The International Tree-Ring Data Bank at Fifty: Status of stewardship for future scientific discovery

Running head: Stewarding the ITRDB

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Abstract

Marking its 50th year in 2024, the International Tree-Ring Databank (ITRDB) is a lasting and invaluable scientific resource, composed of over 6,000 tree-ring chronology sites and more than 9,000 publicly-available measurement data files. It is the central global repository for tree-ring chronologies and associated measurements, providing the foundation for centennial to millennial length climate reconstructions, including large-scale spatially gridded datasets and hundreds of studies on earth systems, ecological processes, and societal responses to global change. As the stewards of the ITRDB, we report on significant progress made to ensure its vitality in an era of big data, with all sites and associated measurement files meeting FAIR data standards, including citable DOIs and the achievement of machine readability via computing languages such as R and other software. This progress is thanks in large part to the global dendrochronological community for their collaborations on data checking and software development. It is a time to celebrate the repository and the tree-ring community that had the foresight and generosity to create and contribute to it. We look forward to another 50 years of innovation and insight from the community, and to maintaining the ITRDB as an ever-growing network of tree-ring chronology sites.

Keywords: Dendrochronology, tree-ring, FAIR, Open Access, publicly available data

Text body

Among the many remarkable features of tree rings is that networks of tree-ring chronologies accumulate information (Fritts 1976), empowering discoveries across multiple earth systems (Babst *et al.* 2018). The dendrochronology community recognized the synergistic capacity of combining individual site chronologies across large areas relatively early in the history of the science, leading to the founding of the International Tree-Ring Data Bank (ITRDB) in 1974 (Babcock 1974). The ITRDB was created to encourage global cooperation among the various branches of dendrochronology, especially dendroclimatology, and provide a permanent location for the storage of dendrochronological data from around the world. As the name states, the ITRDB originally operated as a sort of bank from which researchers could deposit and request data. Harold Fritts at the University of Arizona's Laboratory of Tree-Ring Research led the effort to create the ITRDB and oversaw it until 1989 when it was transferred to the National Geophysical Data Center at the United States National Oceanic and Atmospheric Administration (NOAA). At that point the ITRDB became fully publicly available, and currently resides with the World Data Service for Paleoclimatology (WDS-Paleo) at NOAA's National Centers for Environmental Information (NCEI), housed and managed along with more than a dozen other types of global paleoenvironmental proxy data. The ITRDB makes up roughly half of the total data holdings at WDS-Paleo, echoing the commitment of the dendrochronology community to develop and share tree-ring chronologies for public use.

In understanding global change and its effects, the ITRDB has proven invaluable. By capitalizing on the ways in which the network records variation in climate (St. George and Ault 2014), it has been used to develop large-scale, regional to continental reconstructions of drought (Cook and Krusic 2004; Cook *et al.* 2010a, 2020; Boucher *et al.* 2011; Stahle *et al.* 2016; Herrera and Ault 2017), temperature (Mann *et al.* 1999; PAGES 2k Consortium 2013;

Wilson *et al.* 2016), soil moisture (Williams *et al.* 2020; Zhang *et al.* 2020), and seasonal precipitation (Stahle *et al.* 2020), along with hundreds of more spatially specific reconstructions of runoff and other climatic features and phenomena. The strengths of dendroclimatic collections have also enabled assessments of climate and land-surface models (Cook *et al.* 2010b; Woodhouse *et al.* 2010; Ault *et al.* 2014; Jeong *et al.* 2021) and provided accessible data to resource managers (Rice *et al.* 2009). Although some studies have demonstrated limitations for ecological forecasting due to the targeted nature of tree-ring collections in the ITRDB (Nehrbass-Ahles *et al.* 2014; Klesse *et al.* 2018), the suite of tree-ring growth sensitivity to climate variation embedded in the network has nonetheless underscored vulnerabilities of global forests to Anthropogenic climate change (Salzer *et al.* 2009; Liu *et al.* 2013; Williams *et al.* 2013; Charney *et al.* 2016; Babst *et al.* 2019). As the dendrochronology community continues to grow into "frontier" regions (*e.g.* Solomina *et al.* 2022; Zuidema *et al.* 2022) and develops new data collection and analysis techniques (Pearl *et al.* 2020; Griffin *et al.* 2021), the future of the science is promising, highlighting the continued need to expand and maintain the ITRDB as a central repository for tree-ring chronologies (Babst *et al.* 2017).

Our team operates the World Data Service for Paleoclimatology at NOAA's NCEI. The WDS-Paleo is certified by the CoreTrustSeal as a Trustworthy Data Repository that complies with established standards in data stewardship. We receive federal funding to support stewarding the ITRDB and associated paleo archives with the mission of making these valuable environmental data publicly accessible, updated, and secure. It is our job to work with the tree-ring community to build the ITRDB as a resource by curating new submissions in a timely manner, performing quality checks, and collaborating on building new tools and adding linked resources to the data bank. These efforts are guided by the dendrochronological community through the ITRDB advisory committee, which is currently composed of active dendrochronologists from around the world. Our work has benefited immensely from multiple independent efforts of dendrochronologists within the community, including an exhaustive review of datasets in the ITRDB by Zhao *et al.* (2019), who error-checked and reformatted numerous measurement files. We can now report that all of the issues identified by Zhao *et al.* have been resolved on the ITRDB. Other efforts to improve the ITRDB have been helpful and inspiring, and we encourage such efforts to continue in collaboration with our team.

At the time of writing, the ITRDB contains more than 9,000 tree-ring measurement files, the raw data of dendrochronology. This is still a growing network, with hundreds of new or updated sites submitted each year. Each site has associated metadata that describe the location, species, investigators, related publications, and funding sources. Measurement data, including total or partial ring widths and other derived measurements such as density and blue intensity, are provided in separate text files in "Tucson decadal" format and the tab-delimited, spreadsheet-like NOAA/WDS-Paleo archival template format. An additional text file provides chronology statistics from the COFECHA program (Holmes 1983), which is used as a rough check on measurement data quality as described below. All data files associated with an ITRDB site are stored in an HTTPS web accessible folder (Table 1). The tree-ring measurement data in both Tucson and NOAA formats are stored in the same directory, while the crossdating statistics from COFECHA are stored in a separate directory for tree series statistics. All of the files are linked from the site's landing page for easy access. Users may obtain site metadata in several ways (Table 1), including searching for landing pages via the NCEI WDS-Paleo search engine, through an interactive map, and programmatically through our web service, or the application programing interface (API; Gross *et al.* 2022). Various researchers have used these services to build tools that access and display the data (*e.g.* Dendrobox, Zang 2015). Since the release of `dplR` (Bunn 2008), a growing suite of Open Source tools for analyzing tree-ring measurements is available in the R programming language (R Core Team 2020). Our team is currently developing tools to aid in searching and accessing NCEI WDS-Paleo resources, including the

ITRDB and climate reconstructions. As a prelude to those future packages, we provide an R script that imports the entirety of ITRDB metadata and raw measurement files into R (see Guiterman 2023).

All of the measurement data housed on the ITRDB meet the FAIR guiding principles, making them “findable, accessible, interoperable, and reusable” (Wilkinson *et al.* 2016). We recognize limitations in the Tucson decadal format, but emphasize that because of ongoing efforts to clean existing data sets and quality check new ones, every one of the raw data (.rwl) files is machine readable. Specifically, the files can be read into R by using the `dplR` function `read.rwl()` with the added parameter, `format=”tucson”`. In addition, we provide the same data in a tab delimited format in NOAA template files. Following community needs (*e.g.* Zhao *et al.* 2019), each site is assigned a unique and permanent dataset digital object identifier (DOI). These identifiers are important for documenting the completion of data management plans to many funding agencies (including the US National Science Foundation) and in meeting Open Data standards at a growing number of peer-reviewed journals. The data DOIs, from one of the earliest contributions (Fritts 1997) to one of the most recent (Khan 2022), can also be cited directly in research papers and reports. The citability of data DOIs is particularly useful in instances of datasets without an associated peer-reviewed publication, which should also be cited along with the data DOI. To further aid in identifying and searching for ITRDB records, we have implemented the use of standardized variable names in the NCEI WDS-Paleo dataset search (Table 1) (PaST; Morrill *et al.* 2021).

We welcome and accept dataset contributions at any time. Researchers are encouraged to submit their data in advance of journal submission and funding agency deadlines; we will work with you to plan the timing of dataset release. For instance, some journals require an embargo period on data until a paper is published, or contributors may independently want to hold the release of data for publication. In such situations, we can delay the data release until a specific date, ensuring that datasets are finalized and data DOIs are minted well ahead of the deadlines. Before submitting data, please consult our contributions page for instructions and guidelines (Table 1). Note that all raw measurement files must be readable by `read.rwl()` in the dplR library, and additionally pass basic quality standards. Although we rely on contributors to guarantee the accuracy of the tree-ring measurements and their associated crossdating, we provide COFECHA output for users to assess the data quality according to their own standards. We have, however, only accepted submissions that have fewer than 40% “problem segments” and greater than 0.35 mean series intercorrelation, based on standards provided to us decades ago. Contributors are recommended to check that they achieve these standards in their own COFECHA output, and to also ensure the readability of their Tucson decadal files in R prior to submission. Once the data is ingested into the ITRDB and publicly released, it will be available through the NCEI WDS-Paleo search page and site landing page (Table 1).

As the dendrochronology community expands and builds greater diversity of its people, along with the regions, species, and methods it represents, we are excited to continue to support the community and its collections. We recognize the challenges this growth poses to the ITRDB, which may have rigid statistical standards of crossdating for trees from some areas and is inherently limited in capturing the rich data and metadata of many subfields of dendrochronology, including archaeology and ecology. From our position of support to the paleosciences communities, we look forward to discussions about how to encourage and accommodate this essential growth, whether that be within the ITRDB or in a new data archive.

The foresight of dendrochronologists to create the ITRDB a half-century ago generated innumerable insights into earth systems and societal responses to global change, and with continued commitment to making tree-ring data publicly accessible and usable, the future of dendrochronology is equally bright.

Table 1. Webpages and hyperlinks for NCEI WDS-Paleo resources. Since URLs can change in the future without our control, if any of the links do not work, we recommend using a search engine to find the NOAA Paleoclimatology main page and then navigating to the other pages from there. All links successfully accessed as of August 21, 2023.

Webpage	**URL**
NOAA Paleoclimatology main page	https://www.ncei.noaa.gov/products/paleoclimatology
Example ITRDB site landing page	https://www.ncei.noaa.gov/access/paleo-search/study/3264
Map service	https://www.ncei.noaa.gov/maps/paleo/
HTTPS web accessible folder	https://www.ncei.noaa.gov/pub/data/paleo/treering/measurements/
Data API protocol	https://www.ncei.noaa.gov/access/paleo-search/api
Data search engine	https://www.ncei.noaa.gov/access/paleo-search/
Contribution guides	https://www.ncei.noaa.gov/products/paleoclimatology/contributing-data
PaST Thesaurus	https://www.ncei.noaa.gov/access/paleo-search/cvterms

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