

**Craters of the Moon Dendrochronology: An Assessment of Limber Pine and  
Douglas-fir Radial Growth and Climate Sensitivity**

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**Note:** *This is only a preliminary report that summarizes initial findings from this project.  
This report should not be distributed or published anywhere until the research findings  
have been peer-reviewed.*

## Background and Motivation

Ancient lower-forest border arid-site conifers growing across the western US serve as high-resolution proxy-records for long-term moisture change through their annual growth-ring formation (Fritts, 1965; Fritts, 1974). This type of tree-ring proxy record plays a critical role in documenting past and present climatic change across local, regional, and continental scales. Assessing the historical range of drought occurrence, drought magnitude, and drought duration is possible with many centuries of tree-ring widths (Hughes, 2002). The Craters of the Moon National Monument (hereinafter COM) is a unique basaltic-lava complex in the interior western US that sits within a low elevation region – the Snake River Plain (hereinafter SRP). The SRP provides a low-elevation corridor for moist Pacific airflow moving east and northward into interior regions of the North American continent (Mock, 1996). Therefore, because limber pine (*Pinus flexilis*) and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Bessin.) Franco.) trees are growing on porous COM lava flow and weathered cinder cone soil conditions, their growth rings should show elevated sensitivity to moisture availability and change over seasonal and annual timescales. The purpose of this COM project was to develop long tree-ring records on the eastern SRP to document past drought and pluvials, and situate current climatic changes into a historical context.

This project had four main objectives. (1) Develop one long limber pine total ring-width (RW) chronology, and three long Douglas-fir chronologies from total ring-width (RW), earlywood-width (EW), and latewood-width (LW). (2) Compare radial growth variability between limber pine RW and Douglas-fir RW, EW, and LW. (3) Compare radial growth variability for each tree-ring width chronology with instrumental climate records including mean temperature and total precipitation. (4) Reconstruct past climate for the eastern SRP using COM tree-ring records.

## Methodology

### *Field Data Collection and Sample Preparation*

Tree-ring core specimens were collected from living trees and remnant deadwood across the COM. Specific areas included Silent Cone, Grassy Cone, and Devil's Orchard. (Figure 1 – *a more detailed map can be provided at a later date if necessary*). Thirty individual limber pine and Douglas-fir trees were selected for core specimen extraction (2 cores per tree) at approximately 30 cm using an increment borer (Fritts, 1976). Core specimens were processed according to standard techniques and crossdated to an exact calendar year (Stokes and Smiley, 1996). Visual crossdating was verified with COFECHA (Holmes, 1983). Total annual growth increments were measured to the nearest 0.001 mm for limber pine RW and Douglas-fir RW. Also, sub-annual EW and LW increments were measured for Douglas-fir.

### *Tree-ring Chronology Development*

Age-related growth trends associated with tree maturation were removed with deterministic standardization (Cook and Kairiukstis, 1990). Only tree-ring width series having segments greater than 200 years were used in chronology construction. Before detrending, raw ring-width measurements were power transformed adaptively to reduce population skew, improve curve

fits, and minimize trend propagation into the final mean chronology (Cook and Peters, 1997). The variance was stabilized for each tree-ring width series using Briffa's  $\bar{r}$  method (Briffa and Jones, 1990). A conservative detrending approach was applied to each tree-ring width series by fitting a horizontal mean line, negative exponential curve, or linear regression line with a negative slope (Cook et al., 1995). Standardized tree-ring width chronologies were estimated using a bi-robust weighted mean, and the expected tree-ring width was divided by the actual tree-ring width to produce a dimensionless index of average growth. Autoregressive modeling was applied to remove serial autocorrelation, and produce residual RW, EW, and LW indices (Cook, 1985). Lastly, an adjusted latewood-width chronology ( $LW_a$ ) was developed for Douglas-fir using methods outlined by Griffin et al. (2011). Adjusting for latewood's antecedent dependence on earlywood isolates independent sub-annual growth variability contained in latewood-width (Meko and Baisan, 2001).

### *Tree-Growth Climate Analysis*

Limber pine RW and Douglas-fir RW, EW, and  $LW_a$  were compared over time periods where each chronology exhibited an expressed population signal (EPS) greater than 0.85 (Wigley et al., 1984). Simple correlation analysis (i.e., two-tailed significance test) was used to derive a 'Coefficient of Variation' (Crawford, 2012; Hughes and Funkhouser, 2003). Tree-ring width-climate correlations were computed using a Monte-Carlo approach (1000 simulations) with SEASCORR (Meko et al., 2011). Domain averaged Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate data (Daly et al., 2008) was extracted for Idaho climate divisions seven (central plains) and nine (upper Snake River plain) (<http://www.cefa.dri.edu/Westmap/>). 1930-2009 was selected for the climate sensitivity assessment of each tree-ring width chronology. Monthly, seasonal, and annual correlations were computed for a 14-month window spanning prior August to current September. The statistical significance of each correlation coefficient was assessed using non-exceedence probabilities at  $p < 0.05$  and  $p < 0.01$  levels (Meko et al., 2011).

### *Proxy-Based Climate Reconstruction*

A multiple stepwise regression procedure with cross-validation was used to develop proxy-based reconstructions of annual and seasonal precipitation spanning 1532-2008. This methodology will be discussed in greater detail in the final product.

## **Results**

### *COM Tree-Ring Width Chronologies*

COM tree-ring width chronology statistics can be found in Table 1. Time-series plots can be found in Figure 2. The median tree age for limber pine was 400 years. The median tree age for Douglas-fir's was 342 years. Limber pine grows on all types of basaltic-lava soil conditions. Douglas-fir primarily confines itself to north facing slopes on weathered cinder cones. For the most part, these two tree species occupy different local ecological niches at COM.

### *Tree-Growth-Climate Analysis*

Development of a Douglas-fir LW<sub>a</sub> chronology indicated a moderately strong linear relationship between LW and antecedent EW. Douglas-fir EW was able to explain 58% of LW's variance. Simple correlation coefficients between limber pine and Douglas-fir standardized and residual RW, EW, LW, and LW<sub>a</sub> indices can be found in Table 2. Tree-ring widths between species show weak radial growth correlations at interannual timescales, but more similar growth patterns over decades. Tree-ring widths have strong biological persistence, or in other words, lagged carry over effects from the previous year's climatic conditions (Fritts, 1971; Fritts et al., 1980). The standard chronology retains biological radial growth variability over decades, whereas, the residual chronology reflects independent radial growth variability for each year.

Monthly correlation coefficients between each tree-ring width chronology and PRISM mean temperature and total precipitation are summarized in Figure 3. The primary climate-growth control on limber pine and Douglas-fir radial growth is total accumulated precipitation, and the secondary control is mean temperature during the growing season. Low precipitation and high temperatures limit radial growth for each COM tree species. Narrow rings reflect dry and warm climatic conditions. Wide rings reflect wet and cool climatic conditions. Limber pine RW is a proxy for summer-early winter precipitation. Douglas-fir RW and EW are proxies for annual and spring precipitation. Douglas-fir LW is a proxy for annual and late summer-early winter precipitation. Douglas for LW<sub>a</sub> is a proxy for summer-early winter precipitation. Removing LW's dependence on EW, removes the influence of spring precipitation.

### *Proxy-Based Climate Reconstruction*

Using the PRISM total accumulated precipitation data for the eastern SRP, COM tree-ring width chronologies have been used to reconstruct annual and seasonal precipitation. These results will be discussed in greater detail in the final product, and after peer-review.

### **Preliminary Summary**

Limber pine and Douglas-fir trees growing on the COM are unique, ancient, and tree age ranges from 250 to 1000 years. Interestingly, these trees seem to occupy different local ecological niches at COM. In general, this results in a non-competitive interaction that appears through differences in site preference, radial growth, and seasonal climate sensitivity. Annual and sub-annual tree-ring width chronologies show greater covariance at decadal timescales, and much weaker coherence at interannual timescales. Tree physiology and seasonal precipitation sensitivity largely account for the observed growth differences, but as benefit, these trees tell more about the differences between seasonal and annual climatic conditions. Because these tree-ring width chronologies are moisture-sensitive, and carry a strong precipitation signal, seasonal and annual proxy-based precipitation estimates can be derived for the past 500 years at COM and on the eastern SRP. COM has provided an excellent site to develop long tree-ring records and reconstruct past climatic changes for COM and the eastern SRP, namely changes in seasonal and annual precipitation. Once precipitation reconstructions have been peer-reviewed, then current climatic conditions at COM can be placed into a paleoclimate context. That said, what is clear is that the eastern SRP has been drier than normal since the late 1980s, and the ongoing drought

appears centered on the 2000s. If current and future trends towards warming and drying continue to accelerate, then this will spell trouble for freshwater resources on the eastern SRP, and increase the likelihood of tree mortality at the COM.

### **Future Timeline**

This COM project will serve as one chapter in a larger dissertation project aimed at assessing historical trends in mountain snowpack across central Idaho and southwestern Montana. A complete original research manuscript has been written and is currently being reviewed by my co-authors. I plan to submit this manuscript to the peer-reviewed journal '*The Holocene*' shortly. Once this manuscript has been accepted for publication, I will submit a final research report and manuscript copy to the NPS and COM. While processing the COM tree-ring data, evidence of frost damage was identified in Douglas-fir tree-ring widths. Frost rings are currently being analyzed, and represent another aspect of this COM research project. Once samples have been fully analyzed, they will be formally labeled and archived at COM per research permit agreement. After a more comprehensive review has been completed, the Principal Investigator Christopher J. Crawford plans to inquire about collecting 10-20 more limber pine core specimens only from dead and down wood. This additional collection will prove useful for sample replication to support interpretation of drought conditions during 12-15<sup>th</sup> centuries.

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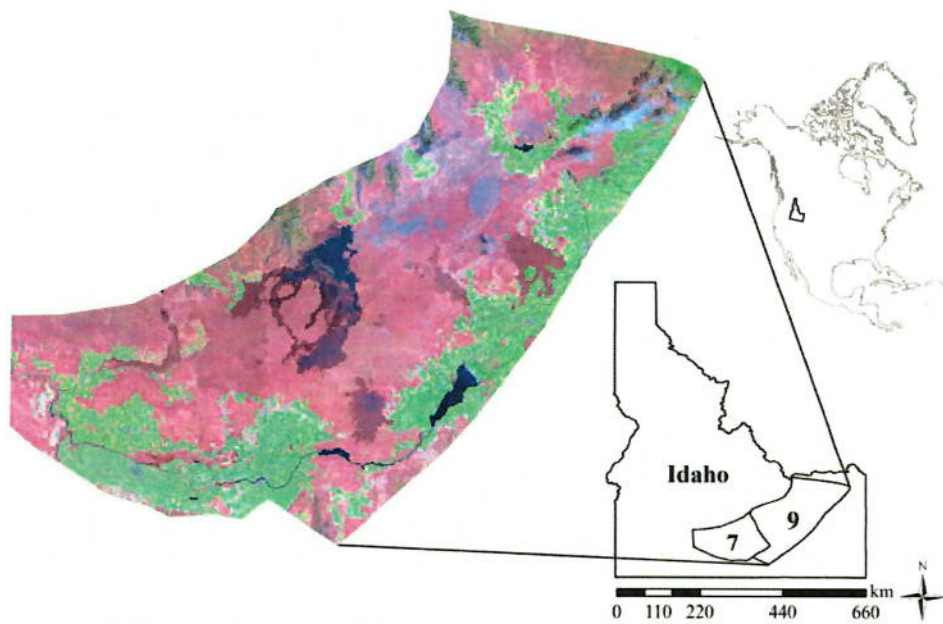


Figure 1. The COM lava-complex on the eastern SRP in south-central Idaho, USA. Notice that the COM lava-complex is situated in-between Idaho climate divisions seven (central plains) and nine (upper Snake River plain). The false-color Landsat image represents the SRP spatial domain under analysis, as well as the target domain for proxy-based climate reconstructions.

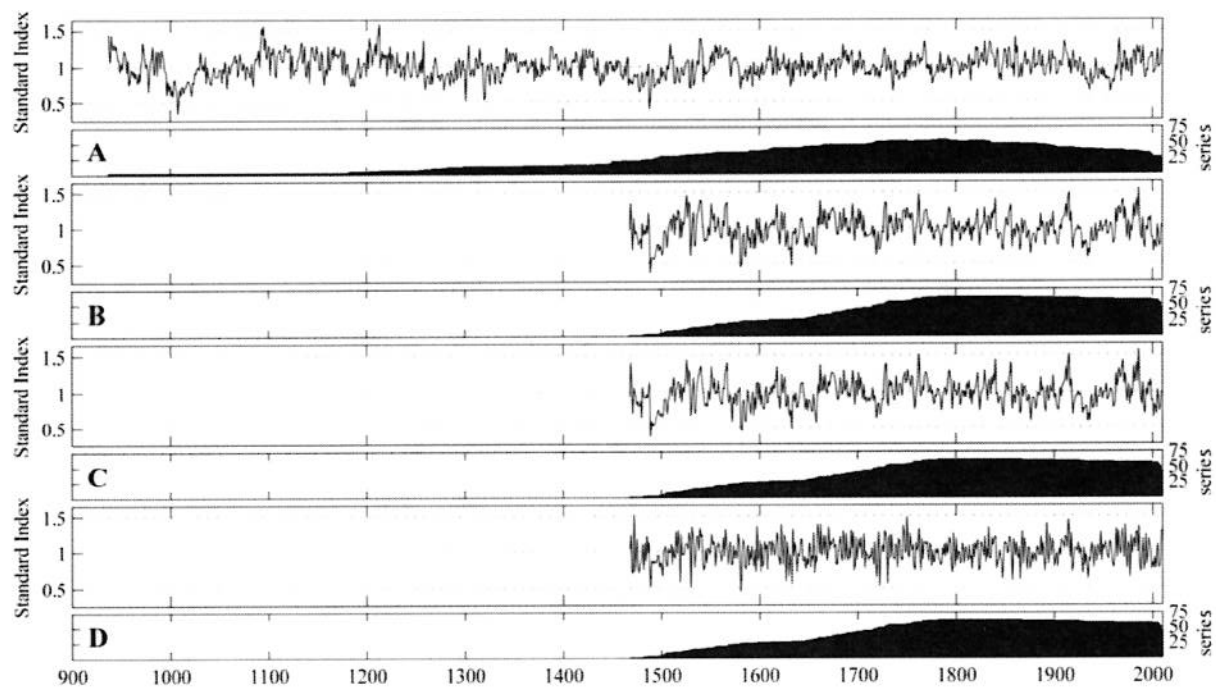


Figure 2. COM tree-ring width chronologies a) limber pine RW; b) Douglas-fir RW; c) Douglas-fir EW; and d) Douglas-fir LW.

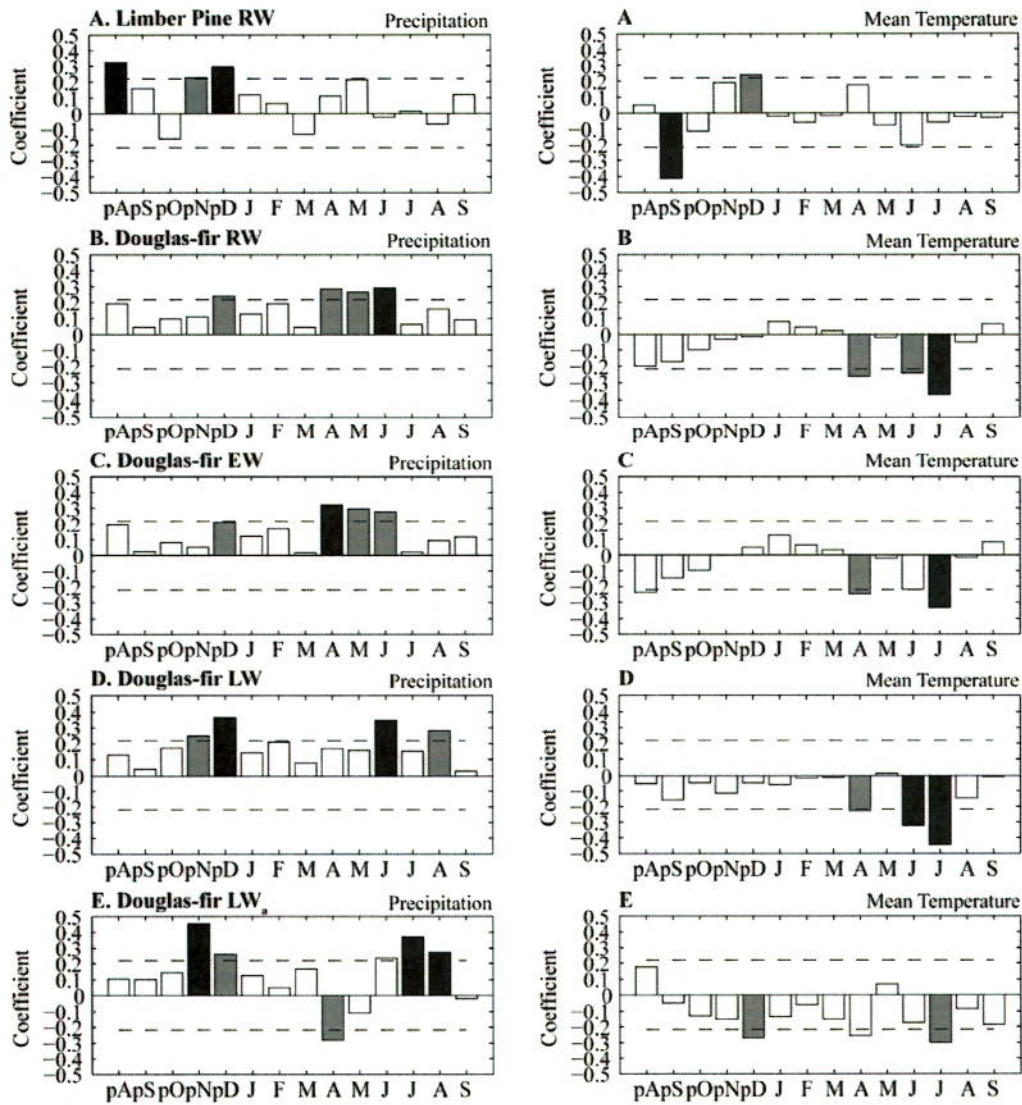


Figure 3. SEASCORR monthly correlations for a 14-month period from prior August to current September between a) limber pine RW, b) Douglas-fir RW, c) Douglas-fir EW, d) Douglas-fir LW, e) Douglas-fir LW<sub>a</sub> and total precipitation (first column primary variable) and mean temperature (second column secondary variable) for 1930-2009. One thousand Monte-Carlo simulations were used to generate monthly coefficients. Dotted lines indicate 95% confidence intervals. Black bars indicate a non-exceedence probability of  $p < 0.01$ , and grey bars indicate a non-exceedence probability of  $p < 0.05$ .

Table 1. COM tree-ring width chronology statistics.

|                | Location       | Elevation<br>(m) | Trees<br>(series) | Chronology<br>Length | Segment<br>Length | <i>r</i> | <i>ms</i> | <i>acf</i> | <i>eps</i> >0.85 |
|----------------|----------------|------------------|-------------------|----------------------|-------------------|----------|-----------|------------|------------------|
| Limber pine RW | 43.45, -113.54 | 1783             | 30 (60)           | 937-2009             | 400               | 0.501    | 0.123     | 0.573      | 1315-2009        |
| Douglas-fir RW | 43.46, -113.58 | 1867             | 31 (62)           | 1468-2009            | 342               | 0.712    | 0.148     | 0.548      | 1520-2009        |
| Douglas-fir EW | 43.46, -113.59 | 1867             | 31 (62)           | 1468-2009            | 342               | 0.683    | 0.146     | 0.557      | 1520-2009        |
| Douglas-fir LW | 43.46, -113.60 | 1867             | 31 (62)           | 1468-2009            | 342               | 0.589    | 0.175     | 0.416      | 1532-2009        |

*r*: interseries correlation

*ms*: mean sensitivity (Fritts 1976)

*acf*: first-order autocorrelation function

*eps*: expressed population signal (Wigley et al. 1984)

Table 2. Time domain correlations between tree-ring width chronologies (1532-2009).

| Standardized chronologies |                |                |                |                             |
|---------------------------|----------------|----------------|----------------|-----------------------------|
|                           | Douglas-fir RW | Douglas-fir EW | Douglas-fir LW |                             |
| Limber Pine RW            | 0.36           | 0.34           | 0.25           |                             |
| Residual chronologies     |                |                |                |                             |
|                           | Douglas-fir RW | Douglas-fir EW | Douglas-fir LW | Douglas-fir LW <sub>a</sub> |
| Limber Pine RW            | 0.09           | 0.08           | 0.16           | 0.15                        |

