxygen ($\delta^{18}O$; **E–H**) in waterlogged, wet-stored oak wood at two radial positions: Surface (~0–1 mm) and Centre (>20 mm from the outer surface), covering the period 1430–1444 CE. (**A,E**) Per-year position means (holocellulose; n = 3 trees per year). (**B,F**) Distributions by position: boxes = interquartile range (IQR), central line = median, whiskers = 10th–90th percentiles; points indicate values outside whiskers (3 tree × 15 years per position; full dataset in Supplementary Material S2). (**C,G**) Year-by-year offsets of position means relative to Centre, expressed as $^{13}\Delta$ or $^{18}\Delta$ = Surface – Centre; negative values indicate lower δ values at the Surface. (**D,H**) Correlations between per-year Surface and Centre mean series; numerical Pearson coefficients (r) are listed in Supplementary Material S2.

submersion produces only minor $\delta^{13}C$ alteration in preserved wood (Savard et al., 2012) and suggests that small positional gradients in oxygen availability or microbial activity do not distort the interannual $\delta^{13}C$ signal in cellulose. At the same time, the greater interannual variability observed in the waterlogged and wet-stored material ($\delta^{13}C$: ≈−23‰ to −28‰; $\delta^{18}O$: ≈19‰ to 25‰) compared to the dry-stored material (Fig. 3) is plausible due to microbial succession during decay. Microbial degradation of waterlogged archaeological wood is often spatially uneven and concentrated near exposed surfaces, where erosion bacteria, tunnelling bacteria, fungi, and hydrolytic processes can selectively modify carbohydrate-rich cell-wall components while leaving more resistant lignin-rich structures relatively better preserved (Björdal, 2012; Blanchette, 2000). In Norway spruce, for instance, fungal species richness increases markedly from early to advanced decay and $\delta^{13}C$ values become progressively lower with increasing decay stage (Mäkipää et al., 2017). Such processes likely contribute to small, local $\delta^{13}C$ shifts in waterlogged wood, even when the mean radial offset is negligible, helping to explain slightly higher variability without compromising year-to-year coherence.

In contrast, $\delta^{18}O$ values (Fig. 3E–H) exhibited a small but systematic radial shift: Surface values were, on average, ~0.91‰ lower than Centre values (95% CI −1.79 to −0.03). This difference is borderline on a two-tailed test ($p = 0.063$) but significant on a one-tailed test under the *a priori* expectation of lower surface $\delta^{18}O$ values ($p = 0.031$). Interannual coherence between positions was low ($r = -0.11$; GLK = 64%), indicating a primarily absolute offset rather than a shared year-to-year pattern. A plausible mechanism is partial oxygen isotope alteration during surface-layer decay. In waterlogged archaeological wood, microbial and enzymatic degradation preferentially affects polysaccharide-rich cell-wall components, particularly in the outer layers exposed to pore water and post-excavation handling (Björdal, 2012; Blanchette, 2000). Hydrolysis and oxidative degradation can break existing oxygen-bearing bonds in cellulose, hemicellulose, and other cell-wall compounds and promote the formation of new oxygen-bearing functional groups. During these reactions, oxygen may be incorporated from surrounding water (Roden et al., 2000; Sternberg, 2009). If this water has lower $\delta^{18}O$ values than the original cellulose, surface-layer alteration can shift cellulose $\delta^{18}O$ values slightly lower. Because degradation is concentrated near the wood surface, this effect is expected to be strongest in the outer layers, whereas the interior remains comparatively protected. These findings are consistent with previous observations that $\delta^{18}O$ in subfossil or waterlogged oak wood is largely preserved, but may show modest shifts to lower values depending on preservation state and burial conditions (Rinne et al., 2013; Savard et al., 2012).

4. Conclusions

This study shows that archaeological and subfossil oak generally preserves robust dendro-isotopic information despite moderate charring and waterlogging. Holocellulose $\delta^{13}C$ and $\delta^{18}O$ values from intact and moderately charred rings closely track those from unaffected rings. Severe charring, by contrast, prevents holocellulose extraction and shifts bulk-wood $\delta^{13}C$ to lower values, although the year-to-year pattern remains recognisable and may still support relative matching for dating. In waterlogged wood, holocellulose $\delta^{13}C$ is consistent between radial positions, with a negligible mean offset, whereas holocellulose $\delta^{18}O$ at the outer surface has modestly lower values than at the centre and shows weaker interannual agreement.

Based on these tests, practical guidance is as follows: $\delta^{13}C$ can be sampled from either radial position in waterlogged material; for $\delta^{18}O$, shallow surface layers should be avoided where possible, or a mean offset should be estimated and removed using overlapping years. Fully charred material should be treated cautiously—bulk-wood $\delta^{13}C$ may aid cross-comparison, but it should not be interpreted as an unbiased absolute value. With these controls, partially degraded archaeological and subfossil wood can be incorporated into isotope-based paleoclimatic reconstructions and absolute dating where perfectly preserved material is unavailable.

CRediT authorship contribution statement

Natálie Pernicová: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft. **Otmar Urban:** Conceptualization, Formal analysis, Investigation, Supervision, Writing – original draft. **Tomáš Kolář:** Formal analysis, Methodology, Writing – review & editing. **Michal Rybníček:** Data curation, Methodology, Writing – review & editing. **Eva Koňasová:** Investigation, Methodology, Writing – review & editing. **Julia Weidemüller:** Data curation, Investigation, Methodology, Writing – review & editing. **Franz Herzig:** Data curation, Investigation, Methodology, Writing – review & editing. **Charles Norman:** Formal analysis, Writing – review & editing. **Josef Čáslavský:** Formal analysis, Investigation, Methodology, Writing – review & editing. **Miroslav Trnka:** Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Jan Esper:** Supervision, Writing – review & editing. **Ulf Büntgen:** Conceptualization, Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.qsa.2026.100334.

Data availability

The data underlying this article are openly available in ASEP repository at https://doi.org/10.57680/asep.0650649.

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