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ORIGINAL ARTICLE

Climate-growth relationships for Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) on the volcanic badlands of western New Mexico, USA

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ABSTRACT

We sampled Rocky Mountain junipers (RMJ) to produce a multi-century tree-ring chronology from a relict lava flow, the Paxton Springs Malpais (PAX), in the Zuni Mountains of western New Mexico. Our objective was to assess crossdating potential for RMJ growing on the volcanic badlands of the region, investigate potential relationships between climate and RMJ growth, and investigate temporal variability in relationships identified between climate and RMJ growing at our site. We hypothesized that, similar to other drought stressed-conifers growing on the lava flows, RMJ responds to climate factors that influence and indicate moisture availability. We found a high average mean sensitivity value (0.53), which indicated the PAX chronology exhibited enough annual variability to capture fluctuations in environmental conditions. The average interseries correlation (0.74) indicated confident crossdating and a significant association of annual growth among trees within the stand. The positive correlation between the PAX chronology and total precipitation for the local water year was significant ($r = 0.53$; $P < 0.001$). Significant positive correlations also were identified between monthly PDSI, monthly total precipitation, and RMJ radial growth. Analyses of temporal stability indicated that the positive relationship between RMJ growth at the PAX site and monthly PDSI was the most stable relationship during the period of analysis (1895–2007). More importantly, we identified a unique inverse relationship between radial growth and monthly mean temperature during periods of the preceding year and current growing year, the first such finding of a strong temperature response for a low-mid elevation tree species in the American Southwest. Our results confirm that RMJ samples collected on the Paxton Springs Malpais are sensitive to climate factors that affect moisture availability, further suggesting that RMJ may be suitable for use in dendroclimatic research at additional locations across the broad distribution of the species.

Introduction

Rocky Mountain juniper (*Juniperus scopulorum* Sarg., hereafter "RMJ") (Fig. 1) is one of the most widely distributed juniper species in North America. The species inhabits low to middle elevations (1500–2700 m) within the Western Cordillera. RMJ grows in a range of communities across the western United States and Canada (e.g., mixed-conifer woodlands and montane forests), but is particularly suited for arid, high-light conditions (Burns and Honkala, 1990). Despite its broad distribution, the species has rarely been used in dendrochronological studies (Sieg et al., 1996). Dendrochronologists often favor co-dominant species (e.g., ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and piñon (*Pinus edulis* Engelm.)) that produce more-clearly defined growth rings and fewer locally absent growth rings. RMJ often produce irregular ring patterns and exhibit occasional false rings (i.e., "expanded latewood") that are easily misidentified as true rings (Schweingruber, 1993). Currently, only three RMJ chronologies are archived in the International Tree-Ring Data Bank (ITRDB), and none of the chronologies were produced on the Colorado Plateau (Sieg et al., 1996; ITRDB, 2013). Grissino-Mayer briefly addressed the growth history of RMJ living on the volcanic environments of

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Fig. 1. Rocky Mountain juniper growing on the Paxton Springs Lava Flow, NM, USA (35.066997 N, 108.060219 W; 2375 m amsl).

west-central New Mexico (Grissino-Mayer, 1995; Grissino-Mayer et al., 1997) and suggested that the species was likely the longest-lived on the lava flows of El Malpais National Monument (EMNM). Preliminary dendrochronological analysis of the species at EMNM did not investigate potential relationships between climate and radial growth (Grissino-Mayer, 1995; Grissino-Mayer et al., 1997).

Previous dendroclimatic studies conducted in western New Mexico sampled moisture-stressed conifers to produce a 2000-year proxy record of regional climate that contained evidence of regional climate dynamics (D'Arrigo and Jacoby, 1991; Grissino-Mayer, 1995, 1996; Grissino-Mayer et al., 1997; Stahle et al., 2009). Our purpose was to address the following question: Are RMJ growing on the lava flows of west-central New Mexico sensitive to climate? We pursued the following objectives: (1) assess crossdating potential for RMJ growing on the lava flows of west-central New Mexico; (2) investigate potential relationships between climate and RMJ growth on the badlands; and (3) elucidate temporal variability in relationships identified between climate and RMJ. We hypothesized that, like the other drought-stressed conifers growing on the lava flows, RMJ respond to climate factors that influence moisture availability. Our results are intended to augment the robust tree-ring research previously conducted on the lava flows with other conifer species. An improved perspective of the dendroclimatic potential of RMJ could enhance our understanding of climate effects in multiple ecosystems and strengthen the spatial and temporal resolution of the tree-ring record in western North America.

Materials and methods

Study area

Malpais (Spanish for "bad country") refers to the inhospitable lava flows of the Zuni-Bandera volcanic field. Ironically, the harsh terrain harbors one of the most celebrated old-growth woodlands on the Colorado Plateau (Grissino-Mayer, 1995, 1996; Grissino-Mayer et al., 1997; Lewis, 2003). Trees on the malpais are primarily non-commercial timber characterized by irregularly shaped stems, sparsely foliated crowns, and other diagnostic old-growth features (Schulman, 1954; Stahle and Chaney, 1994). The malpais region is located near the boundary of New Mexico Climate Division 1 (Northwestern Plateau) and Climate Division 4 (Southwestern Mountains) (NOAA, 2011). Summers are typically hot (average maximum July temperature >30 °C) and winters are cold (average minimum January temperature <−10 °C) (NPS, 2011). Average annual precipitation is ca. 400 mm (NPS, 2011) and is bimodally distributed, with a pronounced maximum during July, August, and September and a secondary peak between December and March. A large percentage of regional precipitation is associated with the North American Monsoon during the summer months (Sheppard et al., 2002; Stahle et al., 2009; Woodhouse et al., 2010, 2013; Griffin et al., 2011). Our study analyzed an old-growth stand of RMJ living on a small section of the Paxton Springs Lava Flow in Cibola National Forest, ca. 10 km north of EMNM. Elevation at the Paxton Springs Malpais study site (PAX) is approximately 2375 m. The elevation gradient within the site is minimal; however, the rugged basalt surface is jagged and uneven. Tree species diversity in the vicinity of the PAX site is greater on the basalt formations than in adjacent areas not covered by the ancient lava flows. RMJ, quaking aspen (*Populus tremuloides* Michx.), and Douglas-fir inhabit the basalt formations while the forest off the basalt consists almost entirely of ponderosa pine. Much of the area that surrounds the Paxton Springs Crater was heavily logged and grazed during the late 19th and early 20th centuries (Rother, 2010). The mixed-conifer woodlands at the PAX site appear to have suffered less from recent anthropogenic activity than the ponderosa pine forest that surrounds them, but cut stumps, severed branches, and small amounts of human refuse indicate that the PAX site is not pristine.

Field and laboratory methods

We recovered 100, 5-mm diameter increment cores at PAX during July 2008. The specimens were taken from 60 living RMJ trees. All RMJ > 10 cm diameter at breast height were cored for dendroclimatological analyses. Once mounted with all cells vertically aligned (Stokes and Smiley, 1996), all cores were surfaced using progressively finer sandpaper, beginning with ANSI 100-grit (125–149 μm) and finishing with ANSI 400-grit (20.6–23.6 μm) (Orvis and Grissino-Mayer, 2002). Although 100 cores were collected at PAX, some cores could not be included in our dendroclimatological analyses due to ring anomalies associated with the lobate growth form, twisted stems, and predominance of false rings that mimicked true rings (Schweingruber, 1993). We selected 60 cores from 45 trees for visual and statistical crossdating. The selected cores had attached bark and contained minimal ring abnormalities (e.g., reaction wood) that could complicate tree-ring dating and subsequent dendroclimatological analyses. Selected RMJ cores from the PAX site were scanned with a high-resolution digital scanner (EPSON, Expression 10000XL) at 1200 dpi and measured using WinDENDRO™ computer software (version 2009C, Regent Instruments, Canada) to the nearest 0.001 mm. Cores were visually crossdated using the list method (Yamaguchi, 1991) and statistical output from COFECHA (Holmes, 1983; Grissino-Mayer, 2001) for the Malpais Long Chronology (Grissino-Mayer, 1995). COFECHA removes low-frequency growth and disturbance trends using both spline-fitting algorithms and autoregressive modeling. Each measured radius was processed by COFECHA as an individual time series subdivided into 40-year segments sequentially overlapped by 20 years. We standardized all series to remove adverse growth effects from age-related growth trends, autocorrelation, and possible natural or anthropogenic influences that could interfere with the macroclimate signal within the growth rings. We used the program ARSTAN (Cook, 1985) to first derive an annual value of growth for each year for each series based on a negative-exponential curve fit to the measurement data. The actual ring measurement was then divided by the predicted value to produce a dimensionless index of growth for that year (mean = 1.0). A final master chronology was created from the PAX data by averaging all indices of tree growth for each year across all series (Cook, 1985). ARSTAN created three index chronologies, standard, residual, and ARSTAN, but our preliminary correlation analyses between monthly temperature and precipitation data for New Mexico Climate Division 1 revealed that the standard chronology produced the strongest correlations with climate, prompting us to use the standard chronology for all additional analyses.

Climate-tree growth analyses

We used DendroClim 2002 (Biondi, 1997; Biondi and Waikul, 2004) to investigate relationships between regional climate variables and the standard RMJ chronology at the PAX site (Fritts, 1976). We used DendroClim 2002 because the program calculates coefficients with bootstrapped confidence intervals, which increases the accuracy of results (Biondi, 1997). We selected monthly mean temperature, total precipitation, and Palmer Drought Severity Index (PDSI) values (1895–2007) for New Mexico Climate Division 1 for our analyses, obtained from the National Climatic Data Center (NOAA, 2011). PDSI is a drought index based on temperature, precipitation, and soil moisture. PDSI values range between −6 (very dry) and +6 (very wet) (Palmer, 1965). We conducted correlation analyses to test the strength of association between climate and RMJ radial growth. Correlation coefficients were deemed statistically significant at the $P < 0.05$ level as shown by bootstrapped-confidence intervals. The analysis spanned between the previous May and current December (20 months) to include the effects of climate during the previous year on current year radial growth (Fritts, 1976; Grissino-Mayer, 1995). We then conducted forward evolutionary interval analysis (FEI) to provide a complementary assessment of temporal stability for significant monthly climate-tree growth relationships. Our objective was to elucidate temporal variability in the relationships identified between climate and RMJ radial growth (Biondi, 1997; Biondi and Waikul, 2004). FEI begins with the earliest year in common to all variables, from which forward evolutionary intervals are progressively enlarged by adding one year to a base interval length at each iteration (Biondi and Waikul, 2004). Persistent relationships between climate variables and tree growth over the 20th century would further substantiate the results of correlation analysis and suggest the suitability of RMJ tree-ring data for use in dendroclimatic reconstructions.

Results

The PAX chronology

The PAX standard chronology consists of 24 tree-ring series (3577 total annual rings) collected from 24 RMJ trees (Table 1). The final chronology spans from 1692 to 2007 (316 years) (Fig. 2). Cores from 21 trees that were initially selected for crossdating were ultimately excluded due to erratic growth rings that resulted in low correlations with the remaining well-dated series (Fig. 3). Although many of the cores we collected could not be included in our chronology due to rot, fractures, or compressed growth, intact cores with clear growth patterns dated well against the

Table 1
Rocky Mountain juniper PAX standard chronology: COFECHA descriptive statistics.

Rocky Mountain juniper PAX chronology description	Value
Number of dated series[a]	24
Master Chronology (1692–2007)	317 years
Total rings in all series	3577
Series intercorrelation	0.74
Mean sensitivity	0.53
Possible problem segments[b]	4
Total segments	177
Percent of problem segments	2.25
Mean length of series	149

[a] Dated series are crossdated cores.
[b] Flagged segments contained possible dating errors that were dismissed after additional visual inspection.

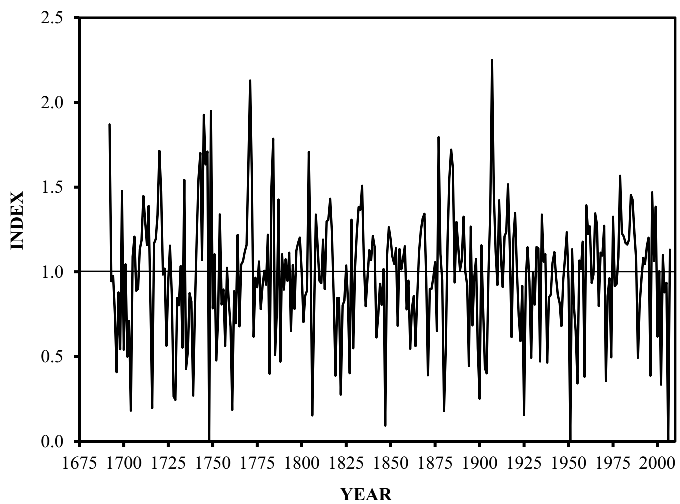

Fig. 2. Rocky Mountain juniper standard chronology for PAX. Values on the *y*-axis >1 represent above average growth, while values <1 represent below average growth.

Malpais Long Chronology (Grissino-Mayer, 1995). Confident dating was aided by several marker rings (very narrow or locally absent rings) identified by Grissino-Mayer (1995) and Stahle et al. (2009): 1761, 1782, 1819, 1847, 1876, 1900, 1925, 1951, 1971, 1996, and 2002. We also found the 2006 growth ring to be consistently narrow or locally absent. Missing rings complicated dating but were temporally located via intra-site crossdating and the persistent relationship to previously identified narrow marker rings. Locally absent rings represented 2.8% of the total rings in the chronology. Intra-annual density fluctuations within growth rings, commonly called "false rings," were distinguishable from actual annual ring boundaries by careful identification of terminal latewood cells (Hoadley, 1990).

Crossdating quality was assessed by two statistical descriptors, average mean sensitivity and average interseries correlation. Average mean sensitivity for the PAX master chronology was 0.53. The average interseries correlation for the PAX chronology was 0.74. COFECHA tested 177 40-year segments, but only four of the segments (2.25%) were flagged for possible dating errors. Careful

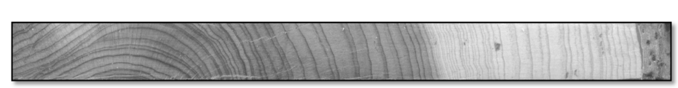

Fig. 3. This photograph shows a core specimen taken from a young Rocky Mountain juniper at the PAX site. Erratic juvenile growth, particularly near the pith of the tree, weakened the average interseries correlation of the PAX chronology. The weak crossdating prompted us to ultimately exclude the core from the PAX master chronology.

Table 2
Rocky Mountain juniper chronologies in the International Tree-Ring Data Bank (ITRDB) and the PAX chronology from the Paxton Springs Malpais.

Chronology	Location	Elevation (m)	Investigators	Dated series	Period	Average interseries correlation	Average mean sensitivity
1. Cedar Butte, SD, USA	43.60 N, 101.12 W	785	Meko and Sieg	17	1691–1991	0.63	0.43
2. Jarbridge Canyon, NV, USA	41.90 N, 115.42 W	1825	Holmes et al.	42	1334–1984	0.66	0.33
3. Theodore Roosevelt National Park, ND, USA	46.92 N, 103.48 W	1630	Meko and Sieg	42	1597–1991	0.68	0.40
4. Paxton Springs Malpais, NM, USA	35.06 N, 108.06 W	2375	Spond et al.	24	1692–2007	0.74	0.53

inspection of the flagged segments and the presence of strong crossdating within other segments of the suspect series suggested that the potential dating errors were the result of a reduced climate signal, not incorrect dating. The average mean sensitivity value for the PAX standard chronology is consistent with average mean sensitivity values for other studies conducted in the malpais region (Grissino-Mayer, 1995; Stahle et al., 2009; Rother, 2010). The average interseries correlation values for the PAX chronology is lower than the average interseries correlation that Grissino-Mayer (1995) produced with ponderosa pine and Douglas-fir data collected at EMNM (0.86), but is still high enough to indicate a strong association among annual radial growth for the trees in our sample. Comparing our chronology statistics with those from other RMJ chronologies is complicated by the lack of available chronologies. However, the PAX chronology has a higher average interseries correlation and substantially higher average mean sensitivity than the three chronologies currently listed in the ITRDB (2013) (Table 2).

Relationships between climate and tree growth

Significant negative correlations were identified between RMJ radial growth and monthly mean temperature for previous year August, October, and November and current April–July (Fig. 4). Significant positive correlations were identified between RMJ growth and monthly total precipitation for October of the previous year through May of the current year. PDSI displayed the greatest number of statistically significant monthly correlations. PDSI was positively correlated with RMJ growth between August of the previous year and December of the current year. The PAX chronology was also positively correlated ($r = 0.53$; $P < 0.001$) with total precipitation for the local water year (previous July–current June) (Fig. 5). FEI suggested that these relationships were not all persistent during the period of inquiry. However, FEI indicated a sustained negative relationship between radial growth and previous August, and current May–July, monthly mean temperatures (Fig. 6). Our analysis showed a nearly continuous positive relationship between growth and monthly total precipitation for the previous November–current January (Fig. 7). FEI also indicated a persistent positive relationship between RMJ growth and PDSI for the previous November–current September.

Discussion

Radial growth trends shared between RMJ at the PAX site and other conifer species growing on the malpais suggest the regulating influence of local climate on tree growth. Significant correlations between the PAX chronology and monthly climate data for New Mexico Climate Division 1 support our hypothesis that RMJ growing on the malpais of western New Mexico are suitable for dendroclimatic analyses. The relationship between water year precipitation and Rocky Mountain juniper growth at the PAX site further suggests the ability of trees growing on the basalt malpais to record environmental data that would be unavailable from trees growing on less porous surfaces. Correlation analysis did not reveal results identical to those identified in ponderosa pine and Douglas-fir at EMNM by Grissino-Mayer (1995) and ponderosa pine atop the Paxton Springs Crater (Rother, 2010), but they did show similar seasonal trends. Tree growth in the southwestern United States is strongly tied to moisture availability (Fritts, 1976). The trees we sampled at the PAX site are most strongly correlated with monthly PDSI values, which can be used as a measure of soil moisture availability. A significant positive relationship between indexed growth at the PAX site and monthly PDSI emerges during

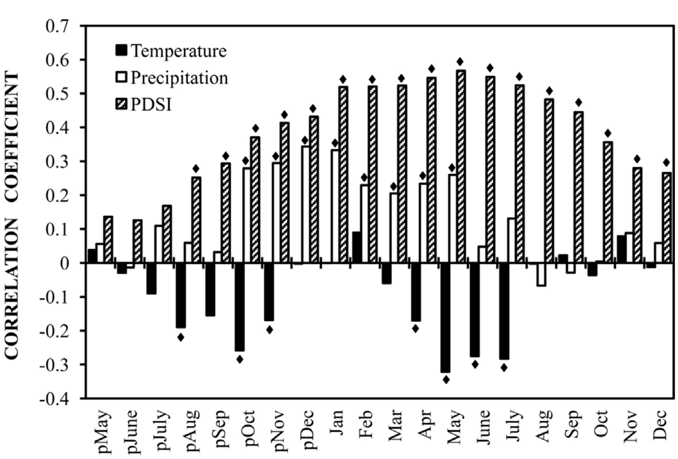

Fig. 4. Correlation coefficients (y-axis) showing the relationship between the PAX Rocky Mountain juniper standard chronology and monthly mean temperature, monthly total precipitation, and monthly PDSI from the previous May (pMay) to the current December (Dec) (1895–2007). The black diamonds indicate significant relationships ($P < 0.05$).

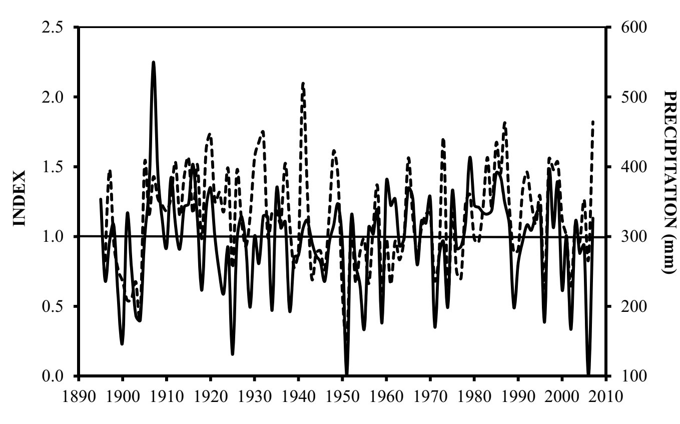

Fig. 5. Relationship between the PAX Rocky Mountain juniper standard chronology (black line) and previous 1 July–current 30 June total precipitation (local water year; dashed black line) for New Mexico Climate Division 1 (1895–2007) ($r = 0.53$; $P < 0.001$). The time series indicate that Rocky Mountain junipers growing at the PAX site produced narrow growth rings during the current Southwestern drought and the severe drought that affected much of the region during the middle of the 20th century.

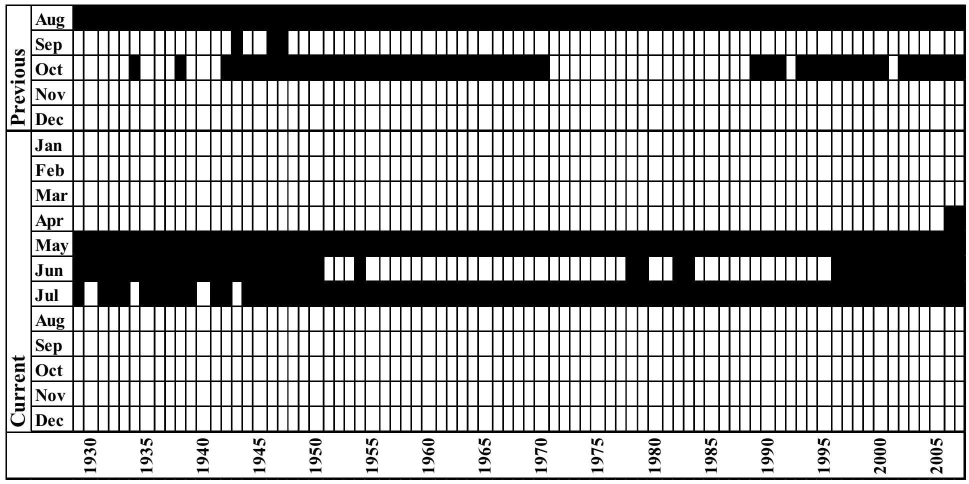

Fig. 6. Results for forward evolutionary interval analysis (1896–2007) between monthly mean temperature and the PAX chronology (34-year base interval). Monthly variables are shown on the *y*-axis, beginning with the previous May and ending with current December. The last years of the forward intervals are listed on the *x*-axis. Significant ($P < 0.05$) negative correlations are black.

August of the previous year and persists through the current December. The relationship could indicate the importance of heavy rains produced by the North American Monsoon during the previous summer to recharge water stored in the porous basalt for use by trees during the drier phases of the subsequent growing season (Grissino-Mayer, 1995). Clouds associated with increased precipitation during the previous fall could reduce evaporation loss, while higher levels of precipitation during this period would recharge the water supply stored in the basalt malpais for use by trees during the next growing season. Increased precipitation during the winter months would likely produce more persistent snow cover on the basalt, which would prohibit large levels of insolation from reaching the lava surface and reduce the evaporation of water stored in the lava. Higher amounts of precipitation during the current spring might also reduce evaporation rates due to increased cloud cover, while recharging the porous basalt.

The inverse relationship between annual radial growth and monthly mean temperature is unique to the PAX chronology, as it is the first such finding of a strong temperature response for a low-mid elevation species in the American Southwest. The association between RMJ growth at the PAX site and monthly mean temperature is possibly related to temperature regulation of moisture availability. Evaporation increases as monthly mean temperature increases, restricting the amount of water available for photosynthesis, which may result in increased tree mortality (Fritts, 1976; McDowell et al., 2008). Higher monthly mean temperatures during the previous late summer and previous fall would increase evaporation rates and decrease the amount of water stored in the basalt from summer rains. The decrease in available moisture the following growing season could decrease photosynthetic rates and cause trees to allocate fewer carbohydrates for radial growth (Fritts, 1976; McDowell et al., 2008). The negative correlation between monthly mean temperature and RMJ growth at the PAX site resumes between April and July of the current growing season. Warm monthly mean temperatures during the early portion of this period (i.e., current April) would likely melt any snow that accumulated during the previous winter, which would dramatically decrease surface albedo as the black basalt is exposed. Decreased albedo would elevate evaporation rates and reduce the moisture available to trees growing on the malpais. High monthly mean temperatures during the late spring and early summer months of the current year would further reduce moisture available to trees on the malpais and restrict additional radial growth (Fritts, 1976).

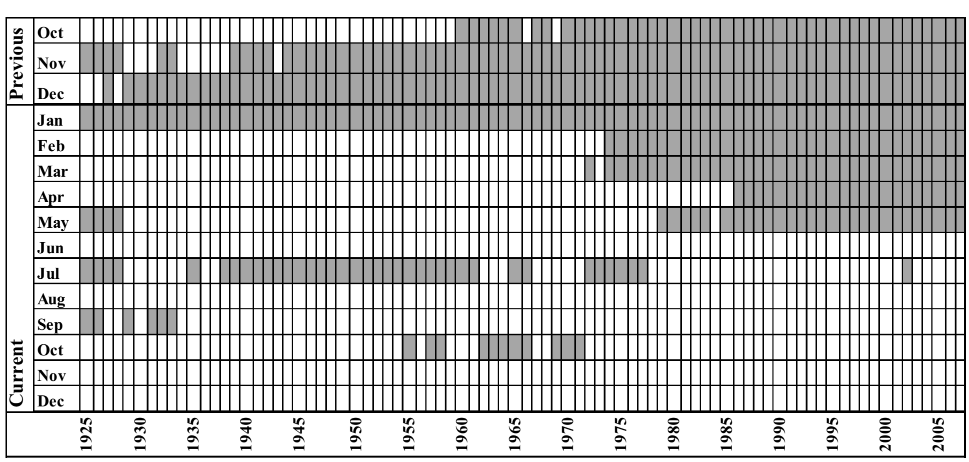

Fig. 7. Results for forward evolutionary interval analysis (1896–2007) between monthly total precipitation and the PAX chronology (30-year base interval). Monthly variables are shown on the *y*-axis, beginning with the previous May and ending with current December. The last years of the forward intervals are listed on the *x*-axis. Significant ($P < 0.05$) positive correlations are gray.

Several possible explanations exist for the temporal instability of climate-growth relationships at the PAX site. Climate data for New Mexico Climate Division 1 is less spatially comprehensive during the early part of the instrumental record (i.e., 1895–1930). New Mexico Climate Division 1 currently consists of >70 meteorological stations in western New Mexico. However, many of these stations were not established until the middle of the 20th century (NOAA, 2011). Earlier records are based on far fewer recording stations. Quality-control issues might also negatively affect some early instrumental data. Early weather data were obtained with instruments that were less accurate than modern instruments. The potential for human error when recording data was also greater prior to technological advances during the 20th century. The combined effects of poor spatial coverage and potentially inaccurate data during the early instrumental period may partially explain the temporal instability of climate-growth relationships at the PAX site.

Fluctuations in broad-scale atmospheric-oceanic oscillations may influence climate-growth relationships at the PAX site. Teleconnections are associations between oceanic-atmospheric oscillations and distinct meteorological and climatological effects in areas that are often thousands of kilometers away from the causative source (Caviedes, 2001). Numerous studies have shown relationships between fluctuations of the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) and precipitation patterns in the southwestern United States (Andrade and Sellers, 1988; Swetnam and Betancourt, 1990; D'Arrigo and Jacoby, 1991; Seager et al., 2005; Stahle et al., 2009; Woodhouse et al., 2010, 2013; Griffin et al., 2011). Temporal instability in climate-growth relationships at the PAX site may be linked to phase changes in ENSO, PDO, and other climate oscillations that could affect the timing and intensity of atmospheric conditions that facilitate tree growth.

Climate is not the only environmental variable that affects the widths of tree rings (Fritts, 1976). Biotic factors and fluctuations in nutrient availability are potentially a third explanation for temporal instability in climate-growth relationships at the PAX site. Physical and biological competition (e.g., shading, water and mineral uptake) from other plants that inhabit the site (e.g., shorter-lived quaking aspen) potentially disrupted the climate signal of sampled RMJ during portions of the period of analysis (Fritts, 1976). It is possible that biological agents are also responsible for erratic-ring patterns that prevented the inclusion of many samples in the PAX chronology. Anthropogenic activity (e.g., logging and fire wood collection) may explain some of the temporal variability in the relationships between radial growth and local climate. The PAX site is not pristine. Rother (2010) reported that the surrounding ponderosa-pine forests were heavily logged during the early 20th century. Hundreds of stumps still litter the area around the PAX site. Some of the sampled trees may have suffered damage from logging crews that operated only a few meters off the lava. Crown removal or cambial damage could affect tree growth for years, reducing the influence of climate on ring formation (Fritts, 1976). We noticed what appeared to be recent branch scars and wounds on some trees at the PAX site. Perhaps the injuries were the result of people gathering firewood or collecting building materials. Therefore, anthropogenic activity, past and present, may partially explain the temporal instability of climate-growth relationships at the PAX site.

Conclusions

Contorted growth forms and severely compressed growth rings complicated crossdating on many samples. However, 40% of the trees we sampled produced cores that were suitable for confident crossdating and chronology development. Dating was complicated by locally absent rings, which were typically contemporaneous with the narrowest rings on ponderosa pine and Douglas-fir samples used in The Malpais Long Chronology (Grissino-Mayer, 1995). Our results confirm that RMJ samples collected on the Paxton Springs Malpais have potential for use in additional dendroclimatic analyses. We conclude that, like Douglas-firs and ponderosa pines growing on the volcanic badlands of nearby EMNM, RMJ on the malpais are highly sensitive to climate factors that influence and indicate moisture availability during dry periods of the growing season. Climate-growth relationships are likely related to the ability of the porous basalt to store water during dry months, providing a sustained water supply for resident trees throughout the growing season.

The inverse relationship we identified between annual radial growth and monthly mean temperature is unique among conifer chronologies from the Southwest, and may prove valuable to future investigations of climate dynamics in the region. Positive correlations between monthly PDSI and radial growth at the PAX site persisted throughout the period of analysis. However, temporal variability in the relationships between radial growth, monthly total precipitation, and monthly mean temperature were less stable. Additional research is needed to investigate the potential role of broad-scale climate oscillations in changes to the relationships between local climate and tree growth. Future dendroclimatic research should analyze the old-growth RMJ growing on the lava flows at EMNM. Preliminary analysis of cores and cross-sections collected at EMNM suggests that many of the sampled trees are >500 years old. Identifying relationships between climate and the radial growth of RMJ at EMNM would further substantiate our findings at the PAX site and encourage future research at other locations within the wide distribution of the species.

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