



Dendroecological Data for Forested Parks in the National Capital Region Network

Natural Resource Data Series NPS/NCRN/NRDS—2023/1393





ON THIS PAGE

Tree cores arranged vertically beside each other.
NPS

ON THE COVER

NPS biologist twists a tree borer into the wide trunk of tulip poplar.
NPS

Dendroecological Data for Forested Parks in the National Capital Region Network

Natural Resource Data Series NPS/NCRN/NRDS—2023/1393

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April 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Elmore A. J., S. L. Brosi, S. M. Guinn, E. Matthews, J. P. Schmit, A. Brolis, and J. R. Foster. 2023. Dendroecological data for forested parks in the National Capital Region Network. Natural Resource Data Series NPS/NCRN/NRDS—2023/1393. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2297322>

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Abstract

Dendroecological records are useful tools for establishing forest stand age and inferring tree species response to climate variability and disturbance. This report describes dendroecological data collected for these purposes from permanent vegetation monitoring plots spanning the National Park Service's National Capital Region Network. Tree cores were collected 2016–2018 using standard protocols and subsequently measured for ring width (including early and late wood when available) from 36 different tree species. The species selected were representative of co-dominant and intermediate trees at each monitoring plot suitable for establishing stand age, and for other dendroecological applications. Ring widths were cross dated by park unit using standard methods. The resulting database contains complete records for 2695 measured cores taken from 1518 trees. Cores were collected from 408 plots that spanned 11 park units. Widths were measured from 221994 rings (mean ring width was 2.71mm). The oldest tree cored was a *Quercus alba* at Prince William Forest Park that was 239 years old in 2022, and the mean tree age across all trees cored was 90 years. To facilitate interpretation and enable future studies of forest dynamics, we include in this record climate and remote sensing canopy reflectance data for each plot. In this report, we describe how the data were collected, database organization, and key summary statistics that will support future data use.

Acknowledgments

The authors thank K Heater, E Green, E Duda, M Audie, L Smith for collecting and measuring tree cores. This work was funded by the United States Department of Interior National Park Service under Task Agreement # P17AC01102.

Introduction

The National Capital Region Network (NCRN) monitors ~424 permanent forest vegetation plots, distributed among 11 park units (Figure 1). Monitoring began in 2006 and plots are surveyed every four years (Fancy and Bennetts 2012; Schmit et al. 2014). Therefore, these plots represent an important long-term record of forest attributes. Complementary records that place these monitoring data in context, or otherwise extend the available suite of observations, increase the value of inventory and monitoring data for understanding responses to global change factors. One important source for such information are tree rings, which can provide dendroecological information on stand age and the sensitivity of wood growth to local environmental variability (Fritts and Swetnam 1989). For the NCRN plots in particular, stand age is an important unknown, due to its wide variation among and within parks with diverse land use histories and its influence on ecosystem processes. Tree ring records are often used to reconstruct past climates but can also be used to interpret differential impacts of climate change on tree species and to understand successional dynamics at the scale of forest stands. Other useful sources of information include observations from remote sensing, which provide a record of canopy reflectance since 1983 via the Landsat historic record (Pasquarella et al. 2016). Variation in canopy reflectance can be related to numerous influences on ecosystem processes, including variation in weather, the activity of defoliating insects, or trends in leaf phenology, all of which might be difficult to infer from inventory and monitoring data alone. Finally, climate records are clearly complementary to dendroecological records, and are now freely available as grids interpreted from the observational record (Thornton et al. 2012).

There are several considerations to ensure tree ring, remote sensing, and weather data are complementary to vegetation inventory and monitoring data. First, all data must be spatially and temporally referenced. The spatial grain of gridded products must be considered, but not necessarily aggregated to a common grain. Similarly, a common temporal reference of year is typically sufficient; however, remote sensing observations always include the day of year of collection. Specific to tree ring data, trees to core must be selected that are representative of the plot but cored in a way that does not influence the integrity of future forest monitoring data. Finally, all data must be curated in a relational database suitable for a diversity of future needs.

The measurement goals of this project were to assemble tree ring, remote sensing, and weather data to complement the long-term vegetation monitoring data collected by the park service. This report describes the measurement process, cross dating procedures, and data curation procedures. We also describe characteristics of the data set that will be useful to those interested in ecological characteristics of the plots, including estimates of stand age and tree growth patterns over time. We do not attempt to use these data to reconstruct past climates or establish a reference chronology.

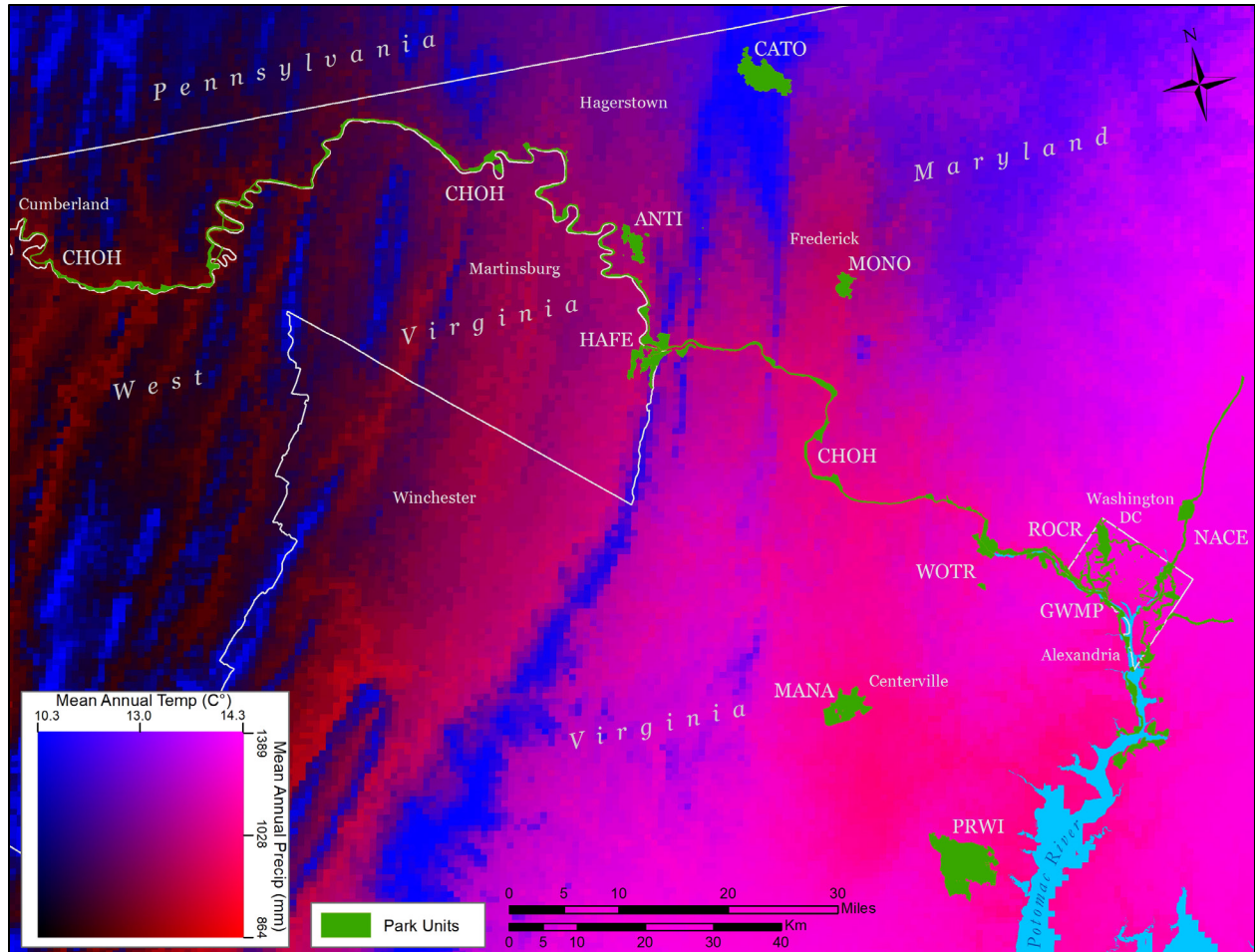


Figure 1. Park units of the National Capital Region Network span a range in mean climate variables, from wet and warm coastal plain forests to cool and dry mountain ridges. Climate data are from Daymet (Thornton et al. 2012).

Methods

The National Capital Region Network monitors permanent forest vegetation plots, distributed among 11 National Park Service (NPS) units. Monitoring began in 2006 and a few plots were added in subsequent years. This report uses 424 plots that contained trees and where monitoring began prior to the start of the project. Each plot is a 15m radius circle in which all woody plants with a diameter at breast height (DBH) greater than or equal to 10cm are tagged and monitored for species identity, DBH, pests, and other characteristics. A complete description of the monitoring program and methods have been discussed elsewhere (Schmit et al. 2014). Plots span 11 parks: Antietam National Battlefield (ANTI), Catocin Mountain Park (CATO), Chesapeake & Ohio Canal Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park (WOTR). All plots used in this report are located in forested portions of these parks ranging from early successional to late secondary growth stands, primarily in mesophytic forests of the Appalachian Oak sub region (Dyer 2006). There is considerable habitat diversity across the parks spanning dry upland forests to mesic floodplains.

Vegetation measurements made at the plots between 2006 and 2020 demonstrate that 10 species occur at 92% of the plots. Selected from this list, seven species were initially identified for coring, as these species occupy a diversity of habitats and were sufficiently common to expect at least one to be found at each plot. However, beyond commonality, species selected for coring were expected to reliably produce rings that can be measured using methods described below. The list of targeted species ultimately included seven species (Table 1). In practice, due to the diversity of habitats across plots, it was necessary to expand the species list and core additional tree species when the target species were not present. Common species that are difficult to core were avoided (e.g., *Fagus grandifolia*).

Table 1. Tree species targeted for coring.

Species	Common name	Occupancy (%)
<i>Pinus virginiana</i>	Virginia pine	24.1
<i>Juniperus virginiana</i>	eastern redcedar	1.9
<i>Quercus alba</i>	white oak	31.4
<i>Quercus montana</i>	chestnut oak	18.2
<i>Quercus rubra</i>	northern red oak	18.6
<i>Quercus coccinea</i>	scarlet oak	17.2
<i>Liriodendron tulipifera</i>	Tuliptree	48.3

Field Methods

Many of the methods are adapted without citation from a U.S. Forest Service technical report that details methods for collecting and processing tree cores (Maeglin 1979).

Tree selection and coring

At each plot, two co-dominant and two intermediate trees (4 trees total) were selected outside the plot, but within 10 m of the plot boundary. Trees were selected based on a preferred-species list (Table 1) and to be representative of co-dominant trees in the plot. If preferred species were not present outside the plot, trees were selected that were representative of the plot even though they were not preferred species.

Individual trees were selected to increase core quality and ease of coring. Therefore, based on visual inspection, trees were assessed for abnormal growth patterns, wounds, rot, and decay. Any trees with these characteristics were avoided. Additionally, multistem trees were avoided due to asymmetrical growth and potential rot in the crevice between the stems, as were leaning trees, which may form “reaction wood,” which is difficult to interpret and not representative of the true age. Finally, trees were avoided that exhibited substantial cover of vines in the canopy, unless this was typical for the plot.

Once selected, trees to be cored were marked with an aluminum tag with a pre-stamped number. Tags were fixed to the tree with a single nail at the base of the bole. Two cores, positioned at right angles from each other, were extracted from each tree. For small trees, the core was taken through the tree.

Cores were taken ~1 meter from the ground where it was comfortable for the person coring the tree to have maximum leverage. When possible, the core was collected along the longest bole radius to the pith. The borer was aligned as horizontal as possible. The goal was to reach the pith of each tree. Therefore, the core was aimed at the center of the tree using branch stubs and bole shape as indicators. The core extractor was held next to the borer to estimate if the center of the tree was reached. When the tip of the borer was estimated to be past the center of the bole, the core was extracted from the borer.

Cores were stored in a paper straw that was sealed with masking tape at both ends. If the core was too long to fit in one straw, multiple straws were taped together to create a longer storage tube. Filled straws were stored in a core-carrying tube with desiccant for safe transport to the laboratory. Each core was labeled with the park 4-digit code, plot number, tree letter (A–D), core number (1 or 2), and date on a piece of masking tape or mailing label and attached to the straw containing the core. Each component of the core ID was separated with a hyphen; for example, ANTI-0025-1A is the first core from tree A at plot 0025 at Antietam National Battlefield.

Event Information Collected

As each core was removed, data was recorded (along with the core ID) that identified the tree and other parameters necessary to interpret the core data. These data included the tree species, crown class, tree distance from plot center, tree azimuth from plot center, the diameter of the tree at the

coring height, geo-coordinates, and any notes. Data collected on crown class followed NCRN monitoring protocols (Schmit et al. 2014):

- 1) Open-grown: crown has received full sunlight from above and all sides through most of its life, particularly during early development.
- 2) Dominant: crown extends above canopy, receiving full light from above and some light from sides. Taller than the average tree in stand and has well-developed crown.
- 3) Co-dominant: crown at the general level of the canopy, receiving full light from above but little direct light from sides. Typically, co-dominant trees have medium-sized crowns and are crowded on the sides; in dense stands, co-dominant trees have small crowns.
- 4) Intermediate: tree is shorter than co-dominant trees but with a crown that extends into the general canopy. Crown receives little direct light from above and none from the side; tree has small crown and is very crowded from the sides.
- 5) Overtopped: crown is entirely below the general level of the canopy and receives no direct sunlight.
- 6) Light Gap Exploiter: crown that receives full sunlight from above as it is in a light gap in the canopy but is shorter than the surrounding canopy (added 2009).
- 7) Edge Tree: Tree below canopy height but receives direct sunlight due to its position on the edge of the forest. (added 2009).

Dendrochronology methods

Collected cores were transported to the laboratory of Dr. Sunshine Brosi at Frostburg State University where they were prepared, measured, and cross dated.

Core preparation and measurement

Cores were examined for evidence of bark and pith. If the core was excessively curved or was clearly incomplete, it was discarded. However, an attempt was made to prepare and measure at least one core from each tree. When this was not possible, the tree was added to a list of trees to potentially re-core in a subsequent field trip.

Cores were dried within their paper straws in a 60 C oven for a minimum of 24 hours. When dry, cores were mounted on prepared mounting strips using common wood glue. Cores were oriented so the xylem vessels were facing vertically when placed on the core mounts. The Core ID was transferred to the mounting strip. Each core was then hand sanded using progressively increasing grit (finishing with at least a 320 grit) until smooth and rings were clear and easy to measure. A damp paper cloth was rubbed along the length of each core to remove sawdust and increase ring visibility. A Velmex system and Measure J2X software was used to measure annual increment (0.001 mm precision). Using ring position relative to the bark, the year of growth was associated with each ring. A random sample of 10% of the cores was selected for remeasurement by a second technician and any discrepancies were addressed through remeasurement (see *Chronology cross dating* for the iterative process used). Cores from Oak species were measured separately to include the measurement of both total ring width and late wood width.

Chronology cross dating

Each measurement series was cross dated against all cores within 3km of the focal core. In most cases this meant cross dating by park; however, Chesapeake and Ohio Canal NHP (CHOH) extends along several other parks and was therefore divided into sections. COFECHA software (Grissino-Mayer 2001) was used for cross dating to identify gaps (missing rings) and additions (false rings). As corrections were made, each series was updated with new measurements and associated years. In some cases, multiple iterations of measurement, cross dating, and remeasurement were implemented. Resulting ring widths were summarized in COFECHA data reports, which are included with this data record (Appendix A).

Public Data Collection

All remote sensing and meteorological data were acquired from public websites. In all cases, data was retrieved for the plot locations only. Any future work that requires the full extent of each raster layer, will have to acquire these data separately. We have indicated how this would be done in the below methods, but do not attempt a full description of methods we did not implement.

Landsat data processing

A record of Landsat surface reflectance from a 45.1m radius (9 pixels) circle centered on each plot location was constructed from all available Landsat observations. Google Earth Engine (Gorelick et al. 2017) was used to identify and extract these data from the Landsat 5 (LANDSAT/LE05/C02/T2_L2), 7 (LANDSAT/LE07/C02/T2_L2) and 8 (LANDSAT/LE08/C02/T2_L2) image archives, collection 2. Quality Assurance Quality Control information for each observation was used to remove cloud-affected observations. The resulting data spanned from 1984 to 2018 and consisted of 6 multispectral observations, representing wavelength bands in the blue, green, red, near infrared, and two bands in the shortwave infrared. The exact wavelength positioning, and spectral resolution of these observations varied by sensor, but are available from various sources. Additionally, sun zenith and azimuth angles, sensor path and row values, and acquisition date were extracted from the Landsat metadata. All values were recorded directly into the database without transformation or any other processing.

Spectral Mixture Analysis

Spectral Mixture Analysis (SMA) (Elmore et al. 2000) was used to measure the vegetation cover from each Landsat surface reflectance observation. Spectral mixture analysis assumes each spectrum results from the linear combination of endmember spectra, in this case representing photosynthetic vegetation, non-photosynthetic vegetation, soil, and shade. These endmember spectra were extracted from Landsat image data following standard approaches (Elmore et al. 2012). Prior to applying the SMA model, a sun canopy sensor correction (Gu and Gillespie 1998) was applied that normalizes variation in canopy reflectance due to topographic position relative to the illumination angle. SMA results in an estimate of the fraction of each endmember present in the sampled area. Endmember fractions are not constrained to the range 0–1, but a well-formed model with appropriate endmembers generally results in fractions that are within this range. A constraint was applied such that the sum of the four endmember fractions always summed to one. Spectral mixture analysis has been used for decades to characterize spatial and temporal vegetation patterns in remote sensing data. Validation

against field data has been accomplished for many ecosystems (Asner, Hicke, and Lobell 2003; Elmore et al. 2000; Small and Lu 2006), but we did not attempt a validation step for these data. Previous work using this same model (same endmember spectra) was used to observe a temporal variation in spring phenology and relate this trend to dendroecological characteristics.

Phenology curve fitting

The fraction of photosynthetic vegetation (f_{PV}) estimated from each Landsat observation (1984–2018) was further analyzed for mean phenological characteristics. Despite variation from year to year, the fraction of vegetation is typically low in January–March, increases in April and into May, decreases slowly through the growing season, followed by a period of senescence and a return to winter levels in October/November. This phenological pattern has been characterized as a double logistic, one increasing in spring and a second decreasing in autumn, and connected with a sloped line (Elmore et al. 2012). The equation for this phenology model is:

$$f_{PV}(t) = m_1 + (m_2 - t(m_7)) \left(\frac{1}{1 + e^{\frac{m_3 - t}{m_4}}} - \frac{1}{1 + e^{\frac{m_5 - t}{m_6}}} \right) \quad (1)$$

Where m_1 is the f_{PV} in winter, m_2 is the change in f_{PV} from winter to spring (amplitude). The parameters m_3 and m_4 adjust the position and slope of the spring logistic, and m_5 and m_6 similarly adjust the autumn logistic. The parameter m_7 adjusts the slope of the growing season, with positive values indicating a decline in f_{PV} between the two logistic curves.

To calculate the parameters in equation (1), we organized all observations of f_{PV} by day of year (DOY) and fit equation (1) using non-linear inverse modeling (Elmore et al. 2012). The resulting fit is a representation of the mean phenology pattern observed over the observation period (e.g., Figure 2). From this model fit, an estimate of the mean spring onset of vegetation, m_3 , and autumn offset of vegetation, m_5 , were recorded for each plot. Although not included in the data record, it is a simple matter to calculate the residual vegetation fraction for each vegetation fraction observation by subtracting the modeled $PV(t)$ from the measured f_{PV} .

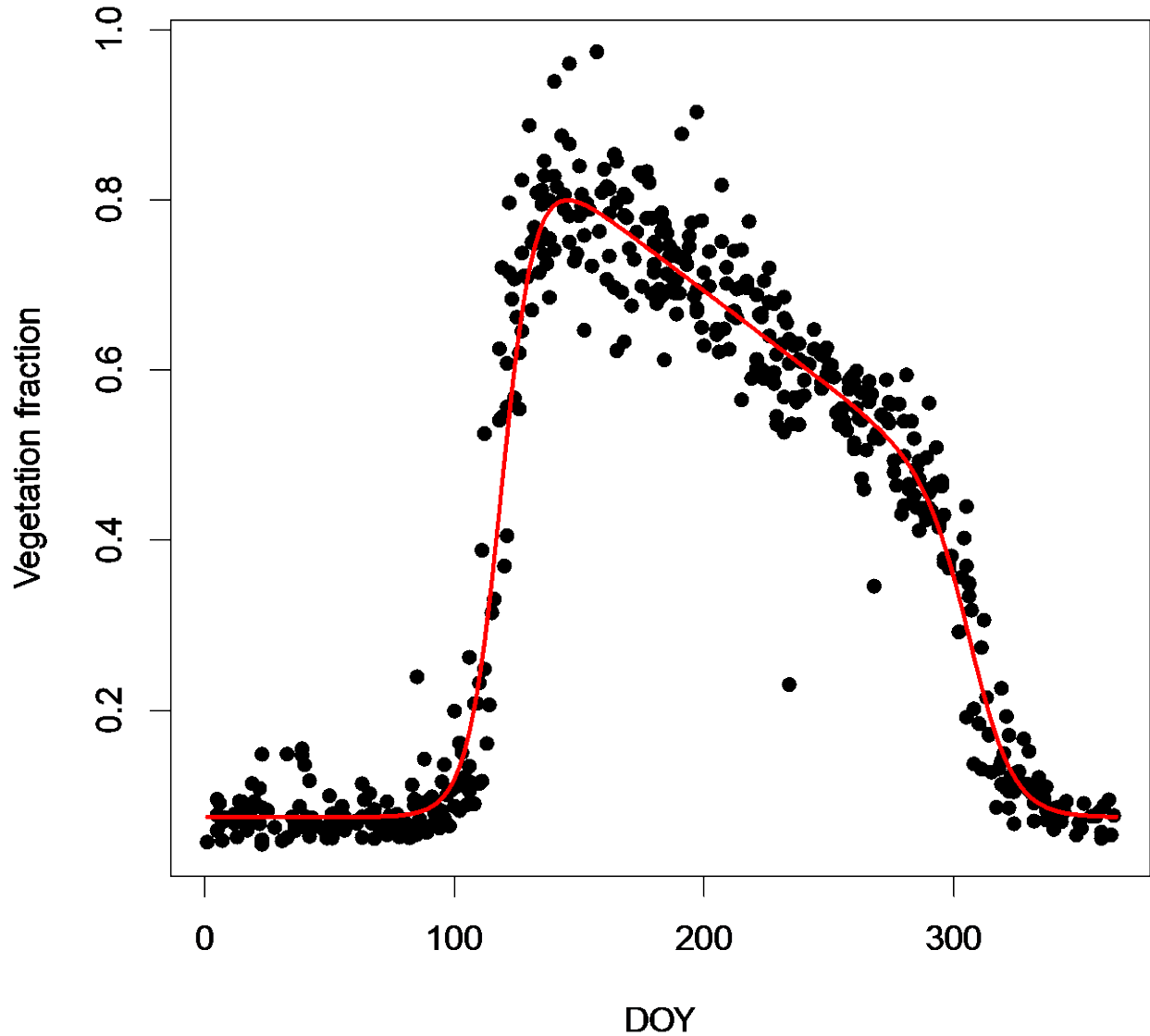


Figure 2. Vegetation fraction from Landsat remote sensing vs. Day of Year (DOY) with example fit of equation (1). The site shown is PRWI-0722, a late successional forest stand with continuous canopy cover.

Daymet climate data

Daily meteorological data for each plot were obtained from Daymet Version 4 data products. Daymet provides long-term (1980-present), spatially and temporally continuous, 1km x 1km gridded estimates of daily weather and climatology variables, which are statistically modeled from ground-based observations (Thornton et al. 2012). Daymet meteorological variables include daily minimum and maximum temperature, and precipitation. Using the geographic location of each monitoring plot, we used the single pixel extraction tool provided by the Oak Ridge National Lab DAAC to retrieve the full Daymet time series for each location. These data were added to our relational database using the plot name as the key identifier, and the year and day of year for each meteorological variable.

Topography

Topographic data were acquired from the National Elevation Dataset for each plot location using Google Earth Engine. Using a 45m buffer around each plot center, we retrieved the mean elevation, slope and aspect of each plot.

Database

All collected data was stored in a SQL relational database (Figure 3). The database consists of 5 tables, each named according to its contents. The table, *plots*, contains environmental data for each plot, including the 7 parameters from Equation 1. The primary key, *plot_name*, is used to join the table, *landsat*, which contains all Landsat observations and endmember fractions from spectral mixture analysis. Similarly, *plots* joins to *trees*, which provides taxonomic information for each tree at each plot. The primary key, *tag_number*, is unique to each tree and is used to join *trees* to *cores*. Up to 3 cores are available for each tree. Finally, the primary key, *core_label*, is used to join *cores* to *rings*. The ring table contains *year*, *width*, and *width_lw* (late wood) for each measured ring. Further details on database usage are provided later in this report.

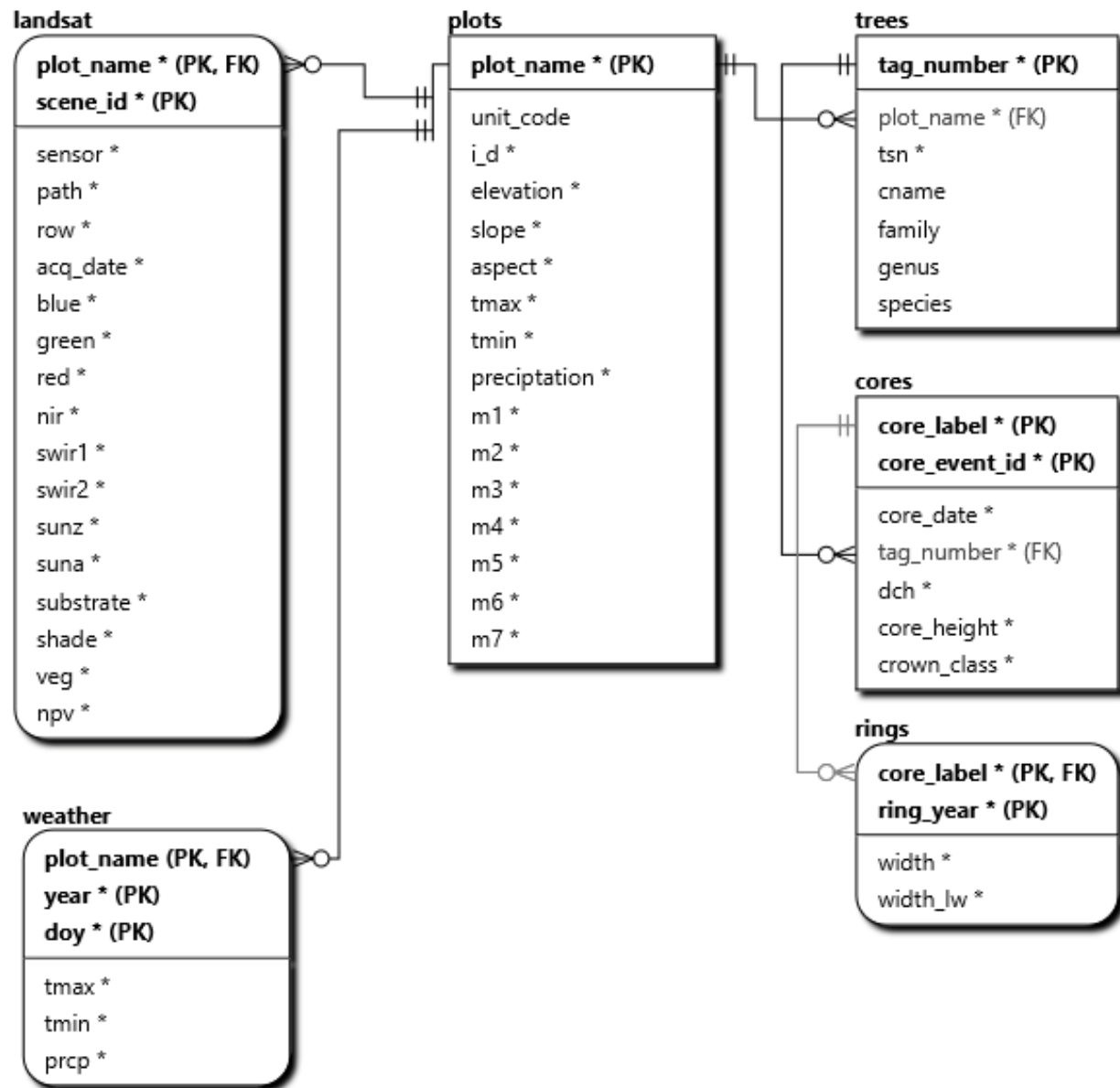


Figure 3. Entity relationship diagram illustrating the database structure (i.e., relational data model) and identification of keys (in bold) that can be used to link tables for plots, trees, cores, and rings. Line styling indicates the number of times an instance in one entity can relate to instances of another entity. Two symbols are used: a line with two dash marks at the end (——++) represents one and only one; a line with a ring and a crow's foot at the end (——⊗) represents zero or many.

Results

Dendrochronologies

The resulting database contains complete records for 2695 measured cores taken from 1518 trees. Out of the 1518 trees cored, 1172 trees were cored more than once (77%). Cores were collected from 408 plots that spanned 11 park units. No cores were collected from 16 plots due to a lack of trees or other difficulties in retrieving suitable cores. Widths were measured from 221994 rings. Additionally, 123878 late-wood ring widths were measured. Mean ring width across all cores and rings was 2.71mm.

Trees cored and measured spanned 36 different species (Figure 4). The most frequently cored species were *Pinus virginiana* (245 trees), *Quercus alba* (225 trees), *Liriodendron tulipifera* (211 trees), *Quercus montana* (182 trees), and *Quercus rubra* (141 trees). Of the 36 cored species, *Liriodendron tulipifera*, *Quercus velutina*, and *Quercus rubra* were cored at all 11 park units, and 8 species were cored at more than 5 park units (Table A1). As mentioned in the methods, Oak and Pine species were targeted for coring, thus 49% of all cores were taken from Oaks and 17.5% from Pines.

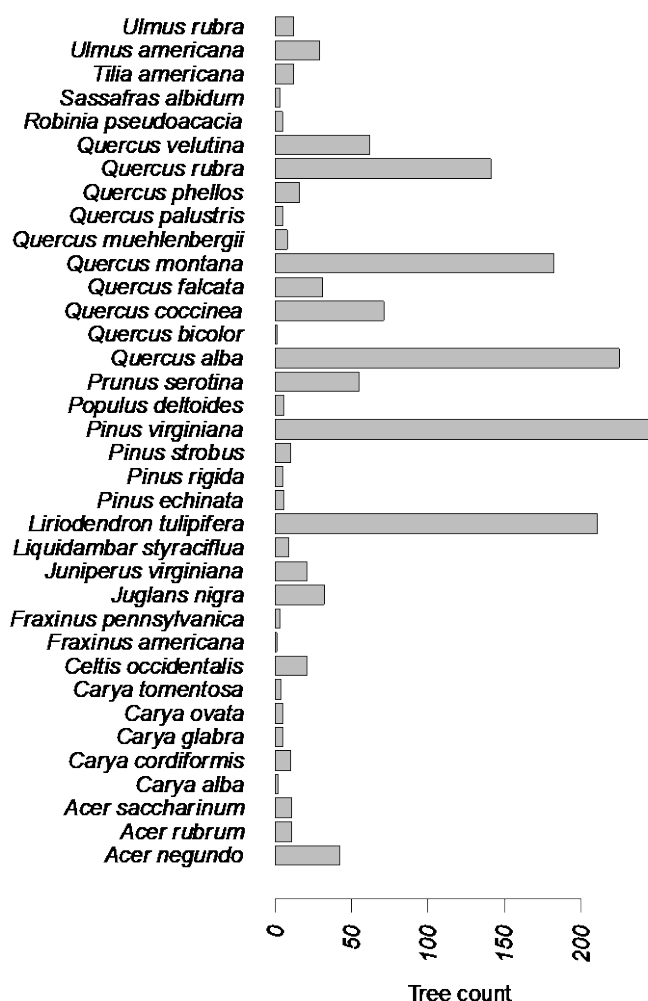


Figure 4. The number of trees cored for each species in the data record.

The oldest tree cored was a *Quercus alba* at PRWI that was 239 years old (in 2022) with a diameter at core height of 60.5cm. The youngest tree cored was a *Liquidambar styraciflua* at NACE that is 13 years old with a diameter at core height of 16cm. The oldest ring from each tree approximated a normal distribution between these extremes (Figure 5) with a mean tree age across all trees cored of 90 years. Tree diameter at core height was related to, but poor predictor of, tree age ($R^2 = 0.12$; $P < 0.001$) (Figure 6). Contrary to the broad relationship between tree diameter and tree age, the oldest tree cored was approximately half the diameter of the largest tree cored.

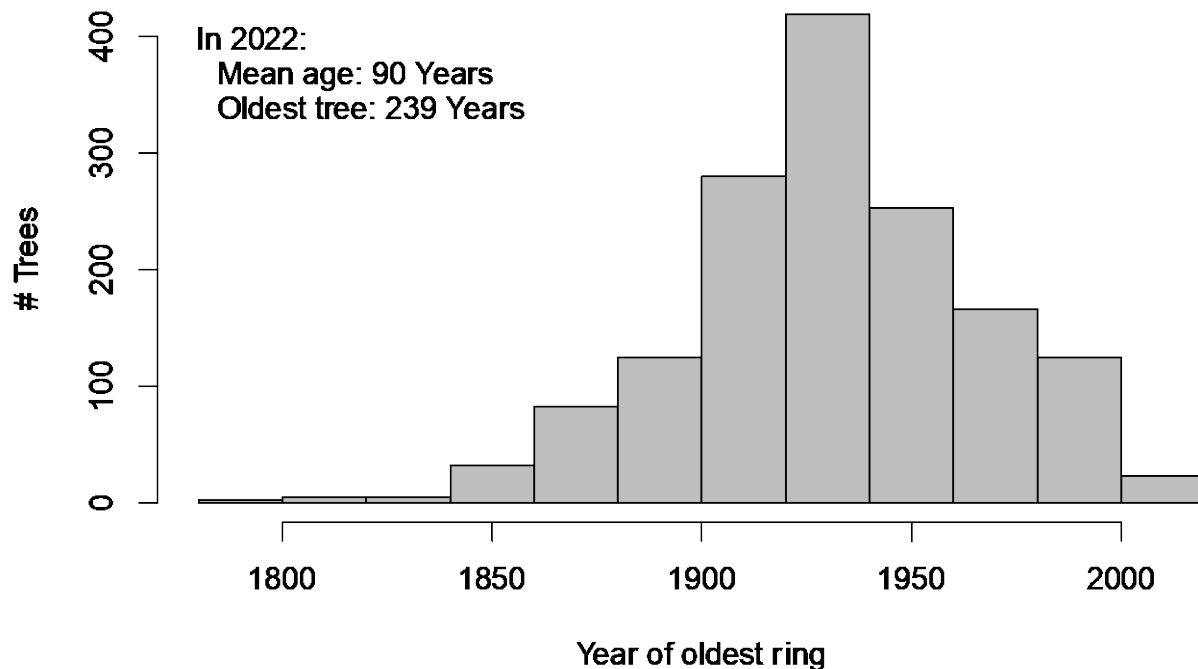


Figure 5. Distribution of tree age (represented by the year of the oldest ring) for all trees in the data record. In 2022, the mean tree age was 90 years. A total of 87 trees cored (5.7%) were found to be older than 150 years.

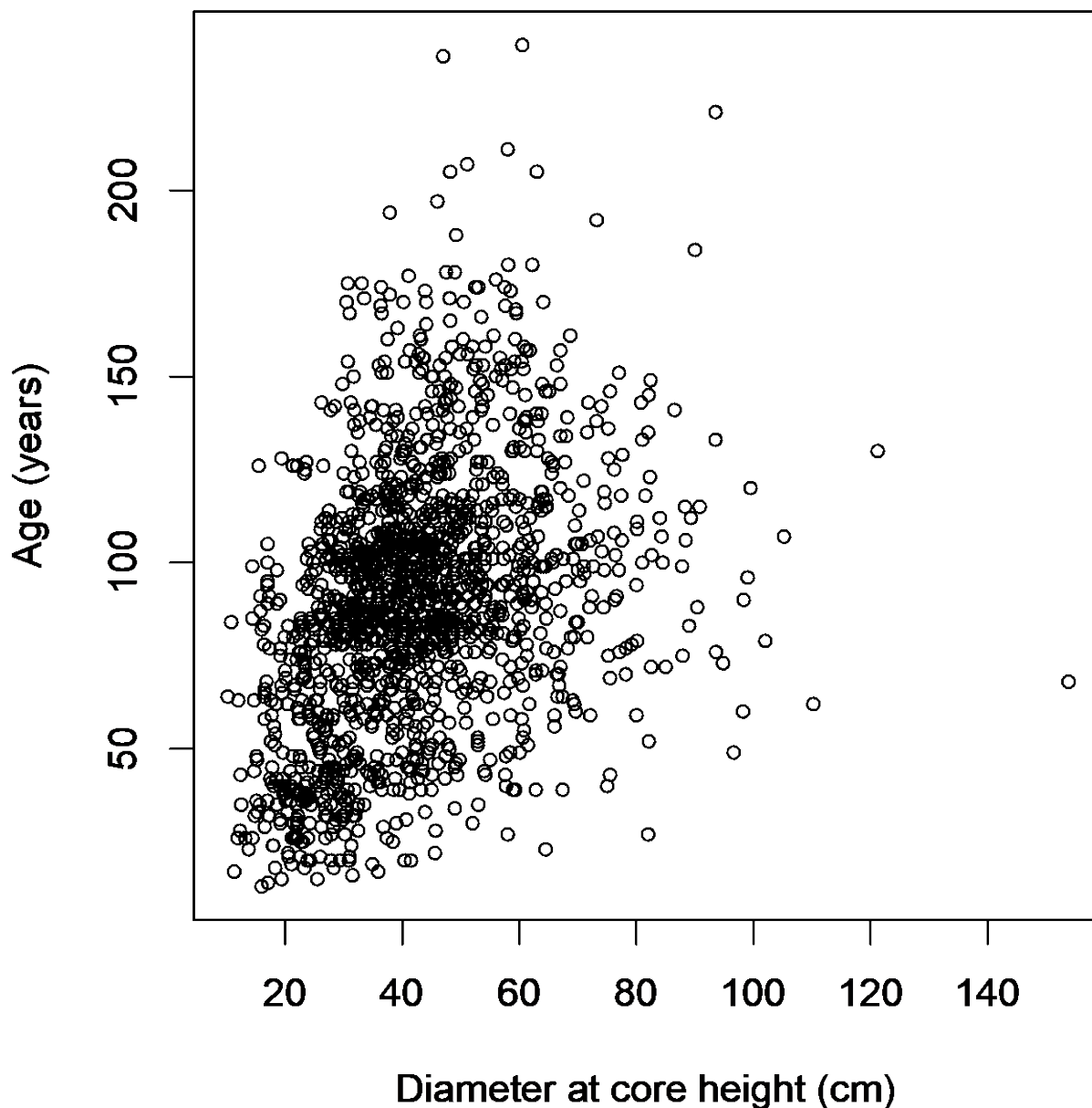


Figure 6. Tree age vs. diameter at core height.

We defined stand age at each plot as the age of the oldest tree cored. This is likely a minimum estimate due to the potential occurrence of older trees in the plot that were not cored. Most of the forest in these parks was cleared and used for agriculture prior to park establishment. Aggregating to the park level, mean stand age (mean plot-level stand age across all plots in a park) was greatest at CATO and least at MONO (Table 2). Oldest trees and even plot-level stand age predate park unit establishment at many parks (Figure 7). For example, the area currently named Catoclin Mountain Park (CATO) has been designated recreational land since 1954, suggesting an age of 68 years. Yet, the oldest tree at CATO is 197 years old and 96% of the trees cored contained rings that pre-dated park establishment. Conversely, Antietam National Battlefield was established in 1890 and at that

time the park was largely agricultural land with few trees. Therefore, just 2% of the trees cored pre-date park establishment. The fraction of trees pre-dating park establishment for the remaining parks varied between these extremes (Table 2).

Table 2. Information on the oldest tree and distribution of tree ages by park unit. Park establishment dates (Est.) are an estimate of when the land entered some form of protection, which generally pre-dates the formation of the National Park Service.

Park unit	Est.	Oldest tree year	Oldest tree age in 2022	Species	Plot	Mean plot stand age in 2022	Fraction of trees older than park establishment
ANTI	1890	1885	137	<i>Carya tomentosa</i>	ANTI-0036	86	0.02
CATO	1954	1825	197	<i>Quercus montana</i>	CATO-0237	134	0.96
CHOH	1938	1844	178	<i>Quercus montana</i>	CHOH-0577	80	0.22
GWMP	1930	1868	154	<i>Carya ovata</i>	GWMP-0147	97	0.34
HAFE	1944	1864	158	<i>Quercus montana</i>	HAFE-0028	109	0.69
MANA	1936	1865	157	<i>Quercus alba</i>	MANA-0253	94	0.38
MONO	1934	1880	142	<i>Quercus montana</i>	MONO-0106	78	0.2
NACE	1965	1861	161	<i>Quercus montana</i>	NACE-0084	82	0.65
PRWI	1936	1783	239	<i>Quercus alba</i>	PRWI-0722	123	0.81
ROCR	1890	1830	192	<i>Liriodendron tulipifera</i>	ROCR-0094	114	0.17
WOTR	1966	1842	180	<i>Quercus alba</i>	WOTR-0009	95	0.62

The oldest tree species at each park were generally of the genus *Quercus*, but specifics varied based on geography. As mentioned, *Quercus alba* was the oldest species cored (at PRWI) and was also the oldest species cored at WOTR and MANA. However, *Quercus montana*, generally occupying higher elevation ridges with thin soils, was the oldest species cored at CATO, CHOH, NACE, HAFE, and MONO. Given that the systematic sampling used did not target the oldest trees in each park for coring, it is reasonable to assume that older trees exist at each park.

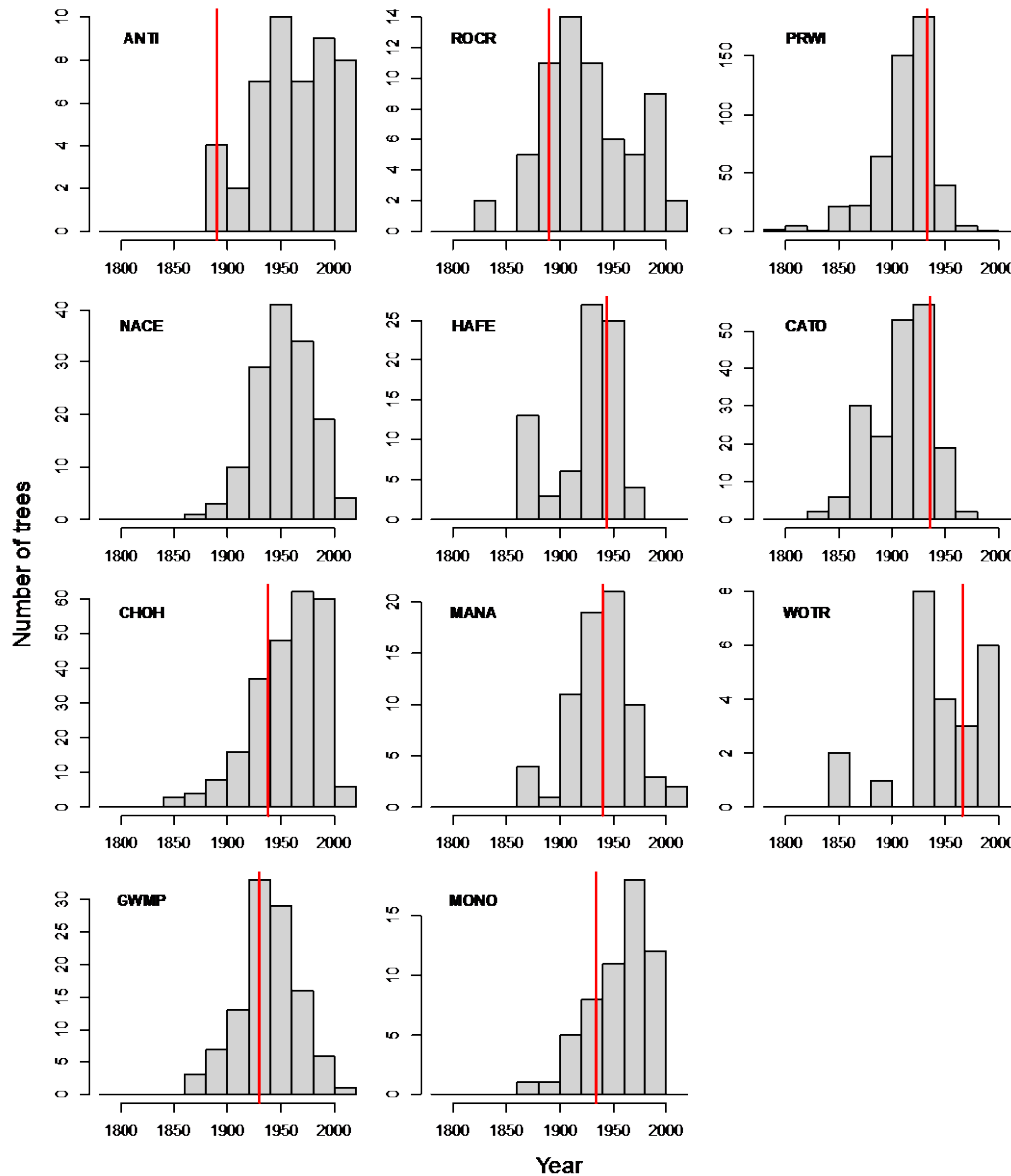


Figure 7. Park level histograms for the number of trees cored vs. the year of the oldest ring measured from each tree. From upper left to lower right, the parks shown are Antietam National Battlefield (ANTI), Rock Creek Park (ROCR), Prince William Forest (PRWI), National Capital Parks-East (NACE), Harpers Ferry National Historical Park (HAFE), Catocin Mountain Park (CATO), Chesapeake & Ohio Canal Historical Park (CHOH), Manassas National Battlefield Park (MANA), Wolf Trap National Park (WOTR), George Washington Memorial Parkway (GWMP), and Monocacy National Battlefield (MONO). The vertical red line indicates the year of park establishment. There is no red line for NACE because park establishment spanned many years.

Surface reflectance and climate data

Landsat surface reflectance and Daymet daily climate data were successfully curated for all 424 plots, 408 of which contained trees that were successfully cored. All Landsat data span the period 1984 to 2019 and are acquired by three different sensors (Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI) each in a polar orbit that provides a revisit time of 16 days, however at times these

sensors were in orbit simultaneously, providing an observation every 8 days. Furthermore, locations that overlap two orbits were observed twice as often by any given sensor. Therefore, the total number of cloud-free observations provided by these sensors for each plot varies from 347 to 1226.

Plot ANTI-0072 is an illustrative example of a plot with a large number of Landsat observations (1215) and with observable trends in canopy reflectance. Many forest stands at Antietam National Battlefield have been in a state of regrowth for nearly 100 years. Plot ANTI-0072 is a very young example. The tree ring data from this site reports a stand age of 18 years as of 2022, making it the youngest forest of any measured plot in the NCRN. Because young forests typically exhibit a period of rapid growth, we would expect the surface reflectance of the forested canopy at this plot to exhibit recent trends observable by Landsat. Indeed, the near infrared reflectance at ANTI-0072 has been increasing in summer and decreasing in winter since 1985 (Figure 8). These trends are consistent with a canopy that is increasing in summer leaf area and increasing in structural complexity, causing increased shade between trees, which is observable in winter. Conversely, plot PRWI-0722 contained the oldest tree cored at any plot and has a modest number of Landsat observations (510). Reflectance at PRWI-0722 has been largely stable for the past 35 years. No trend in summer reflectance was measured and winter reflectance only declined minimally (Figure 9).

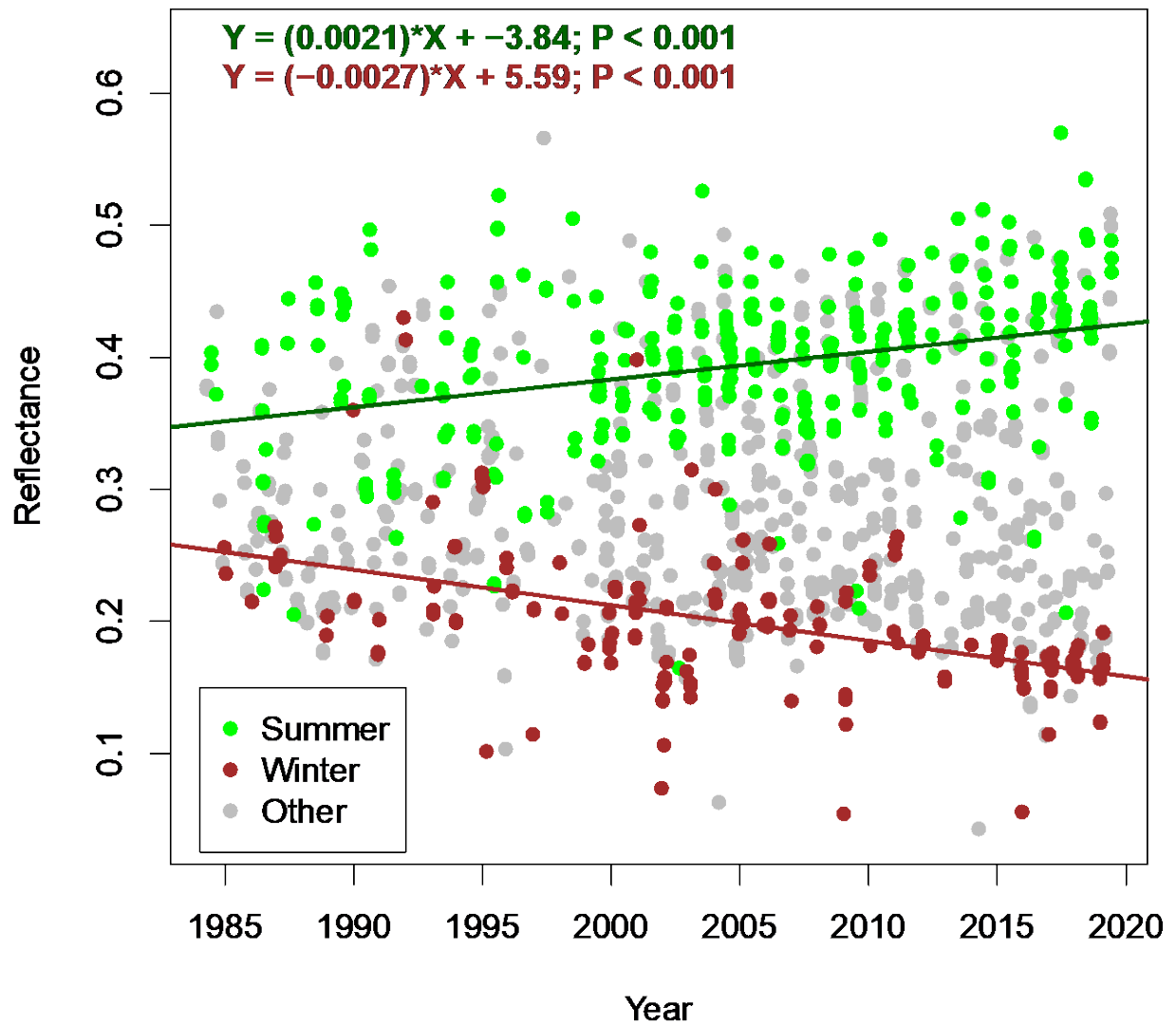


Figure 8. Landsat near infrared surface reflectance vs. date of image acquisition for plot ANTI-0072. This plot, located at Antietam National Battlefield, is an early successional stand and exhibits increasing near infrared reflectance in the summer over the period of record. Conversely, winter reflectance has been declining over time.

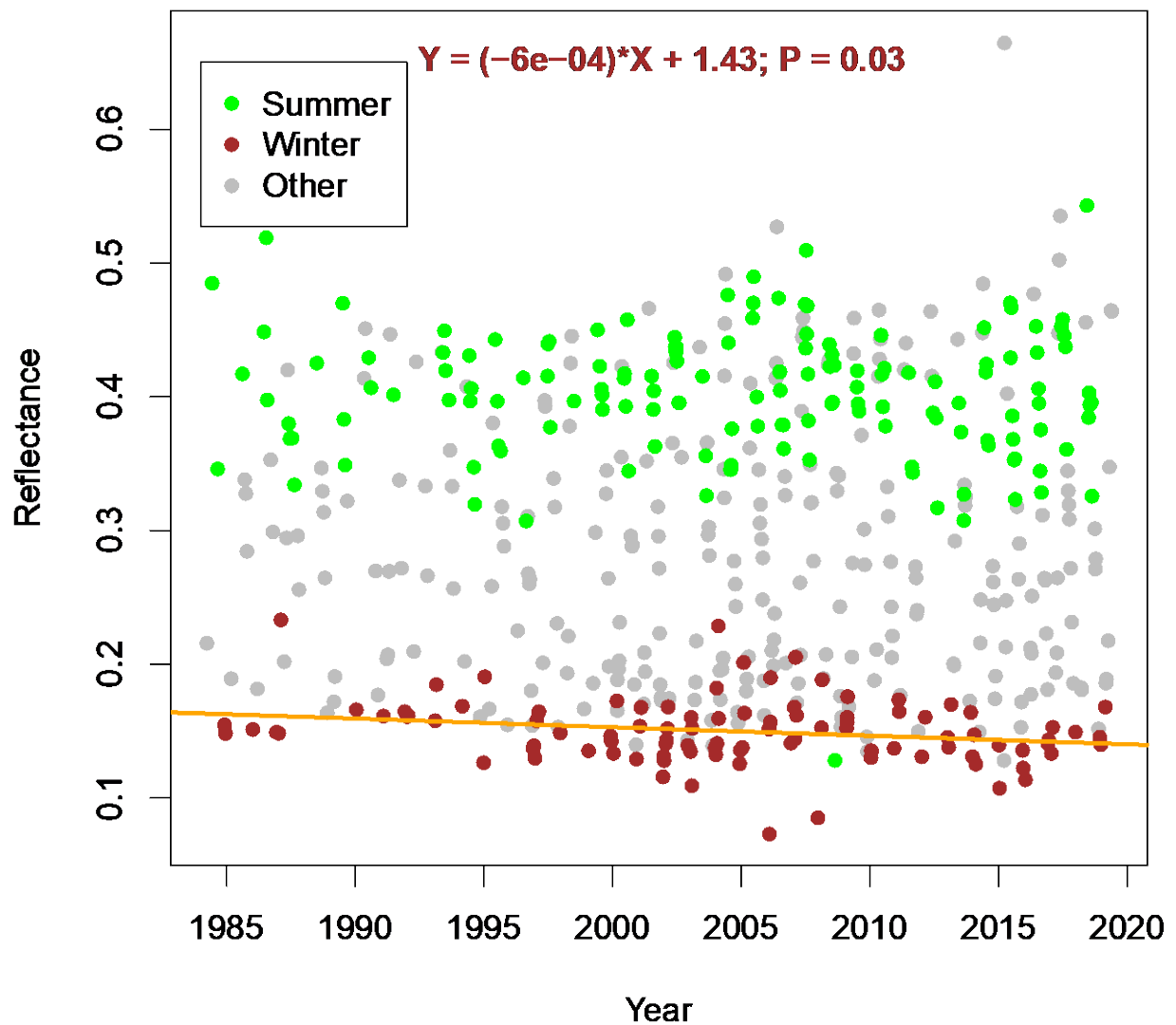


Figure 9. Near-infrared reflectance at PRWI-0722 (Prince William Forest) exhibits stability over the period of record. This is a late successional stand. Also see Figure 2.

To provide additional information on changes in canopy condition, we measured photosynthetic vegetation fraction from all Landsat reflectance measurements and used these measurements to model the annual trajectory of vegetation cover (phenology) at each plot. Data on vegetation cover derived from reflectance can be used to evaluate trends in the fraction of photosynthetic vegetation over time. For example, at ANTI-0072 summer vegetation cover has increased at a rate of 1.1% cover/year, from 40% cover in 1985 to 80% cover in 2022 (Figure 10). Vegetation phenology at stable sites, such as PRWI-0722, can be characterized using the 7 parameters from Equation 1 (Figure 2). The spring onset at this site is approximated using the inflection point of the rising logistic curve, which is day 119 and recorded as m_3 in the database. Across all plots, the spring onset of greenness ranged from day 106 to day 135. Early spring onset was observed at low elevation plots at many of the park units. Late spring onset was observed primarily at Catocin Mountain Park, which reaches elevations above 300m (Figure 11).

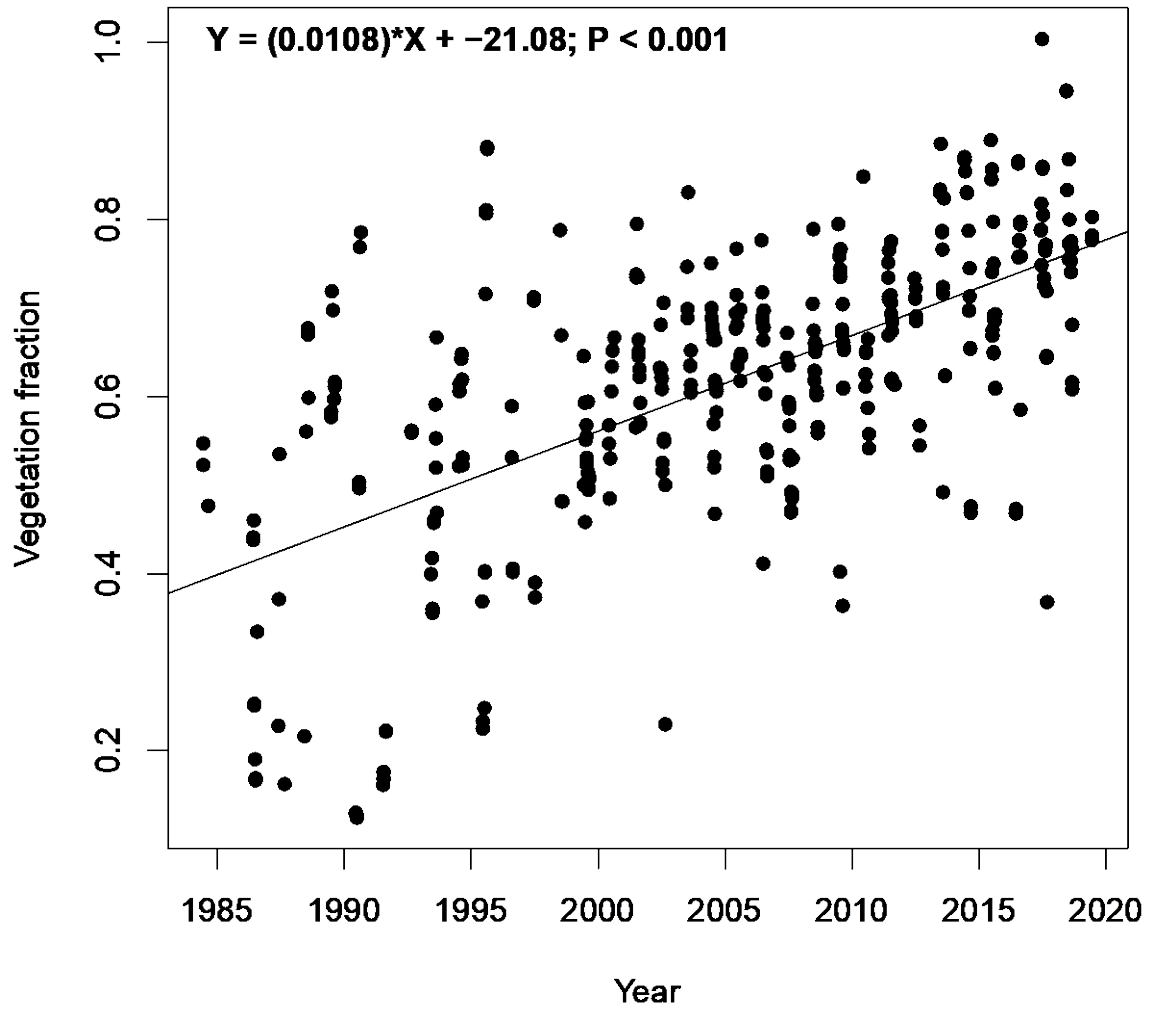


Figure 10. Growing season vegetation fraction at ANTI-0072 derived from spectral mixture analysis of Landsat data from 1984 to 2022.

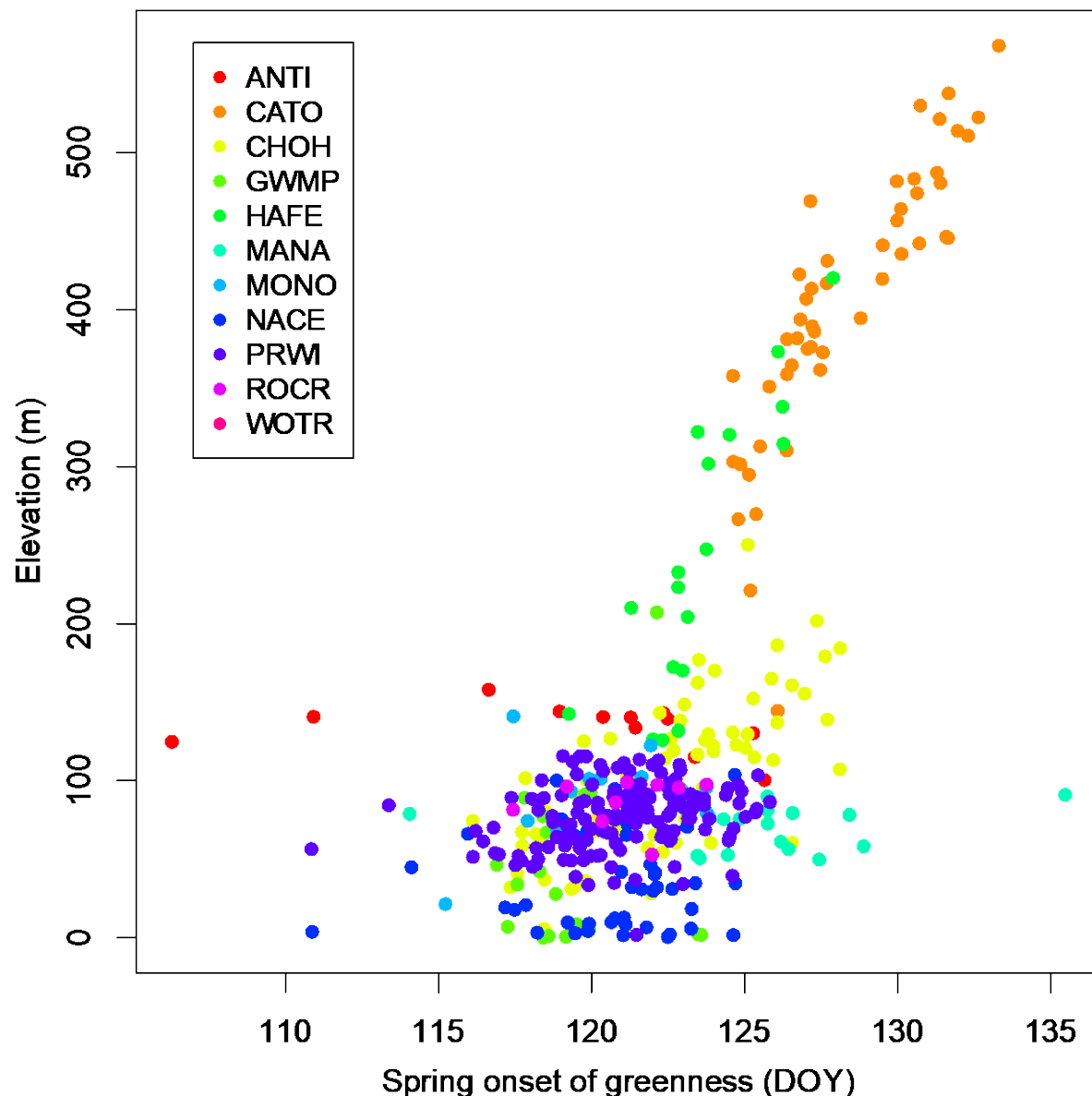


Figure 11. Elevation vs. the day of year of the spring onset of greenness derived from all available Landsat observations (1984–2022).

Across the NCRN vegetation plots, mean annual temperature (MAT) ranges from 10.61 to 14.02 °C and mean annual precipitation (MAP) ranges from 956.6 to 1318.2mm.

Database usage

The entire tree ring database (Figure 3), with ancillary observations from topographic, climatic, and remote sensing data is stored in a compact SQLite database file (<https://www.sqlite.org/>). There are multiple ways to connect to the file using a variety of data analysis software, join tables based on key words, subset tables by any number of features, including by park, species, tree age, elevation, climate, etc. Specific geolocations are not provided for cored trees but are available upon request.

For example, typical usage might leverage the power of the R statistical programming language to query the data and generate plots of ring width. The first step would be to connect to the data base file:

```
install.packages("RSQLite")
library(RSQLite)
conn <- dbConnect(RSQLite::SQLite(), "ncrn_treecores.db")
```

Once a connection is made, any of the database tables can be queried using standard SQL syntax. For example, a table of all trees cored, or rings measured can be generated:

```
tree_data <- dbGetQuery(conn, statement = paste("SELECT * FROM
trees"))
ring_data <- dbGetQuery(conn, statement = paste("SELECT * FROM
rings"))
```

However, such queries do not leverage the power of SQLite for data queries that result in tables specifically tailored to researcher questions. For example, a more involved query might extract the year of the oldest ring collected from each tree in the database:

```
tree_age <- dbGetQuery(conn, statement = paste("WITH _oldest
AS(SELECT core_label,tag_number,dch,MIN(ring_year) AS oldest_ring
FROM rings JOIN cores USING(core_label)GROUP BY
core_label,tag_number,dch)SELECT tag_number,dch,MIN(oldest_ring)AS
oldest_ring FROM _oldest GROUP BY tag_number,dch"))
```

Extensive resources are available for constructing simple and complex queries. Importantly, the SQL syntax (provided within the quotes in the script provided above) is independent of the data analysis software used. For example, using an ODBC Driver for SQLite, Microsoft Excel users can connect to the provided data base file and execute queries.

All variables in the database are listed in the data dictionary (Table 3). For most variables the definition provided, along with the contents of this report, is sufficient. However, in the case of ring width, the variable *width* is the early wood width, or total ring width for tree species where early wood and late wood are indistinguishable. The variable *width_lw* represents the width of late wood only and is zero for tree species with indistinguishable late wood. Therefore, to retrieve the full ring width for each tree, query the ring table thus:

```
ring_data <- dbGetQuery(conn, statement = paste("SELECT core_label,
ring_year, (width + width_lw) AS width_full FROM rings"))
```

Data Dictionary

Table 3. Data dictionary defining all database variables. Key variables are in bold and have an asterisk (*).

Variable	Definition
plot_name*	NPS plot name
unit_code	Four-digit park unit code
i_d	Date of plot establishment
elevation	Plot elevation in meters
slope	Plot slope in degrees
aspect	Plot aspect, in degrees relative to north
tmax	Mean maximum temperature in degrees Celsius, summarized from Daymet 1980–2018
tmin	Mean minimum temperature in degrees Celsius, summarized from Daymet 1980–2018
precipitation	Annual mean precipitation in mm, summarized from Daymet 1980–2018
m1	Mean minimum annual vegetation fraction (see eq. 1)
m2	Mean maximum vegetation fraction amplitude (see eq. 1)
m3	Mean day of year of the spring onset, inflection point in rising logistic function (see eq. 1)
m4	Mean spring logistic growth duration (see eq. 1)
m5	Mean day of year of the autumn offset, inflection point in descending logistic function (see eq. 1)
m6	Mean autumn logistic decrease duration (see eq. 1)
m7	Mean growing season rate of vegetation decrease in units of vegetation fraction (0–1) per day (see eq. 1)
tag_number*	A 3- to 5-digit integer unique to each tree cored. The tag number is affixed to the tree near the bole on an aluminum tag.
tsn	Taxonomic Serial Number (see https://www.itis.gov/)
cname	Common species name
family	Tree Family
genus	Tree genus
species	Tree species
core_label*	Core label containing plot_name, tree number (1–4) and core letter (AB)
core_event_id*	Key used to join this data base to additional NPS I&M vegetation monitoring data.
core_date	Date the core was collected
dch	Diameter at core height (cm)
core_height	Height above the ground at which core was collected (cm)
crown_class	Crown class number: (1) Open-grown, (2) Dominant, (3) Co-dominant, (4) Intermediate, (5) Overtopped, (6) Light Gap Exploiter, (7) Edge Tree.
ring_year*	Year of ring formation
width	Width of early wood or all wood if tree lacks late wood (mm)
width_lw	Width of late wood (mm)

Table 3 (continued). Data dictionary defining all database variables. Key variables are in bold and have an asterisk (*).

Variable	Definition
scene_id*	Landsat scene ID, used to join to other sources for Landsat data
sensor	Landsat sensor number for Landsat 8, 7 and 5
path	Landsat path number in the wrs-2 indexing system
row	Landsat row number in the wrs-2 indexing system
acq_date	Date of Landsat acquisition
blue	Surface reflectance in the visible blue (~450–510 nm)
green	Surface reflectance in the visible green (~530–590 nm)
red	Surface reflectance in the visible red (~640–670 nm)
nir	Surface reflectance in the near infrared (~850–880 nm)
swir1	Surface reflectance in the shortwave infrared (~1570–1650 nm)
swir2	Surface reflectance in the shortwave infrared (~2110–2290 nm)
sunz	Mean sun zenith angle across the Landsat scene (degrees from verticle)
sunaz	Mean sun azimuth angle across the landsat scene (degrees from N)
substrate	SMA fraction of bare soil, rock, or other substrate
shade	SMA fraction of shade
veg	SMA fraction of photosynthetic vegetation
npv	SMA fraction of non-photosynthetic vegetation
year*	DayMet weather year
doy*	DayMet weather day of year
tmax	Maximum daily temperature (DayMet)
tmin	Minimum daily temperature (DayMet)
prcp	Daily precipitation (DayMet)

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Appendix A

Database files

This data record includes one database file organized as in Figure 3. The file name is *ncrn_treecores.db*.

Formatted tables

For selected applications this data record includes formatted tables in addition to the SQLite database file. These formatted tables are included to simplify data exploration for common research questions.

plotage.csv: Provides the park unit, stand age (in 2022), and year of oldest ring sampled for each plot.

speciesbypark_numtrees.csv: Provides the number of trees cored for each species in each park.

species_maxage.csv: Provides the park and year of the oldest ring sampled from each species (across all trees of that species).

speciesbypark_oldestyear: Provides the oldest ring cored from each species in each park.

COFECHA output

COFECHA is a computer program that assesses the quality of cross dating and measurement accuracy of tree-ring series. As described in this report, output from COFECHA was used iteratively through the measurement and cross dating process. Final COFECHA reports are provided to aid any future investigation into the quality of individual cores.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 800/188074, April 2023

National Park Service
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