

Online Resource 1: Supplementary information

Seasonal water stress in a hyperhumid forest: evidence from multiple tree-ring variables and dekadal climate analysis

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Trees – Structure and Function

Contents and analytical scope

This Supplement supports the seasonal hydroclimatic analysis (H1), temporal relationships (H2), and regional growth coherence (H3), with the corresponding component-model diagnostics and full candidate sets. The long-record analyses use 1902–2004; the modern seasonal TRW models use 1951–2004; and the fixed dekadal component models use 1950–2004. Tables S11 and S12 summarize inverse soil-water verification and the modern seasonal coefficient contrasts, respectively. Table S14 summarizes all archived ERA5-Land–JMA meteorological comparisons over 1981–2004. The main-text hypothesis numbers follow the ecological sequence: seasonal water conditions, temporal variation, and regional context. The Methods overview in the main text maps H1 to seasonal screening and fixed component models, H2 to temporal analyses, and H3 to external chronology comparisons. The CRU coordinate comparison is reported in Table S15.

Regional chronology correlations evaluate shared growth variability. Local climate coefficients and their temporal diagnostics derive from the single Yanase stand and the represented 18-tree archive. Trees are within-stand subsamples, and the five metrics are paired measurements; neither constitutes replication

among forest sites. Monthly screening, dekadal localization, and model comparison reuse the observed record, so the subsequent intervals and validation scores remain conditional on candidate selection.

Abbreviations and notation

Named measured and derived variables are set in upright lowercase roman type so that a symbol such as *rwi* is read as one quantity rather than as the product *rwi*. Established acronyms remain uppercase. Unless stated otherwise, a superscript * denotes z-standardization over the 1950–2004 model interval.

Symbol or abbreviation	Definition
Indices and conventions	
i	Tree-level series index.
m	Annual-ring metric; the metric labels are EWW, TRW, LWW, MRD, and MXD.
t	Ring year to which the chronology response and aligned climate window are assigned.
d	Dekad (10-day interval) within a month.
j	Day within a dekad.
k	Predictor index within a fixed local climate-growth model.
q	Fixed large-scale context-series index.
h	Standardization or detrending-method index.
$b, b(t)$	Withheld contiguous CV block and the block containing ring year t .
w, n_w	Moving-window index and number of moving windows.
n_b	Number of leave-one-decade-out or blocked-CV omissions, as specified.
n_{obs}	Number of observations contributing to a prediction-error summary.
p prefix	Previous calendar year relative to ring year t ; for example, pJul13 is the third dekad of July in year $t - 1$.
Superscript *	Z-standardized value over the stated model interval, normally 1950–2004.
Hat $\hat{}$	Fitted, estimated, or predicted quantity.
Overbar $\bar{}$	Arithmetic mean; $\bar{r}$ is separately defined as mean interseries correlation.
Annual-ring measurements and chronology quantities	
EWW	Earlywood width.
TRW	Total ring width.
LWW	Latewood width.
MRD	Mean ring density across the complete annual ring.
MXD	Maximum density within the annual ring.
$\text{rw}_{i,m,t}$	Raw measured width for tree i , width metric m , and ring year t .
$\widehat{\text{rw}}_{i,m,t}^{\text{trend}}$	Fitted age-dependent width trend used for ratio standardization.
$\text{rwi}_{i,m,t}$	Ratio-standardized tree-level width index; for $m = \text{TRW}$, the conventional ring-width index.
$\text{den}_{i,m,t}$	Raw annual density value for tree i and density metric m .
$\widehat{\text{den}}_{i,m,t}^{\text{trend},(h)}$	Fitted density trend under sensitivity method h .
$\text{denres}_{i,m,t}^{(h)}$	Additive density residual under sensitivity method h .
$\text{denz}_{i,m,t}$	Within-tree standardized density value; superscript (h) identifies a sensitivity method.
$\text{series}_{i,m,t}$	Standardized tree-level value supplied to the robust chronology mean: <i>rwi</i> for width metrics or <i>denz</i> for density metrics.
$\text{chron}_{m,t}$	Metric-specific Tukey-biweight chronology. For width metrics this is a width-index chronology; for density metrics it is a chronology of within-tree standardized density.
$\text{rwi}_{m,t}$	Tukey-biweight width-index chronology used as the EWW, TRW, or LWW response before model-period z-standardization.

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Symbol or abbreviation	Definition (continued)
$\text{mrd}_t, \text{mx}_d_t$	MRD and MXD chronologies before model-period z-standardization.
$\text{med}_{m,t}, \text{mad}_{m,t}$	Annual median and median absolute deviation used in the Tukey biweight.
$u_{i,m,t}, \kappa$	Tukey-biweight standardized residual and tuning constant; $\kappa = 9$.
$\bar{r}_{m,w}$	Mean interseries correlation for metric m in moving window w .
$n_{m,w}$	Number of trees represented for metric m in moving window w .
SSS	Subsample signal strength, used here as a descriptive annual replication diagnostic.
Climate variables, datasets, and temporal alignment	
$\text{clim}_{t,d,j}$	Daily value of a generic local meteorological variable on day j of dekad d , aligned to ring year t .
$\overline{\text{clim}}_{t,d}, \text{clim}_{t,d}^\Sigma$	Dekadal mean and dekad accumulation.
$\text{clim}_{k,t}$	Fixed local meteorological predictor k aligned to ring year t .
temp	Air temperature.
prec	Precipitation.
evap	ERA5-Land total actual evaporation, converted to positive upward water loss.
vpd / VPD	Vapor-pressure deficit.
swvl1, swvl2 / SWVL1, SWVL2	ERA5-Land volumetric soil-water content in soil layers 1 and 2.
PET	Potential evapotranspiration.
$P - \text{ET}$	Precipitation minus evapotranspiration or potential evapotranspiration, as specified for the relevant analysis.
SST	Sea-surface temperature.
$C_{q,t}$	Generic fixed large-scale ocean–atmosphere context series q .
$L_{q,t}$	Fixed local meteorological-window series paired with context series q .
JMA	Japan Meteorological Agency.
JST	Japan Standard Time.
ERA5-Land	Land component of the fifth-generation ECMWF reanalysis used for gridded meteorological and land-surface variables.
COBE-SST2	COBE-SST2 gridded sea-surface-temperature dataset.
CRU TS	Climatic Research Unit Time-Series dataset.
scPDSI	Self-calibrating Palmer Drought Severity Index.
Large-scale climate modes and indices	
ENSO	El Niño–Southern Oscillation.
PDO	Pacific Decadal Oscillation.
MEI.ext	Extended Multivariate ENSO Index.
NPI	North Pacific Index.
AO	Arctic Oscillation.
EASMI	East Asian summer monsoon index.
Statistical methods, model parameters, and diagnostics	
OLS	Ordinary least squares.
GLS-AR(1)	Generalized least squares with first-order autoregressive residuals.
AR(1)	First-order autoregressive process.
AICc	Small-sample corrected Akaike information criterion.
CV	Cross-validation.
$\text{RMSE}_{\text{CV},m}$	Root-mean-square prediction error from blocked CV for metric m .
VIF	Variance inflation factor.
FDR	False-discovery rate.
BH	Benjamini–Hochberg multiplicity adjustment.
CI	Confidence interval.
n_{eff}	Effective sample size after adjustment for lag-1 persistence.
R_{adj}^2	Adjusted coefficient of determination.
P_{eff}	P -value calculated using the effective sample size.
q	BH-adjusted FDR value within the stated comparison family.

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Symbol or abbreviation	Definition (continued)
ΔAICc , ΔR_{adj}^2	Change after adding a context term; the sign convention is stated in the relevant table or figure.
$\alpha_{1,q}$	Context-to-local-window coefficient for context series q .
$\delta_{1,m,q}$	Supplementary context-to-chronology coefficient for metric m and context series q .
$\beta_{k,m}$	Standardized coefficient for local predictor k in metric m .
$\gamma_{m,q}$	Incremental context coefficient added to the fixed local model.
ϕ_m	First-order autoregressive coefficient for residuals of metric m .
ε , η , ξ	Model residual or innovation terms, with subscripts identifying the relevant metric, predictor, or context series.
ℓ	Maximized log-likelihood.
K_m	Number of fixed local predictors in the model for metric m .
k_{par}	Number of estimated parameters in the AICc calculation.
post_t	Indicator equal to 1 for 1978–2004 and 0 for 1950–1977.
τ_t	Centred continuous time.
$\rho_{1,\text{clim}}$, $\rho_{1,\text{chron},m}$	Lag-1 autocorrelations of the climate series and metric chronology.
$r_{\text{clim},m}$	Pearson correlation between a local climate series and metric chronology m .
$r_{C,L}$, $r_{C,\text{chron}}$	Full-period context–local-window and context–chronology correlations.
s_k^{LODO}	Leave-one-decade-out directional-retention fraction for candidate k .
$s_{k,m}^{\text{sign}}$	Fraction of moving windows in which predictor k retains the sign of its full-period coefficient for metric m .
$s_q^{(R)}$	Sign-retention fraction for context series q and relation type R (context–local or context–chronology).
$\mathbb{I}[\cdot]$	Indicator function equal to 1 when the stated condition is true and 0 otherwise.
Common-signal and validation quantities	
$\bar{r}_{m,\text{model}}$	Mean of the 153 distinct tree-pair correlations for metric m over the complete 1950–2004 model interval.
$\widehat{\text{EPS}}_{m,\text{model}}$	Descriptive EPS estimate calculated from $N = 18$ and $\bar{r}_{m,\text{model}}$; not used as a retention threshold.
n_{tree}	Number of tree-level series in the paired multimetric dataset; $n_{\text{tree}} = 18$.
n_{year}	Number of annual observations in the fixed climate model; 54 or 55 according to the complete-case rule and model (Supplementary Table S13).
LOTO	Leave-one-tree-out omission used here to assess sensitivity of fixed climate–growth coefficients to tree membership.
LOFO	Leave-one-fold-out temporal-sensitivity analysis.
t_{BP}	Baillie–Pilcher crossdating t value.
t_{Ho}	Hollstein crossdating t value.
GLK	Gleichläufigkeit.
SGC	Synchronous growth change.
SSGC	Semi-synchronous growth change.
$R_{\text{CV,null},m}^2$	Baseline-relative blocked-CV skill for metric m , comparing held-out squared error of the selected and fold-specific null models.

1 Regional chronology coherence and signal transferability

Optical chronology 39yn000_trw2021 supplied the crossdating reference for the X-ray series. The multimetric analyses use X-ray TRW chronology 39yn000_trw2026. Their comparison assesses measurement reproducibility for the same 18 trees.

The three external series are published Japanese cedar chronologies from the Pacific side of Japan but represent contrasting archives. The Yoshino regional chronology was developed from 60 provenance-screened, market-derived specimens representing a centuries-long plantation system shaped by dense establishment, repeated thinning, and long rotations (Yonenobu et al. 2026). The southern Tohoku series were developed specifically as reference chronologies from old planted cedar avenues in Miyagi Prefecture: MGNS at the Sendai Castle Ninomaru avenue and its surroundings, and MGDO at Daioji in Minamisanriku (Ohyama et al. 2021). All four regional series were represented by harmonized 16-year age-dependent-spline chronologies and compared over 1902–2004 at chronology level and after first differencing. Block-bootstrap intervals used 10-year blocks and 5000 replicates. The Yanase member of these regional comparisons was the current X-ray chronology. The primary optical–X-ray reproducibility comparison covered 1768–2004; its reported correlations should not be read as estimates for the 1950–2004 domain.

Yanase and Yoshino were coherent at chronology level ($r = 0.570$, block-bootstrap 95% interval 0.370–0.732) and after first differencing ($r = 0.646$, 0.486–0.764). MGDO showed correlations of $r = 0.233$ (0.035–0.414) and $r = 0.411$ (0.208–0.565), and MGNS showed $r = 0.092$ (–0.153–0.371) and $r = 0.377$ (0.208–0.518), respectively. The contrast between stronger Yoshino coherence at both scales and predominantly interannual coherence with southern Tohoku supports a Pacific-side annual growth component while preserving regional differences in low-frequency variability. It does not establish spatial transferability of the Yanase climate coefficients.

Inverse OLS models predicted previous-July layer-2 ERA5-Land soil water from either EWW or TRW as a single predictor. The climate target remained in its original units, while each predictor was standardized using the calibration mean and standard deviation. The level comparison used 1951–2004: early-period calibration (1951–1977) was verified against 1978–2004, followed by the reverse fit. Blocked CV withheld six contiguous nine-year intervals (1951–1959, 1960–1968, 1969–1977, 1978–1986, 1987–1995, and 1996–2004), with predictor scaling repeated inside each training fold.

Verification correlation compared predictions with the observed target. Reduction of error (RE) was one minus prediction squared error divided by the sum of squared observed departures from the calibration-period target mean. Coefficient of efficiency (CE) used the verification-period mean in the denominator instead. For blocked scores, errors and denominators were summed across all withheld years using the corresponding fold means. Positive RE or CE indicates improvement over its reference mean.

The inverse-model assessment compared four width standardizations: the primary 16-year age-dependent spline, a 32-year age-dependent spline, the Friedman supersmoother, and a fixed 32-year spline. A “strong” classification required positive RE and CE in both period splits and in blocked CV. A “conditional” classification required positive RE in both splits and blocked CV, positive CE in at least one split, and CE above –0.25 in the other. Both classes required $VIF \leq 5$, coefficient-sign agreement with

the full-period fit in both split calibrations, and at least 0.80 agreement across CV fits. The standardization criterion required a non-failing primary fit, at least three non-failing standardizations, and median pairwise correlation of blocked predictions ≥ 0.70 . The combined target criterion required the same proxy to meet this assessment for both soil-water targets and to have positive primary full-period coefficients. These categories describe the recorded inverse model comparison, separately from the forward-model evidence classes.

Inverse tests compared EWW and TRW as predictors of previous-July ERA5-Land layer-2 soil water across two fixed calibration directions (Table S11). For the third-dekad target, earlywood retained positive coefficient of efficiency (CE) in both directions, while total width failed the late-to-early comparison. The weaker earlywood CE was 0.024. Blocked-CV CE was 0.084 for EWW and 0.085 for TRW, limiting the earlywood advantage to the two period splits. July-mean skill was weaker. Only EWW met the combined two-target and standardization criteria; the targets are related aggregations of the same modeled variable. Modest verification skill and failure of the broader July–April $P - PET$ target to transfer at level motivated their use as signal diagnostics rather than historical reconstructions.

2 Measurement provenance and X-ray densitometry

All five metrics were derived from the same 18 cross-cut Yanase stem discs used in the published raw ring-width chronology (Yonenobu et al. 2021). The discs were collected in fiscal year 2006 from the Yanase 2032 i41 compartment within the multi-institutional project documented by Shikoku Regional Forest Office (2008). The optically measured reference chronology 39yn000.trw2021 was used to crossdate the X-ray-profile series and establish the final calendar-year assignments across all five metrics. The multimetric TRW chronology is 39yn000.trw2026; together with EWW, LWW, MRD, and MXD, it was derived from X-ray densitometry profiles measured by K. Yasue.

Radial samples were boiled in distilled water for approximately 5 days and then extracted for approximately 5 days in a Soxhlet apparatus using a 2:1 toluene–ethanol mixture. The samples were mounted, cut parallel to the stem axis to approximately 1.6 mm thickness with a twin-blade saw, and conditioned for approximately 7 days at 20 °C and 60% relative humidity (equilibrium moisture content approximately 12%). Soft X-ray radiographs were obtained together with a standard absorber using a Softex EMBW custom-model system and Fuji IX-FR industrial X-ray film. The films were digitized with an EPSON GTX-970 scanner at 2400 dpi, and the profiles were analyzed with WinDENDRO2009 (Hirano et al. 2020). The earlywood–latewood boundary was set at 0.55 g cm⁻³. Calendar-dated radial profiles were aggregated to tree-level series before chronology construction.

3 Chronology construction and sensitivity

For tree i , ring year t , width metric $m \in \{\text{EWW}, \text{TRW}, \text{LWW}\}$, and detrending method h , the ratio index was

$$\text{rwi}_{i,m,t}^{(h)} = \frac{\text{rw}_{i,m,t}}{\widehat{\text{rw}}_{i,m,t}^{\text{trend},(h)}}. \quad (\text{S1})$$

The primary method used a 16-year age-dependent spline. Sensitivity methods used a 32-year age-dependent spline, fixed 16- and 32-year splines, and a Friedman supersmoother.

For density metric $m \in \{\text{MRD}, \text{MXD}\}$, additive residuals and their tree-wise standardization under method h were

$$\text{denres}_{i,m,t}^{(h)} = \text{den}_{i,m,t} - \widehat{\text{den}}_{i,m,t}^{\text{trend},(h)}, \quad (\text{S2})$$

$$\text{denz}_{i,m,t}^{(h)} = \frac{\text{denres}_{i,m,t}^{(h)} - \overline{\text{denres}}_{i,m}^{(h)}}{s_{\text{denres},i,m}^{(h)}}. \quad (\text{S3})$$

The primary density chronologies instead used within-tree z scores of the complete individual series, with the residual step omitted. This avoids treating a ratio around an age curve as the natural scale for density and preserves positive and negative departures symmetrically. None of the primary methods was chosen by maximizing a climate coefficient.

For a 51-year moving window w containing $n_{m,w}$ trees for metric m , mean interseries correlation was

$$\bar{r}_{m,w} = \frac{2}{n_{m,w}(n_{m,w} - 1)} \sum_{i < j} r_{ij,m,w}. \quad (\text{S4})$$

Annual subsample signal strength (SSS) was calculated with `dp1R::sss()` from the 18 tree-level standardized curves for each metric, without an `ids` mask. The calculation used the metric-specific effective mean interseries correlation, annual sample depth, and a reference count of 18 curves. The commonly used value 0.85 is retained only as a conventional descriptive reference and was not used to retain or exclude a chronology. Primary and sensitivity standardization settings are summarized in Table S1; chronology coherence and annual replication are reported in Table S2 and Figs. S1–S3.

4 Climate screening and dekadal localization

A dekad comprises days 1–10, 11–20, or 21 through the final day of a month. Monthly screening located broad seasonal domains, within which dekadal localization constrained the finer temporal search. JMA–ERA5–Land common-period response agreement was evaluated at monthly resolution; it did not independently validate the exact dekadal windows.

Temperature, VPD, relative humidity, and soil water were averaged within each dekad; precipitation, evaporation, and radiation were accumulated. Previous-year windows were assigned to the following ring year. Promotion considered sign retention when decades were omitted, monthly agreement between JMA

and ERA5-Land where comparable, and sensitivity to chronology standardization. Windows were fixed for subsequent model comparison.

The screening window extended from previous June through current October. Let clim_t denote a candidate local climate series and $\text{chron}_{m,t}$ the corresponding metric chronology. Their Pearson correlation was

$$r_{\text{clim},m} = \frac{\sum_t (\text{clim}_t - \overline{\text{clim}}) (\text{chron}_{m,t} - \overline{\text{chron}_m})}{\left[\sum_t (\text{clim}_t - \overline{\text{clim}})^2 \sum_t (\text{chron}_{m,t} - \overline{\text{chron}_m})^2 \right]^{1/2}}. \quad (\text{S5})$$

The autocorrelation-adjusted effective sample size was

$$n_{\text{eff}} = n \frac{1 - \rho_{1,\text{clim}} \rho_{1,\text{chron},m}}{1 + \rho_{1,\text{clim}} \rho_{1,\text{chron},m}}, \quad (\text{S6})$$

where $\rho_{1,\text{clim}}$ and $\rho_{1,\text{chron},m}$ are the lag-1 autocorrelations of the two series. ERA5-Land is described by Muñoz-Sabater et al. (2021). BH-adjusted q values were reported for the screening correlations. Promotion also considered reproducibility and directional criteria; it did not require every peak to satisfy a fixed FDR threshold. For example, the EWW previous-July layer-2 soil-water peak had $r = 0.385$, $q = 0.380$, while previous-July mean and afternoon VPD peaks had $r = -0.324$ and -0.333 and $q = 0.421$ for both. All three retained their signs in all six leave-one-decade-out fits. These diagnostics characterize the selected candidate evidence without accounting for its full selection uncertainty. Monthly process domains were localized to 10-day periods for 1950–2004.

For candidate k , leave-one-decade-out directional retention was

$$s_k^{\text{LODO}} = \frac{1}{n_b} \sum_{b=1}^{n_b} \mathbb{I}[\text{sign}(r_{k,-b}) = \text{sign}(r_{k,\text{full}})]. \quad (\text{S7})$$

Candidates also had to retain monthly common-period agreement between JMA and ERA5-Land where both represented the same process domain. Thirty-six candidates entered the fixed model stage, and no new climate window was selected thereafter. Thus, the Supplement retains the full response surface and candidate ledger, while the main text reports only the fixed models that emerged from this predetermined sequence (Figs. S4–S7).

5 Model comparison and validation

For candidate comparison, responses and predictors were standardized on common complete years within each metric: 1951–2004 for EWW, TRW, LWW, and MRD, and 1950–2004 for MXD. The complete-year filter included all candidate predictors for the metric, even when a given model used fewer terms. Table S13 distinguishes this analysis frame from that of the temporal diagnostics. For a local climate

series clim_t and metric chronology $\text{chron}_{m,t}$,

$$\text{clim}_t^* = \frac{\text{clim}_t - \overline{\text{clim}}}{s_{\text{clim}}}, \quad \text{chron}_{m,t}^* = \frac{\text{chron}_{m,t} - \overline{\text{chron}_m}}{s_{\text{chron},m}}. \quad (\text{S8})$$

Model comparison used

$$\text{AICc} = -2\ell + 2k_{\text{par}} + \frac{2k_{\text{par}}(k_{\text{par}} + 1)}{n - k_{\text{par}} - 1}, \quad (\text{S9})$$

and predictor collinearity was summarized by

$$\text{VIF}_k = \frac{1}{1 - R_{k|-k}^2}, \quad (\text{S10})$$

where $R_{k|-k}^2$ is obtained by regressing predictor k on the remaining predictors in the same model.

Six temporal blocks were withheld in turn: 1950–1959, 1960–1969, 1970–1979, 1980–1989, 1990–1999, and 2000–2004. Prediction error was

$$\text{RMSE}_{\text{CV},m} = \left[\frac{1}{n_{\text{obs}}} \sum_{t=1}^{n_{\text{obs}}} \left(\text{chron}_{m,t}^* - \widehat{\text{chron}_{m,t,-b(t)}}^* \right)^2 \right]^{1/2}. \quad (\text{S11})$$

Within each fold, scaling was estimated from training years and applied to held-out years. Coefficient signs were also assessed across training folds. CV error contributed to model ranking alongside AICc, VIF, and sign consistency. The full screening and selection procedure was not repeated within an independent outer validation loop; reported scores therefore measure internal performance conditional on the candidate set. Contiguous folds keep neighboring years together and reveal dependence on particular historical intervals.

Effect size, uncertainty, estimator agreement, multiplicity-aware screening, CV behavior, and temporal stability jointly determined the evidence classes. Following Wasserstein and Lazar (2016), P -values were interpreted with these diagnostics. Definitions and model comparisons are reported in Tables S3–S4 and Fig. S8.

6 Temporal stability

6.1 Modern TRW seasonal models: 1951–2004

The modern TRW comparison summarized in the main Results used the ADS16 chronology and the ERA5-Land 3×3 mean. The common baseline contained previous-June precipitation and mean temperature from previous November through current March. Three alternative models each added one summer predictor: previous-July–August radiation, previous-July–September 14:00 JST VPD, or previous-July–September layer-2 soil water. These are separate baseline-plus-one models, not a joint regression containing all three summer variables. They also differ from the dekadal models for the five ring metrics.

For each model, TRW and predictors were standardized over its complete 1951–2004 context. GLS-AR(1), fitted by maximum likelihood, included the predictor main effects, a late-period indicator, and each predictor’s interaction with that indicator. The indicator was zero for 1951–1977 and one for 1978–2004. An interaction coefficient estimates the late-minus-early slope difference directly. The late-period slope is the sum of the early slope and its interaction. Nominal 95% intervals were computed from the fitted coefficient covariance matrix and a residual-degrees-of-freedom t quantile. They are conditional model intervals, without a simultaneous multiple-comparison or model-selection adjustment.

For comparison with the stated directional expectations, slopes and differences were multiplied by +1 for temperature and soil water and by -1 for radiation and VPD; interval endpoints were reordered when their signs were reversed. These oriented coefficients are statistical slopes, not fractions of biological limitation. Table S12 reports the focal term from each model, including both uncertain and clearer contrasts.

Sensitivity analyses considered alternative late-period starts in 1974, 1976, 1978, 1980, and 1982, with at least 20 years on either side; single-year and five-year-block omissions; changes in predictor covariance; and a continuous focal-predictor interaction with time centred on 1978 in decade units. These diagnostics support assessment of boundary and influence sensitivity; no transition year was optimized. For the longer 1902–2004 analysis, the structural-diagnostics output contained no breakpoint estimates. Its overlapping 51-year moving correlations are therefore reported as descriptive temporal comparisons.

6.2 Fixed component models: 1950–2004

For 31-year window $w = [a_w, b_w]$, the fixed model for metric m was

$$\text{chron}_{m,t}^* = \beta_{0,m,w} + \sum_{k=1}^{K_m} \beta_{k,m,w} \text{clim}_{k,t}^* + \varepsilon_{m,t,w}, \quad t \in [a_w, b_w]. \quad (\text{S12})$$

Temporal diagnostics instead retained years complete for each individual model and used fixed scaling from each variable’s available 1950–2004 reference record. The selected width models used 54 years and the selected density models used 55. This scaling was retained among windows, which should not be confused with the candidate-comparison scaling (Table S13). Early–late and continuous-time interactions were

$$\text{chron}_{m,t}^* = \beta_{0,m} + \sum_{k=1}^{K_m} \beta_{k,m} \text{clim}_{k,t}^* + \gamma_m \text{post}_t + \sum_{k=1}^{K_m} \delta_{k,m} \text{clim}_{k,t}^* \text{post}_t + \varepsilon_{m,t}. \quad (\text{S13})$$

$$\text{chron}_{m,t}^* = \beta_{0,m} + \sum_{k=1}^{K_m} \beta_{k,m} \text{clim}_{k,t}^* + \lambda_m \tau_t + \sum_{k=1}^{K_m} \theta_{k,m} \text{clim}_{k,t}^* \tau_t + \varepsilon_{m,t}. \quad (\text{S14})$$

Here $\text{post}_t = 1$ for 1978–2004 and zero otherwise, and $\tau_t = (t - 1977)/10$. Every predictor and every predictor interaction entered together within a model. The seasonal TRW analysis described above has

its own model specification; its time centering is distinct from this component-model diagnostic. Rolling sign retention was

$$s_{k,m}^{\text{sign}} = \frac{1}{n_w} \sum_{w=1}^{n_w} \mathbb{I} \left[\text{sign}(\hat{\beta}_{k,m,w}) = \text{sign}(\hat{\beta}_{k,m,\text{full}}) \right]. \quad (\text{S15})$$

The classification combined OLS–GLS–AR(1) agreement, rolling-window sign retention, split-period interactions, and continuous predictor-by-time interactions. A large full-period coefficient could therefore be classified as unstable, whereas a smaller effect could remain supported if its direction was estimator- and time-consistent (Fig. S9).

7 Ocean–atmosphere context and fixed pathway analysis

7.1 Long-period regional climate context

The regional context analysis used 1902–2004, which provides a common century-scale record for the three COBE-SST2 regions and most climate indices. Three SST domains were fixed before analysis: south of Japan and the Kuroshio region, the Kuroshio Extension–western North Pacific, and the tropical western Pacific. Climate indices comprised PDO, MEI.ext, NPI, AO, and EASMI. Previous-summer series were aligned with the following ring year; winter–early-spring series combined December of the previous year with January–March of the ring year.

The long-period layer was designed to answer a meteorological question: which large-scale modes covary with local temperature, PET, approximate VPD, water balance, and drought state? It was not designed to select tree-ring predictors. Full-period correlations used the AR(1)-adjusted effective sample size in Eq. S6; 31-, 41-, and 51-year moving windows described temporal coherence; and lower- and upper-tercile composites compared local climate under opposing large-scale phases.

7.2 Component-resolved extension for 1950–2004

The component analysis relates large-scale series to the five ring metrics with the local climate windows held fixed. For context series q , $C_{q,t}$ was first related to its fixed local meteorological-window series $L_{q,t}$,

$$L_{q,t}^* = \alpha_{0,q} + \alpha_{1,q} C_{q,t}^* + \eta_{q,t}. \quad (\text{S16})$$

The direct chronology relation was retained as a supplementary diagnostic,

$$\text{chron}_{m,t}^* = \delta_{0,m,q} + \delta_{1,m,q} C_{q,t}^* + \xi_{m,q,t}, \quad (\text{S17})$$

227 and one context term was added to the already selected local model,

$$\text{chron}_{m,t}^* = \beta_{0,m} + \sum_{k=1}^{K_m} \beta_{k,m} \text{clim}_{k,t}^* + \gamma_{m,q} C_{q,t}^* + \varepsilon_{m,t}. \quad (\text{S18})$$

228 Baseline and context-added models used the same complete years. Incremental information was summarized
 229 by the improvement in AICc, the change in adjusted R^2 , the context coefficient and 95% confidence
 230 interval under OLS and GLS-AR(1), and estimator sign agreement.

231 The context seasons were fixed from the local pathway: previous July–September for antecedent-summer
 232 soil water, December–March for late-winter temperature, previous October for the previous-autumn LWW
 233 term, April for spring LWW and MRD, and May for MXD. EASMI was considered only for previous
 234 summer, whereas AO was considered for winter and spring pathways. This restriction avoids an exhaustive
 235 month-by-index search.

236 For relation type R (context–local or context–chronology), 31-year sign retention was

$$s_q^{(R)} = \frac{1}{n_w} \sum_{w=1}^{n_w} \mathbb{I} \left[\text{sign}(r_{q,w}^{(R)}) = \text{sign}(r_{q,\text{full}}^{(R)}) \right]. \quad (\text{S19})$$

237 A pathway is eligible for main-text interpretation only if the context–local link is supported and stable
 238 and the chronology evidence is coherent under estimator and temporal diagnostics. A direct chronology
 239 association without the local link remains exploratory.

240 7.3 Interpretive roles

241 The ocean–atmosphere results are assigned one of four roles. “Coherent pathway supported” indicates
 242 stable context–local information plus coherent direct or incremental chronology information. “Regional
 243 context for local window” indicates that the large-scale series helps explain the meteorological window
 244 but adds no independent growth claim. “Direct or incremental without local pathway” is exploratory
 245 because the proposed meteorological bridge is absent. “Weak or unstable context” receives no substantive
 246 interpretation. These categories describe the strength and role of the statistical evidence.

247 All 55 pathway–context pairs were fitted. Only the tropical western Pacific SST–April precipitation–
 248 MRD pathway was classified as a possible main-text candidate. Its context–local and context–chronology
 249 correlations were negative and retained their signs in 88% and 100% of the 31-year windows, respectively.
 250 The context-added OLS model improved AICc and adjusted R^2 , but the incremental GLS-AR(1) coefficient
 251 was weaker and the two full-period correlations did not pass the descriptive false-discovery threshold.
 252 The pathway is consequently reported as coherent regional context for the April water-input response
 253 of MRD, not as a direct SST control on density. All remaining pairs were assigned to local-window
 254 context, exploratory direct/incremental association without a local bridge, or weak/unstable context. The

Table S1 Primary and sensitivity standardization methods applied to the five Yanase chronologies. Width series were standardized multiplicatively because ring-width measurements are positive and age-related growth trends are represented as expected growth curves. Density series were standardized additively because departures from a tree-specific mean density are the target signal. Primary methods were used in the main-text analyses; the remaining methods quantify detrending sensitivity.

Metric group	Method	Role	Principal setting
Width	Age-dependent spline ratio	Primary	16 years, $f = 0.5$
Width	Age-dependent spline ratio	Sensitivity	32 years, $f = 0.5$
Width	Fixed spline ratio	Sensitivity	16 or 32 years, $f = 0.5$
Width	Friedman supersmoother ratio	Sensitivity	bass = 0
Density	Within-series z score	Primary	Tree mean and SD
Density	Age-dependent or fixed spline residual z score	Sensitivity	32 years, $f = 0.5$
Density	Linear age residual z score	Sensitivity	Linear age term

The seven display rows represent all nine implemented methods: fixed 16- and 32-year splines are grouped in one row, as are the fixed- and age-dependent 32-year density-residual methods. All 23 metric–method implementations completed with finite output for every observed tree-year.

Table S2 Annual replication and subsample signal strength (SSS) for the five primary chronologies over 1713–2005. SSS was calculated with a reference count of 18 tree-level curves and the effective mean interseries correlation ($\bar{r}_{\text{eff}}$). The commonly used value 0.85 is retained only as a descriptive reference; it is not a calibrated inferential threshold or a criterion for retaining or excluding a metric. Exact common-signal statistics for the shared 1950–2004 model interval are reported in Table 1 of the main text.

Metric	Ref. trees	Annual depth range	$\bar{r}_{\text{eff}}$	Minimum SSS	First year SSS ≥ 0.85	Fraction of years SSS ≥ 0.85
EWV	18	1–18	0.283	0.323	1780	0.771
TRW	18	1–18	0.269	0.310	1780	0.771
LWW	18	1–18	0.219	0.262	1783	0.761
MRD	18	1–18	0.373	0.408	1772	0.799
MXD	18	1–18	0.193	0.238	1784	0.758

SSS values below 0.85 remain visible and are reported without smoothing or truncation. The table and Fig. S3 provide long-term replication context; they are not climate-model selection rules.

Table S3 Evidence hierarchy for the climate windows retained after monthly screening, dekadal localization, fixed-model fitting, and temporal-stability evaluation. Dekadal r is the localized 10-day correlation; OLS and GLS-AR(1) columns are full-period standardized coefficients. Adjusted R^2 is model-level and repeats for predictors in the same model. Core effects enter the main conclusions; shared-signal, secondary, and limitation roles identify redundant, weaker, or non-robust evidence.

Metric	Predictor window	Dekadal r	OLS β	GLS-AR(1) β	Adj. R^2	Predictor class	Role
EWV	Previous July dekadal 3 SWVL2	0.385	0.344	0.343	0.168	Stable	Core
TRW	Previous July dekadal 3 SWVL2	0.389	0.346	0.354	0.180	Stable	Shared signal
EWV	Current February dekadal 3 temperature	0.289	0.230	0.167	0.168	Weak/indeterminate	Secondary
LWW	Previous October dekadal 3 evaporation	0.361	0.288	0.235	0.202	Stable	Core
LWW	Current April dekadal 1 evaporation	0.391	0.327	0.254	0.202	Stable	Core
MRD	Current April dekadal 1 precipitation	0.287	0.305	0.182	0.076	Stable	Secondary
MXD	Current May dekadal 1 VPD	-0.402	-0.402	0.066	0.146	Sign-unstable	Limitation

The TRW late-winter temperature effect is retained in the complete results but omitted here because it closely tracks the corresponding EWV term. The two width metrics share the same trees and much of the same growth variation; agreement between them is not independent confirmation.

fixed design and representative results are summarized in Tables S5–S7; full-period, moving-window, and pathway-level displays are given in Figs. S10–S13.

Table S4 Model-level explanatory skill, blocked predictive performance, collinearity, and temporal classification for the fixed 1950–2004 selected-model set. CV RMSE was calculated by withholding each temporal block in turn. Maximum VIF refers to predictors within a model. A complete model may be weak or indeterminate even when one constituent predictor is stable.

Metric	Model	Predictors	Adj. R^2	CV RMSE	Max. VIF	Model class
EWW	Soil water plus winter temperature	2	0.168	0.983	1.03	Weak / indeterminate
TRW	Soil water plus winter temperature	2	0.180	1.000	1.03	Weak / indeterminate
LWW	Previous autumn plus spring	2	0.202	1.022	1.05	Stable
MRD	April precipitation	1	0.076	1.103	1.00	Stable, modest
MXD	May VPD	1	0.146	1.120	1.00	Sign unstable

The term “Stable, modest” for MRD preserves the frozen stable temporal class while emphasizing its limited adjusted R^2 and blocked predictive performance. It denotes the frozen diagnostic class, not exclusion of zero by every interval: the 55-year temporal reference MRD GLS-AR(1) interval is -0.001 – 0.339 . Explanatory and CV statistics use candidate-comparison years; temporal classification uses model-specific years and fixed reference scaling (Table S13).

Table S5 Fixed ocean–atmosphere pathways used in the fixed Step 16k context analysis. Each row begins with a local meteorological window already present in the selected or supporting climate–growth model. Large-scale context variables were restricted by season and process relevance; they were not allowed to replace the local predictor.

Ring metric	Fixed local window	Context season	Pairs	Fixed large-scale sources
EWW, TRW	Previous July dekad 3 soil water layer 2	Previous July–September	14	Three SST regions; PDO; MEI; NPI; EASMI
EWW, TRW	Current February dekad 3 temperature	December– March	14	South-of-Japan/Kuroshio SST; Kuroshio Extension SST; Tropical western Pacific SST; PDO; MEI; NPI; AO
LWW	Previous October dekad 3 evaporation	Previous October	6	South-of-Japan/Kuroshio SST; Kuroshio Extension SST; Tropical western Pacific SST; PDO; MEI; NPI
LWW	Current April dekad 1 evaporation	Current April	7	South-of-Japan/Kuroshio SST; Kuroshio Extension SST; Tropical western Pacific SST; PDO; MEI; NPI; AO
MRD	Current April dekad 1 precipitation	Current April	7	South-of-Japan/Kuroshio SST; Kuroshio Extension SST; Tropical western Pacific SST; PDO; MEI; NPI; AO
MXD	Current May dekad 1 VPD	Current May	7	Three SST regions; PDO; MEI; NPI; AO

The three SST regions are South-of-Japan/Kuroshio, Kuroshio Extension, and Tropical western Pacific.

The six grouped design rows expand to 55 fixed pathway–context pairs because EWW and TRW are evaluated separately and the permitted index set differs by season.

8 Analysis-period common signal and validation of fixed climate–growth estimates

The five annual-ring metrics were derived from the same 18 biological trees. This section keeps four evidence domains separate: internal common-signal strength over the shared 1950–2004 model interval, reproducibility across measurement systems and regions, sensitivity of fixed climate coefficients to tree membership, and predictive skill across temporal blocks. None of these analyses multiplies the number of independent annual climate observations.

8.1 Analysis-period common signal

Table 1 of the main text reports the exact 1950–2004 mean interseries correlation and descriptive EPS for each primary metric, based on all 153 tree-pair correlations and complete annual depth of 18. Table S2

Table S6 Representative full-period associations from the 1902–2004 regional climate-context analysis. These statistics characterize the large-scale setting of local temperature, atmospheric demand, and moisture balance; they are not direct tree-growth models. P_{eff} uses the AR(1)-adjusted effective sample size, and q is the Benjamini–Hochberg value within each fixed local-target comparison family.

Local target	Large-scale context	n	r	P_{eff}	q
Previous November-current March temperature	South of Japan / Kuroshio SST	103	0.673	< 0.0001	< 0.0001
Previous November-current March temperature	Kuroshio Extension SST	103	0.636	< 0.0001	< 0.0001
Previous November-current March temperature	Extended MEI	103	0.356	0.0003	0.0007
Previous November-current March temperature	Arctic Oscillation	54	0.358	0.0145	0.0253
Previous July-September approximate VPD	South of Japan / Kuroshio SST	103	0.577	< 0.0001	< 0.0001
Previous July-September approximate VPD	Tropical western Pacific SST	103	0.529	< 0.0001	< 0.0001
Previous July-August PET	Tropical western Pacific SST	103	0.318	0.0045	0.0225
Previous July-September scPDSI	Tropical western Pacific SST	103	-0.317	0.0086	0.0491
Previous July-September precipitation minus PET	East Asian summer monsoon index	103	0.243	0.0135	0.0943

Table S7 Representative results from the completed Step 16k component-resolved context analysis. $r_{C,L}$ and $r_{C,\text{chron}}$ are the full-period context–local-window and context–chronology correlations; $s_{C,L}$ and $s_{C,\text{chron}}$ are 31-year sign-retention fractions. Positive ΔAICc values indicate improvement of the OLS model after adding one context term. Only the tropical western Pacific SST–April precipitation–MRD pathway met the fixed rule for main-text consideration, and it is interpreted as coherent regional context rather than direct SST control of density.

Ring pathway	Large-scale context	Context role	$r_{C,L}$	$s_{C,L}$	$r_{C,\text{chron}}$	$s_{C,\text{chron}}$	$\Delta\text{AICc}_{\text{OLS}}$	$\Delta\text{adj. } R^2$	Classification
April precipitation to MRD	Tropical western Pacific SST	Secondary	-0.293	0.88	-0.477	1.00	8.87	0.158	Coherent pathway
Late-winter temperature to EWW	South of Japan / Kuroshio SST	Secondary	0.295	1.00	0.102	0.96	-2.20	-0.013	Local-window context
Previous-October evaporation to LWW	Pacific Decadal Oscillation	Core context	-0.364	1.00	-0.237	1.00	-1.89	-0.008	Local-window context
April evaporation to LWW	North Pacific Index	Core context	0.295	1.00	0.176	1.00	-2.39	-0.015	Local-window context
April precipitation to MRD	North Pacific Index	Secondary	0.303	1.00	0.163	0.88	-1.95	-0.011	Local-window context

and Fig. S3 retain the longer-term annual depth and SSS context. The conventional value 0.85 is displayed for transparency but is not an inferential threshold or a model-selection rule.

8.2 Measurement-system and regional chronology comparison

The optical and X-ray-profile TRW data came from the same stem discs but were measured independently. Harmonized age-dependent-spline chronologies were compared in levels and first differences, with circular moving-block intervals. Raw arithmetic mean curves were compared only at the fixed calendar alignment; no lag was searched or selected. Baillie–Pilcher and Hollstein t values are reported as conventional crossdating diagnostics, not as probabilities from a Student t distribution. Gleichläufigkeit is accompanied by synchronous and semi-synchronous growth changes. Fixed external comparisons were limited to the published MGNS, MGDO, and Yoshino sugi chronologies. These comparisons describe regional common variation and do not test the Yanase-specific climate coefficients.

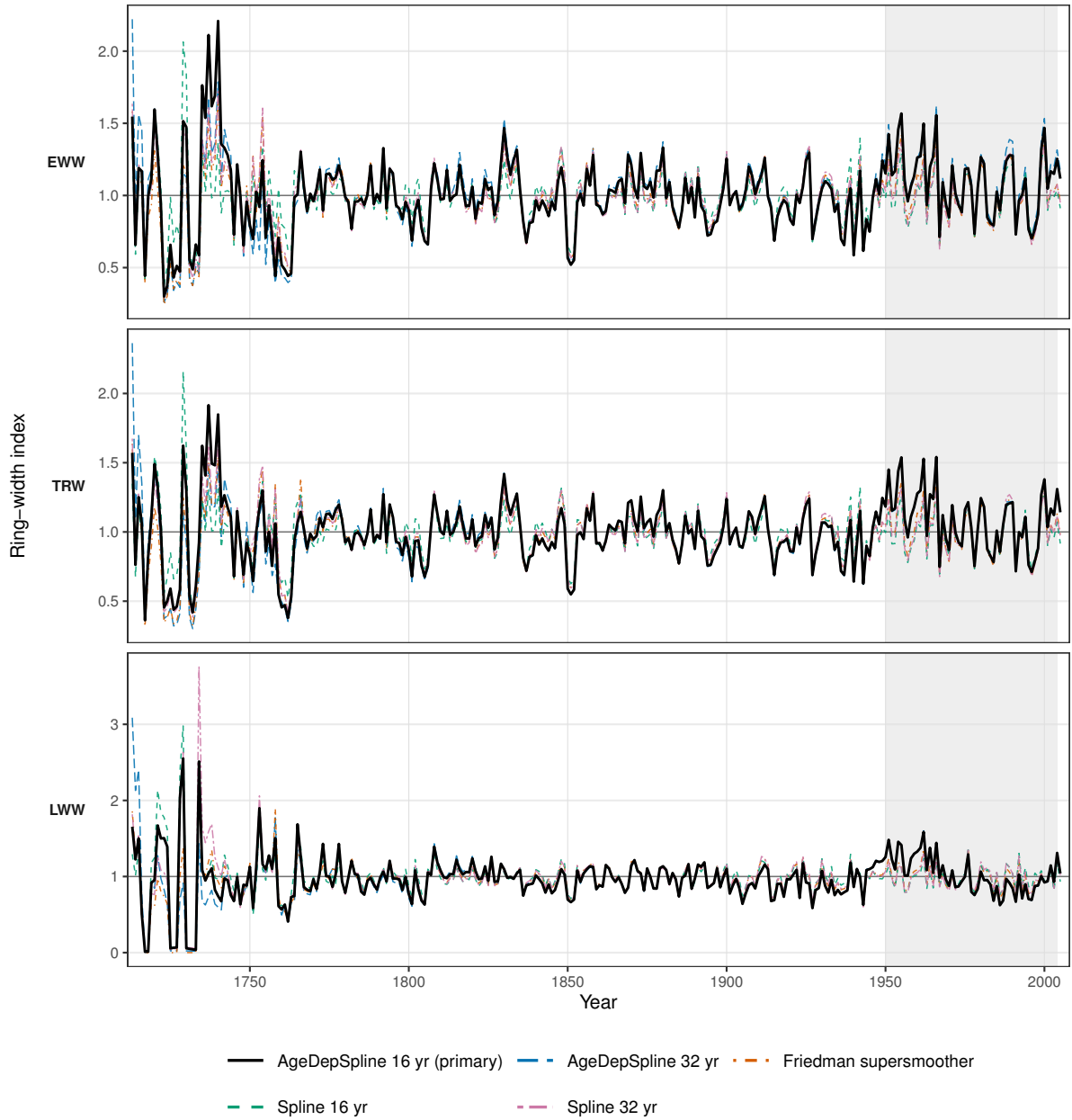


Fig. S1 Sensitivity of EWW, TRW, and LWW chronologies to five width-standardization methods. The primary chronologies use a 16-year age-dependent spline ratio; alternative age-dependent and fixed splines and the Friedman supersmoother quantify detrending sensitivity. The shaded interval is the fixed 1950–2004 climate-model period

8.3 Sensitivity of fixed climate coefficients to tree membership

Each primary chronology was rebuilt after omitting one tree, and the fixed 1950–2004 models were refitted by OLS and GLS-AR(1) without repeating predictor selection. Separately, 18 tree IDs were sampled with replacement 2000 times. The same draw was applied to all five metrics in each realization, preserving the paired multimetric structure. The resulting percentile intervals describe sensitivity of the fixed coefficients to membership in the observed tree pool. They do not include uncertainty in the 55-year climate sequence, climate-window selection, or the wider stand population.

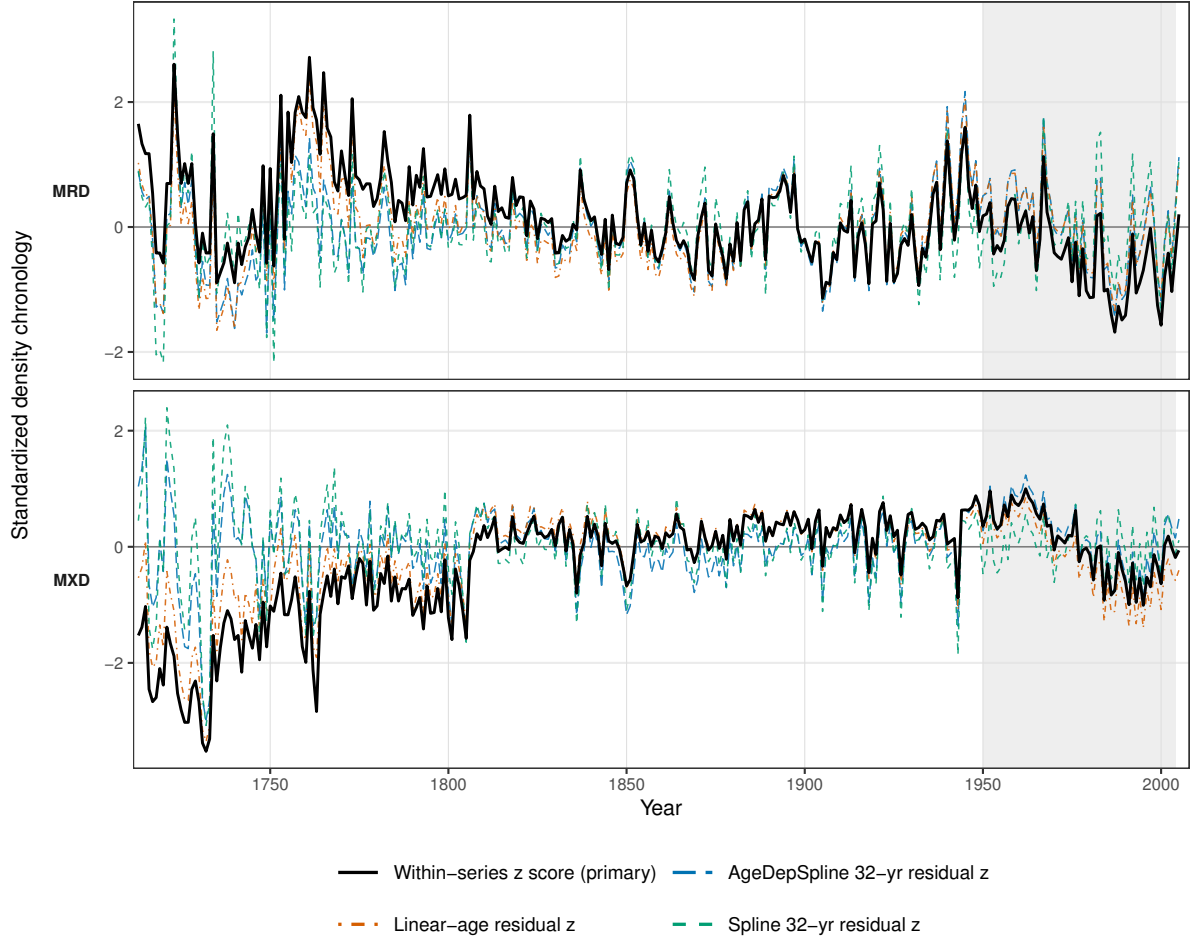


Fig. S2 Sensitivity of MRD and MXD chronologies to four density-standardization methods. The primary chronology is the within-series z score; spline-residual and linear-age-residual z scores provide sensitivity estimates. The shaded interval is the fixed 1950–2004 climate-model period

8.4 Blocked-CV skill relative to a null model

For metric m , the baseline-relative score was

$$R_{CV, null, m}^2 = 1 - \frac{\sum_t \left(\text{chron}_{m,t}^* - \widehat{\text{chron}}_{m,t}^{*, \text{selected}} \right)^2}{\sum_t \left(\text{chron}_{m,t}^* - \widehat{\text{chron}}_{m,t}^{*, \text{null}} \right)^2}. \quad (\text{S20})$$

The selected and null predictions used the same held-out years and training folds. Positive values indicate lower held-out squared error for the selected model. Fold-specific scores and scores recomputed after omitting one fold are temporal-sensitivity diagnostics, not confidence intervals.

9 Meteorological agreement and spatial support

The archived ERA5-Land-JMA evaluation covered January 1981 through December 2004. Eleven primary comparisons used the Yanase precipitation record and temperature, precipitation, and sunshine records

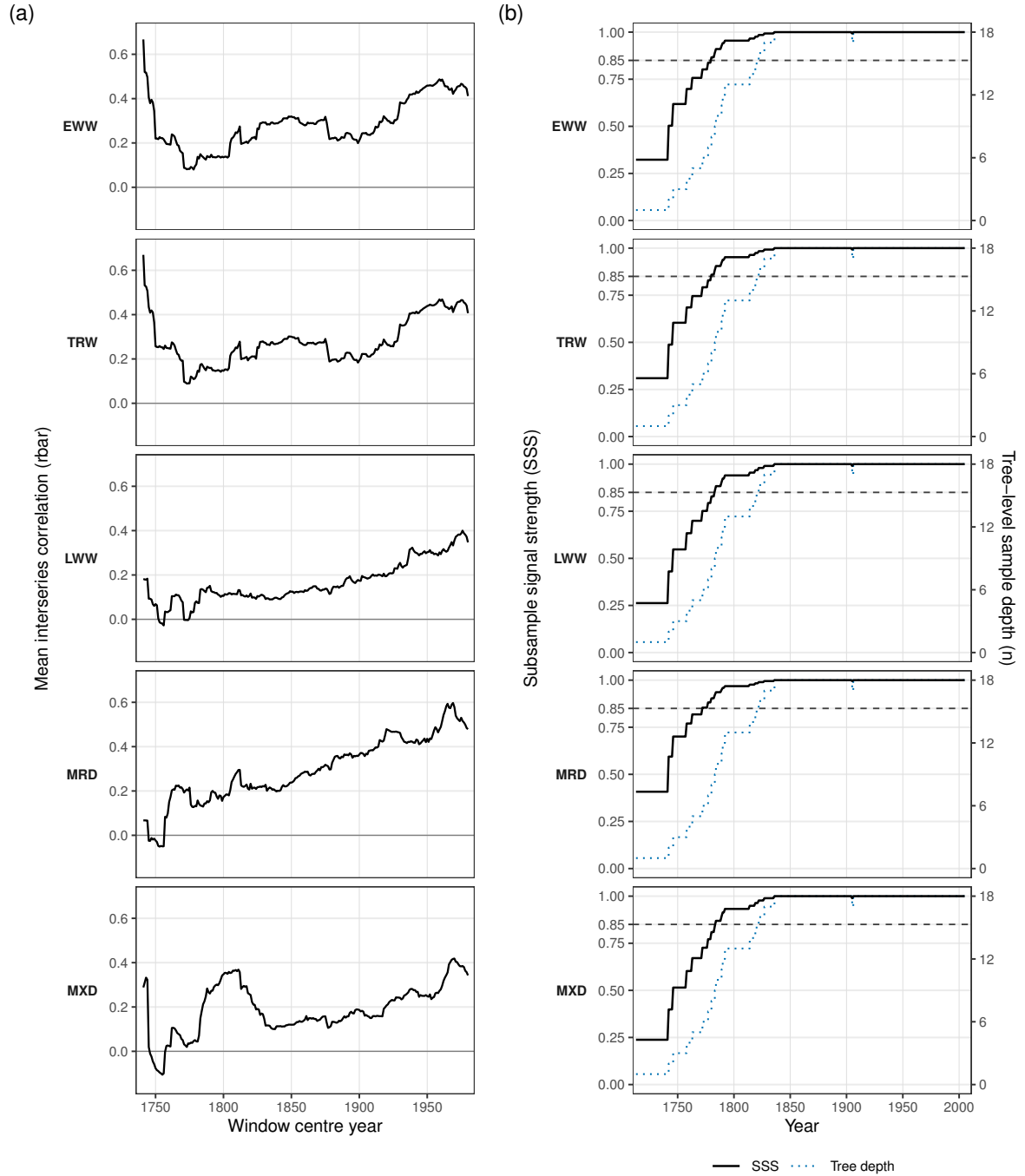


Fig. S3 Chronology coherence and annual replication diagnostics for the five primary metrics. (a) Fifty-one-year moving-window mean interseries correlation. (b) Annual subsample signal strength (SSS; black) and tree-level sample depth (blue dotted line; right axis, with the left-axis display scaled to the 18-tree reference count). The horizontal SSS = 0.85 line is retained only as a conventional descriptive reference and was not used to include or exclude a chronology

from Kito and Odochi. Five further pairs used Muroto as a coastal reference. Table S14 reports all 16 pairs for the 3×3 ERA5-Land mean, including the weaker comparisons. Nearest-point extraction was also evaluated. The primary-pair mean and median anomaly correlations rounded to 0.841 and 0.900 for either method; spatial averaging was not demonstrably superior by these summaries.

For each climate series, the mean for each calendar month over the comparison period was subtracted before calculating anomaly correlations. Radiation and sunshine-duration anomalies were additionally standardized within calendar month because they have different units. Bias is the mean ERA5-Land minus JMA difference in the unadjusted monthly values, and is reported only for physically commensurate variables. The paired sample size is 288 months, except for the three Muroto humidity-related comparisons with 287 complete pairs. These meteorological comparisons are distinct from the monthly Muroto-ERA5-Land climate-growth response checks used during candidate evaluation. Neither supplies an independent measurement of the selected soil-water or evaporation predictors.

The ERA5-Land neighborhood comprises grid-point coordinates 33.6, 33.7, and 33.8°N crossed with 134.0, 134.1, and 134.2°E. Its central point is the nearest available point to the stand position (33.6674°N, 134.1341°E). The revised CRU TS v4.09 and scPDSI extractions use that same stand coordinate. Bilinear interpolation uses grid-point longitudes 133.75 and 134.25°E and latitudes 33.25 and 33.75°N. The southwest, southeast, northwest, and northeast geometric weights are 0.03829336, 0.12690664, 0.19350664, and 0.64129336, respectively. PET and scPDSI are missing at the southwest point throughout 1901–2004; their interpolation renormalizes the weights over the other three finite points. At least three finite points were required for the primary interpolation. The nearest point is 33.75°N, 134.25°E. The single CRU cell outlined in the map is a geographic reference; the interpolation domain is defined by the four points specified here.

10 Sensitivity to the CRU extraction coordinate

An earlier extraction used 33.666667°N, 134.000000°E, approximately 12.4 km west of the stand. We first reproduced the archived climate series and dependent analyses at that coordinate. The corrected extraction then used the same source versions, period, unit conversions, and statistical procedures. Both bilinear and nearest-point estimates were recomputed, along with derived climate variables, seasonal and moving-window growth associations, varying-coefficient fits, rolling verification, and regional-context analyses. The optical TRW chronology and all analysis windows were held fixed, isolating the effect of the extraction coordinate.

Table S15 compares all six primary seasonal growth correlations and the monthly climate series. Anomaly correlations between the old and corrected bilinear series were 0.997–0.999 across the nine reported variables. All six primary seasonal growth correlations retained their signs; their largest absolute change was 0.018. The corrected previous-June precipitation correlation increased from 0.114 in 1902–1952 to 0.367 in 1954–2004 within the 51-year moving-window analysis.

Regional-context coefficients changed by at most 0.018 in absolute r . The previous-summer PET-EASMI comparison crossed the descriptive $q = 0.10$ threshold (0.086 to 0.110). Two scPDSI context comparisons crossed $q = 0.05$: tropical western Pacific SST (0.051 to 0.049) and EASMI (0.074 to 0.049).

331 Table S6 and Figs. S10–S11 use the corrected extraction. These threshold changes concern the regional
332 meteorological context; the ERA5-Land component-model inputs and coefficients are unaffected by the
333 CRU coordinate correction.

Table S8 Measurement-system and regional chronology validation. Harmonized correlations use the primary 16-year age-dependent-spline chronologies. t_{BP} , t_{Ho} , and GLK are traditional diagnostics from raw arithmetic mean curves at the fixed calendar alignment.

Comparator	Period	Overlap	r_{level}	r_{Δ}	t_{BP}	t_{Ho}	GLK (%)
Yanase optical TRW	1768–2004	237	0.974	0.969	48.64	49.32	93.0
Yanase optical TRW	1950–2004	55	0.989	0.987	61.53	60.48	100.0
Yoshino	1902–2004	103	0.570	0.646	9.17	8.95	65.7
Yoshino	1950–2004	55	0.704	0.709	7.33	7.49	66.7
MGDO	1902–2004	103	0.233	0.411	4.17	4.81	63.7
MGDO	1950–2004	55	0.342	0.496	3.02	3.83	63.0
MGNS	1902–2004	103	0.092	0.377	3.51	3.81	57.8
MGNS	1950–2004	55	0.082	0.362	1.71	2.09	55.6

The optical and X-ray series represent independent measurement systems applied to the same 18 trees and are not independent biological replicates. External comparisons describe regional common signal and do not validate the Yanase-specific climate coefficients.

Table S9 Sensitivity of fixed climate coefficients to tree membership in the common 18-tree dataset. LOTO gives the fraction of 18 single-tree-omission coefficients retaining the full-sample sign. Bootstrap intervals are percentile intervals from 2000 paired tree-resampling realizations.

Effect	LOTO sign OLS/GLS	Bootstrap sign OLS/GLS	OLS 95% interval	GLS-AR(1) 95% interval	Class
EWV: pJul SWVL2	1.000/1.000	1.000/1.000	[0.262, 0.401]	[0.282, 0.385]	Membership-robust
EWV: Feb temp	1.000/1.000	1.000/1.000	[0.132, 0.291]	[0.083, 0.228]	Membership-robust
TRW: pJul SWVL2	1.000/1.000	1.000/1.000	[0.252, 0.400]	[0.279, 0.391]	Membership-robust
TRW: Feb temp	1.000/1.000	1.000/1.000	[0.163, 0.306]	[0.113, 0.243]	Membership-robust
LWW: pOct evap	1.000/1.000	1.000/1.000	[0.199, 0.370]	[0.150, 0.315]	Membership-robust
LWW: Apr evap	1.000/1.000	1.000/1.000	[0.248, 0.374]	[0.172, 0.323]	Membership-robust
MRD: Apr precip	1.000/1.000	1.000/1.000	[0.218, 0.364]	[0.105, 0.242]	Membership-robust
MXD: May VPD	1.000/1.000	1.000/0.902	[-0.447, -0.319]	[-0.037, 0.146]	Estimator-dependent

The same tree-ID draw was used for all five metrics in each realization. Intervals quantify sensitivity of fixed coefficients to membership in the observed tree pool and do not include temporal, climate-window-selection, or reanalysis uncertainty.

Table S10 Blocked predictive skill relative to the fold-specific intercept-only model. Positive $R^2_{CV,null}$ denotes lower held-out squared error for the selected model. The LOFO range is obtained after omitting one temporal fold at a time and is a sensitivity range, not a confidence interval.

Metric	Selected model	Selected RMSE	Null RMSE	$R^2_{CV,null}$	Positive folds	LOFO range	Tree-composition class
EWV	EWV soil water plus winter temperature	0.983	1.057	0.134	4/6	[0.072, 0.166]	Composition-robust
TRW	TRW soil water plus winter temperature	1.000	1.077	0.138	4/6	[0.082, 0.170]	Composition-robust
LWW	LWW previous autumn plus spring	1.022	1.160	0.224	5/6	[0.146, 0.318]	Composition-robust
MRD	MRD April precipitation	1.103	1.146	0.074	4/6	[0.032, 0.105]	Composition-robust
MXD	MXD May VPD	1.120	1.245	0.191	4/6	[0.174, 0.211]	Estimator-dependent

Table S11 Cross-period tests of previous-July ERA5-Land layer-2 soil-water signal transferability. These tests compare retention of earlywood and total-width information across fixed periods; they were not used to produce a historical reconstruction. E→L and L→E denote early-period calibration with late-period verification and the reverse, respectively. The early and late periods are 1951–1977 and 1978–2004. RE is reduction of error; CE is coefficient of efficiency.

Target	Proxy	E→L			L→E			Blocked CV		
		r	RE	CE	r	RE	CE	r	RE	CE
Previous-July dekad 3 SWVL2	EWV	0.460	0.161	0.161	0.336	0.024	0.024	0.332	0.112	0.084
Previous-July dekad 3 SWVL2	TRW	0.504	0.163	0.163	0.327	−0.095	−0.095	0.335	0.113	0.085
Previous-July mean SWVL2	EWV	0.327	0.116	0.074	0.243	0.096	0.023	0.180	0.018	−0.030
Previous-July mean SWVL2	TRW	0.377	0.135	0.094	0.244	0.051	−0.026	0.214	0.031	−0.016

The third-dekad and July-mean targets aggregate the same ERA5-Land variable. Only EWV met the combined two-target and standardization criteria. Its weakest split-direction CE was 0.024. Blocked-CV CE was nearly equal for EWV and TRW (0.084 and 0.085), so the period-split comparison does not establish a general earlywood prediction advantage or a significant skill difference. No pre-instrumental reconstruction was generated.

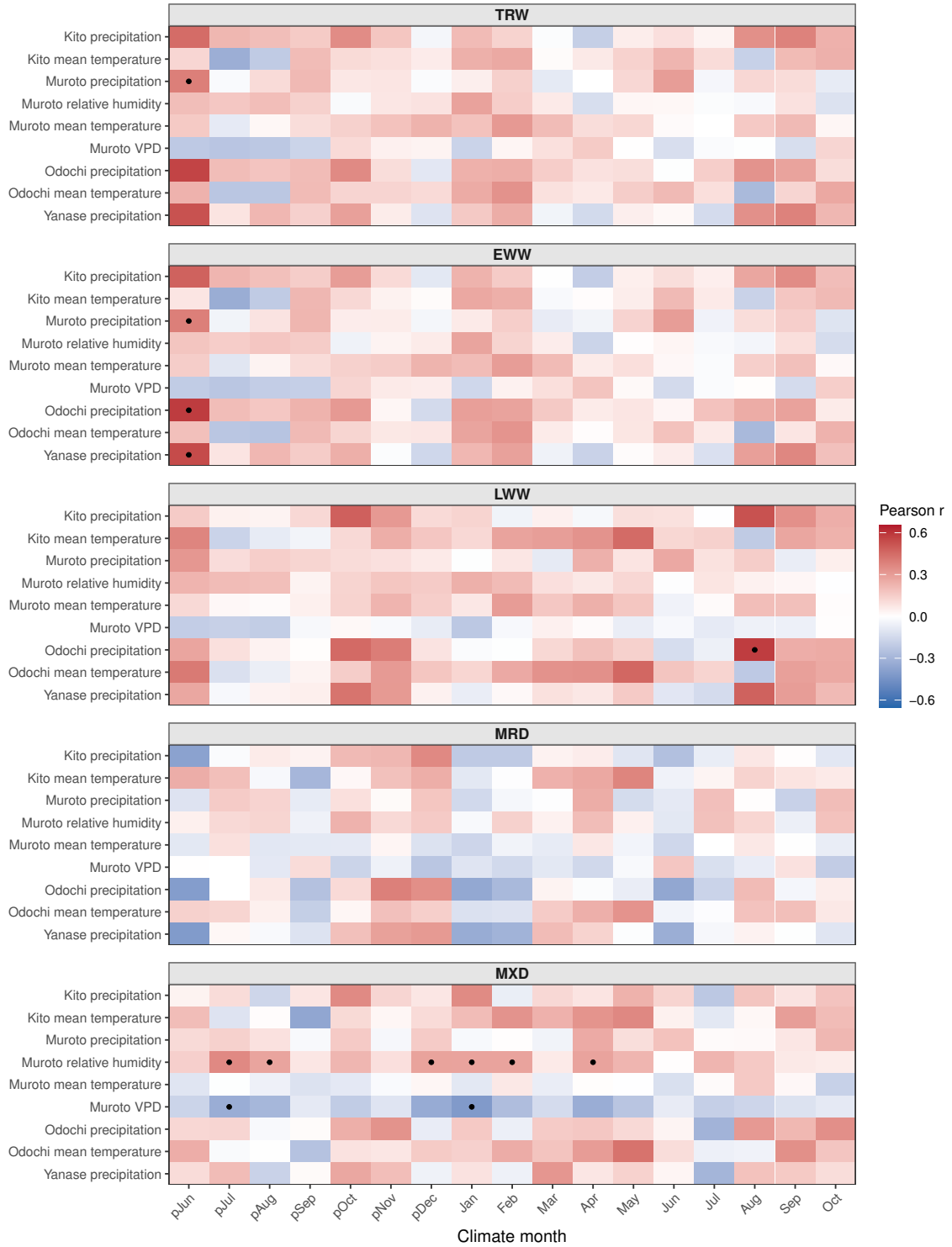


Fig. S4 Monthly climate-response screening using JMA observations from Kito, Odochi, Muroto, and Yanase. Tile colours represent Pearson correlations; black points mark effective-sample-size Benjamini-Hochberg FDR $q \leq 0.10$. Labels pJun–pDec refer to the previous calendar year. The display identifies recurrent response domains and does not itself select the final fixed models

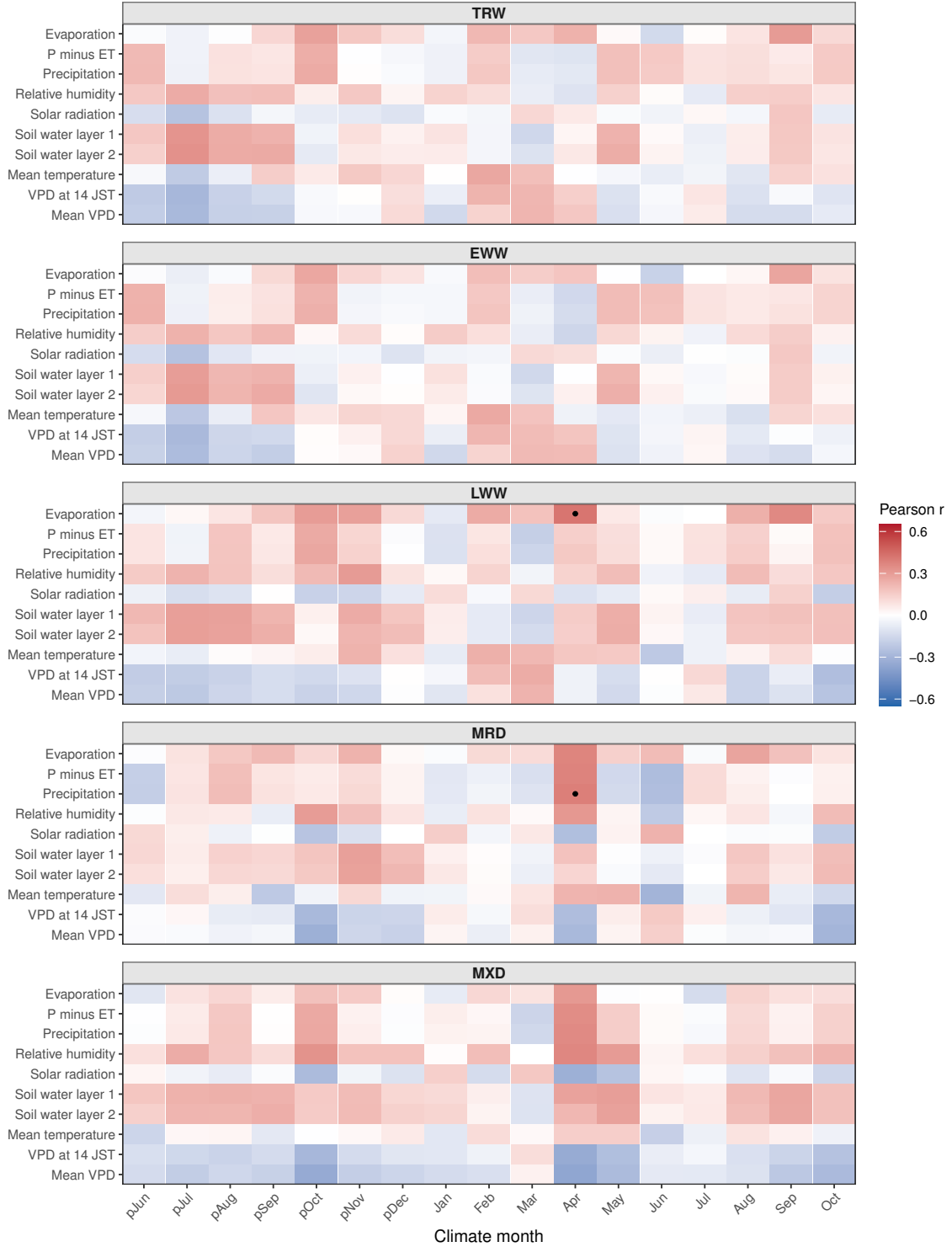


Fig. S5 Monthly climate-response screening using ERA5-Land variables averaged over the 3×3 grid for 1950–2004. Tile colours represent Pearson correlations; black points mark effective-sample-size Benjamini–Hochberg FDR $q \leq 0.10$. Labels pJun–pDec refer to the previous calendar year. The screening is descriptive and does not replace the fixed local windows used in the manuscript models

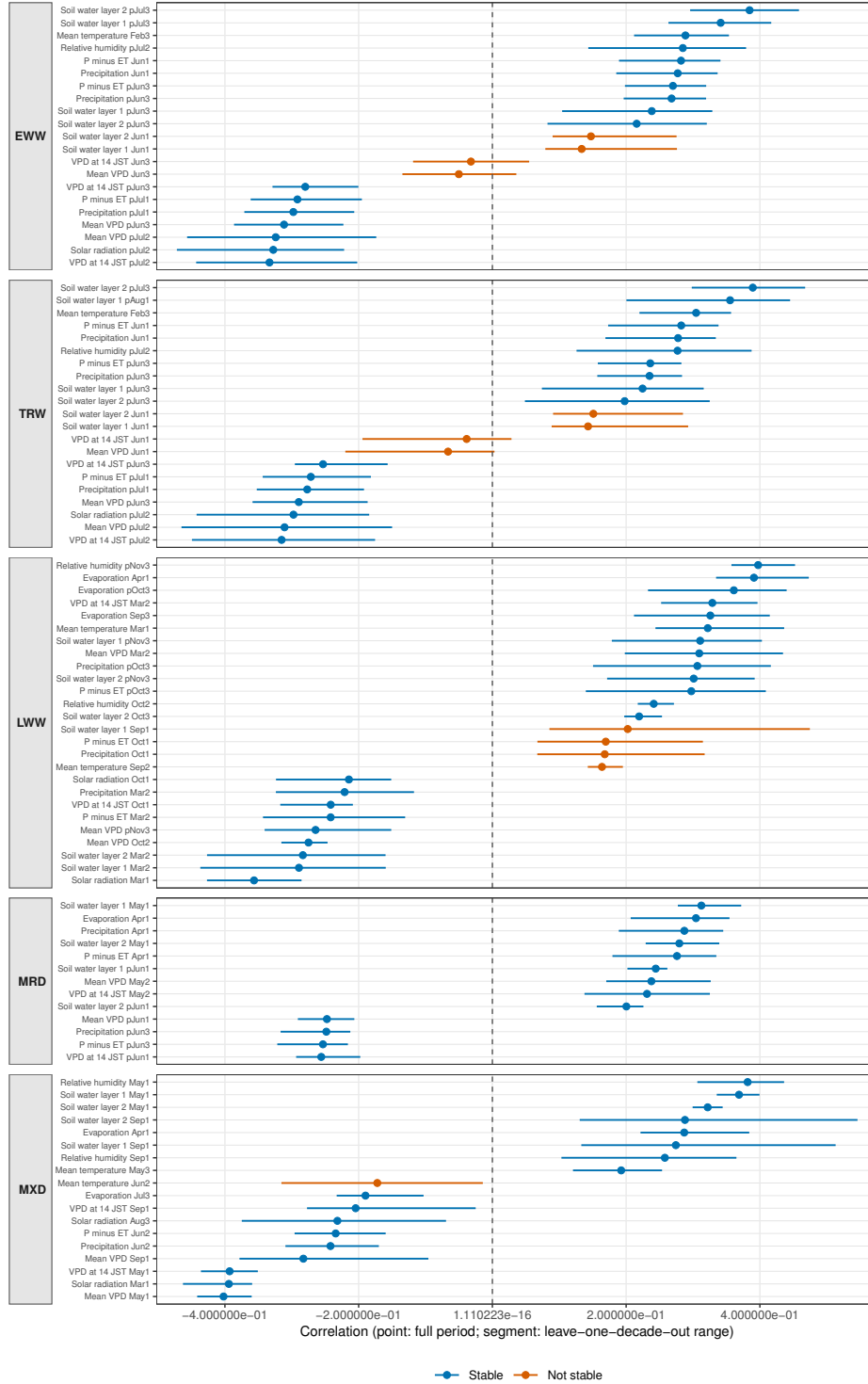


Fig. S6 Leave-one-decade-out robustness of the 99 localized climate-response candidates. Points show full-period correlations, and horizontal segments show the minimum-to-maximum correlation range across the six decade-omission analyses. Colour denotes the reported stability classification. Thirty-six candidates entered the fixed-model stage; the figure reports the complete candidate audit rather than only promoted effects

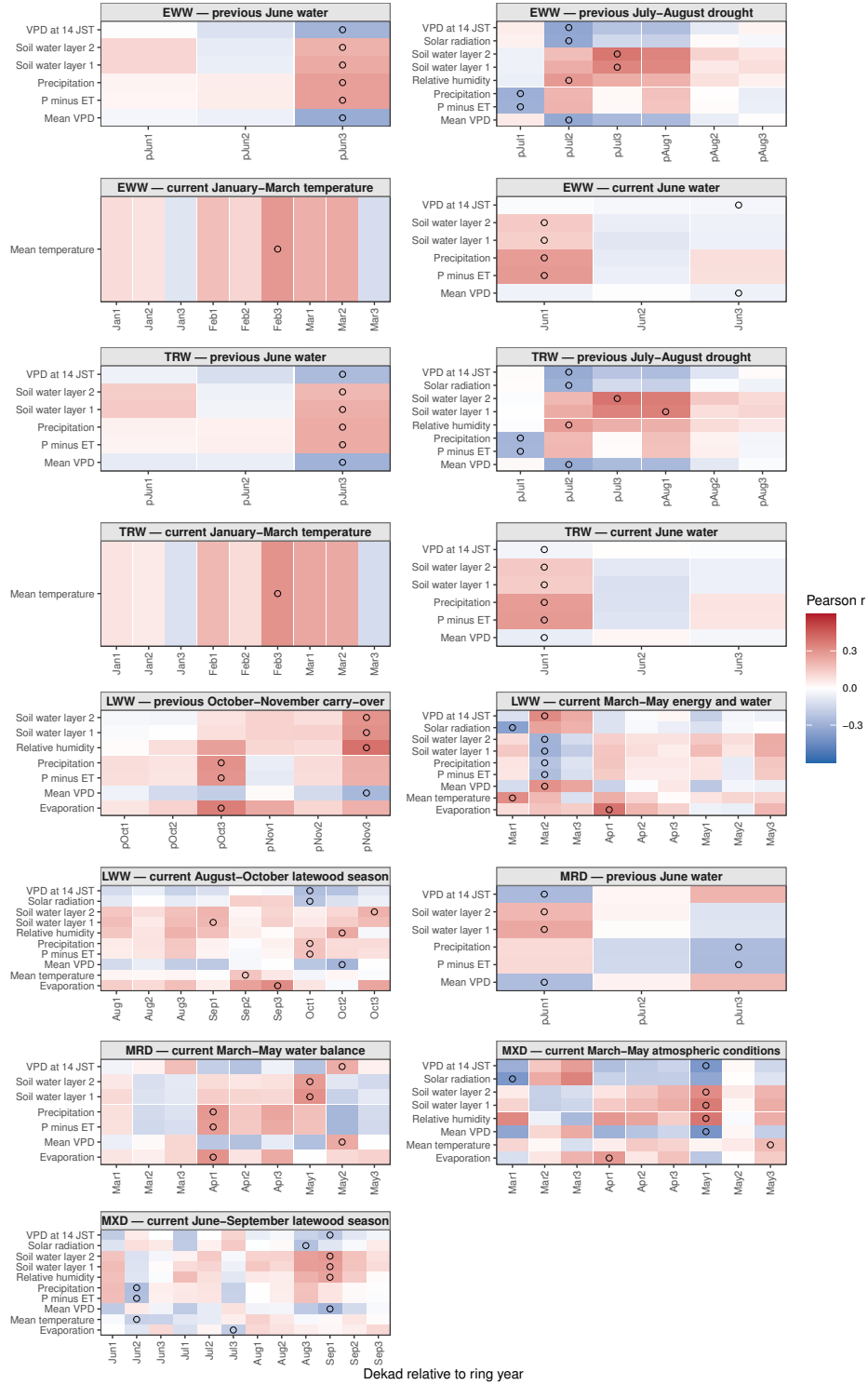


Fig. S7 Complete dekadal localization within the 15 fixed process windows for 1950–2004. Tile colours are Pearson correlations for the fixed ERA5-Land variables and 10-day periods; open circles mark the selected within-window maximum absolute correlation for each variable. The main text reports only the promoted fixed windows, whereas this figure retains all 672 plotted cells and 99 localized peaks. OpenAI Codex assisted with layout corrections; the plotted values and analytical definitions were unchanged

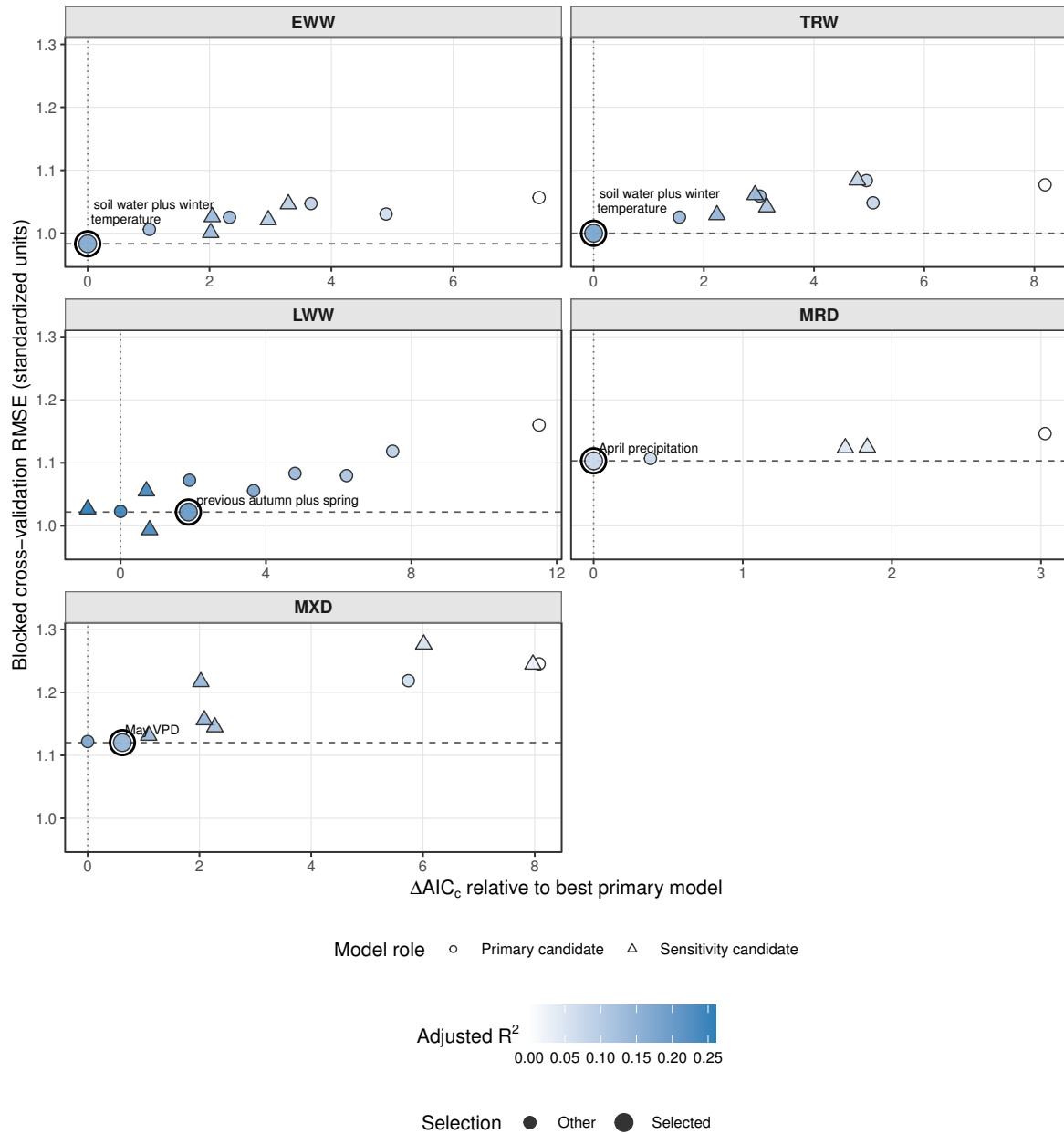


Fig. S8 Comparison of 46 fixed climate-growth models. Coordinates show AICc difference relative to the best primary model and decade-block cross-validation RMSE; fill denotes adjusted R^2 , shapes distinguish primary and sensitivity candidates, and larger black-ringed points are the selected models. Dashed horizontal lines show the minimum CV RMSE within the primary candidate family. Collinearity diagnostics are reported in Table S4

Table S12 Focal coefficients in separate modern TRW seasonal models. Early and late refer to 1951–1977 and 1978–2004. Values and difference intervals are expressed in the expected direction, as defined in the text.

Focal term	Early	Late	Difference	Lower 95%	Upper 95%
Temperature	0.398	0.148	−0.250	−0.721	0.220
Radiation	−0.347	0.353	0.699	0.150	1.249
VPD	−0.116	0.407	0.523	0.011	1.034
Soil water	0.119	0.372	0.253	−0.303	0.808

Temperature is the focal term of the two-predictor baseline model. Each other row comes from a separate model adding the indicated summer variable to that baseline. Differences are late minus early. Nominal intervals are conditional on the model and are not adjusted for multiple comparisons or selection. Temperature and soil-water contrasts were sensitive to individual years or blocks and their intervals include zero. Radiation and VPD intervals exclude zero, with covariance or suppression contributing to interpretation. Values are reported to three decimal places.

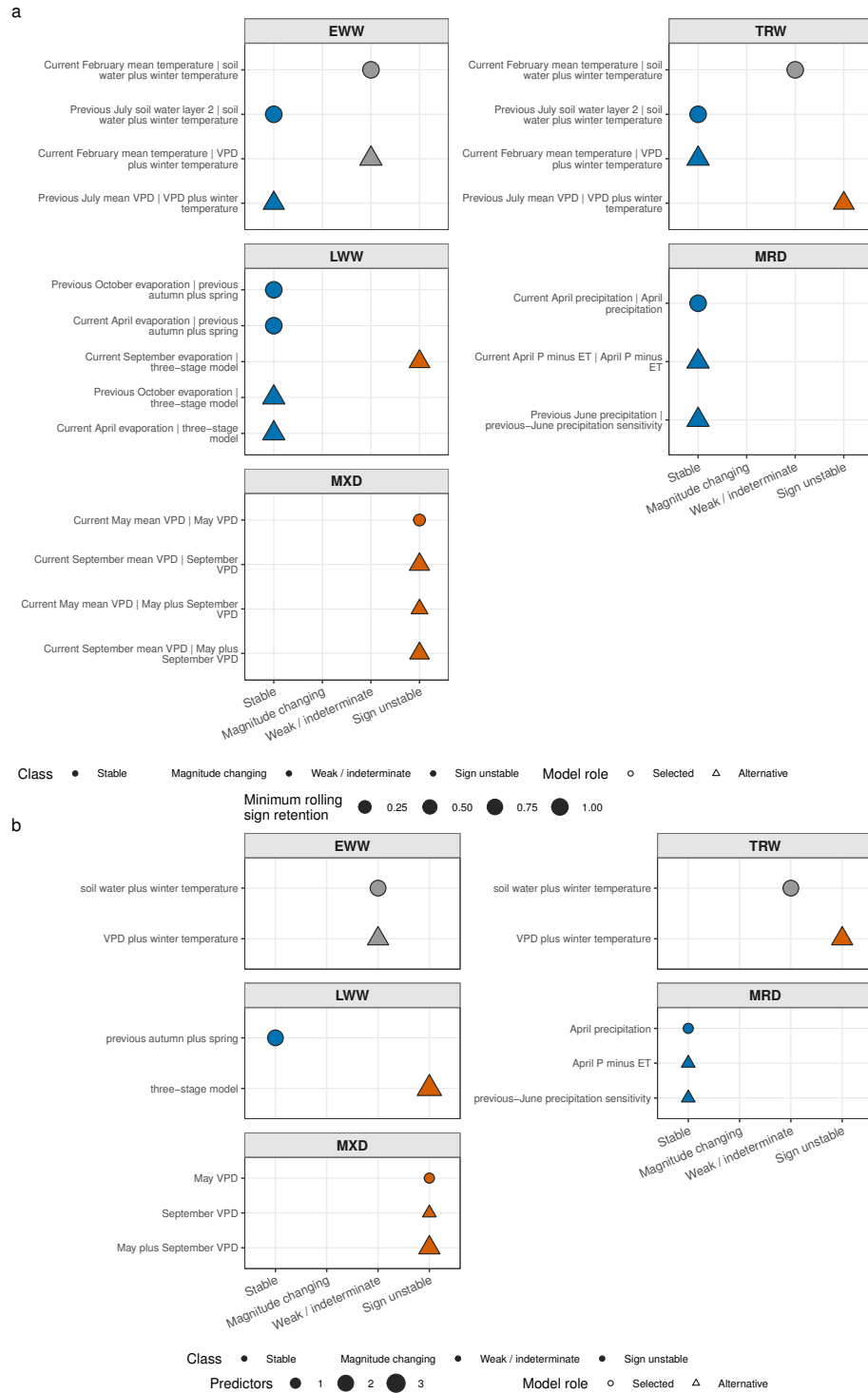


Fig. S9 Temporal classification of (a) fixed predictors and (b) complete models. Fill denotes the reported stability class, shapes distinguish selected from alternative models, predictor-point size gives the minimum OLS/GLS-AR(1) rolling sign-retention fraction, and model-point size gives the number of predictors. Classes combine estimator agreement, moving-window sign retention, early-late contrasts, and continuous predictor-by-time interactions. OpenAI Codex assisted with layout corrections; the plotted values and analytical definitions were unchanged

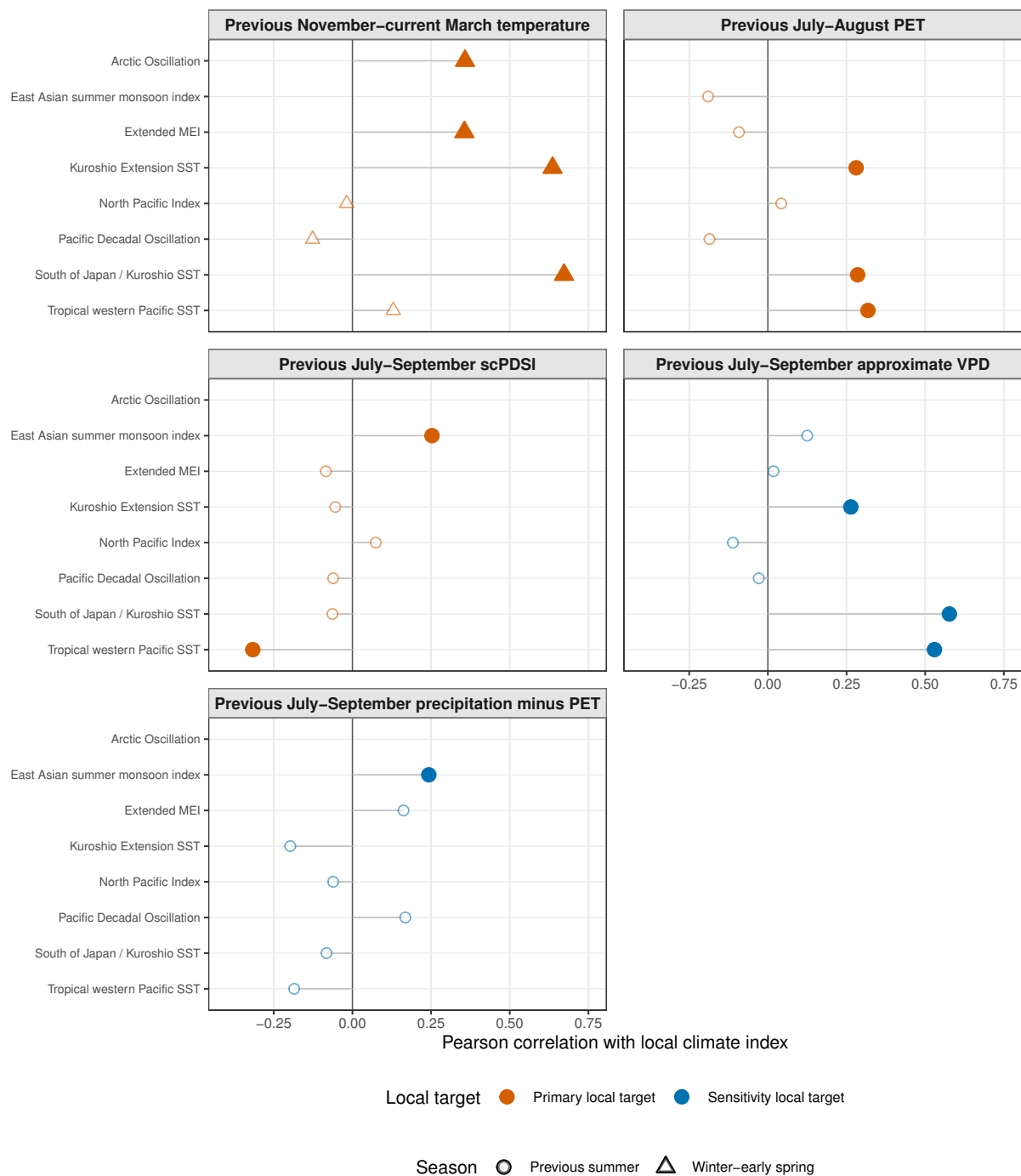


Fig. S10 Full-period 1902–2004 associations between the seven fixed large-scale ocean–atmosphere series and five local climate targets. Point position gives Pearson correlation, shape identifies the fixed season, and colour distinguishes primary from sensitivity local targets; filled larger symbols mark AR(1)-adjusted Benjamini–Hochberg $q \leq 0.10$. These associations describe regional meteorological context, not direct tree-growth effects. OpenAI Codex assisted the computational workflow used to regenerate this figure from the corrected CRU extraction with existing R plotting scripts

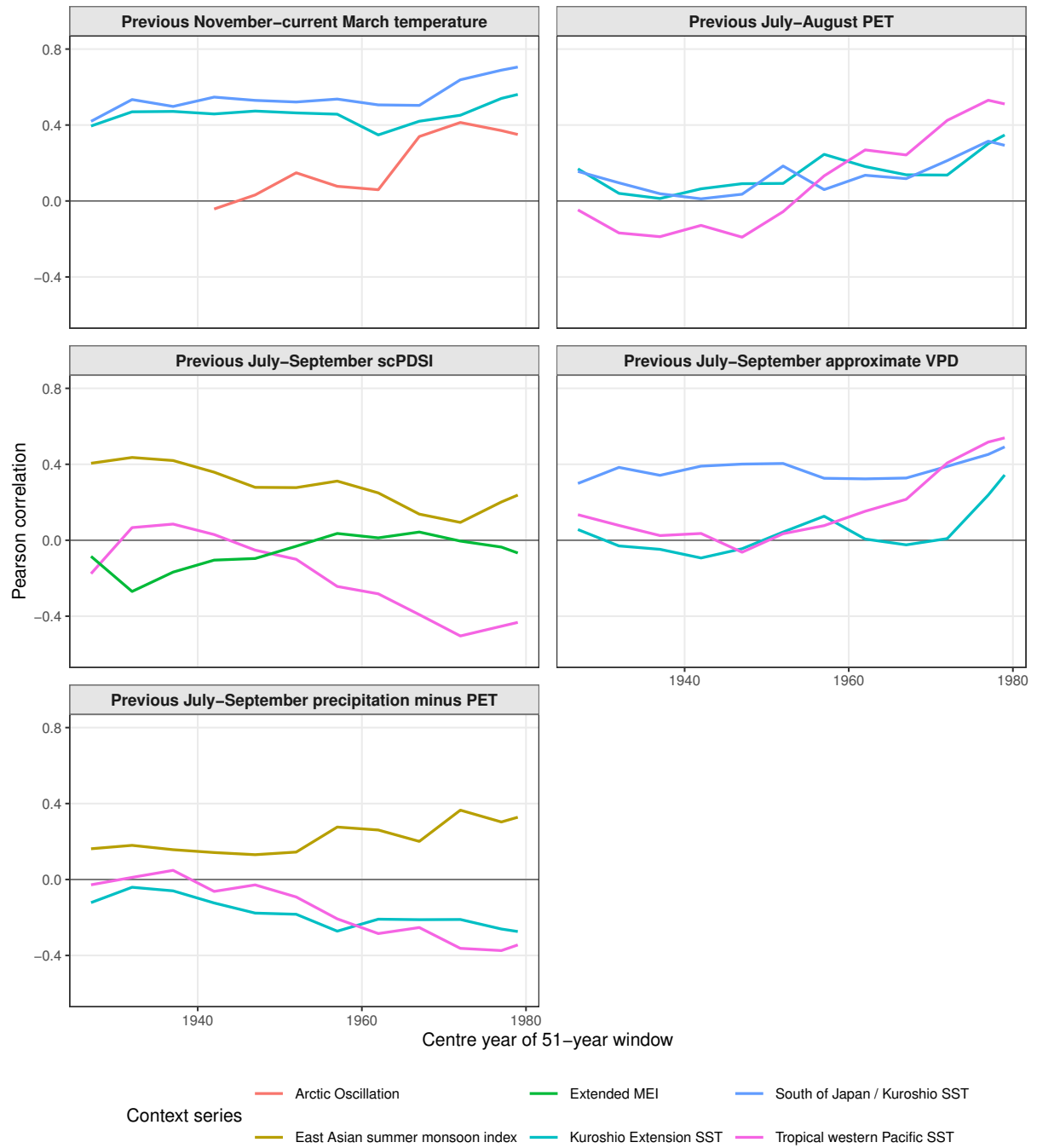


Fig. S11 Fifty-one-year moving-window regional context for the five fixed local climate targets. For each target, the three large-scale series with the largest absolute full-period correlation were retained for a readable display, yielding 15 fixed context pairs and 180 moving-window values. This ranking is a visualization summary of the fixed association set and does not select a new context season or local target. OpenAI Codex assisted the computational workflow used to regenerate this figure from the corrected CRU extraction with existing R plotting scripts

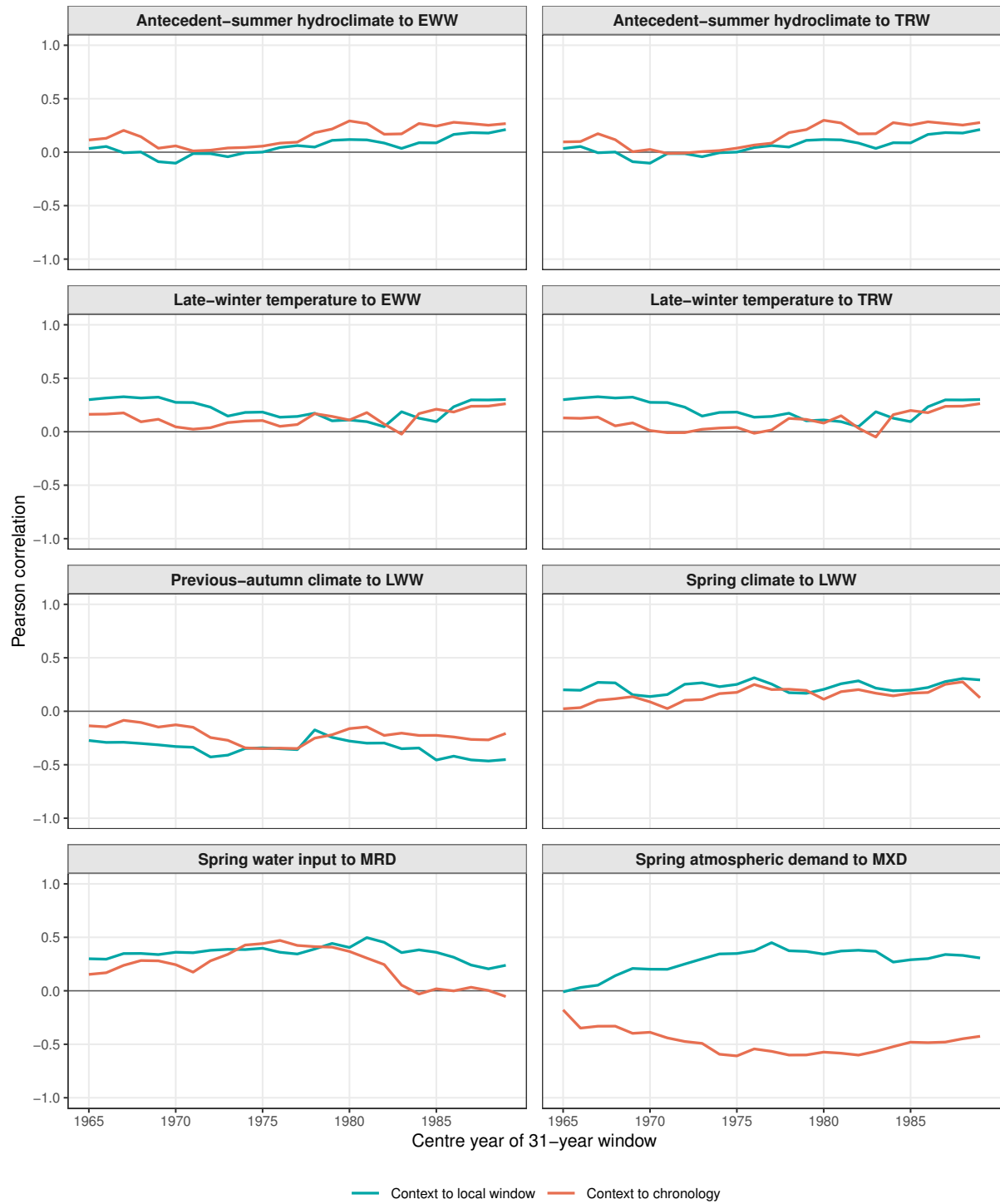


Fig. S12 Representative 31-year moving-window stability for the eight fixed local pathways. One large-scale series per pathway was chosen for display as the series with the smallest full-period effective-sample-size P value for the context-to-local link. Each pathway shows both context-to-local-window and context-to-chronology correlations. The representative selection is for readability only; all 55 fixed pathway-context pairs are retained in Fig. S13

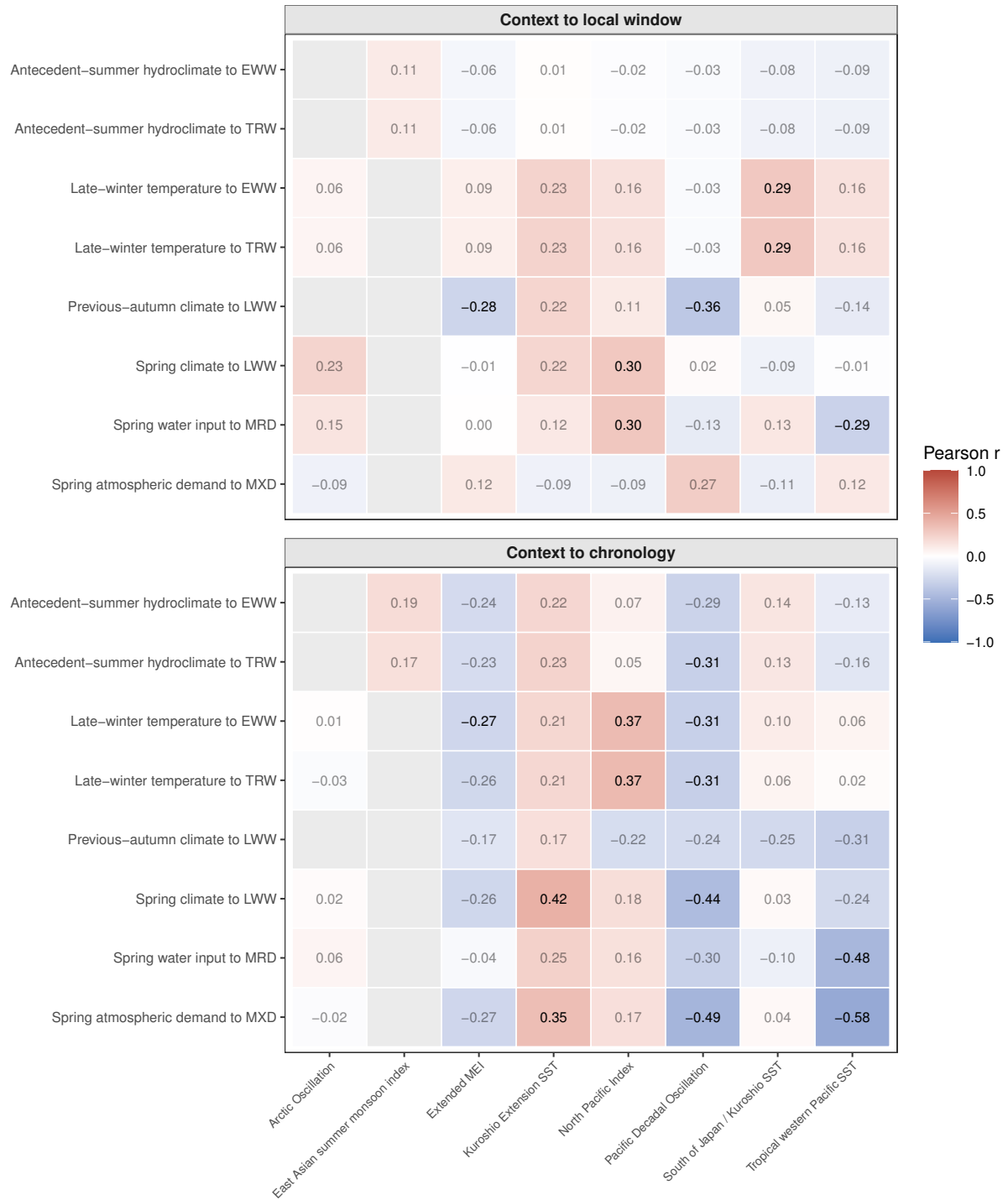


Fig. S13 Complete matrix of the 55 fixed pathway–context pairs for 1950–2004. The upper panel shows context-to-local-window associations and the lower panel shows context-to-chronology associations, for 110 populated cells in total. Blank cells denote combinations outside the fixed pathway design. The matrix preserves the complete result set and does not rescreen context seasons, local windows, or chronology models

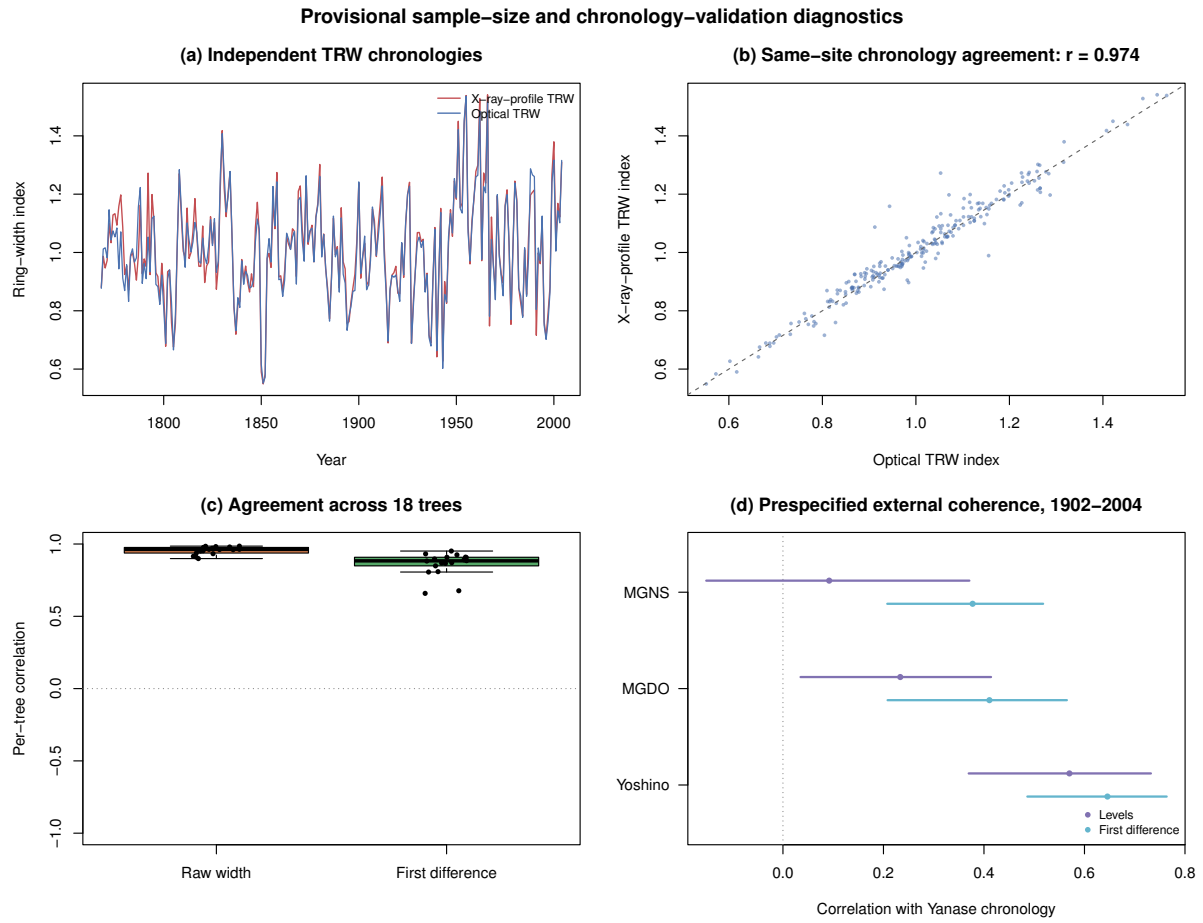


Fig. S14 Measurement-system and regional chronology comparison. (a) Harmonized optical and X-ray-profile TRW chronologies. (b) Same-site chronology agreement. (c) Per-tree raw-width and first-difference correlations for the 18 matched trees. (d) Fixed correlations with Yoshino, MGDO, and MGNS for 1902–2004. Intervals are circular moving-block 95% intervals. The same-site comparison tests measurement reproducibility and does not constitute independent biological replication

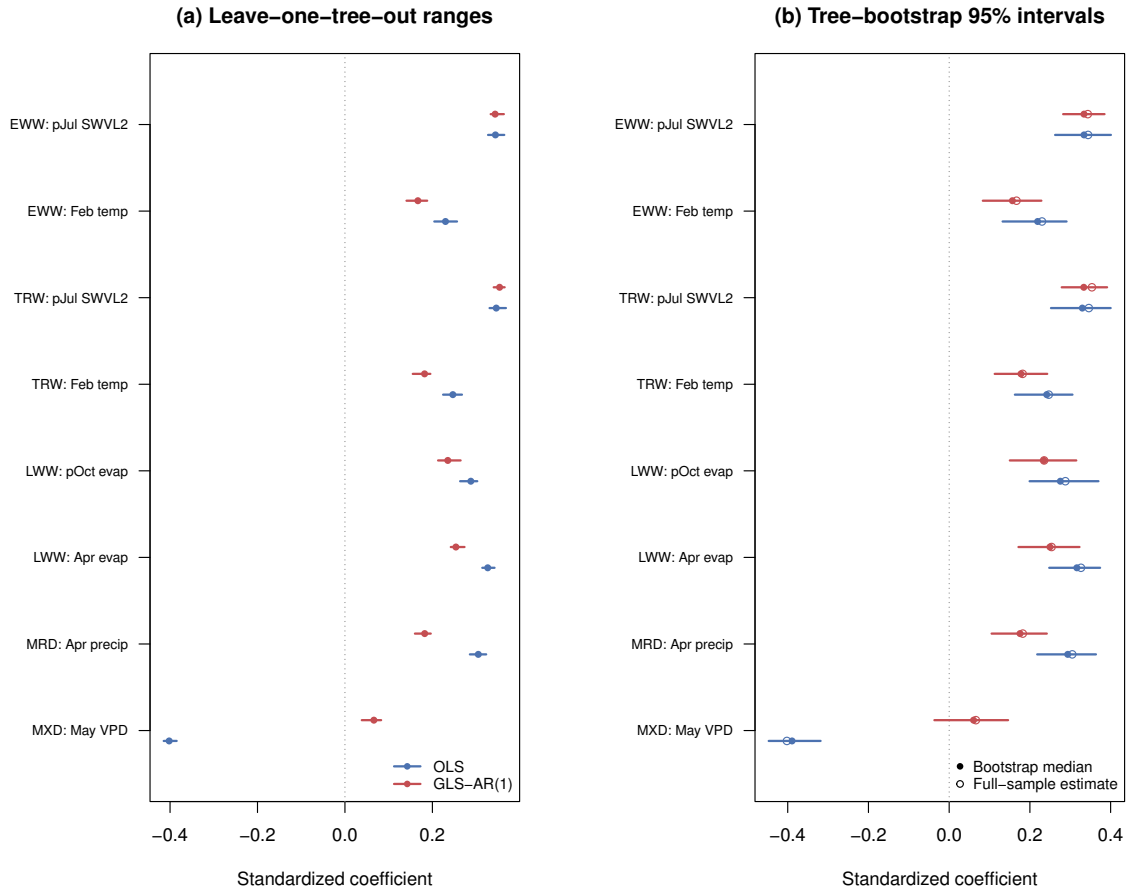


Fig. S16 Sensitivity of the fixed climate–growth coefficients to tree membership. Leave-one-tree-out coefficients and 2000 paired tree-resampling realizations are shown separately for OLS and GLS-AR(1). The EWW, TRW, LWW, and MRD effects retained their expected directions, whereas the MXD–May VPD coefficient remained estimator-dependent

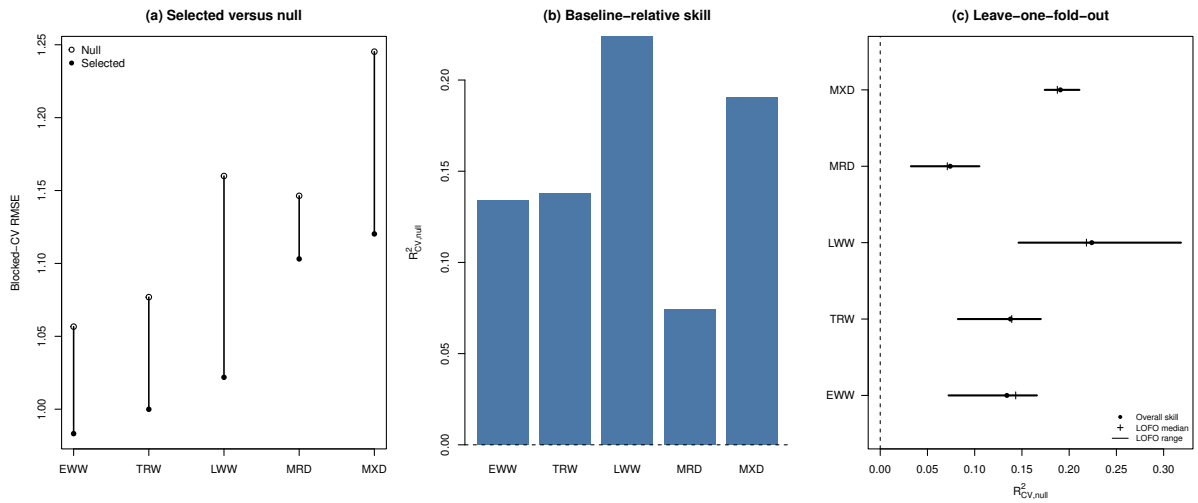


Fig. S17 Blocked predictive skill relative to the fold-specific null model. (a) Selected-model and null-model RMSE. (b) Baseline-relative blocked-CV skill. (c) Overall skill and the range obtained after omitting one temporal fold at a time. Positive aggregate skill does not imply positive performance in every individual fold

Table S13 Analysis coverage and the provenance of full-period estimates. The nominal modern climate domain contains 55 calendar years, but complete-case rules differ among analysis stages.

Analysis	Observations	Reference and complete-case rule
Long-record CRU response	1902–2004; 103 years	Archived optical TRW; ADS16 primary, with ADS32 and supersmoother sensitivities.
Common-signal statistics	1950–2004; 55 years	All 18 trees in each year; describes chronology replication.
Candidate-model comparison and forward CV	1951–2004; 54 years for EWW, TRW, LWW, MRD; 55 for MXD	Common complete cases across all candidate predictors within a metric. Full-period fits scaled on those cases; CV scaled on training cases.
Selected-model tree omission and paired tree bootstrap	54 years for EWW, TRW, LWW, MRD; 55 for MXD	Same complete years as candidate comparison; fixed predictors and windows.
Selected component-model temporal diagnostics	1951–2004; 54 years for EWW, TRW, LWW; 1950–2004, 55 for MRD and MXD	Complete cases for each model’s own predictors. Scaling fixed from each variable’s available 1950–2004 reference record before windowing.
Modern seasonal TRW models and inverse soil-water tests	1951–2004; 54 years	Early/late split 1951–1977 / 1978–2004. These are separate model families; inverse CV uses six nine-year blocks.
Regional chronology coherence	1902–2004; 103 levels, 102 differences	Current X-ray Yanase TRW versus Yoshino, MGNS, MGDO.
Optical–X-ray reproducibility	1768–2004; 237 levels, 236 differences	Primary harmonized 16-year spline comparison for the same trees.

MRD April precipitation	n	OLS β [95% CI]	GLS-AR(1) β [95% CI]
Candidate comparison	54	0.305 [0.040, 0.570]	0.182 [0.007, 0.357]
Temporal reference	55	0.287 [0.023, 0.551]	0.169 [−0.001, 0.339]

The two MRD rows reproduce their respective archived fits; they are not independent replications. They differ in year coverage and standardization, so differences must not be attributed to ecological change. The coefficient direction is positive in both, whereas exclusion of zero by the GLS-AR(1) interval is sensitive to the analysis frame. The nominal intervals do not include climate-window or model-selection uncertainty. Regional and primary optical–X-ray intervals use 10-year block bootstraps with 5000 replicates. The coverage rules were checked against the archived candidate-comparison, temporal-model, chronology-correlation, and tree-composition outputs.

Table S14 Meteorological agreement between ERA5-Land and JMA during 1981–2004. All 16 archived variable–station comparisons are shown for the 3×3 ERA5-Land mean.

Station	Variable pair	Anomaly r	Raw bias	Bias unit
<i>Inland and Yanase reference pairs</i>				
Kito	Mean temperature	0.968	-0.80	°C
Kito	Mean daily maximum	0.900	-2.82	°C
Kito	Mean daily minimum	0.937	0.41	°C
Odochi	Mean temperature	0.955	-2.25	°C
Odochi	Mean daily maximum	0.939	-3.80	°C
Odochi	Mean daily minimum	0.923	-1.14	°C
Kito	Precipitation	0.736	-52.90	mm
Odochi	Precipitation	0.737	-17.94	mm
Yanase	Precipitation	0.746	-139.04	mm
Kito	Radiation / sunshine	0.734	—	—
Odochi	Radiation / sunshine	0.679	—	—
<i>Auxiliary coastal reference pairs</i>				
Muroto	Mean temperature	0.953	-4.11	°C
Muroto	Mean VPD	0.705	-1.31	hPa
Muroto	Relative humidity	0.826	6.32	pp
Muroto	Vapor pressure	0.898	-2.59	hPa
Muroto	Radiation / sunshine	0.832	—	—

Anomaly r is Pearson correlation after removing the calendar-month means for 1981–2004. Radiation–sunshine comparisons use standardized calendar-month anomalies. Raw bias is mean ERA5-Land minus JMA in the unadjusted monthly series: temperature in °C, monthly precipitation in mm, vapor pressure and VPD in hPa, and relative humidity in percentage points (pp). Mean daily maximum and minimum refer to temperature. Each pair has 288 months except Muroto VPD, relative humidity, and vapor pressure ($n = 287$). Bias is omitted for radiation versus sunshine duration because their physical quantities and units differ. Muroto provides coastal context and is not a site-equivalent humidity reference. The primary-pair mean and median anomaly r round to 0.841 and 0.900 for both the 3×3 and nearest-point extractions. Agreement in temporal variation does not eliminate differences in magnitude or validate modeled soil water. Values reproduce the archived product-comparison output; no new climate extraction or model fitting was performed for this table.

Table S15 Sensitivity to the CRU extraction coordinate. The archived reference is 33.666667°N, 134.000000°E; the corrected extraction uses the stand position, 33.6674°N, 134.1341°E. Both panels report bilinear interpolation.

Seasonal optical TRW association	Archived r	Corrected r	
Winter-early-spring temperature	0.323	0.324	
Previous-June precipitation	0.254	0.259	
Previous-summer PET	-0.240	-0.234	
Previous-summer scPDSI	0.328	0.346	
Previous-summer approximate VPD	-0.024	-0.018	
Previous-summer water balance	0.323	0.324	
Monthly climate variable	Anomaly r	Mean difference	Unit
Mean temperature	0.9994	-0.1372	°C
Maximum temperature	0.9986	-0.2058	°C
Precipitation	0.9993	-0.7387	mm
PET total	0.9980	0.4240	mm
Vapor pressure	0.9994	-0.1039	hPa
scPDSI	0.9970	-0.0841	index
Approximate VPD	0.9982	-0.0052	kPa
Precipitation minus PET	0.9994	-1.1627	mm
Temperature-adjusted PET	0.9970	0.0000	mm

The upper panel reports Pearson correlations for the primary 16-year age-dependent-spline optical TRW chronology over 1902–2004 ($n = 103$). Winter temperature spans previous November through current March; PET spans previous July–August; the other summer indices span previous July–September. The lower panel compares 1248 monthly values over 1901–2004. Anomaly r removes each series’ calendar-month means over that interval. Mean difference is corrected minus archived in the stated units; precipitation and PET are monthly totals. The raw climate versions, chronology, windows, and model procedures were held fixed. The original coordinate lay midway between the two longitude grid points, with the tie assigned westward; the corrected nearest-point extraction selects the eastern point. Full comparisons for both spatial methods and all downstream outputs are retained in the reproducibility record. The corrected extraction is used for all reported CRU-dependent results. Coordinate sensitivity does not quantify all uncertainty in gridded climate representation.

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