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RESEARCH REPORT

SIGNAL STRENGTH IN SUB-ANNUAL TREE-RING CHRONOLOGIES FROM *PINUS PONDEROSA* IN NORTHERN NEW MEXICO

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ABSTRACT

The creation of chronologies from intra-annual features in tree rings is increasingly utilized in dendrochronology to create season-specific climate histories, among other applications. A conifer latewood-width network has recently been developed for the southwestern United States, but considerable uncertainty remains in understanding site and species differences in signal strength and sample depth requirements. As part of the 22nd annual North American Dendroecological Fieldweek, the first *Pinus ponderosa* earlywood-width (EW) and latewood-width (LW) chronologies were developed for the Jemez Mountains in northern New Mexico. The aim was to extend an existing total ring-width (TW) chronology and to assess the potential for creating long LW chronologies. Analysis of chronology signal strength suggests that large sample size requirements remain a considerable hurdle for creating *P. ponderosa* LW chronologies longer than 400 years. At the Cat Mesa site, twenty-three sample trees were required to capture a statistically acceptable common signal in adjusted latewood (LW_a), whereas only four samples were required for EW. This is significantly higher than sample depth requirements for LW_a from the few other chronologies in the region where this statistic has been reported. A future priority should be to develop a conceptual guide for site and tree selection in order to maximize the potential for enhancing LW signal and for creating a robust network of multi-century LW chronologies.

Keywords: North American Dendroecological Fieldweek, Jemez Mountains, expressed population signal, signal-to-noise ratio, partial ring widths, ponderosa pine.

INTRODUCTION

The North American monsoon delivers up to 50% of total annual precipitation to northern New Mexico (Sheppard *et al.* 2002) and is important to cultural and agricultural viability across the

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southwestern United States (Ray *et al.* 2007). Historically, tree-ring reconstructions of precipitation for the region have primarily reflected cool-season precipitation (St. George *et al.* 2010), leaving a gap in our understanding of southwestern climate history. Recent studies have revealed the sensitivity of conifer latewood-widths to summer precipitation (*e.g.* Meko and Baisan 2001; Stahle *et al.* 2009; Griffin *et al.* 2011), and a nascent network of paired earlywood-width (EW) and latewood-width (LW) chronologies has the potential to vastly improve understanding of season-specific climate history across the region (Leavitt *et al.* 2011). To date, this network is dominated by *Pseudotsuga menziesii* chronologies that appear to strongly reflect early-monsoon precipitation (June–July), especially across the northern half of the network domain (Stahle *et al.* 2009). There are fewer *Pinus ponderosa* LW chronologies, and those that do exist appear to be more sensitive to late-monsoon precipitation (July–August), pointing to the possibility for reconstructions of summer precipitation that more fully reflect the entire monsoon season (Faulstich *et al.* 2012). A number of hurdles exist to capturing this potential, however, including the development of numerous long chronologies that are both sensitive to late-monsoon precipitation and geographically distributed to adequately capture the spatial variability in the monsoon. Developing these new chronologies will require identifying sites from which the LW signal can be efficiently captured using rare old trees and well-preserved remnant material.

As part of the 2012 North American Dendroecological Fieldweek (NADEF) in Jemez Springs, NM, we developed the first paired EW and LW chronologies for *P. ponderosa* in the Jemez Mountains. Our aims were to bolster an existing tree-ring collection for Cat Mesa (Swetnam and Lynch 1993) in order to develop a 500-year-long tree-ring record that might be used to reconstruct summer precipitation in the region, and to develop a more complete understanding of sample depth requirements for adequately capturing a common signal in *P. ponderosa* LW chronologies. Because this research was conducted in the context of a hands-on dendrochronology training program, we also report on the educational goals and outcomes for the members of the Introductory Group (*i.e.* the authors of this study) that were integral to the production of our findings. Our results are meant to inform future reconstructions of warm-season precipitation in the southwestern United States.

METHODS

Our sample collection continued previous work at Cat Mesa (Swetnam and Lynch 1993). We leveraged the large number of NADEF students to quickly improve age-class stratification at the site across live tree samples, with two cores removed per tree in a targeted sample of 20% young (25–35 cm DBH, less than 120 years old), 50% middle-aged (36–60 cm DBH, 125–250 years old), and 30% older trees (greater than 60 cm DBH, greater than 250 years old) in addition to remnant materials. Samples were collected on the first day using both increment borers and chainsaws, then prepared and processed on subsequent days by the Introductory Group. Samples with wider growth rings and with the fewest number of difficult rings were dated and measured first to develop a new master chronology. All crossdating was conducted visually with skeleton plots according to Douglass (1941), and dates were checked by student peers and instructors. We measured one core per tree for total ring (TW), EW, and LW widths following the methods of Meko and Baisan (2001). Based on prior literature (*i.e.* Meko and Baisan 2001; Stahle *et al.* 2009; Griffin *et al.* 2011) we computed adjusted latewood indices (LW_a) for each series by regressing LW on EW to account for the dependence of LW on the preceding EW index. Crossdating and measurement accuracy were verified using COFECHA (Holmes 1983; Grissino-Mayer 2001). We detrended all series using a cubic smoothing spline with a frequency response of 0.5 at a 100-year wavelength, performed in R (Cook and Peters 1981). Analyses of signal strength were also performed in R version 2.15.1 (R Core Team 2012) using the dplR library (Bunn 2008). We assessed signal strength in terms of the effective chronology signal ($\bar{r}_{eff}$), where values above 0.5

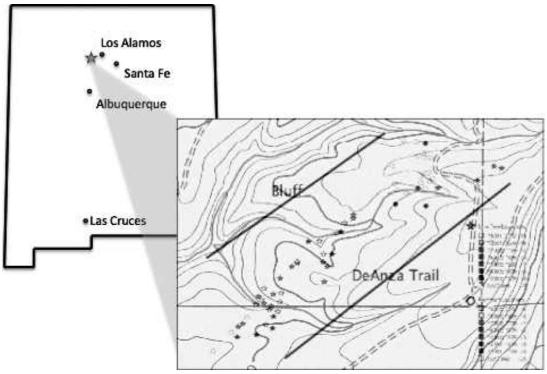

Figure 1. Map of the Cat Mesa site in the Jemez Mountains of northern New Mexico. The star near the center of the map indicates the 2012 sampling site. The Cat Mesa site is located just off Road 135 on the DeAnza Trail.

indicate a common signal between trees, and expressed population signal (EPS), where the value of 0.85 is an arbitrary threshold above which the chronology is deemed statistically acceptable for climate reconstruction (Wigley *et al.* 1984; Briffa and Jones 1990). The effective chronology signal is often miscalculated as a mean-tree correlation, and thus to avoid uncertainly $\overline{r}_{eff}$ was calculated according to Cook and Kairiukstis (1990) using

$$\overline{r}_{eff} = \frac{\overline{r}_{bt}}{\overline{r}_{wt} + [(1-\overline{r}_{wt})/c_{eff}]}$$

where $\overline{r}$ is the correlation coefficient, bt refers to ‘between-tree’, wt refers to ‘within-tree’, and c_{eff} is effective number of cores.

RESULTS AND DISCUSSION

We collected 133 samples from 67 live trees and 25 remnants at Cat Mesa (Figure 1). Forty-six samples were crossdated and 38 were measured. Because of time constraints of the fieldweek, the group was unable to measure all samples; instead samples were prioritized such that cores with wider growth rings and samples with the potential to extend the chronology back in time were measured first. We also measured seven of the original Cat Mesa specimens housed in the archives of the Laboratory of Tree-Ring Research (LTRR). The original Cat Mesa chronology spanned 1572 to 1986, whereas the updated chronology extends from 1531 to 2011 and has substantially improved sample depth (Figure 2A). High inter-series correlations among the total ring width series demonstrate the strong crossdating of the site (Table 1), which facilitated skill development in skeleton plotting and crossdating.

Despite this level of sample replication and good crossdating at Cat Mesa, analyses of chronology strength revealed a lack of coherence in individual LW indices, resulting in a LW_a index that is surprisingly noisy (Figure 2B). The EW indices, in comparison, demonstrate greater coherence and variance consistent with the average chronology in this area (Figure 2C). The $\overline{r}_{eff}$ is also demonstrably more significant in EW indices, reaching a value of 0.6, which is above the 0.5 threshold for an acceptable between-tree signal. The LW indices do not reach this threshold, demonstrating a weak $\overline{r}_{eff}$ of 0.3 and 0.2 in the LW and LW_a index, respectively. The EW chronology reaches an EPS value of 0.85 in 1575, requiring only four trees to capture the population signal (Figure 2D). By sharp contrast, the LW_a chronology maintains a relatively low EPS until a sample depth of 23 trees is reached, in this case 300 years later in 1871.

The need for greater sample depth in LW_a chronologies versus EW or TW chronologies has been reported previously (Griffin *et al.* 2011; Faulstich *et al.* 2012). Our results, however, show substantially more noise in the LW_a chronology at Cat Mesa than at other sites in the region. For example, Faulstich *et al.* (2012) found that 14 *P. ponderosa* trees were needed to reach the critical 0.85 EPS value at the Rio Pueblo site, approximately 80 km to the east. This difference highlights remaining uncertainties in how site and tree selection may influence the quality of LW_a chronologies in the Southwest and beyond. Our finding implies that future studies may have to incorporate far more sampling than is conventional in semi-arid regions in order to build chronologies robust enough for reconstructions of seasonal climate. Development and exploration of climate reconstructions, based upon the results of this and other studies, could prove useful in testing the implications of our study.

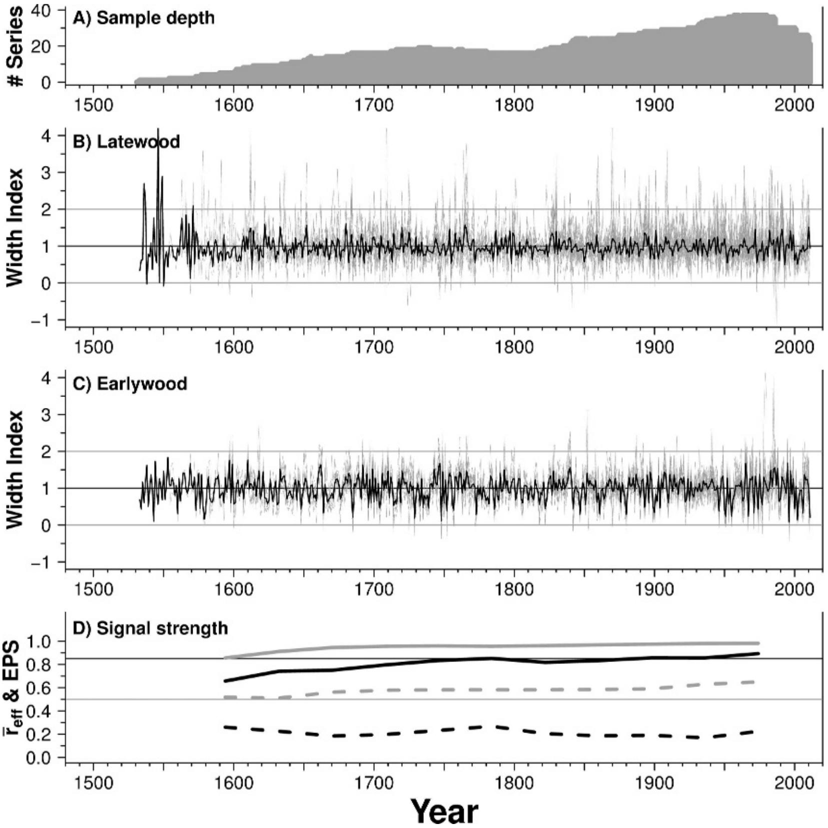

Figure 2. Time series and summary plots for the Cat Mesa partial ring-width chronologies. (A) Sample depth through time. (B) Adjusted latewood-width indices (gray) and robust Tukey biweight mean chronology (black). (C) as in B, but for earlywood-width. (D) Running effective chronology signal ($\overline{r}_{\text{eff}}$; dashed lines) and effective population signal (EPS; solid lines) calculated for 75-year windows. Earlywood values are in gray, adjusted latewood values in black. Horizontal lines indicate thresholds for $\overline{r}_{\text{eff}} = 0.5$ (gray) and EPS = 0.85 (black).

We posit that physiographic factors are likely to be particularly important in determining the strength of *P. ponderosa* LW_a chronologies. The Cat Mesa site occupies a southeast-facing slope above a shallow canyon floor with deep soils at the bottom grading to shallow rocky soils at the canyon lip. These deep soils may be holding winter moisture through the arid foresummer (May and June) and may therefore reduce the sensitivity of soil moisture and tree growth to monsoon precipitation. Although productive sites such as Cat Mesa have yielded good results for monsoon

Table 1. Chronology statistics for total width (TW), earlywood width (EW), latewood width (LW) and adjusted latewood width (LW_a). Statistics defined and referenced in the text.

	TW	EW	LW	LW_a
Mean Measurement	1.3833	1.1163	0.2661	1.6200
Average Mean Sensitivity	0.433	0.472	0.506	0.490
Series Intercorrelation	0.781	0.777	0.577	0.431
Effective Chronology Signal ($\overline{r}_{\text{eff}}$)	0.60	0.60	0.30	0.20
First year of EPS > 0.85	1574	1575	1653	1871
Number of Trees needed for EPS > 0.85	4	4	14	23

reconstruction in southern Arizona (Griffin *et al.* 2011), selecting less productive sites with shallower soils in the northern reaches of the monsoon region may be an improved strategy, particularly for *P. ponderosa*.

Another factor in our results could be the measuring of only one series per tree to build our chronology. Only five trees in our dataset include two measurement series, which were included to ensure consistency in measuring. With so much LW variability between trees, and generally low circuit uniformity of *P. ponderosa*, measuring two or more series per tree may aid in extracting a more coherent common signal without dramatically increasing sampling efforts.

We also note the potential for inconsistent measuring of partial ring-widths across our large group of collaborators. One of our educational goals involved every group member measuring at least one core. Identifying the EW-LW boundary for every ring in *P. ponderosa* can be difficult and multiple technicians may mark these boundaries differently. In our group, however, the majority of measuring was done by only a few members, and so we believe that inconsistent measuring is unlikely to be a factor in our results. Regardless, we encourage thorough training of technicians to ensure the reliability of sometimes difficult determinations of EW-LW boundaries.

CONCLUSIONS

The signal strength in sub-annual LW chronologies for *P. ponderosa* at Cat Mesa is weaker than expected. When compared to EW at the same site, and to other EW/LW chronologies in the region, the common signal is substantially less coherent. This research should raise awareness for others who may be using paired sub-annual chronologies for climate reconstruction in the arid southwestern United States. Larger sample collections, deliberate site and tree selection, and strict adherence to EW-LW boundaries and measurement should be considered.

The bulk of this research was conducted over the course of one week, in an instructional environment. The instructors implemented a lesson plan designed after the training program at the LTRR (available at http://ltrr.arizona.edu/ exercises). Upon completing NADEF, the Introductory Group reported excitement for and general confidence in dendrochronology. The self-reported confidence that group members gained implies that they may integrate dendrochronology into their long-term professional and scientific ventures. Based upon the results of this research, a conceptual guide for site and tree selection should be developed. This could serve to supplement the training literature and maximize the potential for enhancing LW signal while at the same time creating a robust network of multi-century LW chronologies. The success of this study demonstrates that well designed instruction and an integrated education-research approach to dendrochronological studies promotes hands-on educational opportunities and research outcomes that are meaningful to participants and the broader dendrochronology community.

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