
THE DENDROECOLOGICAL NETWORK VERSION 1.0

TECHNICAL REPORT



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The DendroEcological Network Version 1.0 – Technical Report

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Executive Summary

The DendroEcological Network (DEN; <https://www.uvm.edu/femc/dendro>) is an open-source repository of high quality dendrochronological and associated ecological data. The DEN, a collaborative effort among partners from the Geography Department at the University of Vermont, the Forest Ecosystem Monitoring Cooperative, and the USDA Forest Service Northern Research Station, was launched in 2018 with the goal of providing a database and online infrastructure to archive these data, and make those data easy to find, explore, and aggregate across disparate research projects. This technical report serves as documentation of the infrastructure underlying the DEN for reference by those interested in its construction and capabilities, the data model used to develop the DEN, including the implementation of the Ecological Metadata Language standard and the Tree Ring Data Standard, and the technical details of implementing that model. The report closes by identifying potential next steps in the development of the resource.

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Introduction

The DendroEcological Network (DEN; <https://www.uvm.edu/femc/dendro>) is an open-source repository of high quality dendrochronological and associated ecological data. The DEN was launched in 2018 with the goal of providing a database and online infrastructure to archive these data, and make those data easy to find, explore, and aggregate across disparate research projects. The DEN provides a mechanism to gather together a range of studies conducted across space and time into a larger data network. This network has the potential to expand the scale of inquiry through synthesis and aggregate investigations to address pressing ecological questions that no single study can answer alone.

The DEN is the outcome of several years of work with collaborators from the Geography Department at the University of Vermont, the Forest Ecosystem Monitoring Cooperative, and the USDA Forest Service Northern Research Station along with a number of partners in the dendroecological community. The DEN is hosted and maintained by the Forest Ecosystem Monitoring Cooperative. More details on the history of the DEN and why this is a needed advance in the field can be found in Rayback et al. (in prep.). The report that follows serves as technical documentation on the infrastructure underlying the DEN for reference by those interested in its construction and capabilities. This report describes the data model used to develop the DEN, including the implementation of the Ecological Metadata Language standard and the Tree Ring Data Standard, outlines the technical details of implementing that model, and identifies potential next steps in the development of the resource.

Data Model

The DendroEcological Network utilizes a data model that knits together Ecological Metadata Language (EML; Michener et al. 1997), the Tree Ring Data Standard (TRiDaS; Jansma et al., 2010) and actual data to provide a well-described, highly structured data storage system. This model is implemented through a MySQL database using constrained

relationships among a variety of tables. We opted to standardize data upon ingestion, rather than storing data in its native format, to provide more robust search and integration capabilities to users of the DEN. By requiring data imports to conform to certain basic relationships and standards, the DEN makes it easier to

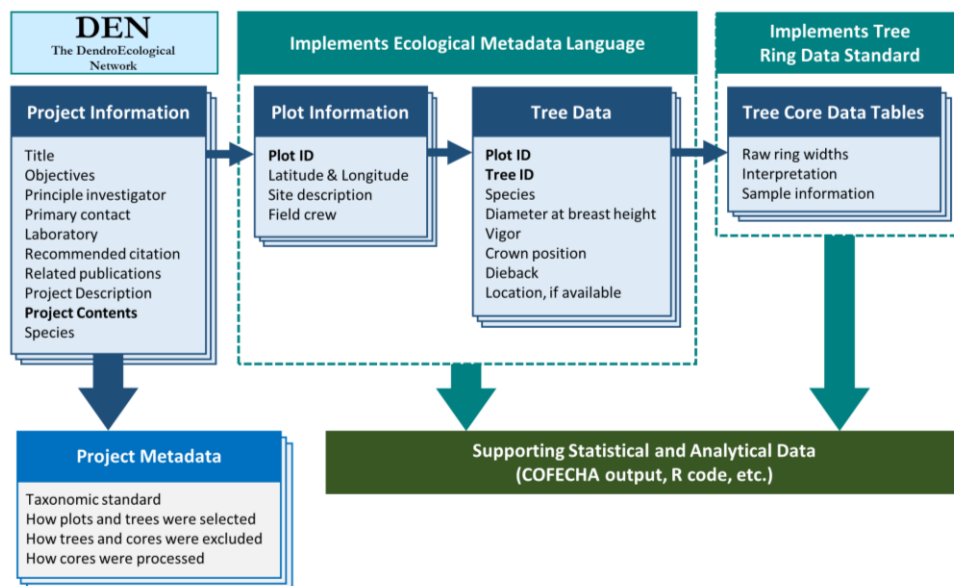


Figure 1. Conceptual diagram of the DendroEcological Network data model, showing certain highlights from each level.

access customized sets of tree- ring data spanning multiple source projects and speeds the process of conducting synthesis studies.

The highest level of organization in the DEN is the project, which collects a number of related objects into a cohesive whole (Figure 1). A project contains general metadata, a series of tables nested hierarchically from plots to individual tree-ring width measurements, a download tracking system, and a file store for supporting files such as COFECHA outputs or R code (Figure 2).

An overview of the key tables used to implement the DEN are shown in Figure 2. A full depiction of the database entity-relationship model is given in Appendix A. Metadata about each field in key tables in the database can be found in Appendix B. The project table contains information about the overall study design and purpose, including objectives, contributors, funding, publications, sampling strategies, project duration and taxonomic standards used. The download table tracks download events of individual datasets for reporting back to contributors and system users. The supporting files table documents reports, images and other media in a file storage system that provide key analytical information such as COFECHA output or R scripts used to process the data, which users can access to evaluate the suitability of a given project for use.

Below the project table are the series of data and metadata tables that form the heart of the DEN. The plot table tracks information about plots or sampling locations used by the contributor, including location, user-defined plot IDs, collection dates, participating crew members, notes, etc. The tree table links to the plot table by plot ID, and contains information unique to the tree level, including user-defined tree IDs, species (as recorded by contributor), diameter at breast height, crown class, forest health metrics such as dieback and vigor, location data if available, and notes.

Each tree will have one or more cores extracted from it, and the tables used to store all measured and derived data about cores were designed to conform to the Tree Ring Data Standard. A full definition of each of these objects can be found by consulting the TRiDaS documentation at <http://www.tridas.org/download.php>. A core is represented in the sample

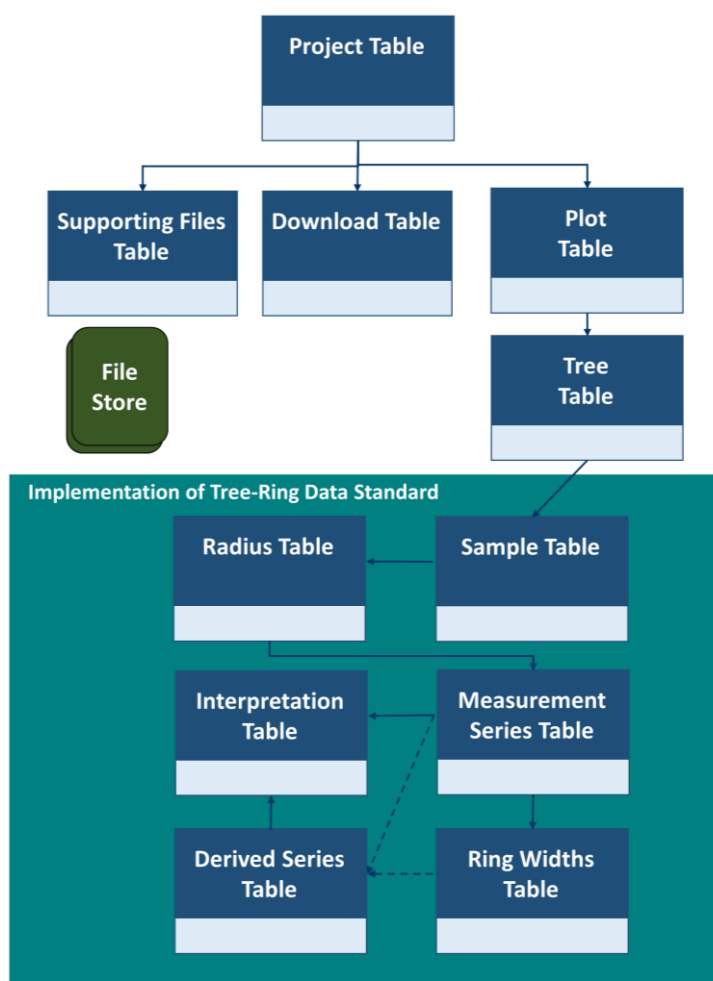


Figure 2. Data tables used to implement the data model for the DendroEcological Network. The metadata and data structure implement two widely recognized standards: the Ecological Metadata Language standard and the Tree Ring Data Standard.

table, which includes information on a user-defined sample ID, sampling date, sample status, notes, etc. Each sample can be interpreted as one or more radii, captured in the radius table, which includes information on the user-defined radius ID, azimuth of sampling, the presence of bark, pith, heartwood or sapwood, overall ring counts, notes, etc. Each radius will have one or more measurement series, and could have one or more derived series. The measurement series table is the starting block for measuring ring widths, and documents information about a set of ring width measurements taken on a tree core, including information about who measured the series, who supervised measurement, the units used, the precision, the measurement method and the date of measurement. Ring widths measured as part of a measurement series are stored in the ring widths table, which documents the parent measurement series ID, the width and the order of that measurement from the outside of the radius (closest to bark) to the inside (closest to pith).

From the measurement series, derived series and interpretations can be created. A derived series table is available in cases where a researcher has created a novel series from the combination of two measurement series, a subset of values from one or more radii, or one or more other derived series. In the database, this is implemented with a set of matching lookup tables between the derived series table and the measurement series table, the values table, and the derived series table, respectively. The interpretation table records information derived from interpretation of a measurement series or a derived series, including the first year and last year represented, the significance level, software used, estimated tree age and the number of years spanned by the core.

Implementation of the Ecological Metadata Language standard

The DEN table structures described above are derived, in part, from structures in the FEMC data archive that implement the Ecological Metadata Language standard. The FEMC has extended the Ecological Metadata Language (EML) standard (<https://knb.ecoinformatics.org/#external/emlparser/docs/index.html>) to document data in its main archive. This metadata language provides an extremely flexible set of modules for documenting and sharing metadata, and because of the wide-ranging and diverse data associated with ecological investigations, this flexibility is its biggest asset. For this reason, EML is the preferred standard for the Long-Term Ecological Research Network, and data in EML are easily federated to other data cataloging systems through the work of efforts such as DataONE (<http://dataone.org/>), in which FEMC is a member node.

The ‘project’ used as the highest-level container for a set of related objects in the DEN is analogous to EML’s ‘dataset’ object. The various components associated with an EML dataset, such as creator, abstract, data tables and attribute information, are captured in a set of tables in the DEN that mirror those used in the FEMC archive. Future work will unlock the full metadata documentation power of the FEMC through direct connection to FEMC’s data archive system, providing additional functionality, including federation to the DataONE network, version control and the connection of ancillary data to the standardized data within the DEN and documentation of that data.

Implementation of the Tree-Ring Data Standard

The sample, radius, ring width, measurement series, derived series and interpretation tables described above implement the fundamental components of the Tree Ring Data Standard for cores taken from trees. The result is that users can download tree core data in an XML file format that validates against the schema implemented by the developers of TRiDaS. There are other components of the standard meant for

documenting information related to archeological and cultural uses of cores, but these are not implemented in the DEN.

Technical Implementation

The DEN is implemented using a Linux-Apache-MySQL-PHP software stack on servers maintained at the University of Vermont, with daily backups of both file system and database content kept for three months. The application is developed in the CodeIgniter 3 PHP framework by the staff of the Forest Ecosystem Monitoring Cooperative, and interactivity on the website is achieved through the use of various JavaScript libraries and frameworks including jQuery, jQuery UI and OpenLayers. All code for the DEN is tracked in a Git repository and hosted in a private GitHub repository. Digital object identifiers can be assigned to datasets and registered with CrossRef.

Data and metadata are added and manipulated through a web-based interface requiring authentication and user-specific roles for editing project information and data. Currently, the web interface for adding data is only available to FEMC staff, and occasionally, direct modification of database tables is required to manage content in the system. A fully featured data management portal is envisioned as a next step in the development of the DEN.

The public-facing website allows users to interact with data in a number of ways, including:

- Browsing projects in the DEN by state, by species, or by viewing locations of plots or trees on a map.
- Searching for data in the DEN using keywords, temporal ranges in the chronology, species, crown position, and/or spatial overlap.
- Viewing data for a particular project, including previews of plot, tree and core data, as well as downloading data as comma-separated values or, in the case of core data, as a comma-separated values file or an XML file.
- Viewing and downloading subsets of data from across projects that match a user's search criteria.
- Accessing supporting analytical and statistical documents for projects.

The DEN's management portal allows administrative users to upload data and curate metadata about the projects. The system provides a number of quality assurance protocols and consistency checks, such as ensuring that user-defined identification codes are consistent throughout the datasets and that taxonomic standards are used consistently within a given project.

Next Steps

The DEN as implemented provides a fully-functional data discovery and access portal for dendroecological data from a range of projects. There are three major next steps that the DEN's implementation team and the larger community has identified as important for the future viability of the DEN.

One is the completion and release of a data management portal open to all contributors to the DEN. Currently, data must be added by FEMC staff due to the limited amount of resources available to develop the back-end functionality for the DEN. Because not all of the features of the management portal are available through the web, this can require complex database administration tasks and other manipulations that are

not feasible to offer to users at this time. Developing a fully-featured management portal will make it much easier to curate data in the DEN and expand the holdings by engaging more researchers to contribute and 'own' their data through the DEN.

A *second* potential next step is to develop a transparent and efficient oversight model for the DEN. This would allow for basic, periodic review of content against minimum standards (such as the requirement for crossdating) in the DEN to ensure that contributions are meeting the standards needed for the community to utilize content in the DEN. This model could also provide guidance for how to further extend the DEN, both in terms of its capabilities and its content.

A *third* potential next step is the extension of the data model to accommodate an unbounded possible list of ancillary fields that could be captured at the three main hierarchical levels in the DEN: the plot level (e.g., stand density, management history, soil classification), the tree level (e.g., foliar transparency, crown volume, height), and the core level (e.g., cell structure, sapwood length). This would enable contributors to add complete datasets with all accompanying data fields to the DEN without losing ancillary data collected for their study that may not fit the more highly structured format implemented in the DEN's core data model.

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Appendix A: DendroEcological Network Database Schema

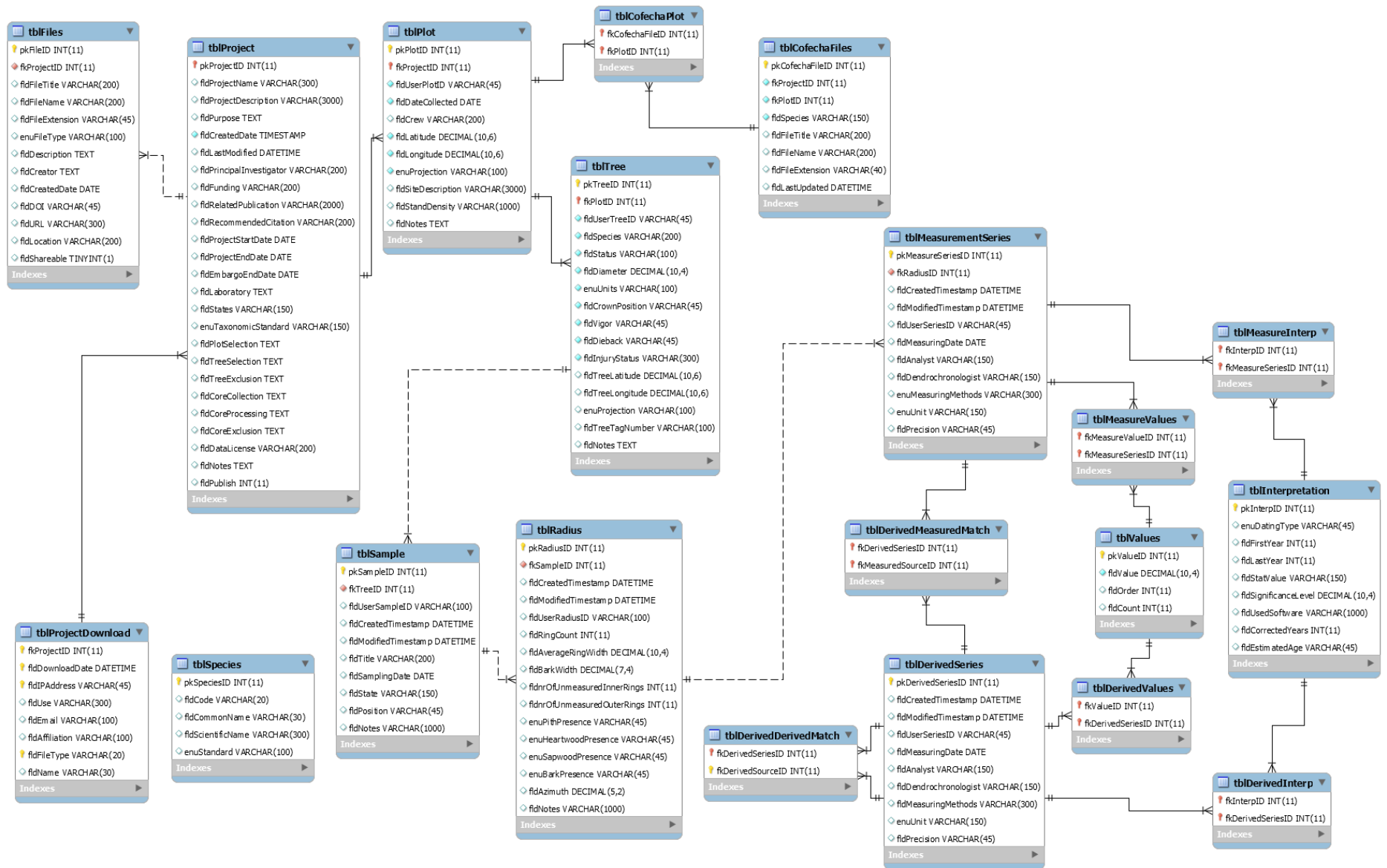


Figure 3. Entity-relationship model for the DendroEcological Network database schema.

Appendix B: Field Definitions of Key Tables

We provide documentation of the fields in key tables below, including their database data type, and a brief description of what they contain. For database data types, “int” is an integer type, “varchar” is a text type, “decimal” is a decimal type, “date” is a calendar date, and “datetime” and “timestamp” are calendar dates plus times. The key tables described are the project, plot, tree, sample, radius, measurement series, ring widths, interpretation, and species tables. We also provide a summary explanation of the purpose of each table from the schema in Appendix A that are not included in the above list.

tblProject

The project table holds basic information about the project.

pkProjectID int: System-generated identifier for the project.
fldProjectName varchar: The title of the project.
fldProjectDescription varchar: A description of the project.
fldPurpose varchar: The purpose or objectives of the project.
fldCreatedDate timestamp: The date and time the project was added to the database.
fldLastModified datetime: The last date and time of an update to the project.
fldPrincipalInvestigator varchar: The principal investigator or project lead.
fldFunding varchar: The funding source(s) for the project.
fldRelatedPublication varchar: Publication(s) related to the data in this project.
fldRecommendedCitation varchar: The user-supplied recommended citation for data in this project.
fldProjectStartDate date: Data collection start date.
fldProjectEndDate date: Data collection end date.
fldEmbargoEndDate date: If there is an embargo, the date that it ends.
fldLaboratory varchar: The lab group that collected the data.
fldStates varchar: Comma separated list of state abbreviations containing plots.
enuTaxonomicStandard varchar: What taxonomic naming standard used.
fldPlotSelection varchar: How plots were selected.
fldTreeSelection varchar: How trees were selected.
fldTreeExclusion varchar: Whether any trees were excluded.
fldCoreCollection varchar: How cores were collected.
fldCoreProcessing varchar: How cores were processed.
fldCoreExclusion varchar: Whether any cores were excluded.
fldDataLicense varchar: The data license accompanying the data.
fldNotes varchar: Any additional information about the project.
fldPublish int: Whether to publish the project to the website or not.

tblPlot

The plot table holds the metadata and data about the plot.

pkPlotID int: System-generated identifier for the plot.
fkProjectID int: System-generated identifier that links this plot to the project.

fldUserPlotID varchar: The plot ID as defined by the user.

fldDateCollected varchar: Date when tree cores were collected.

fldCrew varchar: List of names/initials of people who collected the samples.

fldLatitude decimal: Plot center latitude, in the units defined by the spatial reference system.

fldLongitude decimal: Plot center longitude, in the units defined by the spatial reference system.

enuProjection varchar: Spatial reference system code from spatialreference.org for the plot location coordinates.

fldSiteDescription varchar: Visual description of the plot, possibly describing (but not limited to): the density and composition of understory plants, notable topographic characteristics (slope, aspect, etc.), tree species composition and density, size class distribution, and disturbance evidence.

fldStandDensity decimal: Basal area density of plot, in m²/hectare.

fldNotes varchar: Any additional information about the plot.

tblTree

The tree table holds information and data about the tree.

pkTreeID int: System-generated identifier for the tree.

fkPlotID int: System-generated identifier that links this tree to a plot.

fldUserTreeID varchar: The tree ID as defined by the user.

fldSpecies varchar: Species code as recorded in the data. This should match to a definition in the taxonomic standard defined for the project, such as the USDA Plants Database.

fldStatus varchar: Indicates if tree is alive or dead at time of sampling.

fldDiameter decimal: Diameter, typically measured at breast height (4.5 ft/1.37m above ground).

enuUnits varchar: Units of the diameter measurement, typically inches or centimeters.

fldCrownPosition varchar: Visual assessment of the position of the trees crown: dominant, codominant, intermediate, or suppressed.

Crown position	Description
Dominant	Crown extends above the main canopy; receives full light from above and partial light from the sides.
Codominant	Crown forms the main canopy; receives full light from above and relatively little light from the sides.
Intermediate	Crown lower than or just entering the main canopy; receives little direct light from above and none from the sides.
Suppressed	Crown is fully below the main canopy; receives no direct light from above or sides.

Source: Vermont North American Maple Project. 2006. Manual. Available at: http://www.esf.edu/for/yanai/research_class/06VTNAMPmanual.pdf

fldVigor int: Visual assessment of the vigor class of the trees crown from 1-5.

Vigor	Description
-------	-------------

- | | |
|---|---|
| 1 | Healthy, no major branch mortality; less than 10% branch or twig/foilage mortality or foliage discoloration. |
| 2 | Light decline; branch mortality, twig dieback, or foliage discoloration present in 10-25% of the crown. |
| 3 | Moderate decline; branch mortality, twig dieback, or foliage discoloration present in 26-50% of the crown. |
| 4 | Severe decline; branch mortality, twig dieback, or foliage discoloration present in more than 50% of the crown. |
| 5 | Dead |

Source: Vermont North American Maple Project. 2006. Manual. Available at:
http://www.esf.edu/for/yanai/research_class/06VTNAMPmanual.pdf

fldDieback int: Visual assessment of the proportion of the trees crown with dieback. Dieback begins at branch terminal and progresses in- and downward. To be considered dieback, the branch must be ≤ 1 " diameter at the point of attachment to another branch or bole. Branch mortality at the base of the crown and large, dead branches without fine branches present are excluded from the assessment. Crown dieback are rated in 5% classes following the table below.

Class	Range
1	0
5	1-5
10	6-10
15	11-15
20	16-20
25	21-25
30	26-30
35	31-35
40	36-40
45	41-45
50	46-50
55	51-55
60	56-60
65	61-65
70	66-70
75	71-75
80	76-80
85	81-85
90	86-90
95	91-95
99	96-99

Source: USDA Forest Service Forest Inventory and Analysis
[https://www.fia.fs.fed.us/library/database-documentation/current/ver611/FIADB User Guide P2 6-1-1 final.pdf](https://www.fia.fs.fed.us/library/database-documentation/current/ver611/FIADB_User_Guide_P2_6-1-1_final.pdf)

fldInjuryStatus varchar: Indicates if tree has visible stem injury. Options are Present or Absent.

fldTreeLatitude decimal: Tree location latitude, in the units defined by the spatial reference system.

fldTreeLongitude decimal: Tree location longitude, in the units defined by the spatial reference system.
enuProjection varchar: Spatial reference system code from spatialreference.org for the tree location coordinates.
fldTreeTagNumber varchar: Alphanumeric text string of the tree tag number.
fldNotes varchar: Any additional information about the individual tree.

tblSample

The sample table holds information and data about the tree core sample.

pkSampleID int: System-generated identifier for the sample.
fkTreeID int: System-generated identifier that links this sample to a tree.
fldUserSampleID varchar: The sample ID as defined by the user.
fldDescription varchar: A description of the sample.
fldSamplingDate date: The date on which the sample was collected.
fldState varchar: State of the material sampled.
fldPosition varchar: The position in the element from which the sample was taken.
fldNotes varchar: Any additional information about the individual sample.

tblRadius

The radius table holds information and data about the radius along which a sample was measured.

pkRadiusID int: System-generated identifier for the radius.
fkSampleID int: System-generated identifier that links this radius to a sample.
fldUserRadiusID varchar: The radius ID as defined by the user.
fldRingCount int: The number of rings in the radius before correction.
fldAverageRingWidth decimal: The average ring width of the radius.
fldBarkWidth decimal: The width of the bark from the sample
fldnrOfUnmeasuredInnerRings int: Number of rings at the inner (i.e. towards pith) edge of the sample that have not been measured. This is typically used to note when rings are too damaged to measure.
fldnrOfUnmeasuredOuterRings int: Number of rings at the outer (i.e. towards bark) edge of the sample that have not been measured. This is typically used to note when rings are too damaged to measure.
enuPithPresence varchar: Whether the pith is present or absent.
enuHeartwoodPresence varchar: Whether the heartwood is present or absent.
enuSapwoodPresence varchar: Whether the sapwood is present or absent.
enuBarkPresence varchar: Whether the bark is present or absent.
fldAzimuth decimal: Angle in degrees from north along which this radius lies.
fldNotes varchar: Any additional information about the individual radius.

tblMeasurementSeries

The measurement series table holds information and data about the measurement of a radius.

pkMeasureSeriesID int: System-generated identifier for the measurement series.

fkRadiusID int: System-generated identifier that links this measurement series to a radius.

fldUserSeriesID varchar: The series ID as defined by the user.

fldMeasuringDate date: Date that the measurements were taken.

fldAnalyst varchar: Name of the analyst(s) that made the series.

fldDendrochronologist varchar: Name of the dendrochronologist(s) that oversaw the analyst.

enuMeasuringMethods varchar: Method used to measure tree core. Options are: measuring platform, hand lens and graticule, on-screen measuring, or visual estimate.

enuUnit varchar: Units of the annual increment measurement, typically inches, millimeters, or centimeters.

fldPrecision varchar: Precision of measurements.

tblValues

The values table holds the individual ring width measurements from a measurement series, or derived ring widths from a derived series.

pkValueID int: System-generated identifier for the value.

fldValue decimal: The result of a single ring measurement.

fldOrder int: The order of the measurement along a radius, from bark to pitch.

fldCount int: Optional, denotes how many underlying values went to create this value in a derived series.

tblInterpretation

The interpretation table holds information about the cross-dated interpretation of the core after measurement.

pkInterpID int: System-generated identifier for the interpretation.

enuDatingType varchar: The method for dating (absolute, relative, dated with uncertainty, radiocarbon).

fldFirstYear int: Year of the first measured ring, derived from the chronology that was used to date the series.

fldLastYear int: Year of the last measured ring, derived from the chronology that was used to date the series.

fldStatValue varchar: Statistical value used to support a match with the chronology.

fldSignificanceLevel decimal: Significance of the statistical match with the chronology.

fldUsedSoftware varchar: Software used to perform the statistical match with the chronology.

fldCorrectedYears int: The total number of rings after correction. If there was no correction, *fldCorrectedYears* will be the same as *fldRingCount* in the radius table.

fldEstimatedAge varchar: The estimated total number of years of tree core, based on presence of pith, or if pith is not present, by using a ring estimator.

tblSpecies

The species table is a list of all the codes for species used by a given taxonomic standard that are present in the data. This table allows crosswalking of codes from different standards in the search and browse functionality of the DEN.

pkSpeciesID int: System-generated identifier for the species.

fldCode varchar: The code used for the species in the taxonomic standard

fldCommonName varchar: The common name for the species.

fldScientificName varchar: The scientific name for the species.

enuStandard varchar: The name of the taxonomic standard.

Summary of other tables

Several tables provide additional information about the project, and while we do not provide detailed field information about them, we provide a brief description of the table below:

- *tblFiles* – Lists files to associate with a project, such as field manuals, data sheets or related publications.
- *tblProjectDownload* – Stores a log of downloads of data from a particular project.
- *tblCofechaFiles* – Stores COFECHA file outputs or other supporting statistical files to evaluate the quality of the cross-dating in a particular project.

In addition, many tables in the database serve only to enable many-to-many matching relationships between the key tables above, and are listed here but their fields are not described:

- *tblCofechaPlot* – Links statistical analysis files to the plots to which they relate.
- *tblMeasureInterp* – Links an interpretation to the underlying measurement series that informs that interpretation.
- *tblDerivedInterp* – Links an interpretation to the underlying derived series that informs that interpretation.
- *tblMeasureValues* – Links the values recorded during measurement to the measurement series that created those values.
- *tblDerivedValues* – Links the values in a derived series to the series that created those values.
- *tblDerivedDerivedMatch* – Links a derived series or several derived series to an overarching derived series.
- *tblDerivedMeasuredMatch* – Links a measurement series or several measurement series to an overarching derived series.



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