

INVESTIGATING FOREST INVENTORY AND ANALYSIS-COLLECTED TREE-RING DATA FROM UTAH AS A PROXY FOR HISTORICAL CLIMATE

R. Justin DeRose, W. Shih-Yu (Simon) Wang, and John D. Shaw¹

Abstract.—Increment cores collected as part of the periodic inventory in the Intermountain West were examined for their potential to represent growth and be a proxy for climate (precipitation) over a large region (Utah). Standardized and crossdated time-series created from pinyon pine (n=249) and Douglas-fir (n=274) increment cores displayed spatiotemporal patterns in growth differences both between species and by region within Utah. However, the between-species interrelationship of growth was strong over much of the state and indicated both species respond similarly to climate variations. Indeed, pinyon pine and Douglas-fir exhibited a significant and spatially coherent response to instrumental precipitation data. Previous water year (5-month lag) exhibited the strongest relationship to tree-ring increment for both species. Results suggest increment cores collected by Forest Inventory and Analysis are excellent proxies for historical precipitation.

INTRODUCTION

Tree-ring data have long been recognized as trustworthy proxies for historical climate conditions because of their potential sensitivity to particular climate factors and their precise annual resolution (Fritts 1976). The spatial representation of tree-ring chronologies for the western United States, however, is sparse and can be exceedingly limited for particular areas such as the Great Basin. Due to the gridded nature of the Forest Inventory and Analysis (FIA) sampling design, forest data are collected at a spatial density unparalleled by any station data or dendrochronological data. As a result, increment cores collected by the Intermountain West FIA during the Periodic Inventory (~1990s) represent a potentially valuable source of dendro-climatic data.

The conventional preparation of tree-ring chronologies sensitive to climate requires careful selection of species and sites (e.g., elevation), sample replication of individual trees within sites, crossdating, and finally chronology development (Fritts 1976). As a result, creating an extensive spatial coverage of tree-ring data for paleoclimate reconstruction or growth analysis can be expensive and time-consuming, justifying an examination of possible alternatives. Previous research has indicated that pinyon pine (*Pinus edulis* Engelm.) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) exhibit substantial tree-ring sensitivity, making these species candidates for proxy climate data. There are, however, two important differences between conventionally collected chronologies and the FIA-collected increment cores. These differences can be thought of as trade-offs in the quality or quantity of proxy climate information. First, a conventional tree-ring site is subjectively sampled to maximize both the climate signal and chronology length, and has associated statistical representation issues (Carrer 2011). In contrast, the FIA grid represents a systematic random sample for making population-level inferences. The trade-offs are (1) the differences

¹ Research Ecologist (RJD), U.S. Forest Service, Rocky Mountain Research Station, 507 25th St., Ogden UT 84401; Assistant Professor (SW), Department of Plants, Soil and Climate, Utah State University; Analysis Team Leader (JDS), U.S. Forest Service, Rocky Mountain Research Station. RJD is corresponding author: to contact, call 801-625-5795 or email at rjderose@fs.fed.us.

in temporal length of the resultant proxy time-series (conventional are longer, FIA shorter) and (2) the degree to which a climate signal is expressed at a particular point (conventional should be very sensitive; FIA data should reflect normal growing conditions within the specifications of the sampling). Second, conventional chronologies consist of multiple, averaged series, which require intense investment in time and resources for each sampling point. In contrast, increment cores from FIA plots were collected as part of a standardized protocol on plots ~5 km apart. Given the relatively high spatial density of FIA data in a state or region, tree-ring series combined within a certain distance might reasonably correspond to the variability of tree-ring increment recorded in conventional chronologies.

In this study we explore the potential of using FIA-collected increment cores for studies of spatiotemporal patterns of growth and as possible proxies for historical climate. Specifically, we asked whether pinyon pine and Douglas-fir tree-ring series from Utah (1) display individual variation in ring width, both within and between species and (2) have a predictable relationship with instrumental precipitation data.

METHODS

To address the study questions two data sets were constructed from the available increment cores in Utah (Fig. 1), one for two-needle pinyon pine (n=249) and one for Douglas-fir (n=274). Increment cores were mounted, sanded, and digitized following conventional

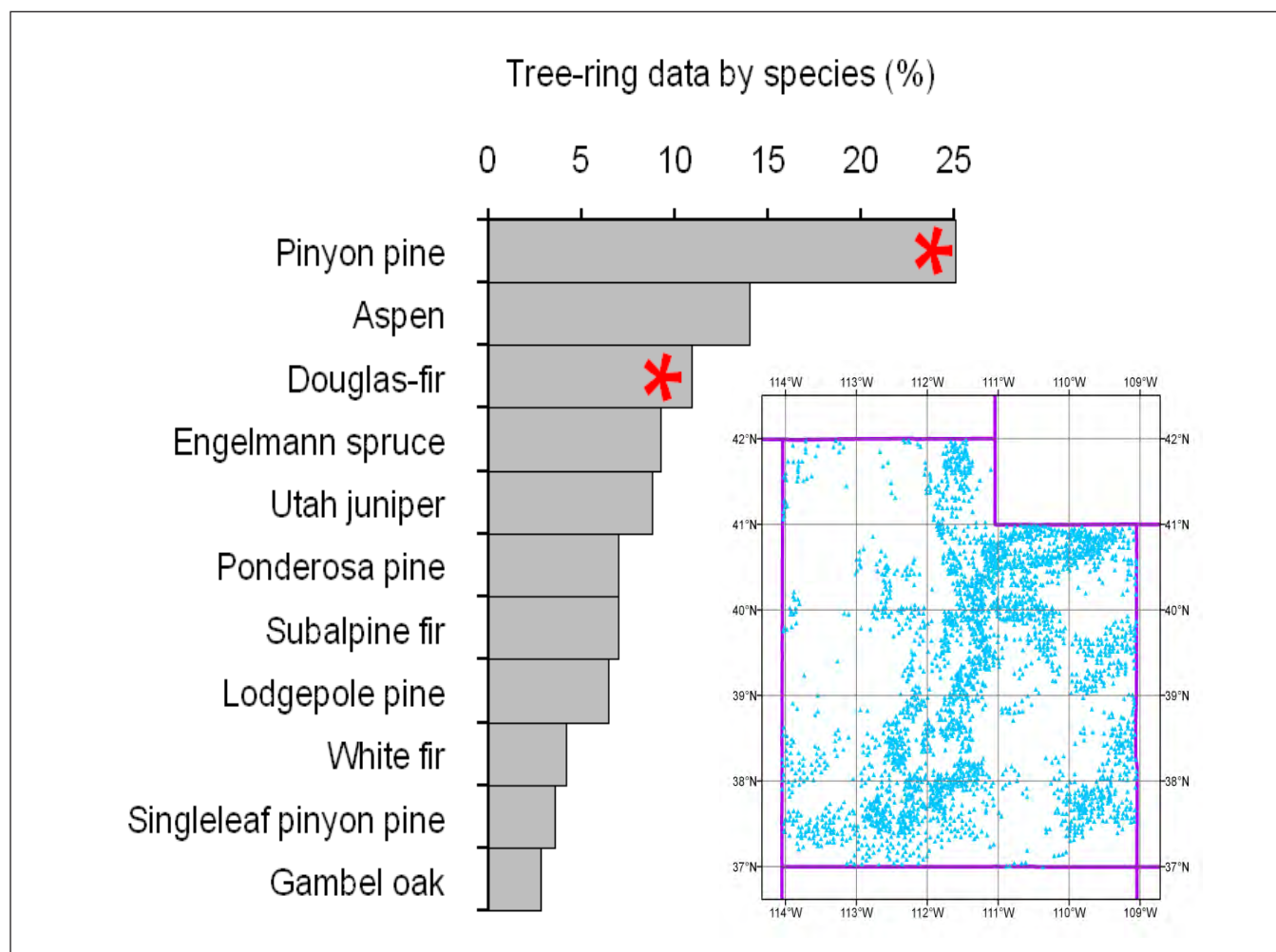


Figure 1.—Representation (%) of species in the Utah tree-ring data set and all plot locations (blue triangles). Red asterisk indicates pinyon pine and Douglas-fir used in this study.

dendrochronological methods before crossdating with the nearest available chronologies. Dated series were then detrended using the “super smoother” (Friedman 1984) in program ARSTAN (Cook et al. 2007) and exported as individual standardized series. The series were used in combination with their jittered coordinates (Note: the term “fuzzswapped” is used within FIA to denote the process that decouples actual spatial locations from landowner information) to create gridded maps, after which we applied the Cressman (1959) objective interpolation scheme at $1/8^\circ$ (longitude by latitude) grid spacing over the Utah FIA network. The Cressman scheme does not include a first-guess field, which has the disadvantage of potentially creating spurious values, as a result of interpolation. The advantage, however, is that the gridded result completely reflects the time-series and is not biased by the first guess, which is impossible to construct for tree-ring data. We gridded the data with a $1/8^\circ$ setting (Fig. 2a) using four radii of influence: $1/8^\circ$, $1/4^\circ$, $1/2^\circ$, and 1° from inner radius to outer

radius. An inverse-square distance ($1/r^2$) weighting centered at the site was then applied to the data.

To examine the spatiotemporal relationship between the FIA data and gridded instrumental precipitation data, a point-by-point correlation map was computed between each grid point of the FIA data and the gridded instrumental precipitation data (1950–1995). Contours were smoothed by averaging over the nearest neighbors. To examine the coherence between the FIA tree-ring data, which reflect the growing season, and the seasonal climate cycle, we calculated the cross-correlation between the FIA data and precipitation, both averaged over Utah. A 12-month precipitation average with a 1-month time-lag, from year-12 (previous calendar year) to year+12 (next calendar year) was calculated to examine lags in the relationship between precipitation and the FIA data (Fig. 3c). Observed precipitation was obtained from the station-based, $1/8^\circ$ -resolution gridded data constructed by Maurer et al. (2002) beginning in 1949.

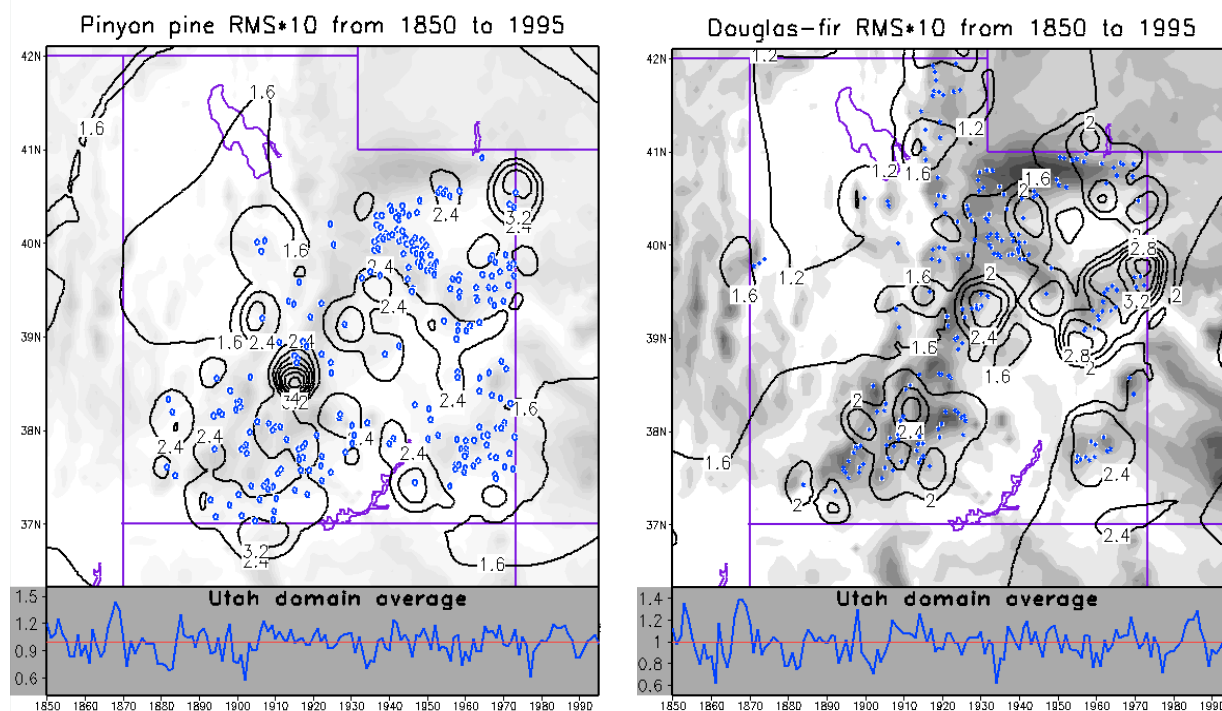


Figure 2.—Contour plots of root mean square (RMS)*10 (to visually accentuate variability) between all pinyon pine (n=249) and Douglas-fir (n=274) tree-ring data. Blue dots indicate FIA plot locations. Lower panel depicts the Utah domain average (37°–42°N latitude and 108°–114°W longitude) tree-ring index (mm), 1850–1995.

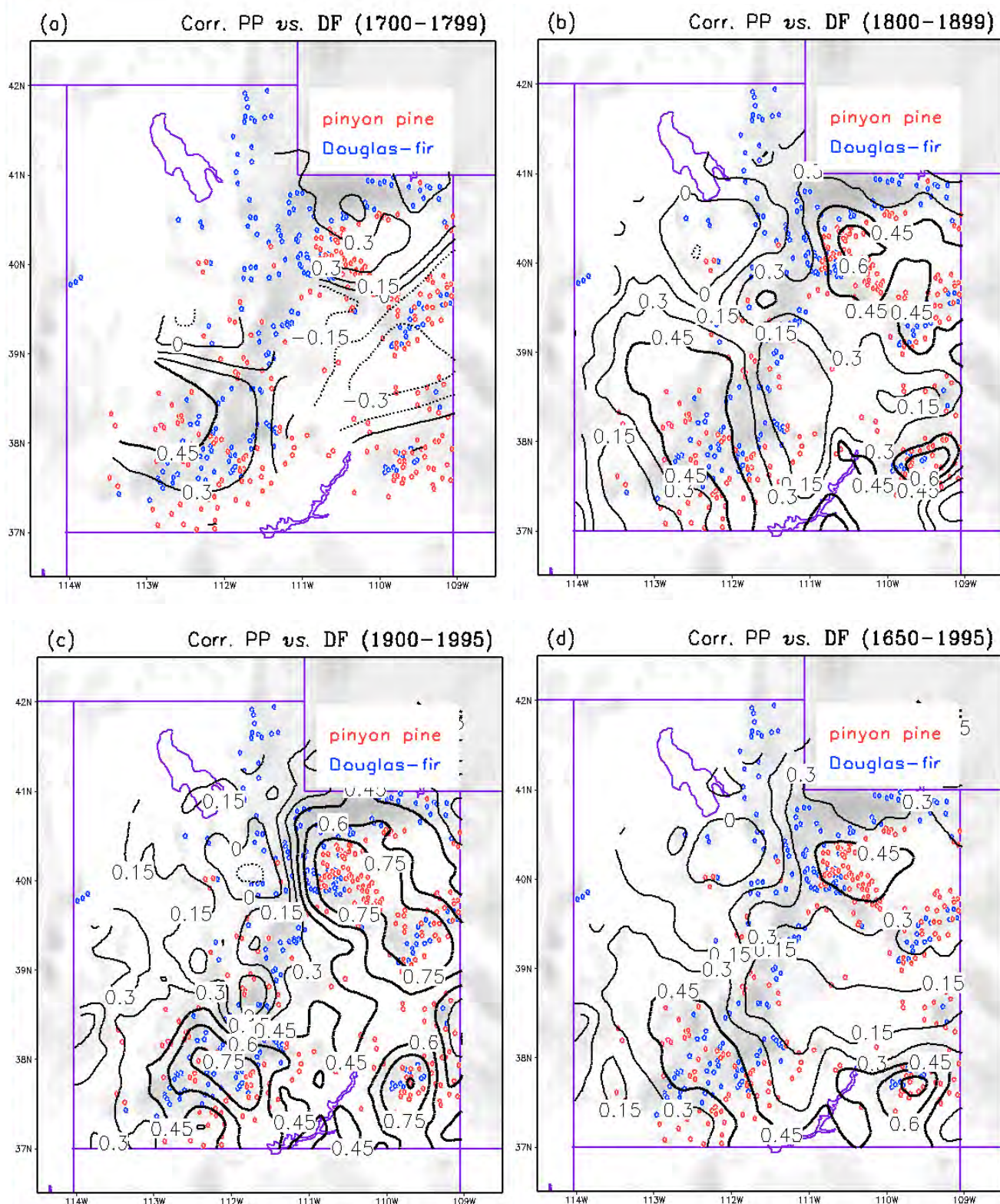


Figure 3.—Contour plots of point-to-point correlations between pinyon pine (PP) and Douglas-fir (DF) gridded tree-ring data for (a) 1700-1799, (b) 1800-1899, (c) 1900-1995, and (d) the 1700-1995. Bold contours indicate significance at the 99-percent level.

RESULTS AND DISCUSSION

Pinyon pine and Douglas-fir were two of the most represented species in the Utah tree-ring data set (Fig. 1), and grow virtually throughout the state (Fig. 2; note the evident pinyon pine northern range limit). Although the totality of tree-ring data could not be crossdated, the preliminary data shown herein included 30 percent of the pinyon pine and 83 percent of the Douglas-fir samples available for Utah. Ongoing work seeks to increase the representation of both species and other species in Utah and the other Intermountain West states (Arizona, New Mexico, Colorado, Wyoming, Idaho, Montana, and Nevada).

Spatiotemporal Patterns of Growth

Contours of the root mean square (RMS) of tree-ring width indicated substantial variability in growth for both species (Fig. 2). Pinyon pine had a larger range of variability in growth than Douglas-fir, which was expected, considering that pinyon pine inhabit low-elevation, dry sites. However, there was notable correspondence between increasing RMS and increasing elevation for both species (Fig. 2). This pattern was especially prevalent for both species in the central and east-central part of the state (i.e., Book Cliffs) and the Wasatch Mountains, which run roughly north-south through the state (Fig. 2). Domain average ring width exhibited striking similarity between species; the pluvials of the late 1860s and early 1980s were evident, as were the droughts of the 1880s, late 1890s, late 1930s, and late 1970s. These drought-pluvial cycles are consistent with those that have prevailed in Utah (Wang et al. 2012). Although occupying somewhat different ecological niches, pinyon pine and Douglas-fir exhibited similarities in interannual growth that suggested both species were suitable for spatiotemporal analyses of growth. However, in the northern tier of Utah (greater than 41°N latitude), where only Douglas-fir were analyzed, the RMS was reduced substantially. This result hinted at potential larger regional patterns of growth that could be driven only by climate.

Inter-species Correspondence

Although both pinyon pine and Douglas-fir chronologies have been previously recognized as having tree-ring growth sensitivity to precipitation (Watson et al. 2009, Woodhouse et al. 2006), further testing was necessary to determine whether the FIA data were also sensitive. Indeed, point-by-point correlation between the two gridded datasets revealed strong spatiotemporal relationships between the two species. There was an increase in significant correlations (bold lines) from 1700-1799 (Fig. 3a), where strongest coherence was in the southwest, to 1800-1899 (Fig. 3b) where the Uinta Basin and the southeast mountains become strongly correlated. During the period 1900-1995 (Fig. 3c) the relationships become significantly correlated for nearly all the mountainous portion of the state. By looking at the entire tree-ring record (1700-1995, Fig. 3d) the southwest, Grand Staircase, southeast, and western Uinta Basin areas were highly significant. It is noteworthy that there were no areas of negative correlation between these two species (Fig. 3). Finally, although pinyon pine and Douglas-fir occupy different ecological niches, their strong interrelationships, particularly for certain regions, suggested tree-ring increment responded similarly to climatic drivers.

FIA Tree-rings as Precipitation Proxy

If the strong growth interrelationship between pinyon pine and Douglas-fir was caused by climate, one would expect a similarity between the species in the response to that driver. Therefore, we examined the point-to-point relationship between gridded instrumental precipitation and tree-ring width from 1949 to 1995 for both species. Results showed highly significant relationships for both species and coherent spatial relationships between species (Fig. 4). For example, both species exhibited their strongest relationships to precipitation in the southwest and western Uinta basin areas of Utah. Additionally, both species showed lower correspondence to precipitation

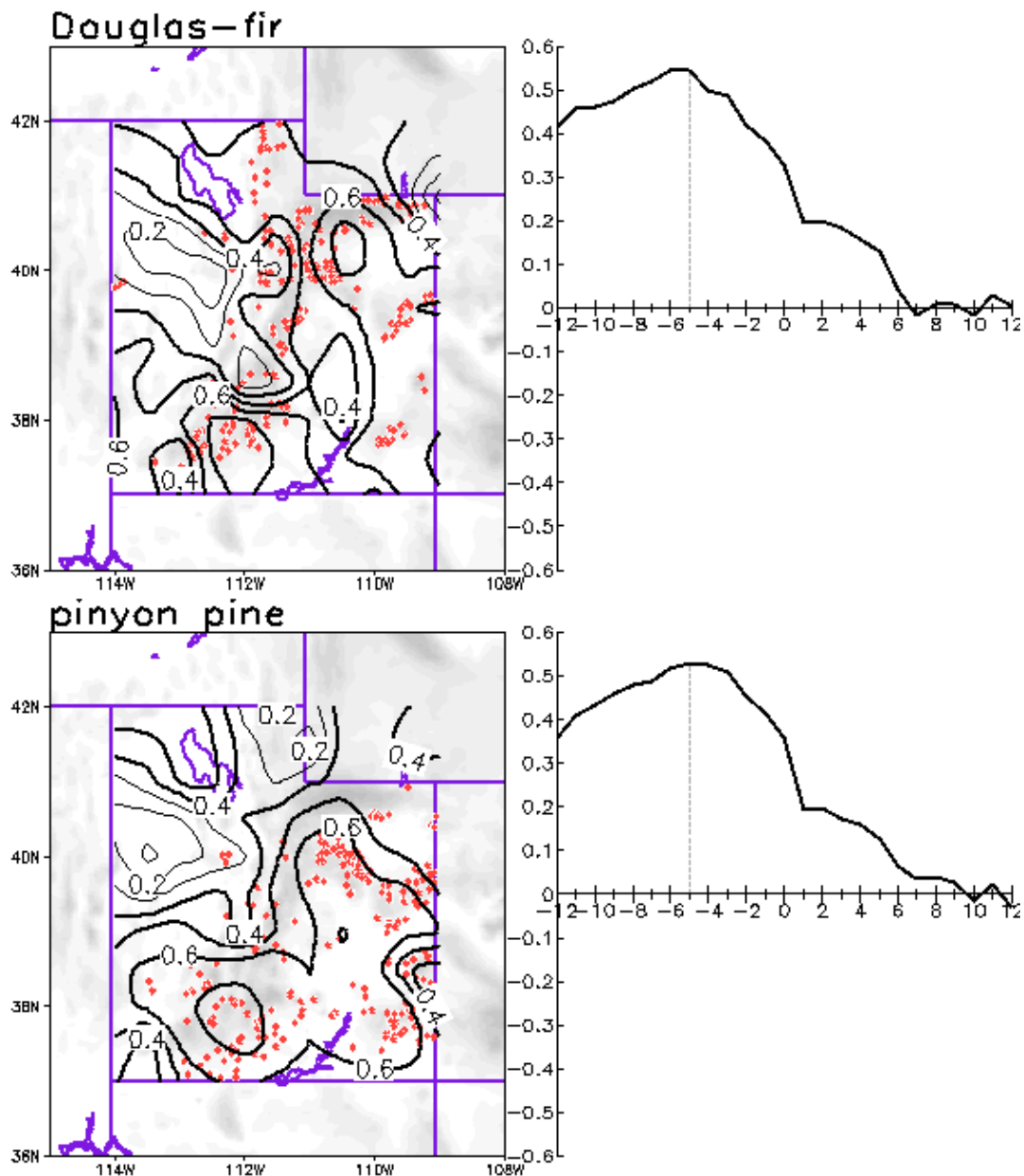


Figure 4.—Contour plots of point-to-point correlations of the gridded pinyon pine and Douglas-fir data sets to precipitation reanalysis data (left panels) and the correlation between Utah domain (37°-42°N latitude and 108°-114°W longitude) average tree-ring index and monthly precipitation data from 1949-1995, lagged from 12 months previous (-12) to 12 months following (12). Bold contours indicate significance at the 99-percent level.

in the basins and western desert, where data were limiting. The peak correlation coefficients between ring width and precipitation for both species occurred around lag-5 month, with a broad peak in significance centered over the water year (previous August through current July), which strongly indicated that water year

precipitation drives tree-ring increment in this region. This finding strongly supports using the gridded tree-ring data sets as a precipitation proxy, augmenting the currently limited station data-based gridded precipitation data sets.

ACKNOWLEDGMENTS

Matt Bekker, Eric Allen, Connie Woodhouse, and Jeff Lukas provided important unpublished chronologies necessary for crossdating the FIA tree-ring series in this study. This manuscript was improved by the comments of two anonymous reviewers.

LITERATURE CITED

- Carrer, M. 2011. **Individualistic and time-varying tree-ring growth to climate sensitivity**. PLoS ONE 7(1): e30002.
- Cook, E.R.; Krusic, P.J.; Holmes, R.H.; Peters, K. 2007. **Program ARSTAN Version 41d**. Available at www.ldeo.columbia.edu/tree-ring-laboratory. [Date accessed unknown].
- Cressman, G.P. 1959. **An operational objective analysis system**. Monthly Weather Review. 87: 367-374.
- Friedman, J.H. 1984. **A variable span smoother**. Technical Report 5. Stanford, CA: Stanford University, Laboratory for Computational Statistics, Department of Statistics.
- Fritts, H.C. 1976. **Tree rings and climate**. New York, NY: Academic Press. 567 p.
- Maurer, E.P.; Wood, A.W.; Adam, J.C.; Lettenmaier, D.P.; Nijssen, B. 2002. **A long-term hydrologically based data set of land surface fluxes and states for the conterminous United States**. Journal of Climate. 15: 3237-3251.
- Wang, S.-Y.; Gillies, R.R.; Reichler, T. 2012. **Multi-decadal drought cycles in the Great Basin recorded by the Great Salt Lake: modulation from a transition-phase teleconnection**. Journal of Climate. 25: 1711-1721.
- Watson, T.A.; Barnett, F.A.; Gray, S.T.; Tootle, G.A. 2009. **Reconstructed streamflows for the headwaters of the Wind River, Wyoming, United States**. Journal of the American Water Resources Association. 45(1): 1-13.
- Woodhouse, C.A.; Gray, S.T.; Meko, D.M. 2006. **Updated streamflow reconstructions for the Upper Colorado River Basin**. Water Resources Research. 42: W05415.

The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.