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RESEARCH ARTICLE

Legacy of the 1941 dam explosion in the Supiy River valley, Ukraine: shifts in drought and wetness sensitivity of *Quercus robur (Fagaceae)*

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Abstract. This study evaluates changes in the sensitivity of radial growth of *Quercus robur* to water balance, assessed using the Standardized Precipitation Evapotranspiration Index (SPEI), in stands located within the Supiy River valley (Kyiv Region, Ukraine) in relation to the dam destruction in 1941 and the subsequent construction of a drainage network in the floodplain. Two valley stands were investigated: Tashan Park (TAS), situated downstream of the former dam site, and Zgurivka Dendropark (ZGU), located upstream. Two extra-valley sites, Bykivnia Forest (BYK) and Feofaniya Park (FEO), were used as the regional reference (REF) sites. The study period was divided into two intervals: before hydrological alterations (1910–1940) and after the completion of major drainage works (1962–2015); 1941–1961 were excluded from the analysis. Statistical modeling revealed a pronounced shift in moisture sensitivity of *Q. robur* within the Supiy valley: at TAS, the previously negative relationship between growth and March SPEI3 became positive after 1961, while the positive relationship with July SPEI3 observed before 1941 shifted to negative. In contrast, ZGU exhibited only weak changes in sensitivity, and the regional reference chronology (REF) maintained a consistently positive response to SPEI throughout the study period. These findings indicate a localized shift in hydroclimatic controls on tree growth within the river valley, particularly downstream of the dam site. The complex interaction of hydrological alterations, water management practices, small-stream regulation, and ongoing climate change complicates the prediction of ecological consequences of dam destruction and drainage works without empirical evidence from comparable settings.

Keywords: climate sensitivity, pedunculate oak, riparian forests, SPEI, statistical modeling, tree rings

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Introduction

Hydrological modification has fragmented rivers and altered flow regimes worldwide (Nilsson et al., 2005; Grill et al., 2019). Flow regulation, channelization, drainage, and barriers are pervasive pressures on river corridors and their connected ecosystems, including riparian forests (Stella, Bendix, 2019). Riparian woody species provide key functions such as bank stabilization, habitat structure, microclimate regulation, and filtration/retention processes (Naiman et al., 2005), yet they are sensitive to altered discharge and groundwater regimes (Nilsson, Berggren, 2000) that shift inundation timing, soil aeration, and the degree of drought buffering (Camarero et al., 2023).

Beyond planned regulation, abrupt dam loss (including wartime destruction) can impose rapid hydro-geomorphic and biogeochemical shocks with cascading ecological and societal consequences (Shumilova et al., 2025). In parallel, connectivity and process-based restoration (e.g., barrier removal, re-meandering, and drainage management) is accelerating in some regions (Wohl et al., 2024), but outcomes can be constrained by legacy infrastructure, competing water demands, and social acceptance. As river corridors increasingly face both gradual engineering trajectories and abrupt regime shifts (e.g., extreme floods, waterlogging episodes, sudden infrastructure failure), management and restoration require empirical evidence linking specific hydrological changes to riparian ecosystem responses (Nilsson et al., 2018).

Tree rings provide annually resolved records of tree performance and can detect long-term responses to hydrological variability in both river valleys and adjacent uplands over decades to centuries (Stoffel, Bollschweiler, 2008; Nolin et al., 2021). Because foundation tree species integrate multiple constraints on growth, their ring-width series can reveal shifts in key growth drivers and changes in hydroclimatic sensitivity associated with hydrological reorganization (e.g., Gričar et al., 2013; Netsvetov et al., 2018; Marcon et al., 2022). Pre/post comparisons around known disturbances provide a direct test of whether growth limitation changes direction (e.g., from drought limitation to wetness limitation) when regulation, drainage, or channel conditions change.

Here, we use tree rings of pedunculate oaks (*Quercus robur* L., *Fagaceae*) to examine a long sequence of hydrological alterations on the Supiy River (Kyiv Region, Ukraine), including regulation, abrupt dam loss during World War II, drainage/canal construction, and subsequent degradation/impoundment of the drainage and channel system. Historical sources and maps indicate that dams were present on the Supiy at least since the early nineteenth century; in late 1941 they were destroyed during wartime actions (Dovhoruk, 2018). Drainage and canal construction then expanded across the floodplain and surrounding landscapes from the 1940s through the early 1960s (Vyshnevskyi, Kutsiy, 2022; Shevchuk et al., 2020).

We compare two river-valley (riparian-corridor) oak stands that occupy first-terrace and adjacent valley-slope positions (i.e., not the active riverbank): a downstream stand near the former dam position (Tashan; TAS) and an upstream stand (Zgurivka; ZGU). For regional context, we use a composite upland reference chronology (REF) built from two non-valley sites (Bykivnia, BYK, and Feofania, FEO; both located within the Kyiv City borders) that primarily capture background climatic forcing; these sites and their chronologies have been described previously (e.g., Netsvetov, Prokopuk, 2016; Netsvetov et al., 2018; Prokopuk et al., 2024).

Our aim was to quantify whether and how tree growth sensitivity to water balance changed across hydrological phases. We tested for shifts in the relationship between ring-width index and drought/wetness variability using the Standardized Precipitation Evapotranspiration Index (SPEI) by comparing a pre-impact period (≤ 1940) to a post-reorganization period (≥ 1962), excluding 1941–1961. We hypothesized that (i) prior to dam destruction, downstream TAS would show growing-season water limitation broadly aligned with the upland climatic signal (REF), consistent with reduced downstream water availability under regulation; (ii) after dam destruction and further drainage development and subsequent evolution of the valley water regime, TAS would become more sensitive to late-winter/early-spring water balance but less positively responsive in early-to-mid summer near the precipitation peak; and (iii) the upstream ZGU stand would show smaller or non-significant shifts in growth–SPEI sensitivity because it was less directly affected by the destroyed downstream dam and its legacy. We evaluated these hypotheses within a Before/After–Control/Impact (BACI) sensitivity-shift framework (Underwood, 1992).

Material and Methods

Study area and sites

The study was conducted in the two administrative units of Ukraine, Kyiv Region and Kyiv City geographically located within Kyiv Region, at four *Q. robur* stands: two upland reference sites (Feofania, FEO; Bykivnia, BYK, in Kyiv City) and two Supiy River-valley sites (Zgurivka, ZGU; Tashan, TAS) (Figs. 1, 2; Table 1). TAS and ZGU are located in the Supiy River basin, a left-bank tributary of the Dnipro River, and represent river-valley oak stands occupying first-terrace/terrace-edge positions and adjacent valley slopes rather than the active riverbank. Both valley stands originated as 18th–mid-19th century private landscape gardens and are currently unmanaged forest massifs with old oak cohorts.

In ZGU, *Quercus robur* occurs primarily as solitary trees or remnants of former alley plantings, while the main stand is situated in quarters. There, it grows together with common park species forming the second canopy layer, including *Aesculus hippocastanum* L., *Acer platanoides* L., *Robinia pseudoacacia* L., and *Tilia cordata* Mill. Introduced species present in the park include *Larix decidua* Mill., *Thuja occidentalis* L., and *Tsuga canadensis* (L.) Carrière. Riparian tree species are mainly represented by *Salix alba* L., *Populus tremula* L., and *Alnus glutinosa* (L.) Gaertn.

In Tashan Park, *Q. robur* forms a forest massif with a secondary canopy layer composed of *Pinus sylvestris* L., *Betula pendula* Roth, *Aesculus hippocastanum* L., and *Acer platanoides* L. The herb layer of the park remains close to natural conditions, supporting the persistence of spring ephemeroids. These are primarily represented by *Galanthus nivalis* L., *Scilla bifolia* L., *Ficaria verna* Huds., *Corydalis solida* (L.) Clairv., *C. intermedia* (L.) Mérat, *C. cava* (L.) Schweigg. & Körte, *Gagea lutea* (L.) Ker Gawl., and *G. minima* (L.) Ker Gawl. (Kalinskyi, 2025). In geobotanical terms, all sites fall within the Eurasian steppe region, forest-steppe subregion, and the Eastern European forest-steppe province characterized by oak forests, steppe meadows, and meadow steppes (Didukh, Shelyag-Sosonko, 2003). FEO is situated on the right bank of the Dnipro, whereas BYK (upland/non-valley), TAS, and ZGU are located on the left bank, i.e. east of the Dnipro River.

Historical sources document substantial hydrological modification in the Supiy valley near TAS, including damming and watermills, phases of flooding and drainage, and development of drainage-canal networks (Dovhoruk, 2018; Fig. 1B–C). According to Dovhoruk (2018), in September 1941, through military action, the melioration system of the Supiy River was destroyed, and bogs and some landscapes around were flooded from two reservoirs. The flooding lasted for about 3 weeks.

Descriptions of the historical maps

The Fig. 1B, C present map fragments illustrating changes in the hydrology of the Supiy River over time. Red squares indicate the locations of Tashan (*Tashan = Тошань*, *Taschan*, *Ташань*) and Zgurivka (*Zgurivka = Згуровка*) in different maps.

The first map (VTK, 1923a, 1923b; Fig. 1B, C) was created in 1923 based on reconnaissance surveys conducted in 1915 and 1922. The map well illustrates the pre-war hydrological state of the valley, before the large-scale melioration and transformation of the channel. The Supiy River is shown flowing into a large lake (greenish-blue area) with islands and a complex coastline. A light zone on both sides of the Supiy River, covering the villages of Pluzhniki and Mylovydov, likely represents floodplain areas with signs of waterlogging or waterlogged areas (hatching). There are also a large number of windmills on the map, reflecting the agricultural character of the landscape at that time.

The second map (Oberkommando..., 1941; only Fig. 1B) was created in 1941 and clearly illustrates the hydrological changes of the Supiy River valley: a network of drainage canals (explanation on the map = *kanal (DEU)*) is clearly visible; there are still green islands, including Tashan Park (*Wald mit Schneise*), which stand on bogs (*Sumpf*), and a system of windmills (*Windmühle*) is still present.

The more recent map (General Staff of the USSR, 1989; Fig. 1B, C) published in 1989 according to the landscape conditions of 1987 depicts the complex network of reclamation canals on both sides of the Supiy River, which completely drained the previously boggy area. The large lake shown on earlier maps was replaced by a defined river valley. However, several small man-made lakes remain in the valley, indicating the presence of underground groundwater. The windmill system is gone.

In contrast to the substantial changes near Tashan, the hydrological system upstream near Zgurivka (Fig. 1C) has less changed over time. Nevertheless, several artificial lakes are visible within

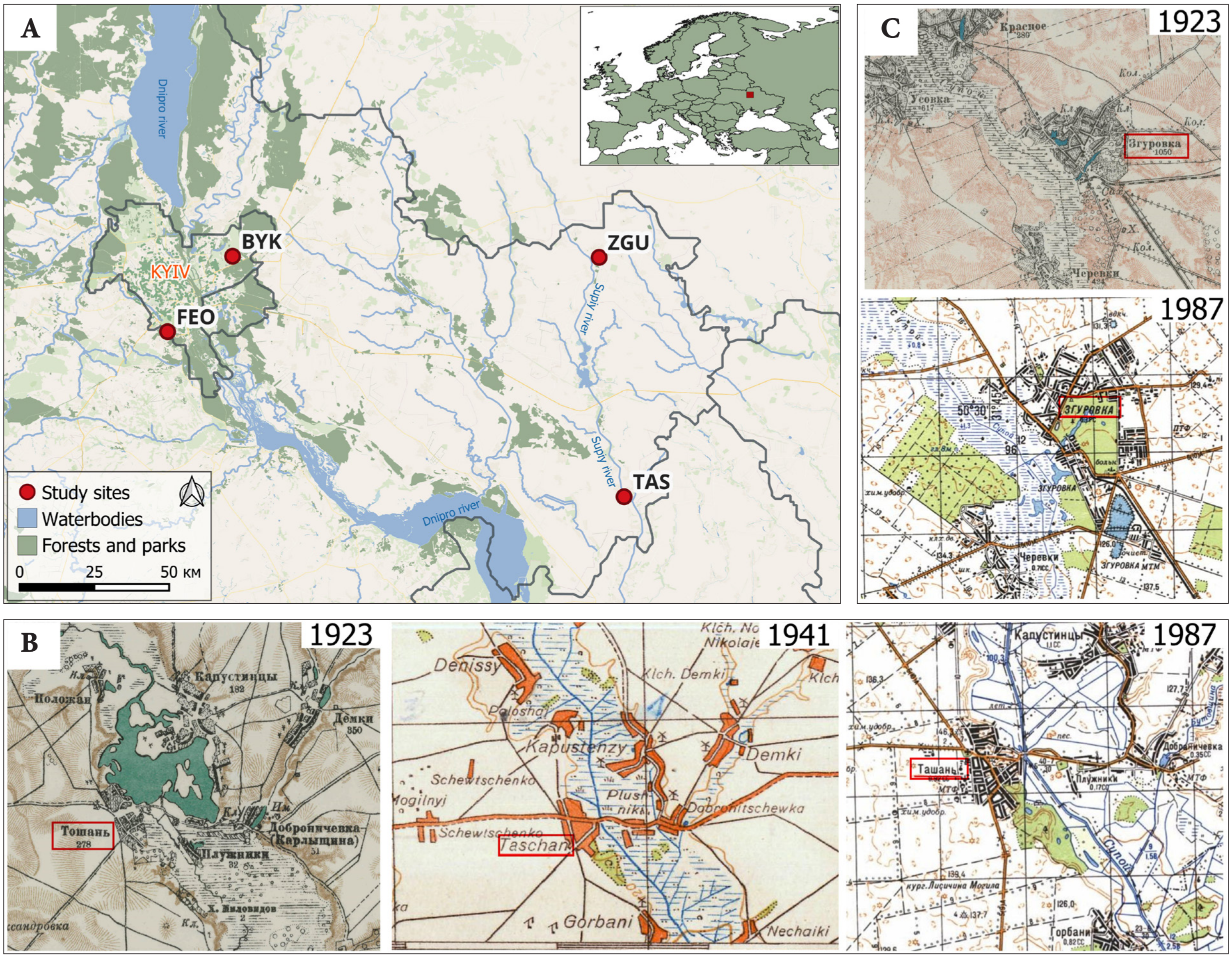

Fig. 1. Location of the study sites (A) and historical maps that describe the changes of hydrology in Park Tashan (B: VTK, 1923b at a scale of 3 verst (1 verst = 1.0668 km) to one inch; Oberkommando..., 1941 at a scale of 1:50 000; General Staff of the USSR, 1989 at a scale of 1:100 000), and Zgurivka arboretum (C: VTK, 1923a; General Staff of the USSR, 1989). See Table 1 for site codes

the Supiy River floodplain. The large pond that appeared downstream of the park is probably located near the treatment facilities (marked as "*очист*" on the map).

Climate

Hydrothermal data from the two nearest meteorological stations were used to characterise the regional climatic conditions. The Kyiv Meteorological Station is located on the right bank of the Dnipro River (50.3917°N, 30.5356°E), approximately 18 km from BYK and 7 km from FEO, at an elevation of 167 m a.s.l. In contrast, the Yahotyn Meteorological Station is located on the left bank of the Dnipro (50.2315°N, 31.7935°E), between ZGU and TAS at approximately 25 km from both sites, at an elevation of 126 m a.s.l.

The Walter–Lieth climate diagrams (Fig. 3) indicate a moderately continental climate with pronounced seasonality at both sites. Mean annual temperature is 9.3 °C in Kyiv and 8.8 °C in Yahotyn, while total annual precipitation amounts to 597 mm and 568 mm, respectively. The coldest month is January (about −3 °C in Kyiv and −4 °C in Yahotyn), whereas the warmest month is July (approximately 21–22 °C). Absolute minimum temperatures reach −5.5 °C in Kyiv and −6.4 °C in Yahotyn, and absolute maxima reach 26.6 °C and 27.0 °C, respectively.

Precipitation is relatively evenly distributed throughout the year, with a distinct maximum in

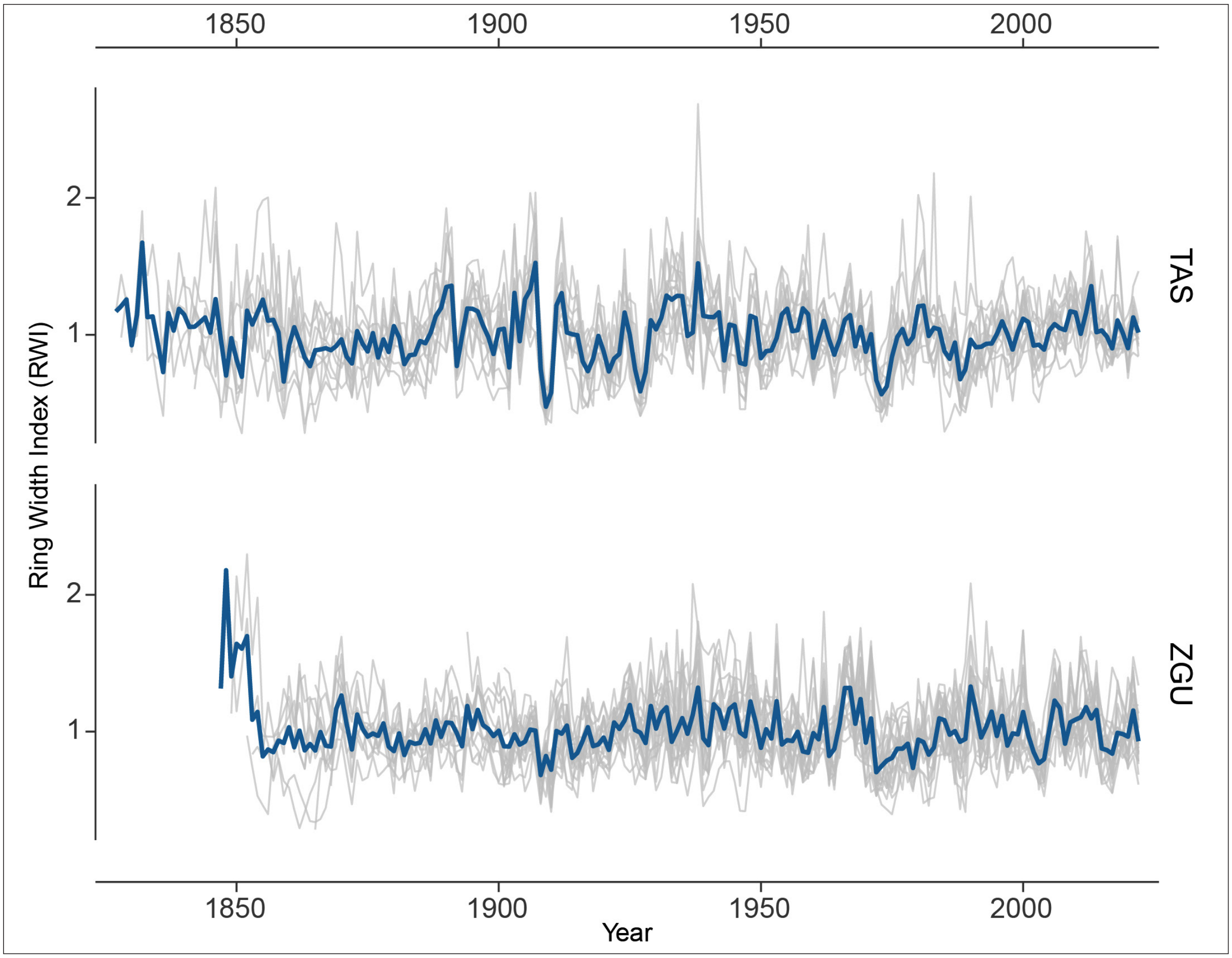

Fig. 2. *Quercus robur* RWI chronologies of ZGU and TAS sites (see Table 1 for site codes). Blue line — mean chronology; grey lines — individual tree-ring series

June–July at both stations. No pronounced summer drought period (P < 2T) is observed; however, short subarid phases occur in early spring and early autumn. Overall, the hydrothermal regime corresponds to typical forest-steppe conditions, characterized by moderate water deficits toward the end of the growing season. Compared to Kyiv, Yahotyn exhibits slightly lower winter temperatures, lower annual precipitation, and a somewhat more pronounced late-season moisture deficit, reflecting a higher degree of continentality in the Left Bank forest-steppe.

Tree-ring sampling and chronology development

At each site, dominant *Q. robur* trees were cored using standard dendrochronological procedures.

Table 1. **Study sites and tree ring-width chronologies description**

Site	Site code	Lat. N	Lon. E	Alt. m a.s.l	Chronology span	N of trees
Bykivnia	BYK	50.4926	30.6850	134	1864–2015	25
Feofania	FEO	50.3480	30.4894	180	1746–2017	51
Zgurivka	ZGU	50.4904	31.7878	147	1846–2022	20
Tashan	TAS	50.0300	31.8629	128	1827–2022	15

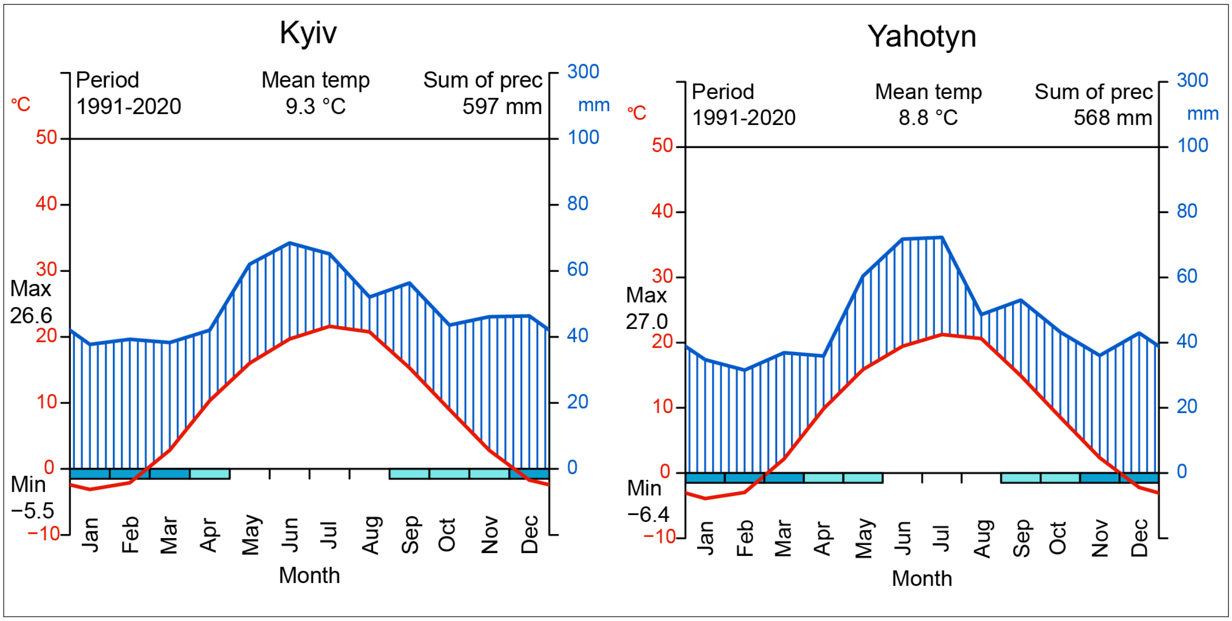

Fig. 3. The Walter-Lieth climatograms (climographs): blue line — precipitation (mm), right axis; red line — temperature (°C), left axis. The diagrams were created using the Climatol software (https://CRAN.R-project.org/package=climatol)

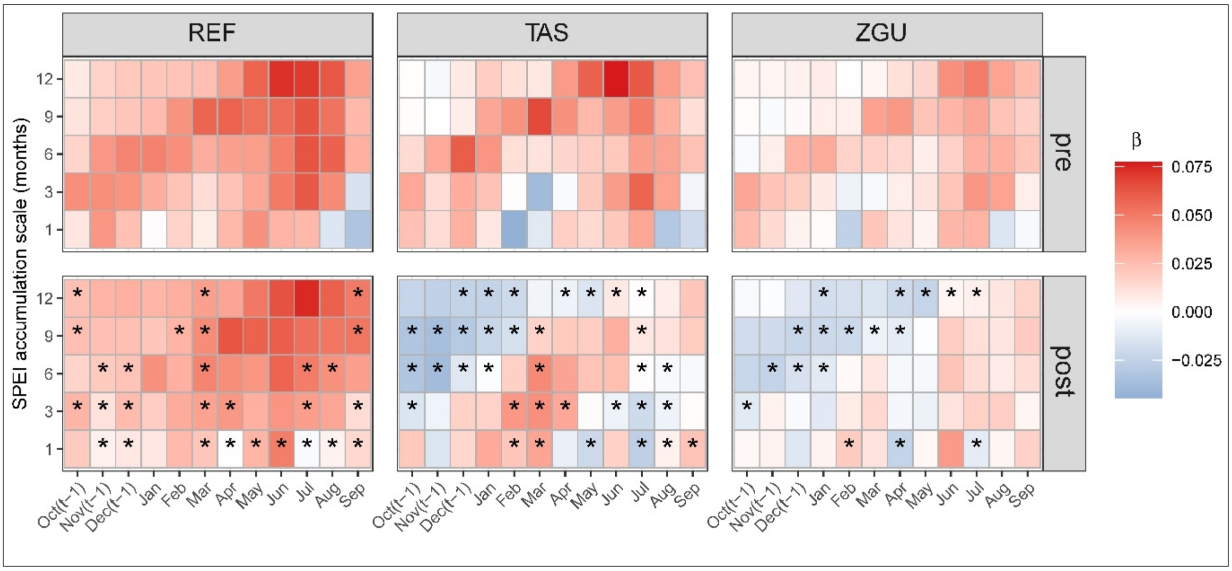

Fig. 4. Estimated *Quercus robur* growth-SPEI slopes (β) across months and SPEI accumulation scales (1, 3, 6, 9, 12). Slopes are from pre-post models relating ring-width index (RWI) to monthly SPEI aligned to the dendrochronological year (Oct(t−1)–Sep). Asterisks denote month × scale combinations with a significant pre-post change in slope (Benjamini-Hochberg adjusted $p < 0.05$ for the SPEI × period interaction, likelihood-ratio test)

Ring-width series were measured and cross-dated using standard quality-control routines (Bunn, 2010). To derive ring-width indices (RWI, Fig. 2), we detrended core-level series using an age-dependent spline (AgeDepSpline) and then averaged detrended series to tree means (dplR). Analyses were performed at tree level to preserve replication for mixed-effects modeling.

Statistical analysis

Descriptive statistics were calculated for both raw ring width (RW) and indexed chronologies (RWI) over the full length of the chronology. For RW, we calculated mean ring width (MW), standard deviation (SD), mean sensitivity (MS), and first-order autocorrelation (AR1). For RWI, we calculated the mean inter-series correlation (Rbar.tot), chronology signal strength and representativeness were evaluated using subsample signal strength (SSS), signal-to-noise ratio (SNR), and expressed population signal (EPS).

To isolate site-specific growth departures from regional background variability, we expressed growth relative to the reference chronology using a tree-level delta index:

$$\Delta i,t = RWIi,t - REFt ,$$

where i denotes an individual tree and t a calendar year. The REF chronology was built from two non-floodplain sites (BYK and FEO) as an equal-weight mean of their site chronologies (i.e., REFt = (BYKt + FEOt) / 2; years with insufficient replication were excluded).

Climatic forcing was represented by monthly SPEI at five accumulation scales (1, 3, 6, 9, 12 months; Vicente-Serrano et al., 2010). To match phenology, predictors were aligned to the growth year as Oct(t−1)–Sep(t).

We defined two confirmatory periods designed to separate pre-disturbance and post-intervention conditions while excluding the disturbance and transition interval: pre (≤ 1940; 1902–1940) and post (≥ 1962; 1962–2015). Years 1941–1961 were excluded from all models because it is corresponding to a transition period in the hydrologic regime, first with floodings after the destruction of the dam and then drainage management with construction of canals.

For each month × SPEI scale combination (12 months × 5 scales = 60 tests), we fitted pre–post models using linear mixed-effects models for TAS and ZGU, with tree as a random intercept and an AR(1)-type continuous-time autocorrelation structure for residuals within each tree:

$$\Delta \sim \text{SPEI} \times \text{period} \times \text{site} + (1 \mid \text{tree})$$

Residual temporal autocorrelation was modeled using a continuous-time AR(1) correlation structure (nlme corCAR1) within each tree (~ year | tree).

The primary inferential target was the three-way interaction SPEI:period:site, which quantifies whether the pre–post change in moisture sensitivity differs between TAS and ZGU (i.e., a difference-in-differences in SPEI slopes). Significance was assessed using a maximum-likelihood ratio test (LRT) comparing models with vs. without the three-way interaction. We controlled the false discovery rate across the 60 tests using Benjamini–Hochberg adjustment of LRT p-values.

All analyses were performed in R (v4.3.1; R Core Team, 2023).

Results

Descriptive statistics

Among the sites, mean radial growth ranged from 2.93 mm at BYK to 2.06 mm at FEO. At the focal sites, TAS and ZGU, mean growth was 2.46 mm and 2.65 mm, respectively (Table 2). Mean sensitivity (MS) averaged approximately 0.20–0.22, with the lowest value observed at ZGU (0.19). First-order autocorrelation (AR1) was high and similar across all sites, indicating a strong dependence of current growth on growth in the previous year.

Mean inter-series correlation (Rbar.tot) was about 0.36 at BYK and TAS, while the lowest value was recorded at ZGU (0.27). Both EPS and SSS exceeded the commonly accepted threshold (≥ 0.85; Wigley et al., 1984), indicating adequate sample representativeness. The signal-to-noise ratio (SNR), which strongly depends on sample size, was highest at FEO and lowest at ZGU (Table 2).

Growth–SPEI relationships

We first screened monthly growth–SPEI relationships across SPEI accumulation scales (1, 3, 6, 9, 12 months) and months (Jan–Dec, with Oct–Dec assigned to the following growth year) using pre-post models (pre ≤ 1940; post ≥ 1962; 1941–1961 excluded) and BH correction across tests. Across all month × scale combinations, the strongest and most robust pre-post changes were observed for SPEI3 in March and July, particularly at TAS; therefore, we performed further analysis on these two months (Table 3; Fig. 4).

Shifts in early-spring responses

At the regional reference (REF) level, growth remained positively related to March SPEI3 in both periods and strengthened after 1962 ($\beta = 0.0130$ to

Table 2. **Descriptive statistics of *Quercus robur* trees for the full period of chronology**

	BYK	FEO	ZGU	TAS
	RW			
MW±SD, mm	2.93±1.16	2.06±0.76	2.65±0.99	2.46±1.08
MS	0.22	0.20	0.19	0.22
AR1	0.72	0.70	0.71	0.71
	RWI			
Rbar.tot	0.36	0.31	0.27	0.36
EPS	0.95	0.97	0.90	0.91
SSS	0.94	0.90	0.95	0.96
SNR	18.7	31.7	9.50	10.7

Table 3. **Estimated slopes (β) from pre-post models linking *Quercus robur* ring-width index (RWI) to monthly SPEI3 in March and July**

padj is the Benjamini-Hochberg adjusted p-value from the likelihood-ratio test of the SPEI × period interaction (post vs pre), fitted separately for each site

Site	Month	N obs	N trees	Slope pre	Slope post	padj
REF	Mar	6595	76	0.0130	0.035	0.0001
TAS	Mar	1465	15	–0.0382	0.042	0.0000
ZGU	Mar	1969	20	–0.0035	0.014	0.1170
REF	Jul	6595	76	0.0614	0.037	0.0000
TAS	Jul	1465	15	0.0577	–0.020	0.0000
ZGU	Jul	1969	20	0.0396	0.018	0.1050

0.0353, pre-post test padj = 0.0001; Table 3). This indicates an increased benefit of higher late-winter/early-spring water balance at the regional scale.

Against that background, TAS exhibited a pronounced regime shift: in the absolute models, the March growth–SPEI3 slope flipped from negative to positive (β = –0.0382 to +0.0422, padj = 1.58×10^{-7}; Table 3). Consistently, the TAS–REF delta also reversed (Table 4), changing from Δβ = –0.0420 (pre) to +0.0165 (post). Together, the absolute and delta frameworks indicate that after 1962 TAS became more positively responsive to spring water availability, both relative to its pre-1941 behavior and relative to the regional reference signal.

In contrast, ZGU showed weak and non-robust spring changes. In the absolute models, March slopes were small and not significant after correction (β = –0.00346 to +0.0144, padj = 0.117; Table 3), and the ZGU–REF delta remained negative and tended to become more negative (Δβ = –0.00821 to –0.0180; Table 3). Importantly, the between-site contrast in the delta framework was significant (site × period interaction: padj = 0.00619), indicating that the magnitude and/or direction of the spring sensitivity change differed between TAS and ZGU under the same regional climatic forcing.

Shifts in mid-summer responses

In July, REF remained positively associated with SPEI3, but the relationship weakened after 1962 (β = 0.0614 to 0.0372, padj = 0.0001; Table 3.), suggesting a reduced regional growth benefit of wetter early-summer conditions in the post period.

In contrast, TAS reversed sign: the absolute July slope shifted from positive in the pre period to negative after 1962 (β = +0.0577 to –0.0201, padj = 5.64×10^{-7}; Table 3). This produced a strong negative shift in the TAS–REF delta slope (Δβ = +0.0227 to –0.0389; interaction test padj = 0.0418; Table 4), indicating that after 1962 higher July SPEI3 no longer corresponded to increased TAS growth relative to REF and instead coincided with reduced growth.

By comparison, ZGU weakened but did not show a clear sign reversal in July: its absolute slope declined but remained positive and was not significant after correction (β = 0.0396 to 0.0176, padj = 0.1050; Table 3), with a small delta shift (Δβ = +0.00664 to

Table 4. **Delta (Δ = site – REF) slopes for SPEI3 in March and July in pre (≤ 1940) and post (≥ 1962) periods**
Site × period padj denotes the Benjamini-Hochberg adjusted p-value for the difference in pre-post slope change between TAS and ZGU (three-way interaction in the delta model)

SPEI scale	Month	ΔTAS pre	ΔTAS post	ΔZGU pre	ΔZGU post	Site contrast padj
spei3	3	−0.042	0.0165	−0.00821	−0.018	0.00619
spei3	7	0.0227	−0.0389	0.00664	−0.00227	0.0418

−0.00227; Table 4). Overall, the post-1962 negative July response appears disproportionately expressed at TAS rather than as a regional feature, consistent with a localized wet-summer limitation, e.g., higher water table, reduced aeration, altered valley hydrology, while REF remained positively responsive.

Discussion

We detected a strong pre–post shift in moisture sensitivity at the downstream valley (first-terrace) stand (TAS): the March SPEI3 slope switched from negative to positive, while the July SPEI3 slope switched from positive to negative. In contrast, the upstream valley stand (ZGU) changed weakly, and the upland reference chronology (REF) remained consistently positive. Together, these patterns indicate a localized reorganization of environmental controls in the Supiy River valley rather than a uniform regional climate effect.

Hydroclimatic backdrop and rationale

Recent climate in the northern forest-steppe (Kyiv Region) is trending toward a warmer growing season, with comparatively low precipitation in late winter — early spring (February–April) and again in late summer and autumn (August; October–November), whereas the precipitation maximum occurs in early summer (especially June). These conditions promote a persistent seasonal water deficit in non-valley reference forests (REF), consistent with sustained positive growth–SPEI relationships, particularly from dormancy through mid-summer (Prokopuk et al., 2024; Sylenko et al., in press).

Against this regional signal, the Supiy river valley has a long history of hydrological regulation (historical map comparison; Fig. 1 B, C). A dam upstream of TAS appears to have existed at least since the early 19th century and was destroyed in late 1941, contemporaneously with the larger dam near Yahotyn, during wartime disruption (Dovhoruk, 2018). Subsequent land-reclamation works especially drainage-canal construction across the valley and wider region in the 1940s–1960s (Pshenychnyi, Semenov, 1957; Vyshnevskyi, Kutsiy, 2022; Zham et al., 2023), likely modified flood duration, groundwater levels, and seasonal soil aeration. Consistent with this, the Supiy discharge decreased markedly after the 1960s (≈ 65% in March and ≈ 38% in July; Shevchuk et al., 2020).

Pre-1941: spring wetness constraint and summer drought limitation

Before 1941, TAS exhibited a pattern consistent with excess moisture constraints in late winter–early spring and moisture limitation in mid-summer. In early spring, TAS showed a negative association with March SPEI3, whereas REF remained positively related to SPEI3. This contrast suggests that wetter late-winter/early-spring conditions at TAS were not growth-promoting and likely reflect soil saturation and reduced aeration typical of river-valley settings during high water levels, even if precipitation level in March is low. Similar spring growth reductions under wet conditions have been reported for *Q. robur* and other flood-tolerant oaks in riparian contexts (Rozas, García-González, 2012; Sample, Babst, 2020; Sample et al., 2023).

By mid-summer, TAS became positively related to July SPEI3, indicating that as seasonal water levels declined, growth became increasingly dependent on atmospheric water balance. In the delta units (TAS — REF), TAS benefited more from July moisture availability than the regional background, consistent with a transition from early-season wetness constraint to summer moisture limitation particularly pronounced under dammed conditions.

ZGU showed broadly comparable pre-1941 behavior suggesting that riparian buffering was seasonally limited and did not eliminate mid-summer constraints. Similar short buffering periods have been reported in floodplains of small and medium rivers in the forest-steppe and steppe, where flooding is brief and followed by rapid summer drawdown (Belgard, 1950; Hritsan, 2000; Netsvetov et al., 2018, 2021; Prokopuk et al., 2026).

Post-1962: emergence of spring drought limitation at TAS

After 1962, TAS shifted toward positive spring sensitivity: the March SPEI3 relationship changed from negative to positive, indicating that higher late-winter/early-spring water balance became increasingly beneficial for growth. Because REF remained positive in spring in both periods (with modest strengthening), this shift implies that TAS partially converged toward the regional drought-limited pattern rather than remaining buffered by valley hydrology. In practical terms, the seasonal rise in water level that previously imposed spring wetness constraints at TAS have weakened and shortened, becoming less effective at sustaining favorable moisture conditions into early growth.

This downstream regime shift, coupled with weaker and less consistent changes at ZGU, is consistent with low soil water saturation in spring due to (i) altered floodplain hydrology following the dam loss, mid-century drainage development, and water intake (Shevchuk et al., 2020; Vyshnevskyi, Kutsiy, 2022); and (ii) increasing evaporative demand under warming, which can intensify spring moisture limitation even without large precipitation declines (Semenova, Vicente-Serrano, 2024).

Post-1962 July reversal at TAS: evidence for wet-summer limitation

A striking post-1962 feature is the July reversal at TAS: the July SPEI3 effect switched from positive to negative. ZGU showed a similar but non-significant tendency, whereas REF remained positively related to July SPEI3 (albeit with reduced magnitude). The delta results reinforce the interpretation that the post-1962 change is not purely regional: under higher July SPEI3, TAS produced smaller ring-width indices relative to REF, consistent with a site-specific wet-summer limitation downstream.

Putative mechanisms linking hydrological change to seasonal growth shifts

Taken together, post-1962 changes at TAS are seasonally opposing: growth became more positively coupled to water balance in early spring (March) yet shifted toward a negative association with wetter mid-summer conditions (July). This combination is difficult to explain by regional climate forcing alone because REF remains consistently positive and ZGU shows weaker, non-reversing responses. A parsimonious explanation is a reorganization of valley hydrology associated with (i) abrupt dam destruction, (ii) drainage infrastructure expansion in the mid-20th century, and (iii) subsequent deterioration of drainage and local impoundment/blockage of small tributaries and ravine streams.

In the pre-1941 period, damming modified discharge and groundwater seasonal variations along the downstream valley (including TAS). During summer, reduced throughflow and altered stage–groundwater coupling may have lowered water availability on first-terrace and valley-slope positions, so that even the June–July precipitation maximum did not fully offset seasonal deficits because part of rainfall infiltrated and drained downslope via ravines toward the channel. For oak trees that had adapted to increased soil moisture and developed shallow root systems, sudden drying likely caused chronic stress and growth reduction until the trees gradually adjusted to the new hydrological conditions. In late winter — early spring, in contrast, snowmelt and ice breakup could generate high soil moisture and a shallow water table (Vyshnevskyi, Kutsyi, 2022), imposing oxygen limitation on roots and producing the negative spring association prior to 1941.

After dam loss and drainage expansion, spring discharge declined (Shevchuk et al., 2020) and, together with warming and reduced snow storage, likely reduced early-season water availability consistent with the emergence of spring drought sensitivity at TAS. Conversely, episodic wet early summers combined with degraded drainage and local impoundment (e.g., ponds/barrages in ravines) could promote temporary soil saturation and reduced aeration, plausibly explaining the negative July association downstream. The weaker response at ZGU suggests partial buffering by upstream hydro-geomorphic context, whereas the stability of REF indicates decoupling from valley-specific hydrological alterations.

Physiological interpretation: waterlogging, carbon costs, and xylem trade-offs

Excess soil water can reduce radial growth via impaired root development and nutrient uptake and by inducing hypoxia (Kozlowski, 1997; Kreuzwieser et al., 2004). Flood-tolerant oaks, including *Q. robur*, can form adaptive structures (e.g., lenticels and adventitious roots) that improve oxygen supply, but these responses increase carbon costs and may reduce the resources available for wood formation (Kreuzwieser et al., 2002; Parelle et al., 2006; Bourgeade et al., 2018). Oxygen limitation also shifts metabolism from aerobic respiration toward fermentation, potentially depleting non-structural carbohydrate reserves and limiting earlywood formation (Parent et al., 2008). In addition, wetter early-season conditions can favor larger earlywood vessels in ring-porous species, increasing hydraulic efficiency but potentially raising vulnerability to cavitation under subsequent summer drought (Gričar et al., 2013; Tyree, 1997; Tumajer, Treml, 2016). Thus, the observed transition from spring wetness constraints (pre-1941) to spring drought limitation and potential wet-summer constraints (post-1962) may reflect a shifting balance among soil aeration, carbon allocation, and hydraulic strategy across seasons.

More broadly, these results suggest that river-valley oak stands are not universally buffered against warming-related moisture stress: when regulation and drainage alter groundwater seasonality, valley forests may converge toward regional drought limitation in spring while simultaneously experiencing episodic wet-summer constraints where drainage is inefficient. This pattern is consistent with observations from oak forests near the dry margin of the species range, where increasing evaporative demand amplifies drought limitation (Stojanović et al., 2015; Mikac et al., 2018; Nechita, Camarero, 2025; Prokopuk et al., 2026).

Conclusion

This study illustrates how sequential hydrological interventions, such as river regulation by dams, abrupt dam loss, drainage-canal construction, and subsequent degradation of drainage and channel systems, can generate non-intuitive and seasonally contrasting growth responses in river-valley oak stands. The unexpected direction of some changes likely reflects the combined effects of (i) rapid disturbance (dam demolition), (ii) mid-term engineering (canalization/drainage development), and (iii) long-term landscape processes (drainage deterioration, ravine-stream impoundment/clogging, and valley-slope land use), all acting under ongoing climatic warming. Even a relatively waterlogging-tolerant species such as *Quercus robur* can therefore be exposed to multiple within-season stressors when regulation is followed by partial deregulation and drainage reconfiguration. Overall, these tree-ring-based results provide empirical guidance for anticipating how riverine forests on small-to-medium rivers may respond to hydrological modifications, whether implemented as planned management/restoration or occurring as abrupt hydrological shocks.

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ETHICS DECLARATION

The authors declare no conflict of interest.

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Наслідки підриву дамби 1941 року у долині річки Супій, Україна: зміни чутливості радіального приросту *Quercus robur* (*Fagaceae*) до посухи та зволоження

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Реферат. У роботі оцінено зміну чутливості радіального приросту *Quercus robur* до водного балансу за індексом стандартизованих опадів та евапотранспірації (SPEI) у деревостанах долини річки Супій у зв'язку з підривом греблі у 1941 році та подальшим будівництвом мережі осушувальних каналів у заплаві. Досліджено два деревостани в межах долини: нижче за течією від місця дамби — Ташанський парк (TAS) та вище за течією — Згурівський дендропарк (ZGU). За регіональний контроль (REF) використано дві позадолинні ділянки: Биківнянський ліс (BYK) і парк Феофанія (FEO). Період аналізу поділено на два інтервали: до гідрологічних змін (1910–1940) та після завершення основних осушувальних робіт (1962–2015); роки 1941–1961 виключено з аналізу. За результатами статистичного моделювання виявлено виражену зміну чутливості *Q. robur* до зволоження в долині Супою: у TAS від'ємний зв'язок приросту з SPEI3 у березні змінився на додатний у період після 1961 року, тоді як додатний до 1941 року зв'язок із SPEI3 у липні змінився на від'ємний. Натомість у ZGU зміни чутливості були слабкими, а контрольний REF демонстрував стабільно позитивну реакцію на SPEI протягом усього періоду досліджень. Отримані результати вказують на локалізовану зміну гідрокліматичних чинників, що контролюють приріст дерев у межах річкової долини, насамперед нижче греблі. Складна взаємодія чинників — гідрологічні зміни, водокористування та загачення малих водотоків на тлі кліматичних змін — ускладнює прогнозування наслідків руйнування греблі та осушувальних робіт без емпіричних даних із подібних умов.

Ключові слова: дуб звичайний, деревні кільця, кліматична чутливість, прибережно-долинні ліси, статистичне моделювання, SPEI