

Preliminary dendrochronology at Muir Woods National Monument

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Overview

During the 2014 Golden Gate National Recreation Area BioBlitz, tree-ring samples were collected from three *Sequoia sempervirens* (SESE) at Muir Woods National Monument, allowing for an initial dendrochronological investigation and establishment of educational material. This data provided for the first redwood tree-ring chronology at Muir Woods, spanning 1318–2013 A.D. and capturing the oldest extent of any crossdated SESE south of Mendocino County. The Muir Woods chronology correlated strongly with the nearest RCCI plot at Samuel P. Taylor State Park ($r = 0.40$, $p < 0.001$, common period 1750–2009 A.D.) reflecting a shared climate signal. Relationships between monthly climate variables (PRISM data, common period 1895–2013 A.D.) and the inter-annual tree-ring chronology (32-year spline detrended) were consistent with patterns identified at SESE locations across the range (Carroll et al. 2014). The year-to-year variation in ring widths was most sensitive to spring and summer soil moisture availability ($r = 0.25$, $p < 0.01$; average of March–August correlations with Palmer Drought Severity Index). While March ($r = 0.24$, $p = 0.01$) showed the strongest monthly correlation for precipitation, the relationship was not as strong as at other sampled locations across the range. Using station data for precipitation at Muir Woods (1941–2013 A.D.) showed a stronger March correlation ($r = 0.46$, $p < 0.01$) perhaps reflecting well maintained data collection at the national monument.

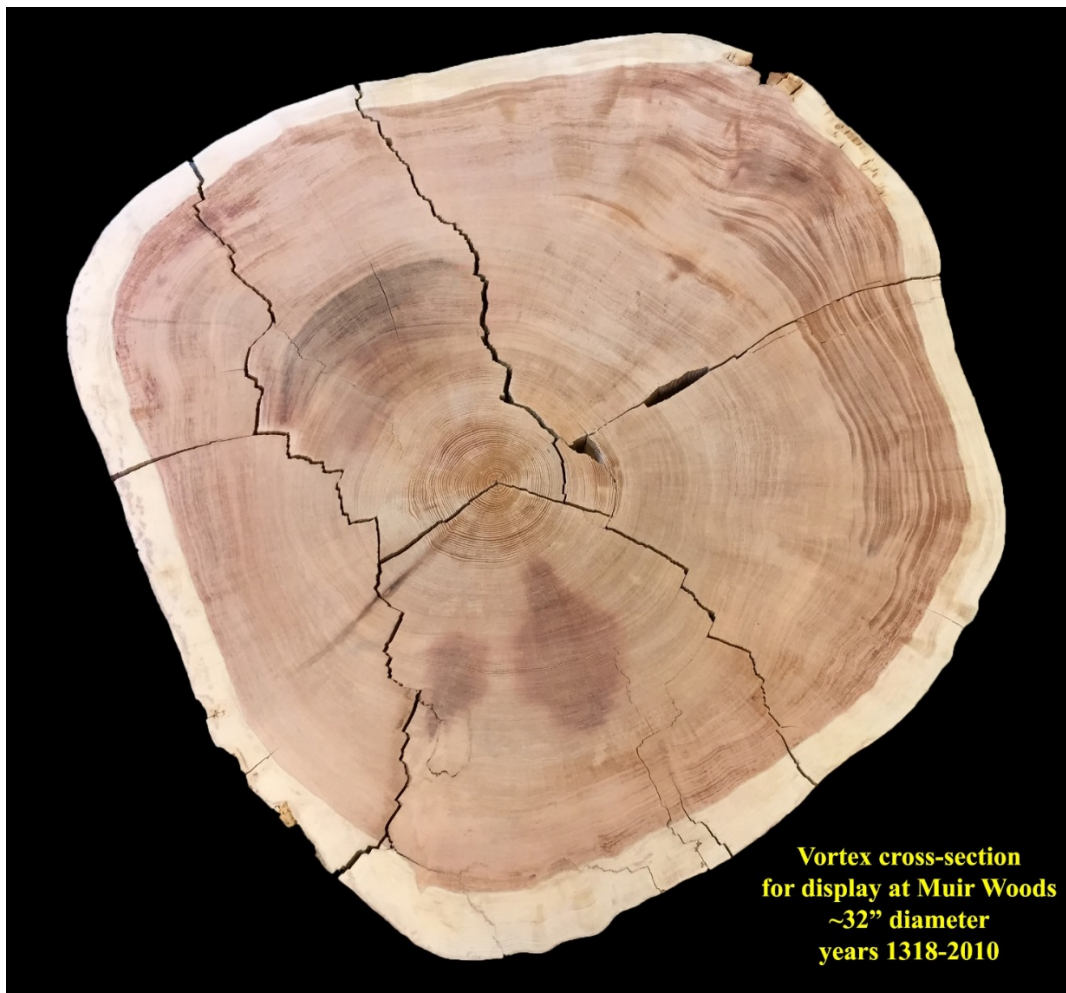
Study Trees

Three coast redwoods at Muir Woods National Monument were sampled for this dendrochronological investigation. One live tree in Cathedral Grove (Tree 76) was climbed via free hanging ropes as part of the 2014 Golden Gate National Recreation Area BioBlitz, with

cores sampled at 10 m intervals. The two other trees, known as the Solstice and Vortex Trees, had fallen within the last five years and were opportunistically sampled at accessible locations on the ground.

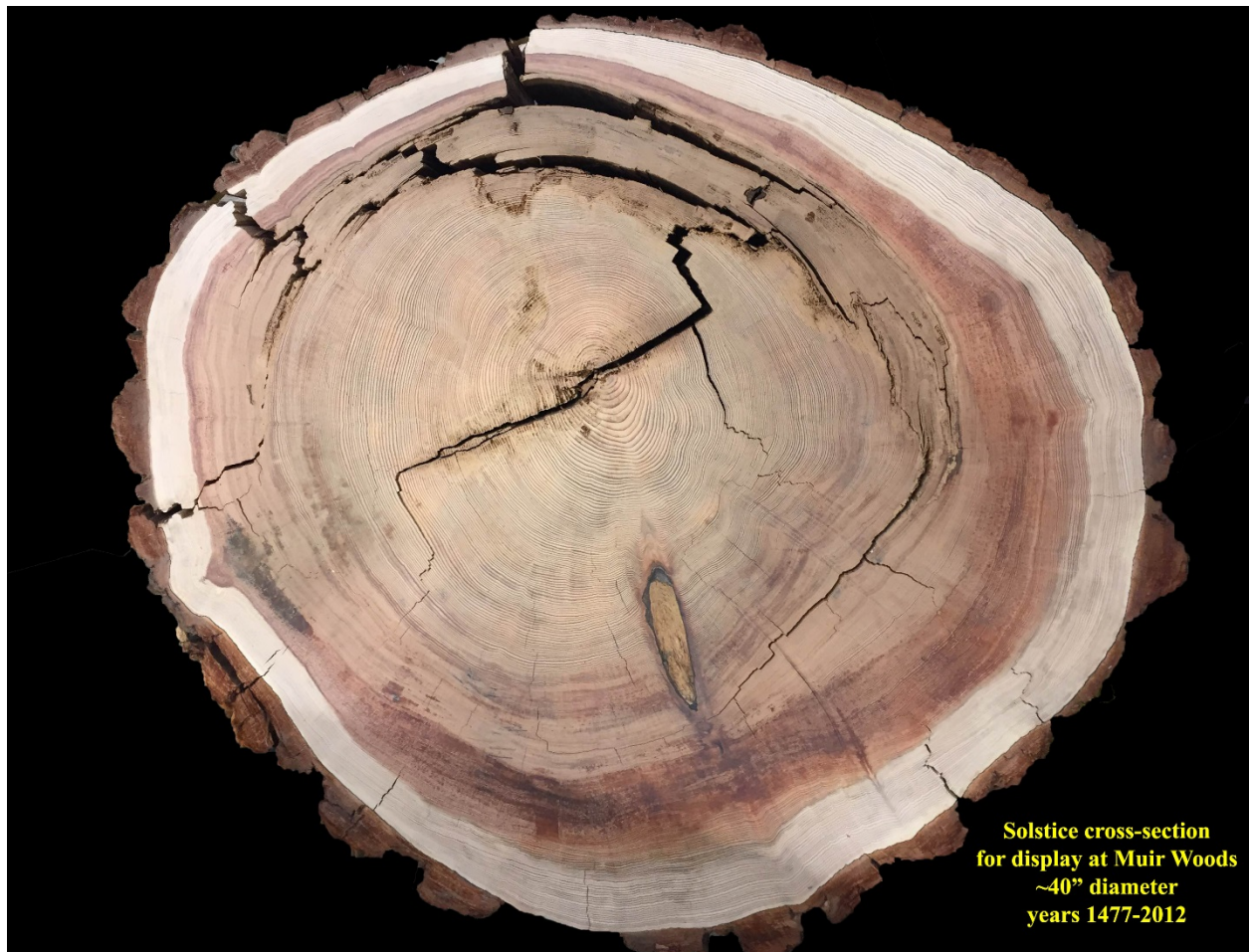
Vortex Tree: The tree known as Vortex fell June 15, 2011, (date to be confirmed by Muir Woods staff) and lies alongside the trail. A cross-sectional sample was taken where the tree crosses the trail, although height of the sample is unknown. The tree dates to the year 1318 A.D., making it the oldest redwood sample in the RCCI dataset south of Mendocino County. Accordingly, its age is > 693 years. The Vortex cross-section was prepared for display at the Muir Woods Visitor Center through a process of mounting it on plywood, sanding with progressively finer grit sandpaper, and applying a polyurethane finish (Figure 1).

Figure 1. Cross-section of Vortex tree, prepared for display at the Muir Woods Visitor Center.



Solstice Tree: The tree known as Solstice fell on the winter solstice, December 21, 2012. A cross-sectional sample was taken where the tree crosses the trail at 11 m from ground level when standing (Figure 2). Ten additional cores were opportunistically taken from the downed log above 11 m. The cross-section at 11 m is the lowest sample, reaching pith with a crossdated year of 1477; accordingly age is > 536 years.

Figure 2. Cross-section of the Vortex tree, 11 m from ground.



Tree 76: A 76 m redwood located in Cathedral Grove was climbed by Steve Sillett and Marie Antoine as part of the 2014 Golden Gate National Recreation Area BioBlitz on March 28–29, 2014. Multiple cores were taken at 10 m height intervals from 10 to 70 m (Figure 3). Using power functions from Samuel P. Taylor State Park, tree age was predicted to be 777 ± 34 years (Sillett, unpublished). Core samples have been archived according to NPS protocol and stored at the Humboldt State University archive.

Figure 3. Tree core collection from Tree 76.



Crossdating

All samples were prepared and crossdated according to standard RCI protocol (Carroll et al. 2014). Samples were sanded with progressively finer grit sandpaper, rings were demarcated

under a stereo microscope, samples were scanned at 1200 dpi resolution, and rings were measured to 0.001 mm using WinDendro software. Tree 76 provided the benchmark for crossdating, as all 17 series from 13 cores were fully dated, establishing a strong within-tree validation of crossdating spanning from 1448–2013 A.D. Of the 5905 rings measured on this tree, 41 were locally absent or “missing” but these locations were accurately deduced from replicate cores. The Vortex cross-section showed continuous rings without anomalous wedging or discontinuous patterns, capturing all rings from 1318–2010 A.D. The Solstice samples provided sections of decipherable rings for crossdating, while other sections contained large numbers of locally absent rings deduced from crossdating. For example, a tree core from 15 m had 148 absent rings between the years 1644–2012 A.D. (no annual resolution of absent rings), while the years 1517–1643 A.D. provided good replication for the chronology with no absent rings. While only 53% of the 4986 rings on the Solstice samples were crossdated with high confidence, these sections still contributed to the site-level chronology.

Chronology Creation

The tree-ring data from the three study trees was used to create a crossdated chronology or tree-ring index for Muir Woods National Monument spanning 1318–2013 A.D. (Figure 4). First, tree-level chronologies were created using only series crossdated with high confidence and series greater than 25 years. Each series was detrended with a 32-year spline using the software ARSTAN. The three tree-level chronologies were then combined into a site-level chronology with no further detrending applied and variance stabilized. Comparison of the Muir Woods chronology with the other range-wide SESE and SEGI chronologies showed the highest correlation ($r = 0.40$, $p < 0.0001$) with the closest study location, Samuel P. Taylor State Park (Table 1). Like other mid to southern SESE chronologies, there was some synchrony with *Sequoiadendron giganteum* (SEGI) chronologies. Interestingly, the year 1580 was a strong marker year on the Vortex cross-section, capturing this significant low growth ring associated with a low water year in SEGI and other Sierra chronologies (Figure 5).

Figure 4: Standardized tree-ring chronologies and sample depths for Muir Woods and the three individual trees.

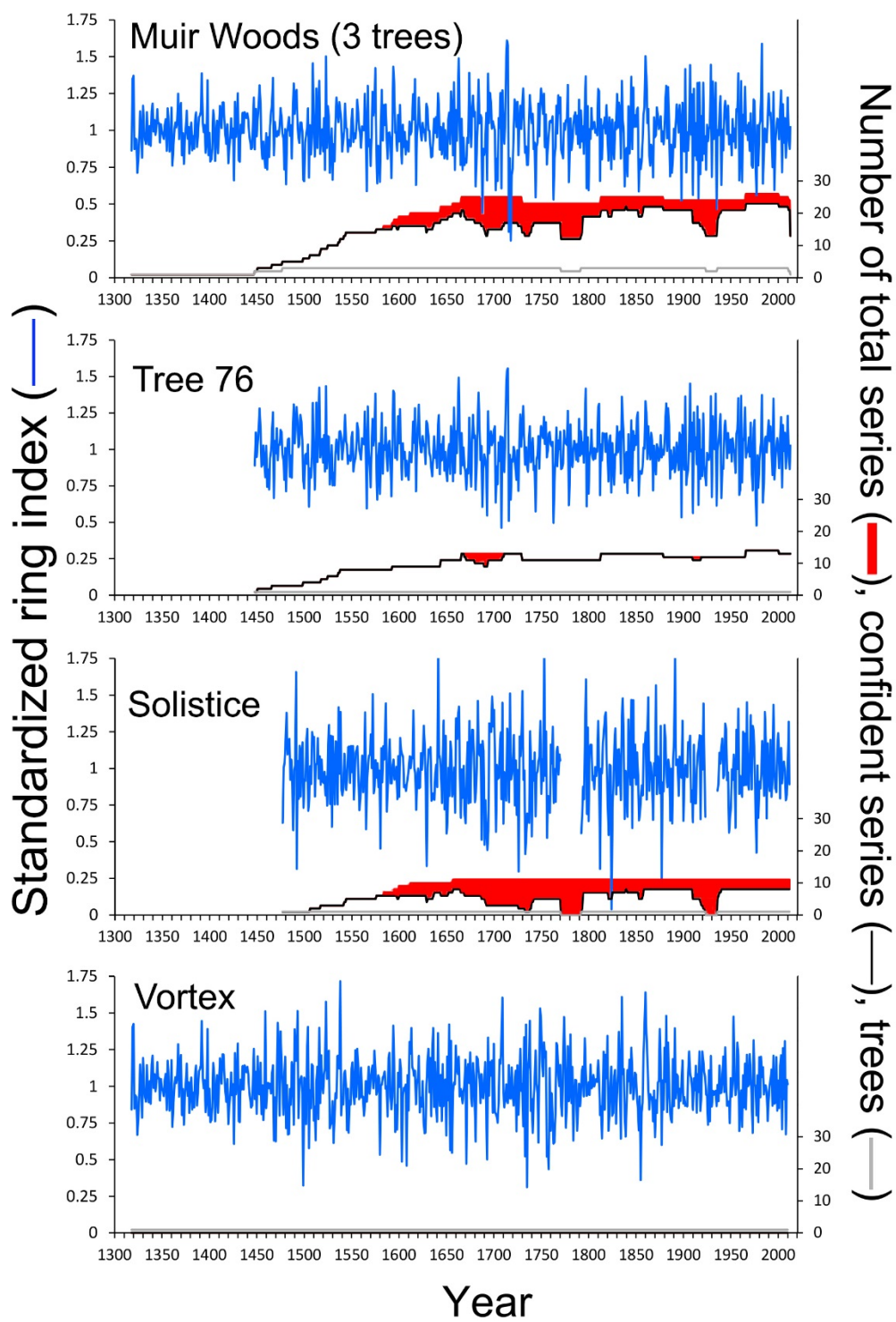


Table 1: Correlation analysis of Muir Woods (37.9 °N, 122.6 °W) with *Sequoia sempervirens* (SESE) and *Sequoiadendron giganteum* (SEGI) chronologies. Common period 1750–2009 A.D., with $r = 0.20$ as cutoff for statistical significance at $p < 0.01$.

Species	Location	Latitude (°N)	Longitude (°W)	Correlation (r)
SESE	JS, Jedediah Smith Redwoods State Park	41.8	124.1	0.29
SESE	PC, Prairie Creek Redwoods State Park	41.4	124.0	0.28
SESE	RNP, Redwood National Park	41.2	124.0	0.19
SESE	HR, Humboldt Redwoods State Park	40.3	123.9	0.26
SESE	MW, Montgomery Woods State Natural Reserve	39.2	123.4	0.32
SESE	SPT, Samuel P. Taylor State Park	38.0	122.7	0.40
SESE	BB, Big Basin Redwoods State Park	37.2	122.2	0.37
SESE	LH, Landels-Hill Big Creek Reserve	36.1	121.6	0.31
SEGI	CBT, Calaveras Big Trees State Park	38.2	120.2	0.20
SEGI	WF, Whitaker Forest	36.7	118.9	0.27
SEGI	RMG, Redwood Mountain, Kings Canyon National Park	36.7	118.9	0.27
SEGI	GF, Giant Forest, Sequoia National Park	36.6	118.7	0.19
SEGI	MH, Mountain Home State Demonstration Forest	36.2	118.7	0.15
SEGI	FC, Freeman Creek, Sequoia National Monument	36.1	118.5	0.23

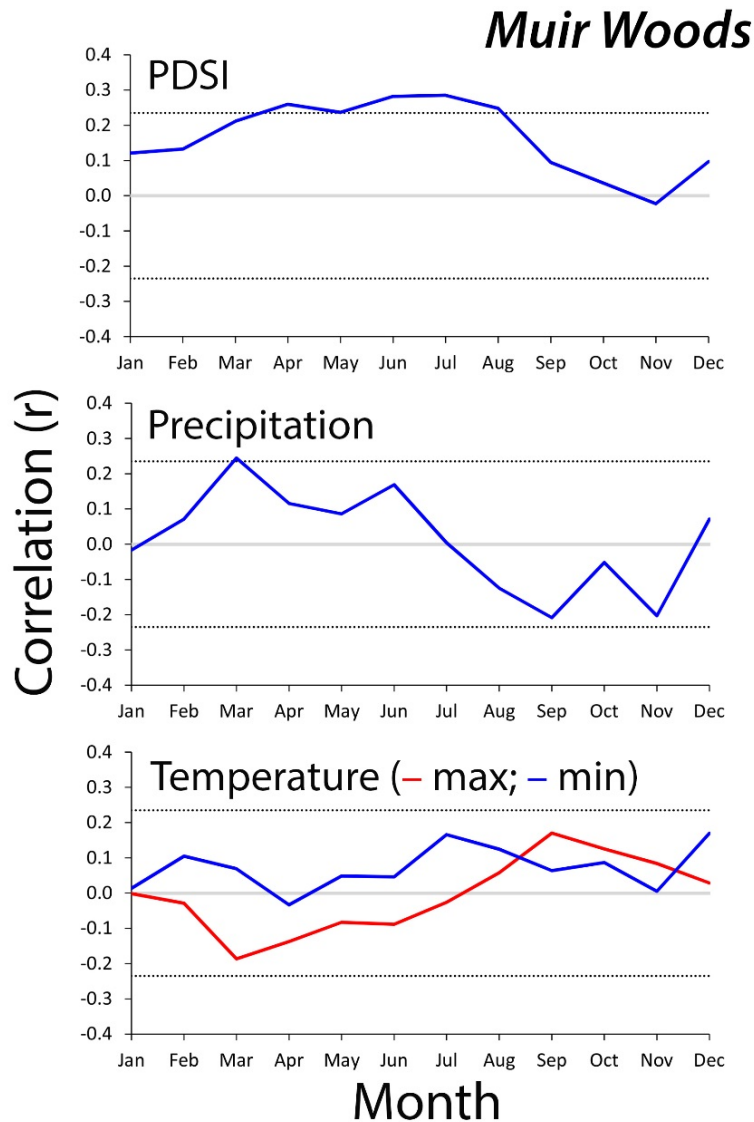
Figure 5: Low-growth marker year 1580 present in Vortex cross-section. This marker year aligns more with SEGI chronologies than with northern SESE chronologies.



Inter-Annual Climate Sensitivities

The inter-annual chronology for Muir Woods was compared to century-long series of climate data to quantify the relationship between ring widths and the climate variables of drought index, temperature, and precipitation (Figure 6). Palmer Drought Severity Index (PDSI) reflects soil moisture availability and incorporates both temperature and precipitation. Monthly PDSI data were obtained from the Western Regional Climate Center's WestWide Drought Tracker. Precipitation and minimum and maximum temperature data were acquired at 800 m resolution from PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping system. The year-to-year variation in ring width over the 1895–2013 A.D. time span correlated highest with spring and summer PDSI, peaking in July ($r = 0.29$, $p < 0.01$). This relationship fits with the sensitivities of SESE across the range and reflects the effect of low moisture availability on radial growth, which is relevant in Mediterranean climates with distinctly dry summers. Correlations with minimum and maximum temperature were not statistically significant. March ($r = 0.24$, $p = 0.01$) showed the strongest monthly correlation for precipitation, capturing the importance of spring rains. Weather station data for precipitation was available for Muir Woods from 1941–2013 A.D. and showed a stronger March correlation ($r = 0.46$, $p < 0.01$). Direct station data is often preferable to interpolated data such as PRISM, however, it is not available for many locations. Due to its long-standing existence as a national monument, mostly continuous monthly precipitation data at this station was available.

Figure 6: Summary of inter-annual climate sensitivities at Muir Woods. Correlations of the 3-tree Muir Woods chronology with Palmer Drought Severity Index (PDSI), precipitation, and maximum and minimum temperature over the common period 1895–2013. Dashed lines represent cutoff for critical significance ($p < 0.01$).



References

Carroll AL, Sillett SC, Kramer RD (2014) Millenium-scale crossdating and inter-annual climate sensitivities of standing California redwoods. PLOS ONE 9: 1–18.