Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index: BACI

Deliverable 3.3: Synthesis dataset of tree ring records

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Synthesis dataset of tree-ring records, with uncertainty analysis

1. Overview

The collection and harmonization of tree-ring data within the BACI project provides an empirical baseline that can be integrated with other ground observations (WP3), contribute to downstream data products (WP4), and support the development and evaluation of the BACIndex (WP5). In particular, tree-ring data can provide large-scale and long-term information on forest growth and its response to environmental drivers (Babst et al. in revision). Such information are useful to inform shorter-term observations (e.g. eddy-covariance or remote sensing data) on forest growth over time scales that are relevant for climate change and to contextualize extreme events (Frank et al. 2015a).

Within task 3.4 of the BACI project, three principal sets of tree-ring data have been compiled:

- A global tree-ring width (TRW) dataset that provides inter-annual information on variability in radial tree growth. For a subset of the sites, additional records of partial ring width and maximum wood density are also available.
- A network of Eurasian sites, where a specialized sampling design has been consistently applied to allow for the quantification of annual above-ground biomass increment (ABI; Babst et al. 2014; Nehrbass-Ahles et al. 2014).
- A network of European sites, where annually resolved chronologies of stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope ratios were extracted from wood cellulose in tree-ring samples. These data reflect (to some extent; Gessler et al. 2014) leaf-level ecophysiological processes and can be used to derive relevant ecosystem metrics, such as water-use efficiency (Frank et al. 2015b).

Subsequently, the three datasets are described together with emerging uncertainties and limitations. The tree-ring data are currently being used to accomplish specific BACI goals (e.g. WP4, task 3: "*Spatialized, long-term tree ring width index data*") and to address different research questions (see Section 4).

2. Datasets

2.1. Global tree-ring width dataset

A total of 6323 single species tree-ring records from 4559 sites have been compiled and homogenized into a global network (Table 1). This network spans most of the world's extra-tropical forests (Figure 1) and a limited number of tropical chronologies are also available. The site records consist on average of n = 35 tree-level series. Data availability peaks in the mid 20th century and decreases both back in time and towards present (as reviewed in Babst et al. 2017).

For more detailed information, please refer to the descriptive document that is available along with the data from the BACI database:

"*Description_treeringwidth_global_BACI2017_v2.pdf*"

Table 1 Overview of the global tree-ring width dataset

Area:	Global
Latitudinal range:	55 °S to 72 °N
Longitudinal range:	164 °W to 177 °E
Elevation range:	0 to 4260 m a.s.l.
Temporal resolution:	Annual
Temporal coverage:	2228 B.C. to 2016 A.D.
Parameters:	Total ring width; earlywood width; latewood width; maximum latewood density
Nr. of tree species:	213
Nr. of sites:	4559
Data source:	International Tree Ring Data Bank

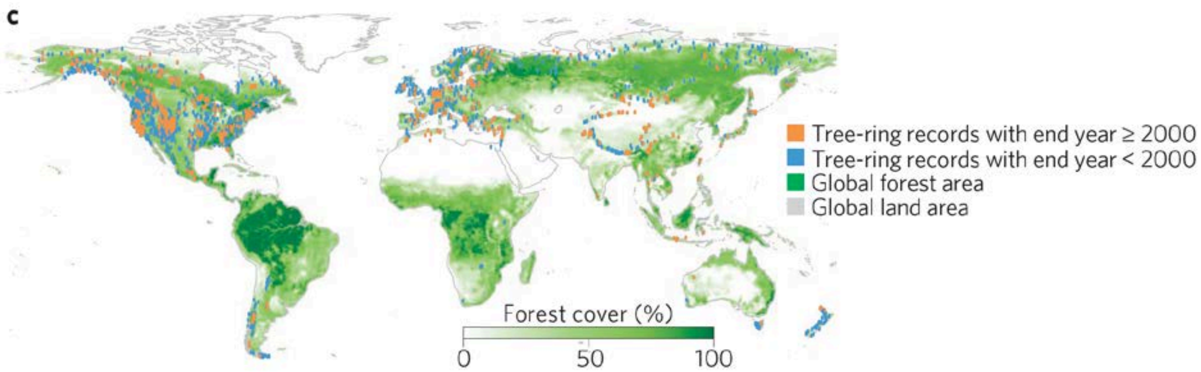

Figure 1 Geographic distribution of sites in the global tree-ring width dataset. (Figure from Babst et al. 2017)

2.2. Eurasian tree-ring width and biomass dataset

This network contains 55 sites from ten countries that have been sampled specifically to estimate annual aboveground biomass increment (ABI) from radial tree growth (Table 2). In contrast to the global TRW dataset (section 2.1), ABI estimates require a sampling design that includes the collection of basic biometric measurements of each tree and that yields a representative sample of the respective forests in terms of stand density and composition (Nehrbass-Ahles et al. 2014). The fixed-plot approach (Babst et al. 2014) was consistently followed at all sites (Figure 2) to ensure data compatibility. The site records consist on average of n = 67 tree-level series. Data availability peaks in the early 21st century and decreases back in time (Klesse et al., in revision).

For more detailed information, please refer to the descriptive document that is available along with the data from the BACI database:

"*Description_treeringbiomass_Europe_BACI2017_v2.pdf*"

Table 2 Overview of the Eurasian tree-ring width and biomass dataset

Area:	Eurasia
Latitudinal range:	37.5 to 62 °N
Longitudinal range:	5 °W to 130 °E
Elevation range:	10 to 2230 m a.s.l.
Temporal resolution:	annual
Temporal coverage:	1417 to 2014 A.D.
Parameters:	Total ring width; above-ground biomass increment
Nr. of tree species:	13
Nr. of sites:	55
Data source:	Swiss Federal Research Institute WSL

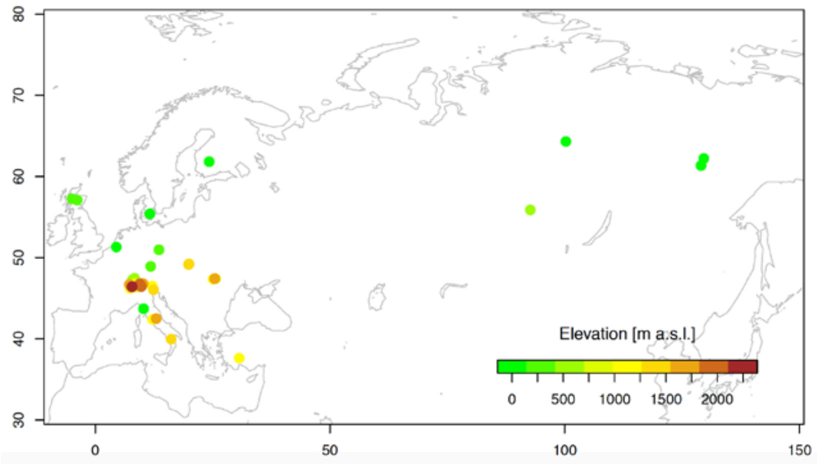

Figure 2 Geographic distribution of sites in the European tree-ring width and biomass dataset (figure adapted from Klesse et al., in revision).

2.3. European tree-ring stable isotope dataset

The stable isotope network consists of 43 sites from 12 European countries and Morocco (Table 3). Data from coniferous and broadleaf species are available from 28 and 15 sites, respectively (Figure 3). Site selection was based upon criteria including stand age, proximity to measurement locations of the isotopic composition of precipitation, and spatial distribution across Europe (Treydte et al. 2007; Frank et al. 2015). Stable carbon isotope ($\delta^{13}C$) measurements are available at 43 sites and stable oxygen isotopes ($\delta^{18}O$) are available at 12 sites. The addition of further sites to this network is intended.

For more detailed information, please refer to the descriptive document that is available along with the data from the BACI database:

“Description_treeringisotopes_Europe_BACI2017_v2.pdf”

Table 3 Overview of the European tree-ring stable isotope dataset

Area:	Europe
Latitudinal range:	33 to 69 °N
Longitudinal range:	5 °W to 31°E
Elevation range:	0 to 2400 m a.s.l.
Temporal resolution:	annual
Temporal coverage:	900 to 2010 A.D.
Parameters:	Tree-ring stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes.
Nr. of tree species:	12
Nr. of sites:	43
Data Source:	ISONET Consortium; Institute of Geography at the University of Mainz (Germany); International Tree Ring Data Bank

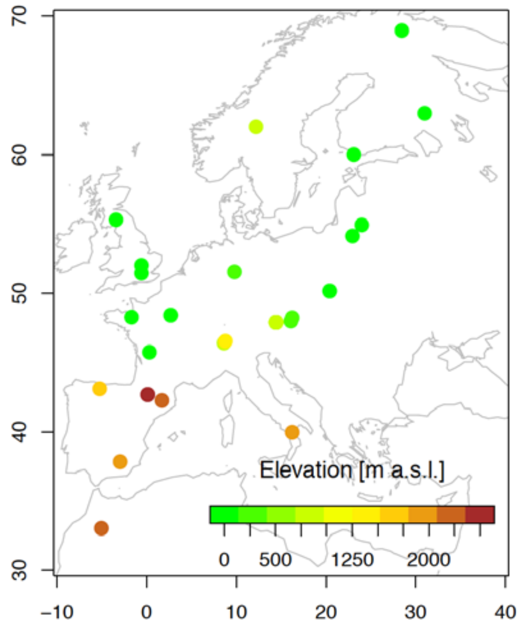

Figure 3 Geographic distribution of sites in the European tree-ring stable isotope dataset (figure adapted from Treydte et al., in prep).

3. Uncertainty

We have identified the following six sources of uncertainty that are relevant for the tree-ring data described in Section 2:

a) Human error during sampling and measurement
b) Measurement precision
c) Standardization / detrending
d) Allometric equations used to derive ABI
e) Upscaling from the tree to the site level
f) Post-carboxylation fractionation during carbohydrate allocation to growth

The relevance of these uncertainties differs between the three tree-ring datasets. In general, (a) is impractical to quantify because >1000 researchers and technicians have contributed to these networks; (b) is considered negligible for TRW and ABI, but relevant for stable isotopes; (c) is relevant for TRW (and possibly for stable isotopes; Esper et al. 2010), but not for ABI; (d) is relevant only for ABI; (e) is relevant for all datasets; (f) is relevant only for stable isotopes, but not understood well enough to be reliably quantified (Gessler et al. 2014).

Within BACI task 3.4, uncertainties b-e are considered and represented in the form of upper and lower boundaries that are provided in separate files along with the main data file (please refer to the descriptive documents listed in Section 2 for details). Regarding (b), we considered the measurement precision reported in the original publications. Regarding (c), we provide eight different detrendings that preserve an increasing amount of low-frequency variability in the site-level TRW chronologies. We emphasize, however, that these detrendings are not suitable for all kinds of tree-ring applications and researchers are encouraged to perform their own study-specific detrending on the raw data. In terms of (d), uncertainty arises from intrinsic uncertainties in the allometric equations (Forrester et al. 2017) and from the fact that the equations were not developed under the exact same ecological conditions as those present at the biomass network sites. To address this, we provide the ensemble maximum and minimum ABI from all allometric equations that are available for a given species, geographic area, and tree size range. Regarding (e), we calculated bootstrapped 95% confidence intervals around the mean site-level chronologies for detrended TRW. For ABI, we purposely do not provide site-level records because the data handling and emerging biases related to stand history and demography (Foster et al. 2014; Nehrbass-Ahles et al. 2014; Dye et al. 2016; Brienen et al. 2016) are highly study-specific. Data users are encouraged to upscale the tree-level ABI data to the site level as they see fit for specific purposes.

4. Use of tree-ring data in the BACI context

The tree ring data described herein are currently being used to develop downstream data products (BACI WP4) and to address specific research questions:

- Within BACI task 4.3, parts of the TRW network (Section 2.1) have been assessed to develop a spatialized and yearly resolved tree-ring width dataset for Europe (see BACI deliverable 4.3). This has been achieved for the genera *Abies*, *Fagus*, *Larix*, *Picea*, *Pinus*, and *Quercus*, from all of which are >100 TRW chronologies available across the European domain. A random forest regression model using 11 climatic predictor variables explained ~33% of the variance in these data. Ongoing efforts aim to improve this performance using deep machine learning techniques (Bodesheim et al., in prep.).
- State of the art: Possibilities to infer large-scale variability in forest growth and its environmental drivers from tree-ring networks have been reviewed with respect to spatiotemporal data availability (Babst et al. 2017). In addition, an invited review article (*Quarternary Science Reviews*) is under way that explores the challenges and opportunities for upscaling tree-ring data from the individual to the global scale (Babst et al., in prep.).
- The climatic limitations inferred from 2710 tree-ring sites have been interpolated in temperature and precipitation space to assess patterns and changes in the climate response of extra-tropical forest growth. We found that the geographic area where forest growth is limited by cold temperatures has decreased by almost 6% between the mid and late 20^{th} century (Babst et al., in revision).
- Both the TRW and ABI data are being used to evaluate net primary productivity as simulated by dynamic global vegetation models (DGVMs). These studies have shown that current DGVMs from the TRENDY ensemble are exceedingly sensitive to climate (Zhang et al. 2017; Klesse et al., in revision) and do not reliably capture variability in forest growth beyond the annual time scale (Pappas et al. 2017). In addition, tests with another land surface model (CLM 4.5) revealed that the model overestimated the initial aboveground biomass at the beginning of the simulation, but strongly underestimated annual ABI (Montane et al. 2017).
- Efforts are being made to facilitate the integration of TRW with periodically collected forest inventory data. Formal integration of the two complementary data sources with a Bayesian hierarchical model significantly reduced uncertainties around the effects of non-climatic drivers on tree growth (Evans et al. 2017).
- A field campaign to extend the ABI network to include further FLUXNET sites (FR-Hes, DK-Sor, BE-Vie, DE-Hai) is planned for autumn 2017. This sampling will follow the established ABI protocol (Babst et al. 2014) and will allow for the integration of ABI and eddy-covariance data. From this dataset, we expect new insight in carbon allocation dynamics to growth.

5. References

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Eurasian tree-ring width and biomass datasets

This document describes the Eurasian network of tree-ring width (TRW) and annual aboveground biomass increment (ABI) data that was compiled and homogenized within BACI WP3, task 3.4 *("Synthesis of available tree-ring records and biomass calculations")*. This dataset is subsequently referred to as the "ABI-network".

Outline:

1. Network description
2. Data source
3. Data processing
4. Uncertainty estimation
5. Files
6. Contact
7. References

1. Network description

The ABI-network consists of 55 sites from ten Eurasian countries that have been collected with the aim to quantify TRW and ABI simultaneously (Figure 1). In contrast to most existing tree-ring data, ABI estimates require a sampling design that includes the collection of basic biometric measurements of each tree and yields a representative sample of the respective forests in terms of stand density and composition. The fixed-plot approach described in Babst et al. 2014a was consistently followed at all sites to ensure data compatibility (see Sections 3 and 5).

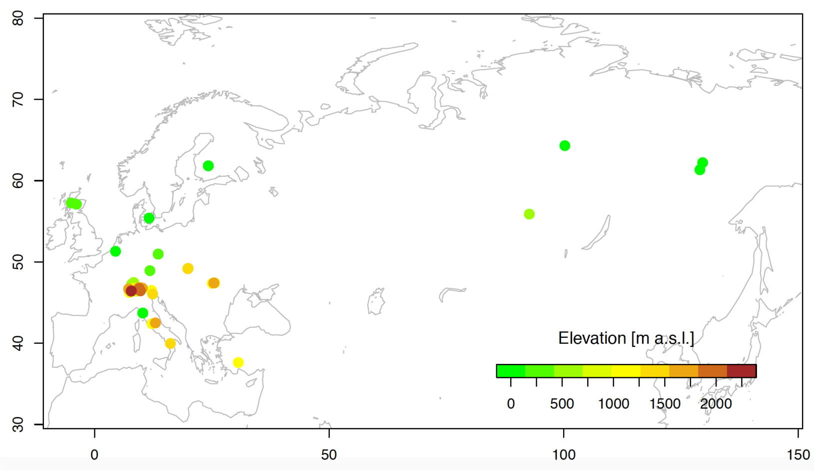

Figure 1: Geographic location of the sites that constitute the Eurasian tree-ring width and biomass increment network.

The records consist of measurement series from an average of n = 67 trees (network max n = 334, min n = 31) collected from increment cores of living or dead trees. These samples were prepared according to standard dendrochronological procedures (Speer 2012) and measured to a precision of 0.01 mm. A total of 13 tree species are present in the network, eight of which represent the dominant species at one or more sites (Figure 2a). The temporal coverage peaks in the late 20th century and decreases backward in time (Figure 2b,c).

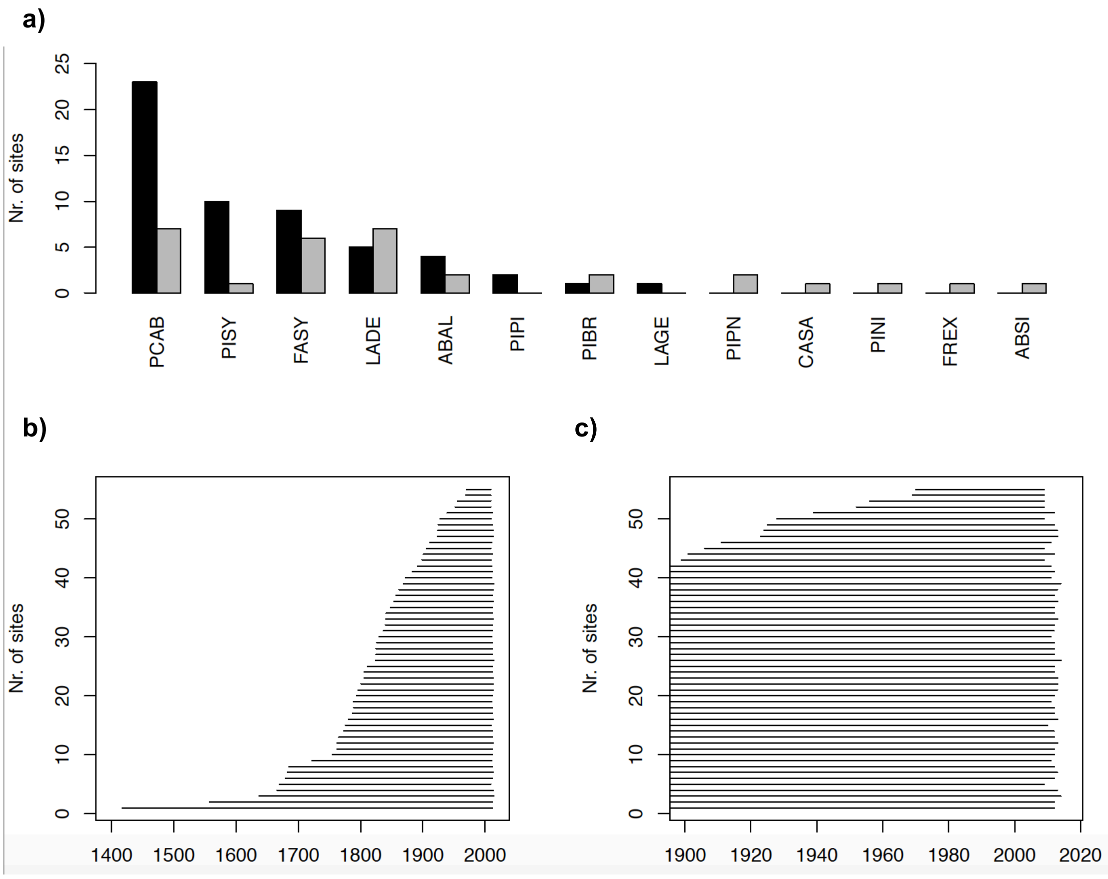

Figure 2: The number of sites with different primary (black) and secondary (grey) tree species is shown in panel (a). Temporal changes in the number of sites that contain data in a given year are shown in panel (b) for the past 600 years and in panel (c) for 1900-2016. PCAB – *Picea abies*, PISY – *Pinus sylvestris*, FASY – *Fagus sylvatica*, LADE – *Larix decidua*, ABAL – *Abies alba*, PIPI – *Pinus Pinaster*, PIBR – *Pinus Brutia*, LAGE – *Larix gmelinii*, PIPN – *Pinus pinea*, CASA – *Castanea sativa*, PINI – *Pinus nigra*, FREX – *Fraxinus excelsior*, ABSI – *Abies sibirica*.

2. Data source

The ABI-network was established by multiple researchers from the Swiss Federal Research Institute WSL (Dendro Sciences Group) and collaborating institutions. The earliest sites were collected in 2009 within the framework of the EU CARBO-Extreme project (www.carbo-extreme.eu/; Babst et al. 2014a,b). Subsequently, the network was greatly expanded within the iTREE project (www.psi.ch/snf-itree; funded by the Swiss National Science Foundation) to its current size (Klesse et al., in revision). The network presented herein contains all data that were available in summer 2017. Future expansion of the ABI-network is intended.

3. Data processing

The data collected at each site include:

- Increment cores to the pith of all trees within circular fixed plots for TRW measurements. Plot radii varied between 10 and 40 m (network mean = 17 m), depending on stand density and heterogeneity

- The position of each tree relative to the plot center
- Biometric variables of each tree: Diameter at breast height (DBH), tree height, crown base height
- Additional metadata (species, social status, condition)

The raw TRW series were visually and statistically "crossdated" using the program COFECHA (Holmes 1983) to ensure the correct assignment of each measured ring to a calendar year. These data were used for ABI reconstruction (see below). For other applications (*e.g.* the detection of environmental signals) the raw tree-ring data need to be "detrended" (= standardized) to remove the biological/geometric age-trend that is inherent to tree-ring data (*i.e.* ring width decreases with tree age). The choice of the detrending method depends on the research question and strongly influences the resulting site chronology. More flexible (rigid) methods are usually chosen to preserve more high (low) frequency variability in the data.

The data provided herein (see Section 5) were detrended using a cubic smoothing spline basis with a 50% frequency cutoff at 8 different lengths: 10, 30, 50, 100, 150, 200 and 300 years, as well as at 2/3 mean segment length (MSL). We emphasize, however, that this detrending is not suitable for all types of research questions and users are encouraged to perform their own standardization. Mean chronologies for each site were calculated from the detrended tree-level series using a bi-weight robust mean.

In preparation of the ABI estimates, the annual changes in the dimensions of each tree (DBH, height) were reconstructed using the TRW measurements and starting from the field observations in the sampling year (see Bakker 2005 and Babst et al. 2014a,b for methodology). The tree-level aboveground biomass in each year was estimated based on the historical tree dimensions and using species-specific allometric equations (Zianis et al. 2005, Tabacchi et al. 2011; Klesse et al. in review). Tree-level ABI was subsequently calculated as the difference in the biomass between year t and t-1.

The software used for data processing included the "dplR" package in R (Bunn et al. 2008), as well as the tree-ring programs ARSTAN and COFECHA (Holmes 1983).

4. Uncertainty estimation

Regarding TRW, the principal source of uncertainty is the upscaling from the tree to the site level, *i.e.* the calculation of a mean site chronology. This is mainly a consequence of genetic differences between individual trees and the micro-environment (topography, competition, climate, soil, herbivory etc.) that they experience. As a measure of this uncertainty, we calculated bootstrapped 95% confidence intervals (CI) around the mean detrended chronologies. The upper and lower CI for each year is provided in separate files alongside the mean chronologies (see Section 5).

Assuming that the sampling captured a representative subset of the respective forest stand (Nehrbass-Ahles et al. 2014), the principal sources of uncertainty in ABI estimates are the applied allometric equations (Alexander et al., under revision). These species-specific equations have intrinsic uncertainties (Nickless et al. 2011) and are often not published with enough detail for appropriate error propagation. In addition, none of them were developed for the exact ecological conditions at the ABI-network sites. These uncertainties were addressed by considering all suitable equations that were available for a given species, geographic area, and tree size range. The ensemble maximum and minimum in a given year were defined as the upper and lower uncertainty boundaries.

5. Files

Metadata

Site level:

Filenames: *"ABI_Europe_metadata_sitelevel_BACI2017.txt"*
Format: Tabular (each row represents one site, each column represents one parameter)

Site-level parameters:

- Site code
- Site name
- Country
- Latitude [°N]
- Longitude [°E]
- Elevation [m a.s.l.]
- Plot radius (radius of the fixed sampling plot)
- Plot area [m^2]
- Stem basal area [$m^2 ha^{-1}$]
- Stem density [ha^{-1}]
- Dominant species
- Co-dominant species
- Percentage dominant species
- Percentage co-dominant species
- First year (start year of the chronology)
- Last year (end year of the chronology
- Total year (length of the chronology in years)

Tree level:

Filenames: *"sitename.csv"* (the site name corresponds to the "SiteCode" column in the site-level metadata)
Format: Comma separated values (.csv) with separator ";"

Tree-level parameters:

- Tree code
- Site code
- Species (for full names, see "ITRDB code" on: http://www.wsl.ch/dendro/products/dendro_species/index_EN)
- Plant functional type
- Status (alive or dead)
- Diameter at breast height (DBH) [cm]
- Tree height [m]
- Crown base height [m]
- Distance from plot center [m]

- Azimuth [°]
- Social status (dominant, co-dominant, dominated, suppressed)
- X coordinate within the plot
- Y coordinate within the plot

Raw tree ring-width data

Content: Raw tree-level tree-ring width measurements
Filenames: Individual filenames correspond to the site code in the metadata
Format: Tabular (each row represents one year, each column represents one tree series, header corresponds to the tree code in the tree-level metadata)
Known issues: measurements from some trees at the TER and VOR sites contain only mean TRW measurements. This error also affects the detrended TRW data and the ABI estimates of the respective trees.

Detrended tree-level data

Content: Detrended tree-level tree-ring width indices
Filename: Individual filenames correspond to the site code in the metadata
Format: NetCDF, (dimension 1 = Time [years]; dimension 2 = measurement series; dimension 3 = spline length used for detrending → see section 3)

Detrended site-level data

Content: Detrended site-level tree-ring width chronologies and uncertainty estimates
Filenames:
"ABIsites_TRW_detrended_sitelevel_mean_BACI2017.nc" (chronologies)
"ABIsites_TRW_detrended_sitelevel_CI95up_BACI2017.nc" (upper uncertainty boundary)
"ABIsites_TRW_detrended_sitelevel_CI95low_BACI2017.nc" (lower uncertainty boundary)
Format: NetCDF, (dimension 1 = Time [years]; dimension 2 = site chronologies; dimension 3 = spline length used for detrending → see section 3)

Tree-level estimates of annual above-ground biomass increment (ABI)

<u>Ensemble spread:</u>

Content: Tree-level ABI estimates from between 1 and 6 allometric biomass functions (depending on availability for a given species and location, see Section 3)
Filenames: Individual file names correspond to the site code in the site-level metadata.
Format: Tabular (each row represents one year; trees are combined by rows → see identifier column "Treeno")

<u>Ensemble mean:</u>

Content: Mean, max (uncertUP) and min (uncertLOW) tree-level ABI estimates from the ensemble spread
Filenames: Individual file names correspond to the site code in the site-level metadata.
Format: Tabular (each column corresponds to one tree, each row corresponds to one year)

6. Contact

For questions or comments, please contact:

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European tree-ring stable isotope dataset

This document describes the European network of tree-ring stable isotope data that was compiled and homogenized within BACI WP3, task 3.4 *("Synthesis of available tree-ring records")*. This dataset is subsequently referred to as the "isotope network".

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7. References

1. Network description

The isotope network consists of 43 sites from twelve European countries and Morocco (Figure 1). Data from coniferous and broadleaf species are available from 28 and 15 sites, respectively. Site selection was based upon criteria including stand age, proximity to measurement locations of the isotopic composition of precipitation, and spatial distribution across Europe (Treydte et al. 2007; Frank et al. 2015). Stable carbon isotope measurements ($\delta^{13}C$, see below) are available at 43 sites and stable oxygen isotopes ($\delta^{18}O$) are available at 11 sites.

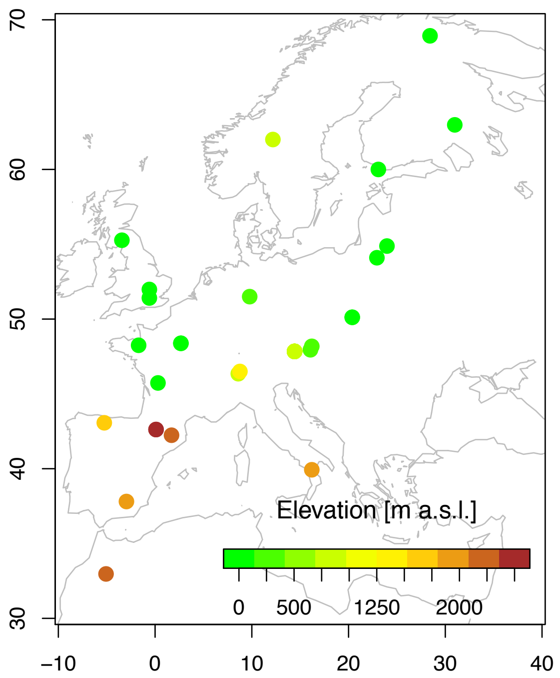

Figure 1: Geographic location of the sites that constitute the European isotope network.

A total of ten species are represented, with the genera *Pinus* and *Quercus* being the most common (Figure 2a). Most of the network covers the 20th century, with some sites extending further towards the present and/or into the past (Figure 2b,c).

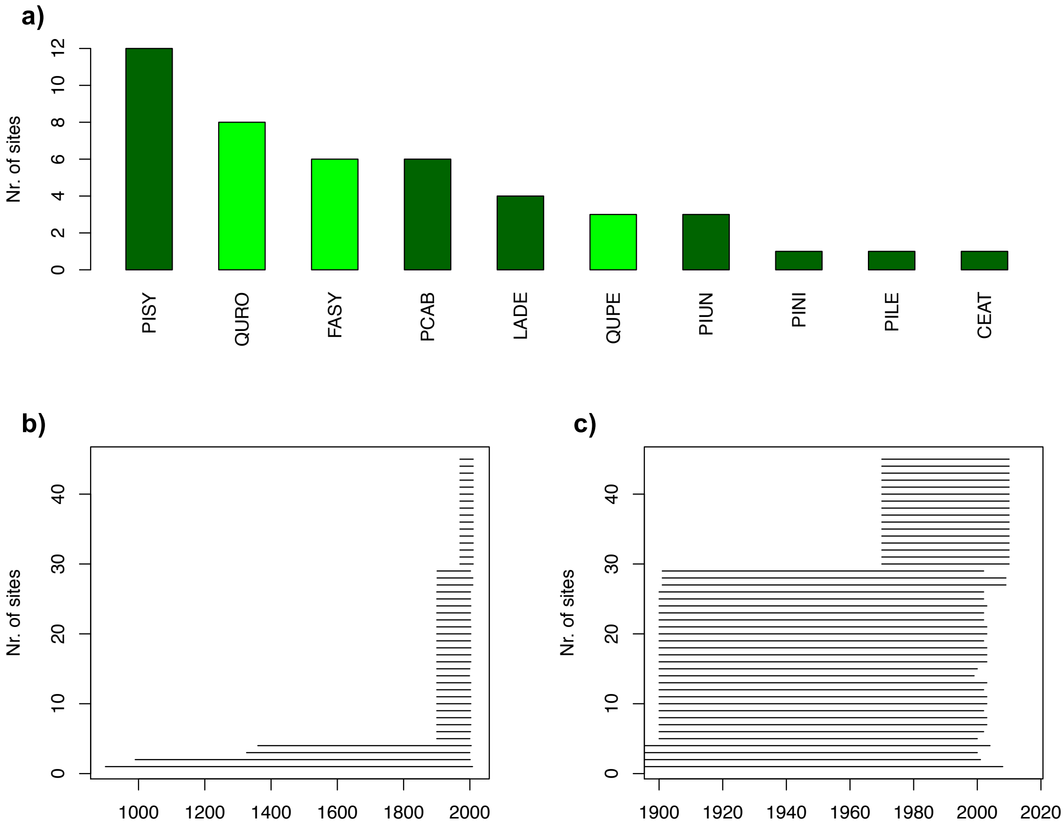

Figure 2: The number of sites with different conifer (dark green) and broadleaf (light green) tree species are shown in panel (a). Temporal changes in the number of sites that contain data in a given year are shown in panel (b) for the past 1000 years and in panel (c) for 1900-2016. PISY – *Pinus sylvestris*, QURO – *Quercus robur*, FASY – *Fagus sylvatica*, PCAB – *Picea abies*, LADE – *Larix decidua*, QUPE – *Quercus petraea*, PIUN – *Pinus uncinata*, PINI – *Pinus nigra*, PILE – *Pinus leucodermis*, CEAT – *Cedrus atlantica*.

The stable isotope records are based on increment cores from 4-8 trees that have been prepared according to established protocols (McCarroll & Loader 2004). These involve separation and milling of the annual rings (except for *Quercus* where only the latewood was analyzed; Treydte et al. 2007). At all sites except one (Lake Gerber; Konter et al. 2014), the material of all tree rings from the same year was combined (pooled) and alpha cellulose was extracted following standard procedures (e.g. Boettger et al. 2007). Subsequently, the cellulose was combusted to CO_2 or pyrolised to CO (depending on the used system), prior to mass spectrometer analysis. The resulting ratios of $^{13}C/^{12}C$ and $^{18}O/^{16}O$ in the pooled tree rings are by convention expressed using the delta notation (δ) and relative to a standard. The current standard for $\delta^{13}C$ is the Vienna-PDB (VPDB) and for $\delta^{18}O$ the Vienna standard mean ocean water (VSMOW).

2. Data source

The isotope network consists of data from the International Tree-Ring Data Bank (https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring), Institute of Geography at the University of Mainz (Prof. Dr. Jan Esper, Dr. Claudia Hartl-Meier, Dr. Oliver Konter), and the ISONET Consortium. ISONET was supported by the European Union within the ISONET (EVK2-CT-2002-00147) and MILLENNIUM (GOCE 017008-2) projects. Please refer to Treydte et al. 2007, Konter et al. 2014, Hartl-Meyer et al. 2015, and Frank et al. 2015 for further details.

3. Data processing

All raw ISONET data were screened for missing values and gap-filled using information from adjacent chronologies (Pederson et al. 2004, Treydte et al. 2007). The tree-level data that were available for the Lake Gerber site (Konter et al. 2014) were averaged into a mean site-level chronology to match the resolution of all other data. All data were visually and statistically "crossdated" using the program COFECHA (Holmes 1983) to ensure the correct assignment of each measured ring to a calendar year. Please note that the isotope network implies no correction for changes in the carbon dioxide content of the atmosphere ("PIN correction"; McCarroll et al. 2009) or the depletion of atmospheric ^{13}C that results from fossil fuel burning and deforestation.

4. Uncertainty estimation

The principal sources of uncertainty in tree-ring stable isotope records are:

1) the measurement precision of the used mass spectrometer system
2) the upscaling from the tree to the site level, *i.e.* the calculation of a mean site chronology
3) post-photosynthetic fractionation that may alter the isotope ratios obtained from tree-rings compared to leaf-level processes. This is related to secondary sugar synthesis, respiration, compound exchange with the phloem, or the storage and remobilization of non-structural carbohydrates (Gessler et al. 2014; Frank et al. 2015)

In the current version of the dataset, only (1) has been quantified. It is intended to add uncertainties 2 and 3 in a future upgrade, together with further site records as they become available.

5. Files

Metadata

Content: Site-level metadata
Filename: *"ISO_Europe_metadata_sitelevel_BACI2017.txt"*
Format: Tabular (each row represents one site, each column represents one parameter)

Parameters:

Latitude [°N]
Longitude [°E]
Elevation [m a.s.l.]
Site name
Site code (corresponds to the ITRDB)
Contributor (as listed on the ITRDB)
Species short name (for full names, see "ITRDB code" on:
http://www.wsl.ch/dendro/products/dendro_species/index_EN)
Genus
Source
First year (start year of the chronology)
Last year (end year of the chronology
Total year (length of the chronology in years)
Parameter (c = δ^{13}C, o = δ^{18}O)

Raw data

Content: Raw site-level tree-ring stable isotope measurements and uncertainty estimates
Filenames:
"ISO_Europe_sitelevel_chrono_BACI2017.txt" (Header corresponds to the site code in the metadata)
"ISO_Europe_sitelevel_uncertUP_BACI2017.txt" (upper uncertainty boundary)
"ISO_Europe_sitelevel_uncertLOW_BACI2017.txt" (lower uncertainty boundary)
Format: Tabular (each row represents one year, each column represents one site)

6. Contact

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7. References

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Frank DC, Poulter B, Saurer M, et al. (2015) Water-use efficiency and transpiration across European forests during the Anthropocene. *Nature Climate Change* 5:579-583.

Gessler A, Ferrio JP, Hommel R, Treydte K, Werner RA, Monson RK (2014) Stable isotopes in tree rings: towards a mechanistic understanding of isotope fractionation and mixing processes from the leaves to the wood. *Tree Physiology* doi: 10.1093/treephys/tpu040.

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McCarroll D, Gagen MH, Loader NJ, et al. (2009) Correction of tree ring stable carbon isotope chronologies for changes in the carbon dioxide content of the atmosphere. *Geochimica et Cosmochimica Acta* 23: 1539-1547.

Pederson N, Cook ER, Jacoby GC, Peteet DM, Griffin KL (2004) The influence of winter temperatures on the annual radial growth of six northern range margin tree species. *Dendrochronologia* 22:7–29.

Treydte K, Frank D, Esper J, et al. (2007) Signal strength and climate calibration of a European tree-ring isotope network. *Geophysical Research Letters* 34, doi:10.1029/2007GL031106

Global tree-ring width dataset

This document describes the global tree-ring network that was compiled and homogenized within BACI WP3, task 3.4 *("Synthesis of available tree-ring records")*.

Outline:

1. Network description
2. Data source
3. Data processing
4. Uncertainty estimation
5. Files
6. Contact
7. References

1. Network description

A total of 6323 single species tree-ring records have been compiled into a network that contains data from 4559 sites on six continents and spans most of the world's extra-tropical forests (Figure 1). A limited number of tropical chronologies are also available. The majority of sites are located in Eurasia, North America, southern South America, and New Zealand.

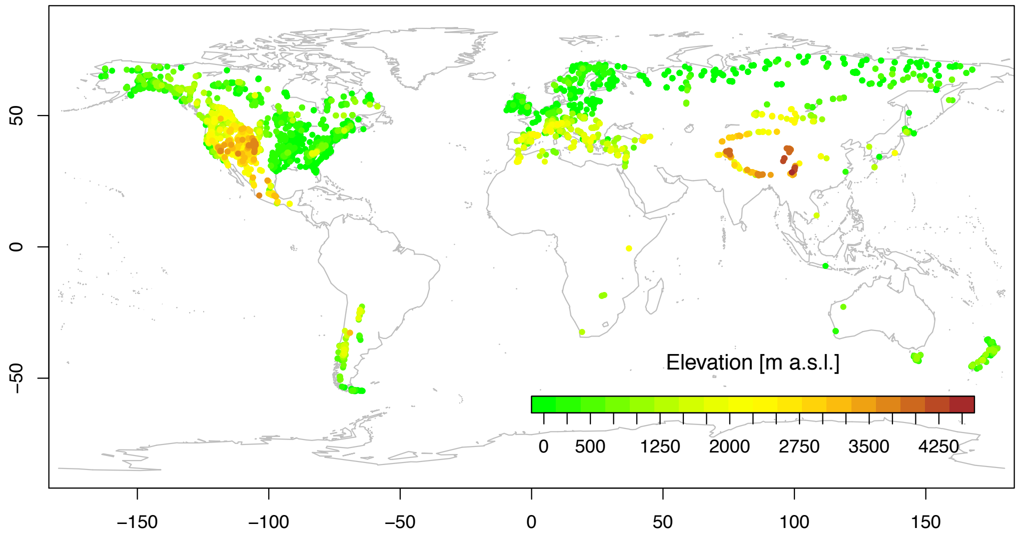

Figure 1: Geographic location of the sites that constitute the global tree-ring network.

The records consist of an average of n = 35 tree-level series (network max n = 1707, min n = 5), usually collected from increment cores or stem cross-sections of living or relic wood material. These samples are prepared according to standard dendrochronological procedures (Speer 2012) and measured to a precision of 0.01 or 0.001 mm, depending on the used devices and software.

Available measurement parameters include:

- Total ring-width (TRW; all sites)
- Earlywood width (EW; 607 sites)
- Latewood width (LW; 603 sites)
- Maximum latewood density (MXD; 568 sites)

EW refers to the “lighter” portion of a tree ring that consists of thin-walled cells and is mainly formed early in the growing season (Figure 2). LW describes the “darker” portion of the ring that consists of thick-walled cells and is formed towards the end of the growing season. MXD refers to the highest wood density that occurs in a coniferous ring. This parameter is a potent proxy for the mean growing season temperature in cold regions (*e.g.* Jones et al. 2009).

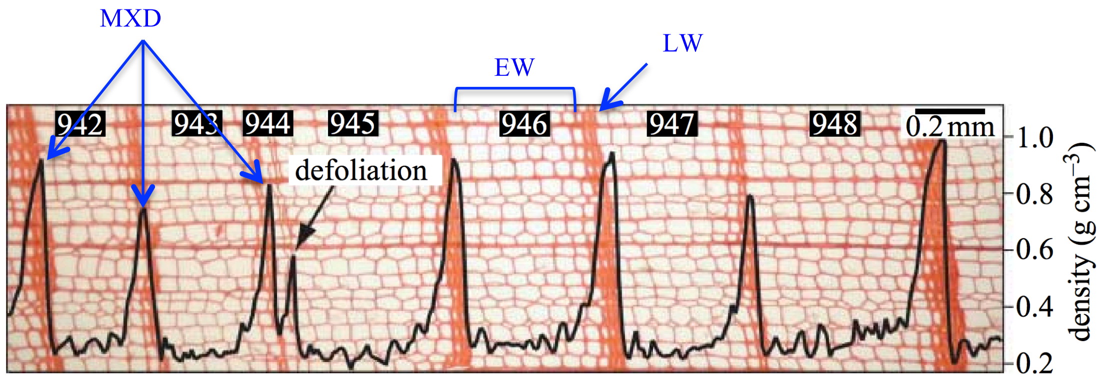

Figure 2: Example of a tree-ring sequence (*Larix decidua*, Switzerland) and corresponding wood density measurements (black line). The parameters of earlywood width (EW), latewood width (LW), and maximum latewood density (MXD) are illustrated in blue. Source of the graph: Esper et al. 2007.

82% of the records were collected from coniferous species and 18% from broadleaf species. A total of 213 species are present in the network, but the genera *Pinus*, *Picea* and *Quercus* are most frequently represented (Figure 3a), together constituting more than half of the network. The temporal coverage peaks in the mid 20th century and decreases both forward and backward in time (Figure 3b,c).

2. Data source

A large number of researchers and technicians have developed the constituting records of the tree-ring network. These data are publicly available from the International Tree Ring Data Bank (ITRDB; https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring), the largest collection of global tree-ring data that is managed by the US National Oceanic and Atmospheric Administration (NOAA). This database grows continuously as new records become available. In its current form, the ITRDB is a diverse and heterogeneous archive with only basic information (metadata) recorded for many sites. However, efforts to standardize and improve future data and metadata collection are being made (Jansma et al. 2010; Brewer et al. 2010; Babst et al. 2014). The network presented herein contains all data that was available from the ITRDB in fall 2016 and could be homogenized with reasonable effort (see Section 3).

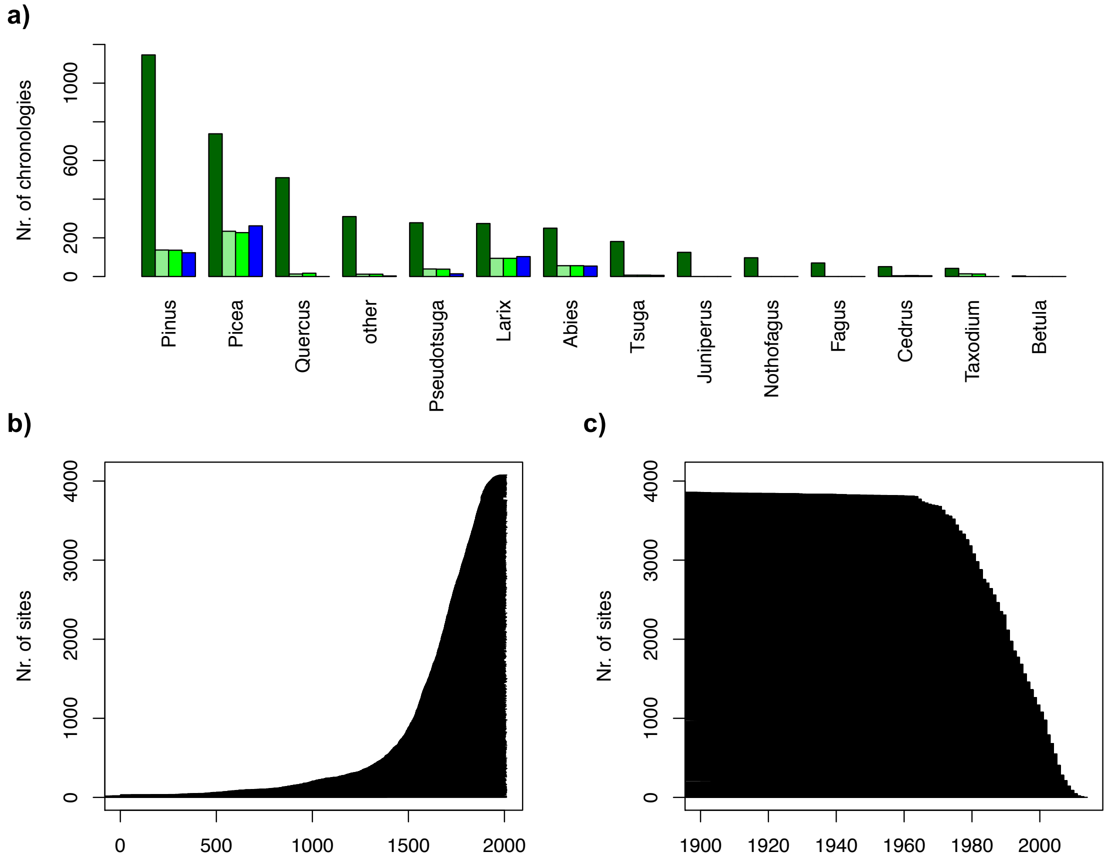

Figure 3: The number of chronologies from different tree genera is shown in panel (a) for tree-ring width (dark green), earlywood width (light green), latewood width (green), and maximum latewood density (blue). Temporal changes in the number of sites that contain data in a given year are shown in panel (b) for the past two millennia and in panel (c) for 1900-2016.

3. Data processing

The raw data for each site were downloaded from the ITRDB in the so-called "Tucson" format (see Section 5). These data come "crossdated", *i.e.* the correct attribution of each measured tree ring to a calendar year has been visually and statistically ensured by the contributing researcher prior to upload to the ITRDB. The metadata that correspond to each site were downloaded and rearranged from the available XML format into a tabular form (see Section 5 for a list of parameters).

Automated processing of the raw data was complicated by format inconsistencies in approximately 300 chronologies. Manual correction of these files was possible with reasonable effort for all except 77 files that were discarded. Each retained file was quality controlled to match the following criteria:

- Minimum coverage of the period 1920-1970 when most data were available.
- Minimum sample replication of n = 5 trees
- Significant mean correlation between the constituting tree-level series within a site (known as "rbar") at $\alpha = 0.05$.

Raw tree-ring data contain a biological/geometric age-trend, *i.e.* ring width decreases with tree age. This trend masks any environmental signals that are preserved in the data and needs to be removed through standardization ("detrending"). The choice of the detrending method depends on the research question and strongly influences the resulting chronology. More flexible (rigid) methods are usually chosen to preserve more high (low) frequency variability in the data.

The data provided herein (see Section 5) were detrended using a cubic smoothing spline basis with a 50% frequency cutoff at 8 different lengths: 10, 30, 50, 100, 150, 200 and 300 years, as well as at 2/3 mean segment length (MSL). We emphasize, however, that these detrendings are not suitable for all types of research questions and users are encouraged to perform their own standardization on the raw data.

Site-level chronologies were calculated from the detrended tree-level series using a bi-weight robust mean. The software used for data processing included the "dplR" package in R (Bunn et al. 2008), as well as the tree-ring programs ARSTAN and COFECHA (Holmes 1983).

4. Uncertainty estimation

The principal source of uncertainty in tree-ring width records is the upscaling from the tree to the site level, *i.e.* the calculation of a mean site chronology. This is mainly a consequence of genetic differences between individual trees and the micro-environment (topography, competition, climate, soil, herbivory etc.) that they experience. As a measure of this uncertainty, we calculated bootstrapped 95% confidence intervals (CI) around the mean detrended chronologies. The upper and lower CI for each year is provided in separate files alongside the mean chronologies (see Section 5).

5. Files

Metadata

Content: Site-level metadata
Filename: *"TRW_global_metadata_sitelevel_BACI2017.txt"*
Format: Tabular (each row represents one site, each column represents one parameter)

Metadata parameters:

- Latitude [°N]
- Longitude [°E]
- Elevation [m a.s.l.]
- Site name
- Site code (corresponds to the ITRDB)
- Contributor (as listed on the ITRDB)
- Species short name (for full names, see "ITRDB code" on: http://www.wsl.ch/dendro/products/dendro_species/index_EN)
- Genus
- Data source
- North-South coordinate of the corresponding 0.5° grid cell in the CRU gridded climate dataset
- East-West coordinate of the corresponding 0.5° grid cell in the CRU gridded climate dataset
- First year (start year of the chronology)
- Last year (end year of the chronology
- Total year (length of the chronology in years)
- NOAA_server_code of the site on the ITRDB

- Parameter (w = total ring width; e = earlywood width; l = latewood width; x = maximum latewood density)
- Mean segment length (MSL) of all measured series
- Number of measured trees
- Raw file name (name of corresponding raw data file)
- Detrended file name (name of the corresponding detrended tree-level data file)

Raw tree-level data

Content: Raw tree-level tree-ring width measurements
Filenames: Individual filenames correspond to the "raw.files" column and the site code in the metadata
Format: Tabular, (each row represents one year (column 1), each column represents one measurement series)

Detrended tree-level data

Content: Detrended tree-level tree-ring width indices (see Section 3)
Filenames: Individual filenames correspond to the "det.files" column and the site code in the metadata
Format: NetCDF, (dimension 1 = Time [years]; dimension 2 = detrended measurement series; dimension 3 = spline length used for detrending → see section 3)

Detrended site-level data

Content: Detrended site-level tree-ring width chronologies and uncertainty estimates
Filenames:
"TRW_global_detspline_sitelevel_chronologies_BACI2017.nc" (chronologies)
"TRW_global_detspline_sitelevel_CI95up_BACI2017.nc" (upper uncertainty boundary)
"TRW_global_detspline_sitelevel_CI95low_BACI2017.nc" (lower uncertainty boundary)
Format: NetCDF, (dimension 1 = Time [years]; dimension 2 = detrended site chronologies; dimension 3 = spline length used for detrending → see section 3)

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7. References

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