

The DendroEcological Network: A cyberinfrastructure for the storage, discovery and sharing of tree-ring and associated ecological data

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ARTICLE INFO

Keywords:

Dendrochronology
Dendroecology
Tree ring
Forest ecology
Database

ABSTRACT

The DendroEcological Network (DEN; <https://www.uvm.edu/femc/dendro>) is an opensource repository of high quality dendrochronological and associated ecological data. Launched in 2018, the mission of the DEN is to provide a centralized, standards-driven cyberinfrastructure for data storage, exploration and sharing. Specifically, the objectives of the DEN are to, 1) act as an integrator of dendrochronological and ecological data, 2) facilitate synthetic investigation and analyses of these data, 3) uphold the scientific community's goals of data transparency and reproducibility of results, 4) serve as a long-term data archiving platform for use by individuals, laboratories and the greater scientific, management and conservation communities and, 5) leverage and extend previous and future research. The DEN facilitates the gathering of individual studies into a larger network, expanding the scale of inquiry to address pressing ecological questions that no single study can answer alone.

1. Mission and scope of the DEN, to correspond with changes in the other section headings.

The DendroEcological Network (DEN; <https://www.uvm.edu/femc/dendro>) is an open-source repository of high quality dendrochronological and associated ecological data. Launched in 2018, the mission of the DEN is to provide a centralized, standards-driven cyberinfrastructure for data storage, exploration and sharing. Specifically, the objectives of the DEN are to, 1) act as an integrator of dendrochronological and ecological data, 2) facilitate synthetic investigation and analyses of these data, 3) uphold the scientific community's goals of data transparency and reproducibility of results, 4) serve as a long-term data archiving platform for use by individuals, laboratories and the greater scientific, management and conservation communities and, 5) leverage and extend previous and future research. The DEN facilitates the gathering of individual studies into a larger network, expanding the scale of inquiry to address pressing ecological questions that no single study can answer alone.

2. The need for a dendroecological database

Centralized databases are playing an increasingly important role in ecology and the environmental sciences (e.g., NOAA National Centers for Environmental Information and datasets therein (<https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets>); Neotoma (Williams et al., 2018); Forest Inventory and Analysis (USDA Forest Service; <https://www.fia.fs.fed.us/tools-data/>); TRY Plant Trait Database (www.try-db.org)). The well-known International Tree Ring Data Bank (ITRDB; <https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring>; Grissino-Mayer and Fritts, 1997) has served as a repository for tree-ring chronologies since 1974. It currently holds data from 238 tree species (accessed March 2019) and more than 4000 sites spanning six continents (Sullivan and Csank, 2016). Tree-ring data are an increasingly utilized measure to understand environmental and ecological change (Babst et al., 2013; D'Orangeville et al., 2016; Girardin et al., 2016) as they provide unique high-resolution information of secondary growth over long periods and across large regions and environmental gradients. However, the ITRDB's

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original purpose was to serve as an archive for tree-ring chronologies used in climate reconstructions (i.e., paleoclimatology). Thus, the majority of the ITRDB chronologies come from canopy-dominant, climate-sensitive, older trees that do not represent the full range of age classes in forest stands, nor species that are insensitive to climate. Furthermore, the ITRDB does not collect key ancillary data useful for ecological investigations and management such as information on sampling protocol (Sullivan and Csank, 2016) or biometric measurements (e.g., stem diameter). While some of these limitations for dendroecological studies were identified and discussed in Nehrbass-Ahles et al. (2014); Sullivan and Csank (2016), and Babst et al. (2017; 2018), until now, no direct and tangible action has been initiated to address the majority of the identified shortcomings (but see Zhao et al., 2018).

Dendrochronological and associated ecological data are not being used to their full potential. Currently, they are not systematically managed or made publicly available (Elger et al., 2014). Instead, the data are buried in the literature (Pauli et al., 2017) or reside within individual laboratories, and are therefore under-utilized or functionally lost to the scientific community. The DEN was developed to address the unintended short-falls of the ITRDB by providing a data archiving platform specifically for forest ecology and management studies where tree-ring and ecological data associated with the chronologies can be stored, queried and accessed by the scientific, conservation and management communities. Now, through the DEN, data will be available from a greater representation of sites, tree species, age and size classes commonly found across forested landscapes.

3. The structure and content of the DEN

The DEN is a comprehensive database accessed through a web-based portal, constructed using open-source software and libraries, and is now open to the larger community to contribute, discover and download data. The DEN utilizes a combination of a rigorous data model for some fields considered fundamental to a dendroecological study, with a flexible storage strategy for ancillary data that may be specific to a single study. Data are organized by study into a hierarchy of plots containing trees with associated core series. A range of ancillary site (e.g., description, latitude & longitude), sampling (e.g., plot and tree sampling protocol) and tree (e.g., stem diameter, height, crown position) information is included at each level, going significantly beyond what is currently available on the ITRDB. Adhering to dendrochronological protocols and data standards for reliability (Holmes, 1983; Speer, 2010), all chronologies must be crossdated and contributors are encouraged to submit supporting statistical information. While the DEN's geographic coverage currently encompasses the northeastern United States as initial archiving was carried out using data gathered by the authors and their affiliates, contributions from studies from around the world are sought to expand the DEN's utility. The DEN now contains data on 5987 cores from 11 studies across 277 plots in five US states. Unlike the ITRDB, the DEN provides a place to archive dendroecological data on all tree ages and size cohorts (e.g., understory, sub-canopy, co-dominant, dominant), as well as tree species not considered climatically sensitive. By expanding the types of dendrochronological data that can be archived in the DEN, submissions from non-traditional contributors who otherwise could not archive their data in the ITRDB, should grow.

The DEN is hosted by the Forest Ecosystem Monitoring Cooperative (FEMC), a long-standing partnership among northeastern state natural resource agencies, the University of Vermont and the USDA Forest Service. The technical implementation of the DEN utilizes a number of metadata standards to ensure compatibility of data and metadata stored in the network with other systems. This includes the use of Ecological Metadata Language (Michener et al., 1997) for documenting the overall metadata of each data package, the Tree Ring Data Standard (Jansma et al., 2010) for storing data elements about cores, ring widths and measurement details, and support for utilizing an array of standards for

representing taxonomic coverage. Detailed documentation about the data models and technical implementation is available on the DEN website (https://www.uvm.edu/femc/dendro/technical_report).

4. Discover and access standardized data

The web-based interface makes the DEN easy to navigate, search for, and download data (Fig. 1). Users may query the network using a map-based interface of project locations, a listing of projects by species, state or title, or a search by keyword(s) with optional additional criteria such as temporal scope of chronologies or tree crown positions. Search criteria yield data organized by individual studies, including study content, description and metadata, and users can download an integrated dataset with all plot, tree and core data that match the selection criteria in combined files (Fig. 2). Users can download data from a single study in a comma-separated values format. In addition, tree core data can be downloaded in the TRiDaS XML format (Jansma et al., 2010) and statistical files (e.g., COFECHA output, R code) are made available. A DEN metadata file accompanies downloads, describing the contents of each column in the constituent datasets.

5. Share data and track utilization

Data in the DEN are added and managed through a web-based interface that ensures that data are internally consistent and meet TRiDaS specifications. Data, metadata and supporting documentation can be added and audited by DEN administrators, and development is underway to provide authenticated contributors with the ability to upload and manage their own project data through the web interface. Contributing researchers benefit through the use of a secure archive and a citable online presence for their data. By archiving data in the DEN, contributors profit from clear data attribution using digital object identifiers, generation of a citation, potential embargo periods to delay data sharing until publication, author information and a data management plan template to satisfy granting agency requirements (<https://www.uvm.edu/femc/dendro#contribute>). With the structure of the DEN in place, its research-enhancing potential and utility (e.g., geographic coverage, number of species) now depends upon the support and contributions of the scientific and management communities.

6. A new resource for research and management

The DEN functions as a new resource for data discovery, integration and citation with the potential to accelerate the capacity of the scientific community to investigate pressing environmental and management questions from the site level to broad-scale analyses. Archived data from earlier studies serve as benchmarks for comparisons, and study site networks can help elucidate spatial homogeneity and heterogeneity in tree species' response to site conditions, as well as explore ecological processes that operate across a range of interacting scales (Heffernan et al., 2014). The annual resolution and temporal length of data archived on the DEN can highlight the influence of rare events, capture slower ecological processes, and link current environmental change with past human agency (McLachlan et al., 2000; Beck et al., 2011; Pederson et al., 2014; Gennaretti et al., 2018; Williams et al., 2018). DEN data will be of interest to multidisciplinary research efforts with the increasing availability of high-resolution geodata (Correa-Díaz et al., 2019) and other biological data (e.g., national forest inventory data; Clark et al., 2007; Evans et al., 2017) that may be analyzed in tandem with tree-ring datasets.

There is growing interest within the ecological, management and other scientific communities to harness networks of tree-ring records to explore, contextualize and predict the responses of tree species and forest types to abrupt and gradual environmental change, investigate the interplay of abiotic and biotic interactions, and discover the mechanisms that promote resilience (Williams et al., 2018). For example,

The DendroEcological Network - Providing seamless access to ecological and dendrochronological data

Data About Contribute People Contact

Explore, locate and download dendroecological data

The mission of the DendroEcological Network (DEN) is to provide an online repository for dendrochronological and associated forest ecology data, as well as offer a cyberinfrastructure for the discovery, exploration, and sharing of that data. The data portal is publicly available and anyone with access to the internet can use it and contribute to it. To maintain the rigor of the overall resource, the DEN is currently limited to only accept datasets containing cores that were cross-dated.

Using data you find here? Find out [how to cite the data](#) stored here and check out the [data use policy](#).

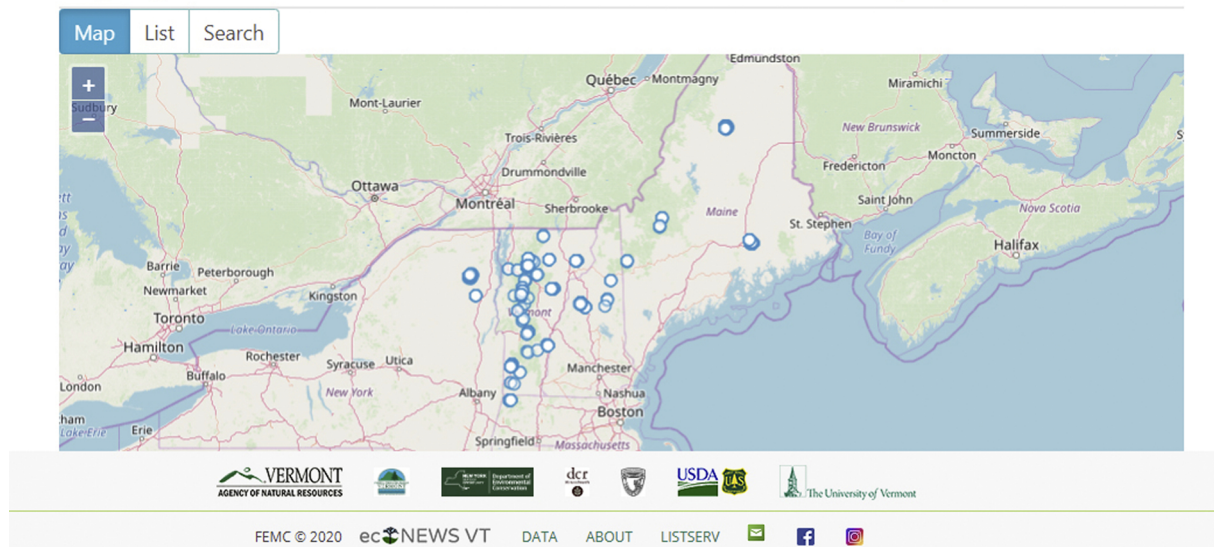


Fig. 1. The DendroEcological Network's (DEN) web interface where users can explore, locate and download ecological and dendrochronological data. The map-based interface shows the location of study sites currently archived in the DEN.

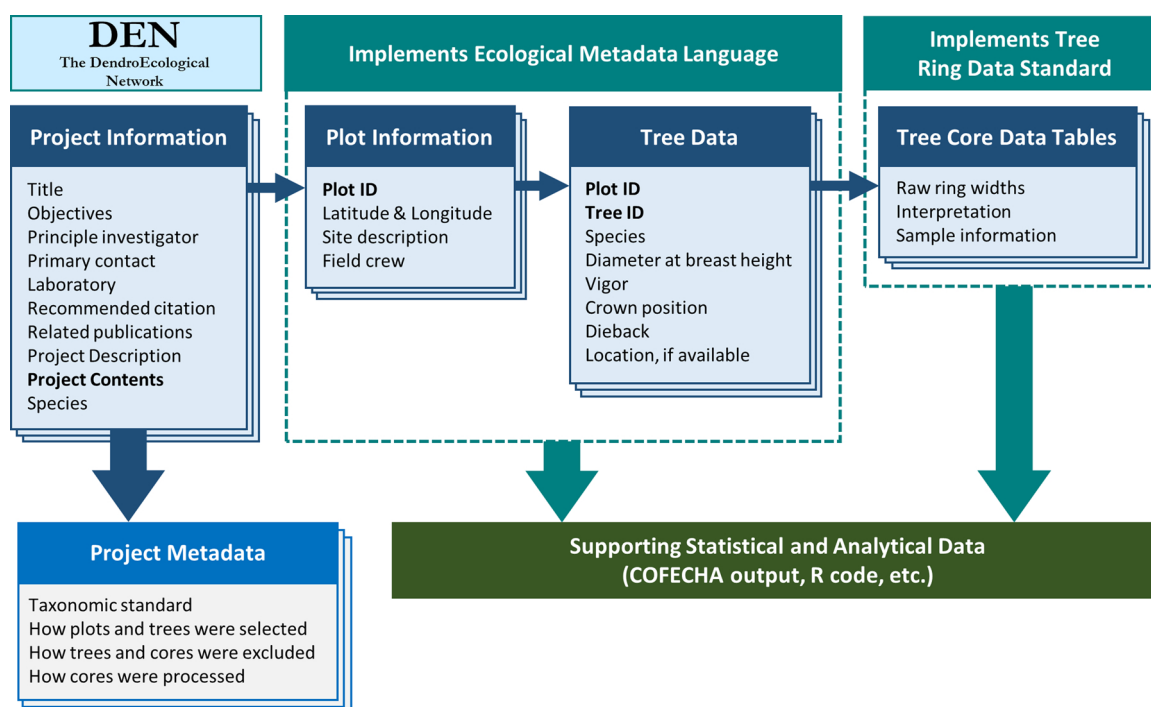


Fig. 2. Organizational structure of the DendroEcological Network (DEN), a comprehensive database of tree-ring and associated ecological data accessible via a web-based portal. Data are organized by project into a hierarchy of plots containing trees and individual core series. Additional information associated with the study, including project metadata, statistical and analytical data are also linked to the project.

DEN data from six studies were used to analyze how temperature, moisture and pollution inputs may be related to the growth rebound of red spruce (*Picea rubens* Sarg.) following decades of decline (Kosiba et al., 2018). Tree-rings from 658 spruce on 52 plots across five states helped identify that increased fall, winter and spring temperatures, and reductions in nitrogen pollution were associated with recent growth increases. This analysis provided scientists with unique information on a surprising consequence of warming, afforded feedback to policy makers following pollution reductions mandated by the 1990 Amendments to the Clean Air Act, and informed managers working to restore a once-dominant tree species that provides ecosystem services including C-sequestration, enhanced biological diversity and critical habitat for endangered wildlife (e.g., Bicknell's Thrush (*Catharus bicknelli*); King et al., 2008).

Without tree-ring data networks, our ability to understand environmental processes and drivers, and detect and attribute changes at intensive and extensive scales is impeded. At best, the slower exchange of data and knowledge impedes important breakthroughs. At worst, it results in delayed knowledge-transfer to policy makers and ultimately, to those tasked with resource management and conservation, further closing the window of response time necessary for effective adaption and mitigation action (Smol, 2002; Kumagai and Vincent, 2003). We therefore, call upon the community of dendrochronologists, forest ecologists and managers to submit their data to the DEN to increase its spatial coverage and utility to inform and respond to the 21st century's most pressing environmental challenges.

Author contributions

SAR, JAD, PGS conceived of idea; SAR, JAD, PFM, CFH, AMK designed the data network; JAD built data network; SAR, JAD, AMK solicited contributions and populated data network; SAR and JAD wrote manuscript with contributions from all authors.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

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