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# Tree-ring data set for dendroclimatic reconstructions and dendrochronological dating in European Russia

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The data set presented represents 15 years of collection. It contains tree-ring width measurements from 64 sites of living trees and ten historical chronologies based on archaeological and construction wood up to year 572 CE, altogether 2909 tree-ring series and more than 450000 measured and cross-dated tree rings. It covers the vast territory of European Russia, including its forested northern and central parts, and the Northern Caucasus mountains. The potential use of these data include climatic reconstructions of regional and hemispheric scale, dendrochronological dating of historical and cultural wood, ecological and remote sensing studies.

## Background & Summary

Tree rings are an important source of ecological, biological, paleoclimatic, astronomic, geomorphic, archaeological, and cultural information<sup>1,2</sup>. In dendrochronology various parameters of tree rings are used, such as total ring width, early and late wood ring width, density, cell wall and cell lumen area, stable isotopes of different elements, chemical composition as well as specific features of the wood (tension and compressive wood, resin ducts, light and frost rings, fire scars, etc.)<sup>2-5</sup>. However, the tree-ring width is the basic parameter that serves to establish the chronology before all other parameters can be measured. In some regions, for example in the North America and Western Europe, tree-ring chronologies are abundant and are represented in the databases with open access. The most comprehensive global tree-ring database is the International Tree-Ring Data Bank<sup>6</sup> (ITRDB, <https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring>) that includes several thousand of entries in standard format. The tree-ring data from the ITRDB are intensively used in various studies, including large-scale regional and global palaeoreconstructions<sup>7</sup>.

Tree-ring data from European Russia is represented rather poorly in the ITRDB so far. Most of those records are from living trees concentrated along the northern tree line and predominantly come from the massive sampling campaigns that occurred in the end of 1990s<sup>8,9</sup>, and a recently submitted collection of 13 chronologies from the central and northern parts of the region<sup>10</sup>. In the 2000s several regional wood collections appeared in the Volga region<sup>11</sup>, in Voronezh region<sup>12</sup>, in the Komi Republic<sup>13</sup> etc., although they are not in the ITRDB. The number of chronologies based on sub-fossil and archaeological wood and submitted to the ITRDB is even smaller<sup>14,15</sup>. These last two types of chronologies are not connected to any living-tree chronology from nearby locations. A more detailed description of the current state of dendrochronological data and research in the region may be found in the recent review<sup>16</sup>.

In this paper we introduce a collection of 64 ring-width chronologies from living trees for European Russia, including Northern Caucasus: pine (*Pinus sylvestris* L.), spruce (*Picea abies* (L.) Karst., *P. obovata* Lebed.), Larch (*Larix sibirica* Lebed.), and oak (*Quercus robur* R.). Beech (*Fagus orientalis* Lipsky) and fir (*Abies nordmanniana* (Stev.) Spach) – are represented by single living tree chronologies. Unlike the East European plain the tree-ring sites at the Northern Caucasus are located predominantly at the high elevation<sup>17</sup>. Most of the samples were

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collected at the upper tree limit. Some as high as the Little Ice Age moraines to date the glacier advances<sup>18</sup>, and some at lower elevations, in the middle of the forest. The natural, drought-sensitive, lower tree limit in the Caucasus has risen by centuries of logging leaving very few opportunities to find long-living trees suitable for dendroclimatic reconstructions and dendrochronological dating.

Moreover, we introduce ten absolutely dated regional conifer and oak chronologies based on archaeological, architectural, and subfossil wood. The wood mostly comes from the old buildings. Some of the buildings have been or are being renovated with the replacement of wooden elements; others are currently crumbling. Many architectural monuments from which we collected wood for the chronologies presented here either do not exist anymore or were totally renovated with all the ancient wood replaced and thus forever lost for scientific use.

The wood in the collection described herein has been collected over the previous 15 years. The collection consists of 74 sites with 1680 trees and 2909 individual tree-ring series, and 456984 measured tree rings (Fig. 1). Most of the wood in the collection is available in the Institute of Geography RAS and accessible for further investigations upon request. Some scientific results based on these data are presented elsewhere<sup>17–22</sup>. The chronologies are plotted in Fig. 2 (the longest ‘living-tree’ chronologies, those that start before CE 1700), Fig. 3 (all the other living-tree’ chronologies), and Fig. 4 (historical chronologies).

The presented data set closes a vast gap in the Eurasian dendrochronological network and will serve for various applications: climatic reconstructions of regional and hemispheric scale, dendrochronological dating of historical and cultural wood, ecological and remote sensing studies.

## Methods

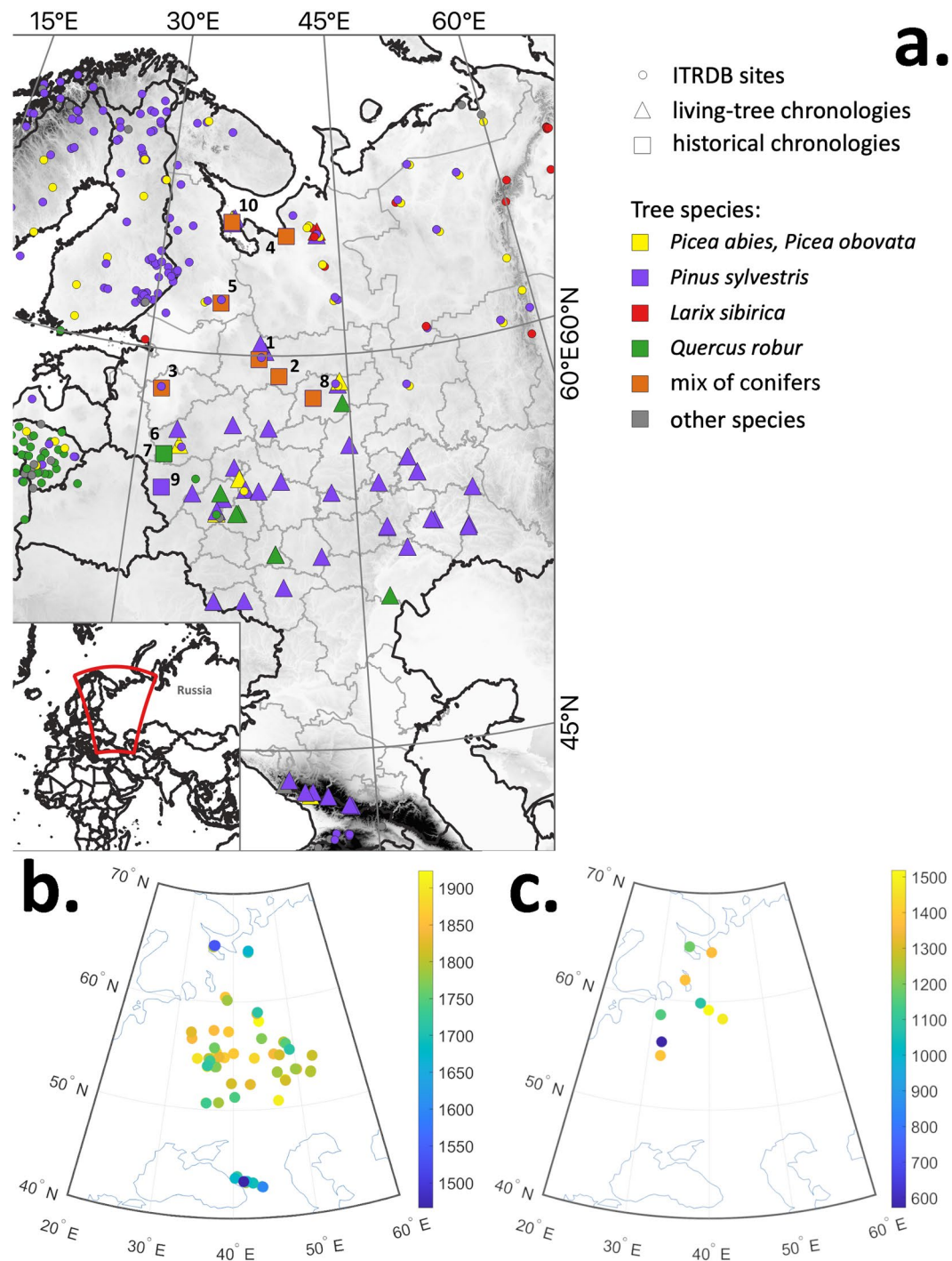
**Region, climate and species.** The study region includes the European Part of Russia (EPR) from its western borders to the Ural Mountains in the East, from the Arctic coast to the Northern Caucasus in the South. The climate of the EPR is characterized by marked seasonal changes, with cold winters and warm summers. Most of the EPR, except for the southern part, is in the humid continental climate zone (by Köppen–Geiger classification). The summer isotherms are located sublatitudinally because summer temperature depends mainly on solar radiation. Mean July temperature is about +8–10 °C at the northern part of the Kola Peninsula and about +25 °C in the Caspian region. The temperature gradient is more pronounced from west to east than from south to north. The climate of the EPR is moderated by westerlies: Atlantic air masses provide increased temperatures and precipitation in winter, while summers are rather cooler and wetter due to westerly transport. The mean January temperature varies from –5 °C in the west to –20 °C in the east. The coldest part of the EPR is the north-east, with snow cover lasting up to 7 months. Total precipitation is about 600–800 mm/year between 55°N and 65°N. From the Arctic Circle to the north, snow cover gradually decreases to 350 mm. Also, total precipitation decreases from 55°N in a south-easterly direction. In the Lower Volga region, it is about 250–400 mm/year, and near the Caspian Sea it can be lower than 250 mm/year. In most of the EPR summer precipitation exceeds precipitation in winter.

The climate of the Caucasus is determined by its location at the junction of temperate and subtropical climate zones, as well as by its elevation. The Greater Caucasus Range (with summits above 5000 m a.s.l.) serves as a barrier preventing humid Atlantic and Mediterranean air masses moving westward. Thus, total precipitation decreases from 3000 mm/year in the western and southern slopes, to 600–800 mm/year in the north-east. Temperature depends on elevation and slope exposition; on average southern slopes are 3 °C warmer than the northern slopes. The climate becomes more continental in the easterly direction, as the difference between summer and winter temperature increases, and the mean temperature at corresponding elevations increases from west to east.

The major biomes represented in the EPR are tundra, forest-tundra, forest, forest-steppe, semi desert and desert. The northern Kola Peninsula is covered by tundra and semi-tundra, the main tree species is dwarf birch (*Betula nana*). Boreal evergreen forests predominantly composed of pines are typical of the Fennoscandia region and the Northern Ridge area. All other territory to the north of 60°N is covered by boreal evergreen forests predominantly composed of spruce. The boundary between evergreen and mixed forest is 56–57°N. The mixed forest biome (the main species are oaks and pines) becomes narrower from east to west: it is located between 56–57°N and 52°N at the far west of the EPR, and between 56 and 58°N in the east. To the south of the mixed forests are the temperate broadleaf forests predominantly composed of oaks. The width of this zone is 200–300 km. The Caucasus plant communities vary with elevation. In the north-western part of the Caucasus mountains broadleaf forests are predominant at lower elevations, the dominant species between 400 and 1000 meters are Georgian oak (*Quercus iberica*) and European hornbeam (*Carpinus betulus*). Oriental beech (*Fagus orientalis*) and Caucasian oak (*Quercus macranthera*) are the predominant species between 1000- and 1500-meter elevation. The mixed forests above 1500-meter elevation include Caucasian spruce (*Picea orientalis*), Nordmann fir (*Abies nordmanniana*), and Caucasian pine (*Pinus sylvestris* var. *hamata*). Dwarf forests are above 1800 m.a.s.l., composed of oriental oak and Caucasian pine in drier areas, birch (*Betula pubescens* var. *litwinowii*) and *Betula raddeana*) in more humid areas. In the Elbrus region, all altitudinal belts shift upwards because of increasing aridity and continentality<sup>23</sup>.

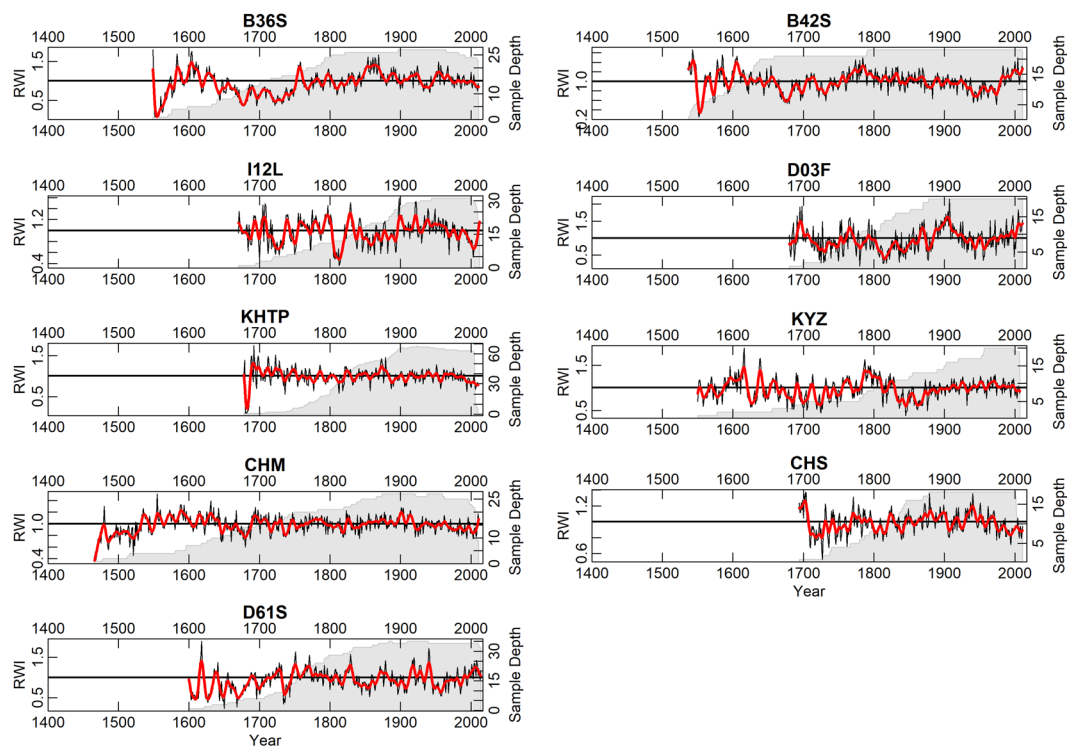
**Sampling and laboratory protocols.** The aim of all the living tree sampling efforts was to produce long chronologies, primarily for use in dendroclimatic studies. First selection priority was given to old trees, both dominant and subdominant undisturbed individuals. Normally, two cores from the opposite sides of the tree were collected at breast height with an increment corer. At each site 10 to 22 trees were sampled, with some exceptions (online-only Table 1).

In the laboratory, the cores were dried, mounted and sanded (in some cases first flattened by a core microtome and then slightly sanded). Then the ring widths were either directly measured on LINTAB device or Velmex Tree Ring Measuring system or scanned with 2800–3600 dpi resolution and measured using Coorecorder software. In all cases, the measurement precision exceeded 0.01 mm.



**Fig. 1** (a) Map of the study region with the chronologies represented in ITRDB and in the described data set. Historical chronologies are: 1 Kirillov, 2 Vologda, 3 Novgorod, 4 Arkhangelsk, 5 Karelia, 6 Zapadnaya Dvina 1, 7 Zapadnaya Dvina 2, 8 Kostroma, 9 Smolensk, 10 Solovki. Grayscale shading shows elevation. (b) Map with the locations of the 'living-tree' chronologies. The first year of the chronologies is shown by color. (c) Map with the locations of the 'historical' chronologies. The first year of the chronologies is shown by color. Note different color scales in (b) and (c).

Samples from wooden buildings and from wooden construction elements of stone buildings were usually collected by a specialized corer designed for use with an electric drill and produced by Schneidwerkzeugmechanik, Berlin (<https://www.schneidwerkzeugmechanik.de/>). In some cases, a traditional, manual increment corer was used, or cut from samples using a saw. Almost all archaeological wood was collected as saw-cuts. The cores from construction wood and the cores from living trees were treated in the laboratory equally. Wooden cuts were dried if wet, polished, and measured across two to four radii. In the case of poor preservation of the wooden samples, when it was impossible to achieve a reasonable quality of surface by polishing, the surface was prepared



**Fig. 2** The longest ‘living-tree’ chronologies: those that start before CE 1700. Black lines show tree-ring indices produced by ‘ModNegExp’ option in ‘detrnd’ function of R package *dplR*<sup>49</sup>. Red lines show 11-yr smoothing splines fitted to the tree-ring indices. Grey shading show sample depth – the number of measurements in each year. As in online-only Tables 1 and 2, the chronologies are represented from North to South.

using a razor blade. For example, all the archaeological samples used in Kirillov chronology (online-only Table 2) were prepared this way.

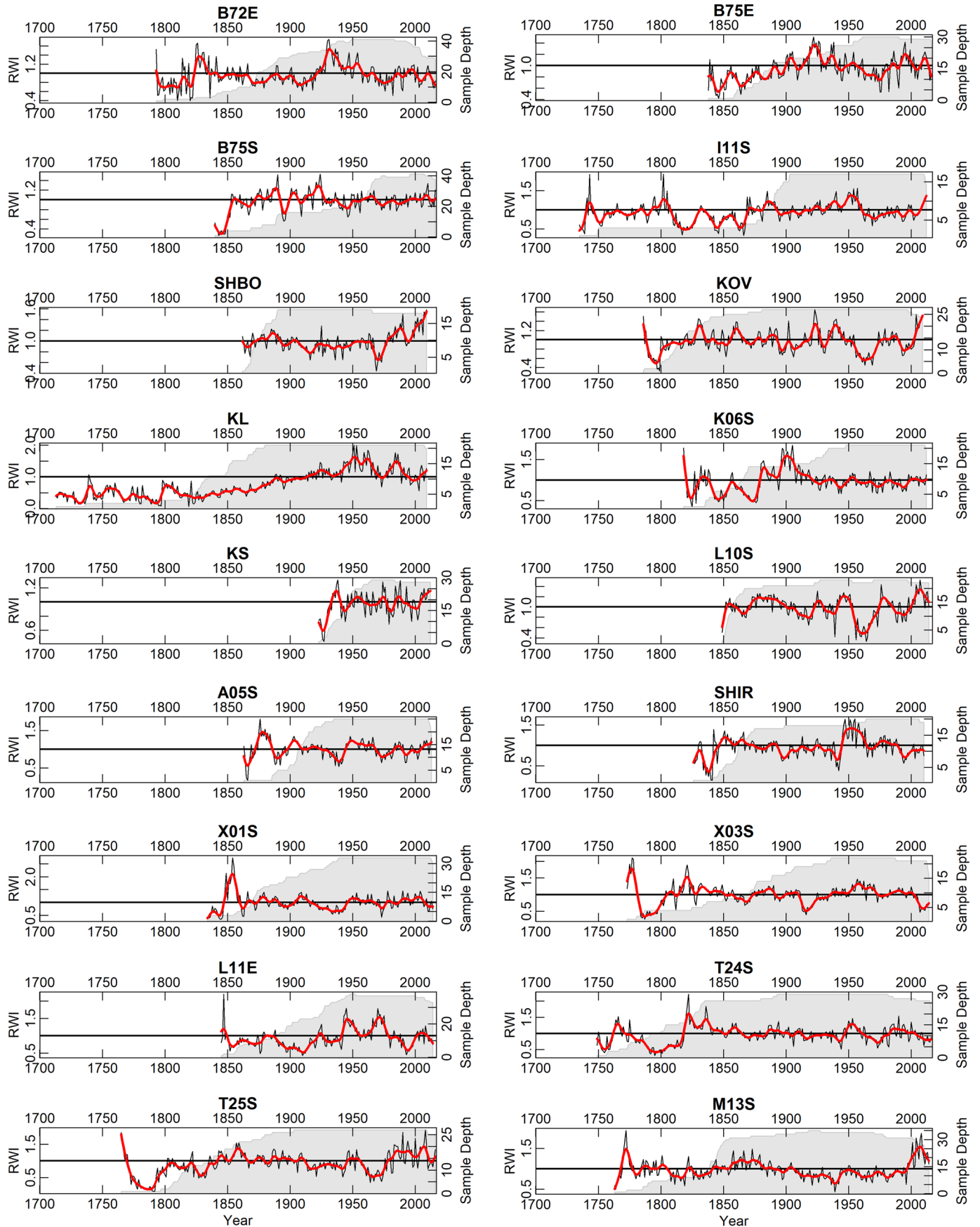
### Data Records

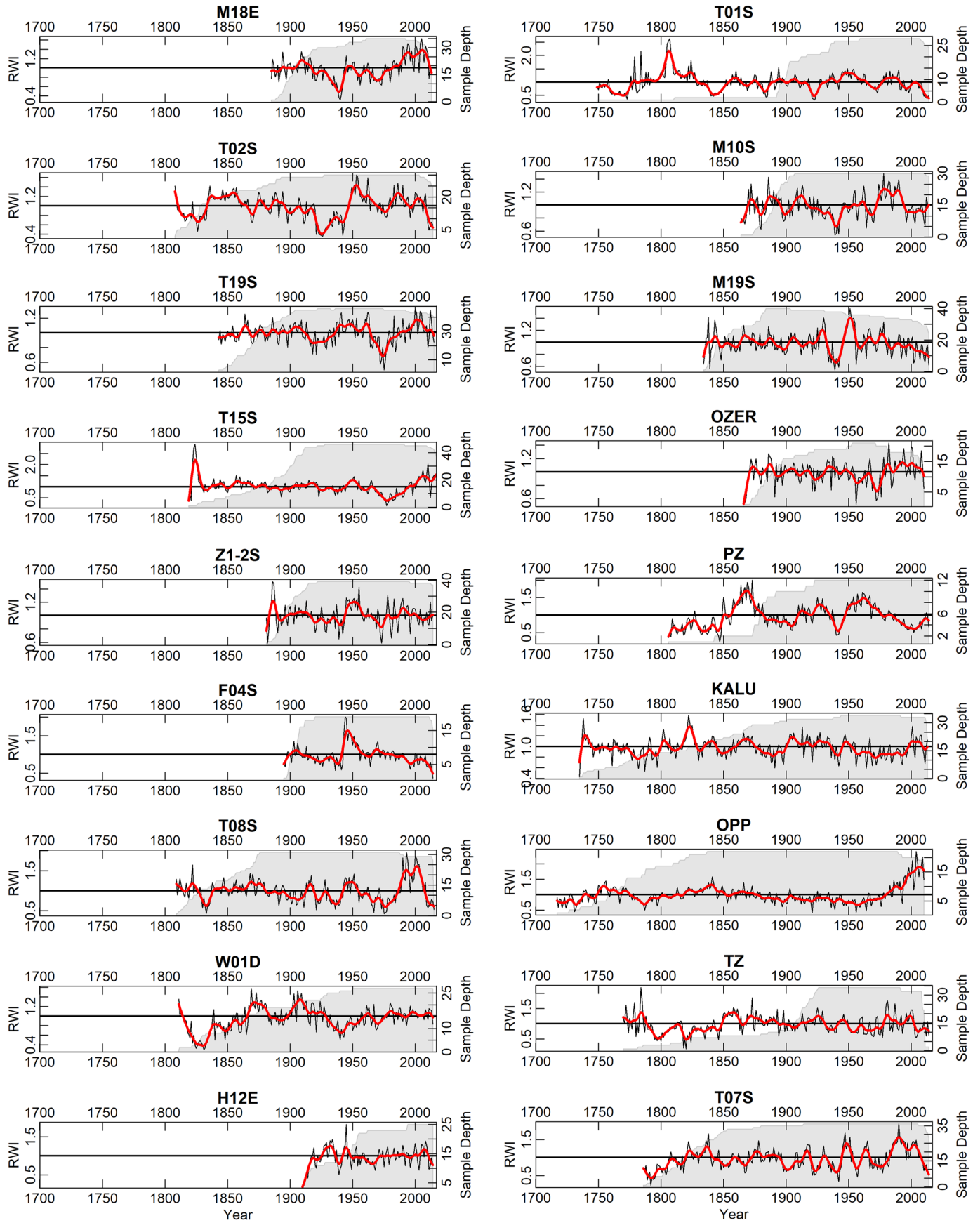
The data set consists of tree-ring width measurements in Decadal/Tuscon RWL format<sup>24</sup>, COFECHA<sup>25</sup> listings for every RWL file, online-only Tables 1 and 2 with the description for every living-tree and historical chronology. In each RWL file the measurements for each tree denoted by a number are usually represented by several cores denoted by the letters a,b,c, etc., e.g. T15S1a and T15S1b are two cores for the first tree at the site T15S, T15S15a and T15S15b are two cores for the 15<sup>th</sup> tree at the site. The historical chronologies usually contain several codes referring to different sources of materials, but the numbering is the same – numbers denote different beams from each source and letters a-d denote the measurements along different radii from each beam.

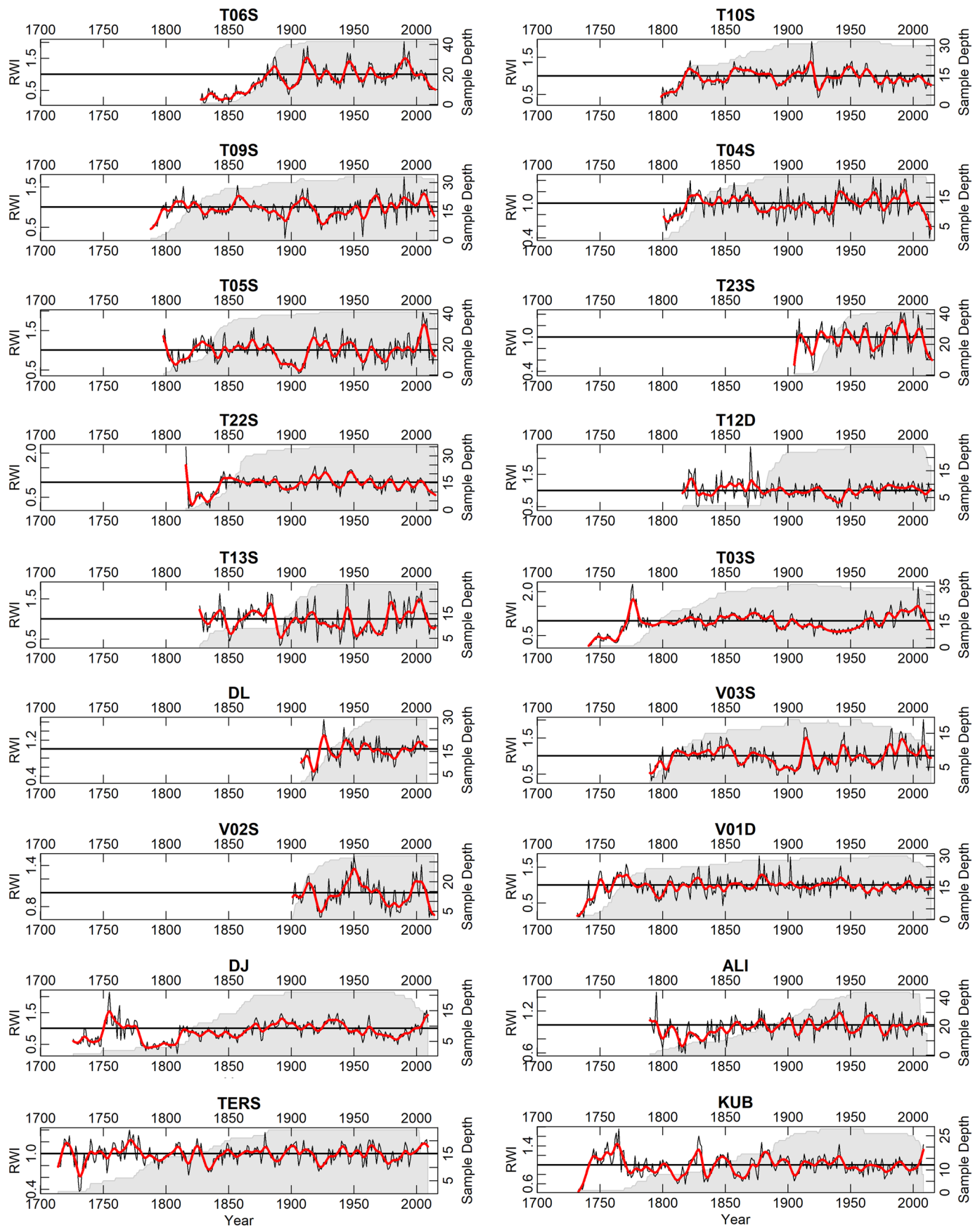
Missing values in RWL files are denoted either by zeroes in the case of missing rings or by –888 in the case of missing core segments. The description of each site contains the information on the location, geographical coordinates, number of trees and samples, information on series intercorrelation, average mean sensitivity, quality of the cross-dating, and related publications (online-only Tables 1, 2). Some sites also have descriptions of vegetation and soils. The RWL files of the measurements and the related COFECHA quality control listings are publicly available in ITRDB. The ITRDB codes and links are provided in the online-only Tables 1 and 2. The whole data set is also available as a standalone set of files<sup>26</sup> in Figshare repository, where RWL files are named as the site code plus ‘.rwf’ extension, the COFECHA listings are named as the site code plus ‘COF.txt’. For example, the site T15S is represented by the files ‘T15S.rwf’ and ‘T15SCOF.txt’. Supplementary Tables 1 and 2 represent printable versions of Online-only Tables 1 and 2, respectively.

Below we describe the sources of material for each historical chronology.

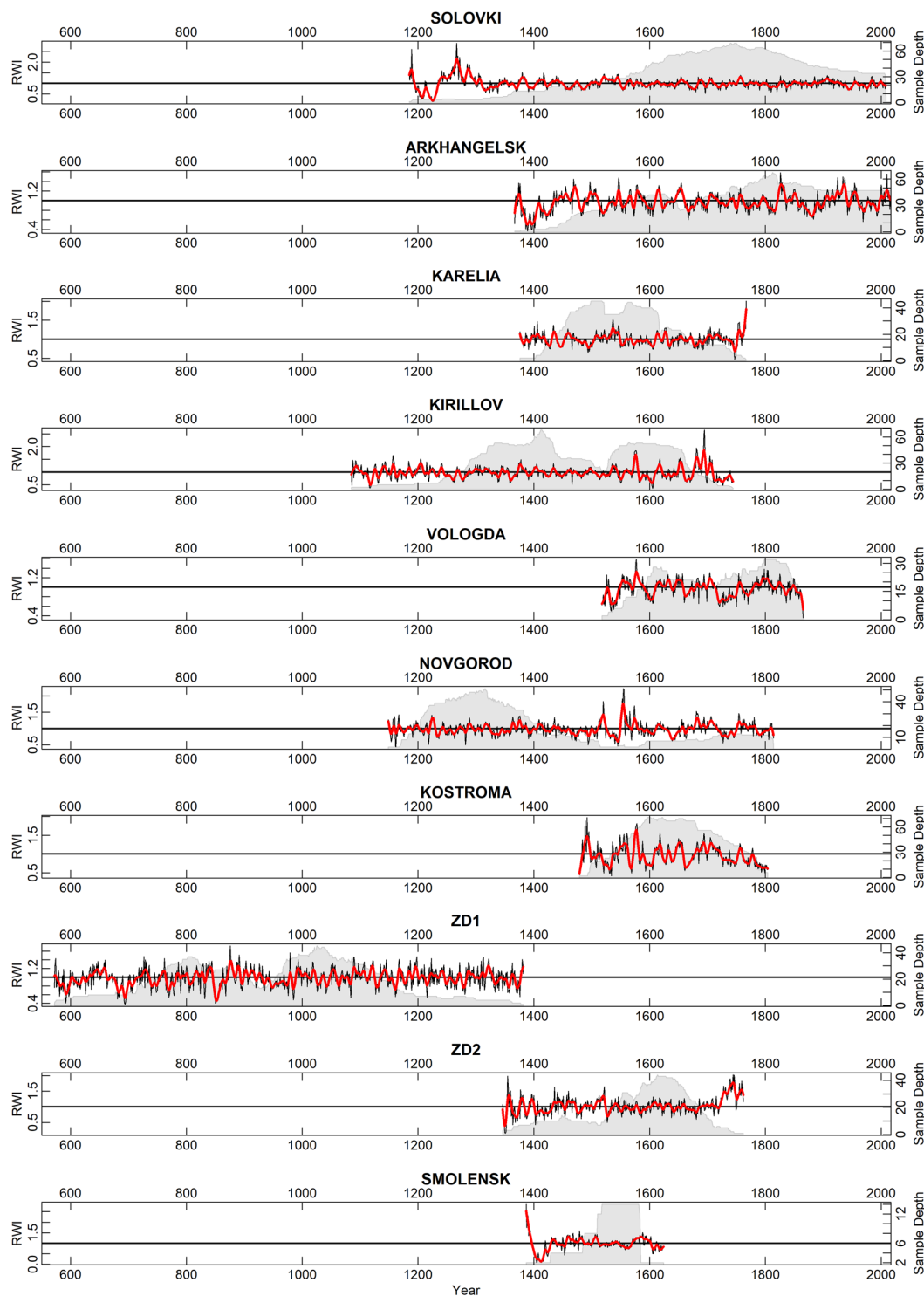
**Kirillov.** Materials for the Kirillov chronology were collected over many years from archaeological excavations in the town of Kirillov, Vologda region. They include wood samples obtained from architectural buildings and various small archaeological excavations in the vicinity of the Kirillo-Belozersky monastery (59.86°N, 38.37°E). During restoration work in 1969, 1971, 1985, and 1987, samples of wooden ties and piles of foundations from brick defensive walls and monastery buildings were collected. The archaeological part of the collection also contains samples from wooden log cabins, wells, and log heaps (remnants of buildings demolished during renovation) and discovered during rescue excavations in 1994, 1998–2000, 2007, 2008, 2011, 2015, 2016, and 2018. The samples were processed in the Laboratory of Natural Science Methods in Archaeology, Institute of Archaeology RAS. Unfortunately, most of the original material has not been archived after the measurements were made. The Kirillov chronology was calendar dated with living trees from the Vologda region (sites KOV and SHBO) and materials from the Museum of Wooden Architecture of the Vologda Region “Semyonkovo”<sup>27</sup>.







**Fig. 3** As Fig. 2, but for all the other 'living-tree' chronologies.



**Fig. 4** As Fig. 2, but for the ‘historical’ chronologies.

**Vologda.** The collection consists of materials from wooden buildings in the city of Vologda (59.22°N, 39.89°E). The data was assembled by D. Kats in the 1990s and later archived at the Institute of Plant and Animal Ecology in Ekaterinburg. In 2009 the collection was transferred again, and now resides at the Institute of Geography RAS, where ring-widths were measured a second time. The data set includes the samples from 19<sup>th</sup> century wooden houses on Gogol Street, numbers 3 and 5 (codes AU and AV), from Gertsen Street number 58 (code BA), from the Spaso-Prilutskiy Monastery in the northern outskirts of Vologda (code BB), and from samples of unknown origin from the 18<sup>th</sup> century (code M). The Vologda chronology was calendar dated with the Kirillov chronology.



**Novgorod.** Materials in the Novgorod chronology are derived from archaeological excavations in the city of Velikiy Novgorod (58.52°N, 31.27°E), in addition to samples from wooden buildings of the Novgorod Region. The latter include materials from building transferred to the Museum of Wooden Architecture “Vitoslavitsy” from the Novgorod region. These include the Chapel of Magdalena (code N04A), the Church of St. Nicolay from the village of Visokiy Ostrov (code N09A), and a church from the village of Tukholi (code N11A). Archaeological materials come from the city of Novgorod, from the excavation of Yaroslavovo Dvorische (archaeologist A.V. Andrienko, code N02A<sup>28</sup>), as well as excavations on Telegina-Redyatina Street (code ‘tere’), Posolskaya Street (code ‘posol’), Znamenskaya Street (code ‘znam’), Troitskaya Street (codes ‘35a-1-b1’ and ‘16a-1-v2’), and B. Konyushennaya Street (code ‘kon’), which were directed by archaeologist O.I. Oleynikov. The Novgorod chronology was calendar dated using the russ1 chronology from the ITRDB (with a correction for the known error of 1 year<sup>29</sup>), and by crossdating with the Kirillov and Vologda chronologies.

**Arkhangelsk.** The Arkhangelsk chronology includes samples from houses and churches from the northwestern part of the Arkhangelsk region (63.4–64.7°N, 37.4–43.4°E). These include wooden houses from the town of Pinega, Kudrina Street 45 and 55 (codes I15A and I14A, 64.70°N, 43.39°E), the house of the Bazheniny family in the village of Vavchuga, Kholmogorskoye district (code I21A, 64.23°N, 41.92°E), the Church of Introduction in the village of Vorzogory (code I02A, 63.89°N, 37.67°E), the Church of Vladimir in the village of Medvedevskaya (code I04A, 63.81°N, 38.32°E), and from the the Ensemble of the Church in the village of Piyala (codes I08A, I09A, P, 63.43°N, 39.08°E), all located in the Onezhskiy District. The chronology was calendar dated using a living pine tree-ring series (code I24S, 64.11°N, 38.03°E) in addition to crossdating with the Solovki chronology<sup>30</sup>.

**Karelia.** This chronology includes materials from eight churches in the Republic of Karelia, all located along the shores of Onega Lake (60.80–62.72°N, 33.06–35.27°E)<sup>31</sup>. Most of these measurements are of lower precision than of the other data in this study (0.05 mm versus 0.001 mm) however, they are vital to the dendrochronological dating in the region. The Karelia chronology was calendar dated using the Solovki and Arkhangelsk chronologies.

**Zapadnaya Dvina (ZD1, ZD2).** Tree-ring chronologies ZD1 and ZD2 were constructed with subfossil oak trees sampled in the alluvial deposits of the Zapadnaya Dvina River and its tributary, the Velsa River. The sample sites include reaches of both rivers upstream of their confluence (56.06°N, 31.97°E). Subfossil oak tree trunks were discovered in the riverbed as well as in riverbank alluvial deposits and oxbow lakes. The ZD1 and ZD2 chronologies do not overlap with the living oak tree-ring series from the region, but were crossdated with chronologies from Belarus and from the Baltic region. ZD1 (CE 572–1382) was calendar dated with oak samples from the Church of the Saviour’s Transfiguration in Polotsk (Belarus) which spans CE 869–1122<sup>32</sup>; it also crossdates with subfossil oak series from Smarhon, Belarus<sup>33</sup> and the Baltic 1 chronology<sup>34</sup>. A detailed report was previously published elsewhere<sup>14</sup>. The calendar age of the ZD2 chronology (CE 1346–1762) was established by comparison with the 2021BLT3 chronology<sup>35</sup>.

**Kostroma.** Materials for the Kostroma chronology come from archaeological excavations in the City of Kostroma and from the wooden buildings from the surrounding Kostroma Region. They include materials from a church in the Andreevskoye village (code K2A, 58.16°N, 41.30°E), two buildings from the Museum of Wooden Architecture in the Kostroma region, which include the house of Skobyolkina (code K13A), and the Church of Ilijah the Prophet (code K14A). The other materials come from the ‘Melochniye Ryady’ excavations in the center of Kostroma, (archaeologist A.Lazarev, code K09A). The chronology was calendar dated using the Kirillov and Vologda chronologies.

**Smolensk.** Seven beams of pine come from archaeological excavations at Pobedy Square in the city of Smolensk (54.78°N, 32.05°E)<sup>36</sup>. They were crossdated using the chronology from the Dannenshtern House in Riga<sup>37</sup>. The material of the Dannenshtern House likely comes from near the headwaters of the Kasplya tributary of the Daugava River (Zapadnaya Dvina River) located near Smolensk.

**Solovki.** The Solovki chronology consists of measurements from living trees (pines PDB and spruce PDEL; 65.12°N, 35.57°E), beams in a church on Malaya Muksalma Island (code MMCH; 65.01°N, 36.00°E), a building built for resin extraction (code SMOL), a barn (code SOLAM), and from a monastery outbuilding (or skit) on Sekirnaya Hill (code SLKL; 64.08°N, 35.57°E). Also included in the chronology are series from a satellite monastery building on Bolshaya Muksalma Island (code BMSK; 65.03°N, 35.90°E), series from a bathhouse nearby (code BMBN), samples from the Church of Andrew the First-Called on Zayatskiy Island (code B24A; 64.97°N, 35.65°E), series from a 19<sup>th</sup> century building (code SOLIZ), along with archaeological materials from the monastery (codes B27A, B28A), and a barn on Anzer Island (codes B39A, B38A; 65.19°N, 35.98°E). The earliest part of the chronology consists of ring-width series from beams from the 16<sup>th</sup> century Spaso-Preobrazhenskiy Cathedral (code SP; 65.02°N, 35.71°E).

### Technical Validation

Measurements were validated statistically with program COFECHA<sup>25</sup>. COFECHA separates each series of tree-ring measurements into 50-yr segments with 25-yr overlap and calculates correlation of each segment (its high-frequency band) with the average high frequency value of all the other series of a file for the same 50-yr segment. The independent comparison of each segment helps to identify possible problems of measurement quality and cross-dating in different parts of the series. Some segments may be marked by ‘A’ or ‘B’ flag. An ‘A’ flag marks an insignificant correlation ( $r < 0.328$ ). A ‘B’ flag marks segments that aligned with the master series with higher correlation coefficient in another position within  $\pm 10$  years. For every site the percentage of segments with ‘A’ and ‘B’ flags was calculated to describe the overall quality of measurements and their cross-dating.

Additional validation included alignment of every chronology with other chronologies of the same region and species to make sure there are no systematic dating errors.

### Code availability

No code was used to generate, test, or process the current dataset.

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## Author contributions

Olga Solomina led the collection of the materials and wrote the manuscript. Vladimir Matskovsky participated in the collection of the materials, collected, validated, and described the measurements, wrote the manuscript. Ekaterina Dolgova contributed the materials from the Caucasus and Solovki islands. Veronika Kuznetsova contributed the materials from the Volga region. Nadezhda Semenyak contributed the materials from Solovki islands. Tatiana Bechuk helped to organize the dataset. Vladimir Mikhailenko participated in the collection of the materials. Alexey Karpukhin contributed the materials for Kirillov and Karelia chronologies. Bulat Khasanov contributed the materials for Zapadnaya Dvina 1 and 2; K.S., P.Z., T.L., D.L. chronologies. All the authors read and discussed the manuscript.

## Competing interests

The authors declare no competing interests.

## Additional information

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