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SPATIOTEMPORAL PATTERNS OF RING-WIDTH VARIABILITY IN THE NORTHERN INTERIOR WEST

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Abstract—A fundamental goal of forest biogeography is to understand the factors that drive spatiotemporal variability in forest growth across large areas (e.g., states or regions). The ancillary collection of increment cores as part of the IW FIA Program represents an important non-traditional role for the development of unprecedented data sets. Individual-tree growth data from increment cores were paired with plot-level variables from the inventory to investigate the spatiotemporal growth patterns for Douglas-fir, ponderosa pine, common pinyon, and limber pine over the northern portion of the Interior West (Idaho, Montana, Wyoming, Utah, and Colorado). Based on dendrochronological theory proposed over 50 years ago, we tested three hypotheses that variability in ring-width increment (calculated as the Gini Coefficient): 1) would decrease as latitude increased; 2) would increase as continentality increases (i.e., west to east); and would decrease as elevation increased. The large range of observations (from 37° to 49° latitude, and from -117° to -104° longitude) were sufficient to test the first two hypotheses, but made it difficult to directly test hypothesis three (elevation). Generally, we did not confirm hypothesis one, except for common pinyon, which inhabits only a portion of the area examined. Hypothesis two was confirmed for the entire dataset, and the results were clearly driven by Douglas-fir and ponderosa pine. Hypothesis three was not supported for Douglas-fir or ponderosa pine, but was supported for common pinyon and limber pine. However, because the sample area encompasses such a huge range of latitude and longitude, which covary with elevation, we developed a corrected elevation. No significant relationships were found between ring-width variability and corrected elevation.

INTRODUCTION

A fundamental goal of forest biogeography is to understand the factors that drive spatiotemporal variability in forest growth across large areas (e.g., states or regions). The ancillary collection of increment cores as part of the IW FIA Program represents an important non-traditional dataset that can be used to ask general biogeography questions. Individual-tree growth data from increment cores were paired with plot-level location variables from the inventory to investigate the spatiotemporal growth patterns for interior Douglas-fir (*Pseudotsuga menziessii*), ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), and common pinyon (*Pinus edulis*).

Historically, the most common way to measure variability in tree-ring growth is referred to as 'mean sensitivity' (Holmes 1983). Unfortunately, mean sensitivity covaries with first-order autoregressive properties and the coefficient of variation, making it undesirable for comparison between species and sites (Bunn et al. 2013). To avoid these issues we elected to use the Gini coefficient (*G*) to evaluate variability. The original use for *G* was as a statistic to compare the difference between samples without using the mean (Biondi and Quedan 2008). The Gini coefficient is robust to time-series that have variability in autoregressive properties or changes in mean values over time (i.e., nonstationarity) (Biondi and Quedan 2008). Therefore, we assumed that G would be appropriate to compare between increment cores collected across a large region.

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We chose Douglas-fir, ponderosa pine, limber pine, and common pinyon because these species generally exhibited a strong relationship to water-year precipitation, and typically occur in relatively lower elevation forests across the West. We examine a wide geographic gradient, the northern portion of the Interior West (Idaho, Montana, Wyoming, Utah, and Colorado). Based on dendrochronological theory proposed over 50 years ago (Schulman 1956), we tested three hypotheses related to the variability in ring-width increment: 1) it would decrease as latitude increased; 2) it would increase with longitude (i.e., west to east); and that it would decrease as elevation increased.

METHODS

Measurements of annual ring width variability used in this study came from individual tree increment cores collected from Interior West FIA phase 2 plots during both the periodic and annual inventories (Table 1). All increment cores were mounted, sanded, polished before viewing under a microscope. Increment cores were crossdated to ensure calendar year resolution, measured on a sliding stage to 1 or 10 micron. Digital ring width data were verified using program COFECHA and locally available chronologies available from the International Tree-Ring Data Bank or unpublished chronologies available from individual researchers.

Once digitized, the tree-ring data were paired with plot-level data from the database (e.g., latitude, longitude, elevation). Trends of sensitivity over latitude, longitude, and elevation were examined graphically and with Pearson's correlations for the entire dataset and as species-specific groups.

RESULTS

Over the entire dataset (n=2,949, Fig. 1), and contrary to our hypothesis, there was no relationship between *G* and latitude (r=-0.01) or elevation (r=-0.05). However, the relationship between *G* and longitude was significant (r=0.27, p<0.001), occurred in the predicted direction (west to east). Because of strong inherent relationships between latitude and longitude (r=-0.37), latitude and elevation (r=-0.77), and longitude and elevation (r=0.28), we calculated a corrected elevation. Multiple linear regression using latitude and longitude and a polynomial term for each was fitted (R^2=0.61). The relationship between *G* and corrected elevation was not significant (r=0.001).

Species-specific relationships between *G* and latitude were variable, with a negative relationship for common pinyon (r=-0.13, p<0.001), and Douglas-fir (Fig. 1a). Positive, but not significant relationships were found for limber pine (r=0.10) and ponderosa pine (r=0.07). The relationship between *G* and longitude was positive for all species but limber pine (r=-0.05). Ponderosa pine had the strongest relationship to longitude (r=0.32, p<0.001), followed by Douglas-fir (r=0.21, p<0.001). The relationship for common pinyon was not significant (r=0.08). The relationships between *G* and elevation were negative, as hypothesized, for all species except Douglas-fir (r=0.06). Common pinyon (r=-0.30, p<0.001), limber pine (r=-0.32, p<0.001), and ponderosa pine (r=-0.11, p<0.001) all exhibited significant relationships. When evaluated over corrected elevation, no significant patterns were found (common pinyon: r=-0.04, Douglas-fir: r=0.07, limber pine: r=-0.09, ponderosa pine: r=-0.07).

Table 1—Sample size, mean ring width (mm) and standard deviation, mean number of rings, mean Gini coefficient, and range (minimum to maximum) of Gini coefficient by species for the study data

Species	Common pinyon	Limber pine	Ponderosa pine	Douglas-fir
Sample size (n)	413	53	972	1511
Mean ring width (SD)	0.828 (0.345)	1.375 (0.538)	1.884 (0.836)	1.821 (0.722)
Mean number rings	107	67	73	84
Mean Gini coefficient	0.234	0.222	0.253	0.230
Range of Gini coefficient	(0.08 – 0.48)	(0.12 – 0.34)	(0.10 - 0.53)	(0.06 – 0.56)

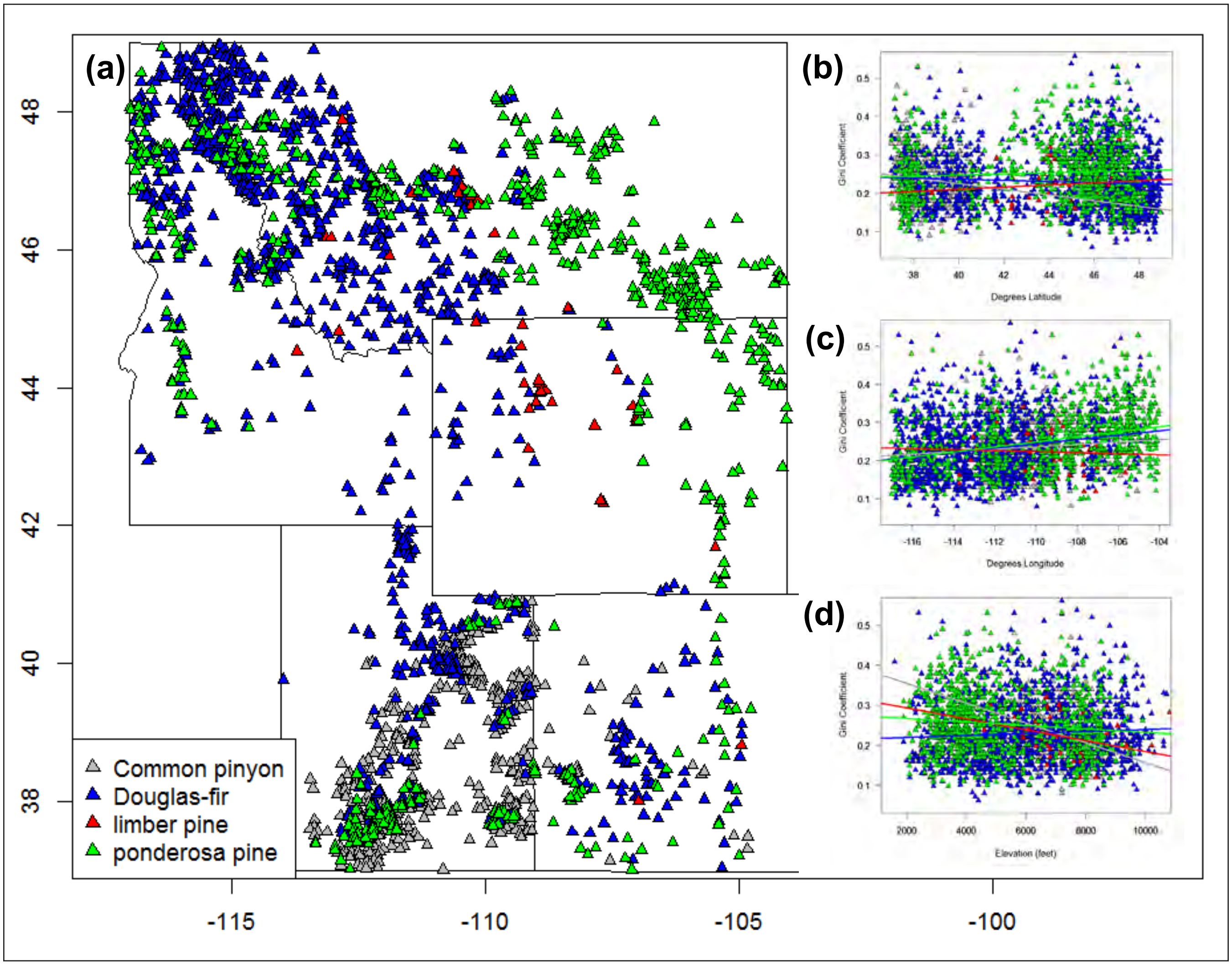

Figure 1—(a) Northern Interior West map with tree-ring locations by species, (b) relationship between Gini coefficient and latitude by species, (c) relationship between Gini coefficient and longitude, (d) relationship between Gini coefficient and elevation. Lines are linear regression models. Colors match species-specific designations.

DISCUSSION

The large range of observations (from 37° to 49° latitude, and from -117° to -104° longitude) of independently sampled tree-ring series were appropriate to test patterns in *G* long thought to vary in space and elevation (i.e., western North America) presumably due to climate variation and relative availability of water prior to and during the growing season (Schulman 1956, Fritts 1976).

Generally, we failed to confirm hypothesis one that *G* decreases with latitude. The negative relationship found for common pinyon might indicate a more regional affect, given that the species is limited to the Colorado Plateau (Fig. 1a). A great deal of dendroclimatological research relies on the desirable water-year signal inherent to common pinyon, and a relatively narrow focus on it might be at least partially a basis for the original hypothesis. It is also possible that the relationship between *G* and latitude become more pronounced once trees from lower latitudes (i.e., Arizona and New Mexico) are included.

Interestingly, hypothesis two has no basis in the published literature, therefore we can only speculate as to why we found such a strong relationship from west to east in ring-width variability (i.e., longitude). Common pinyon and limber pine were represented by fewer samples, and also covered a smaller portion of the study area, which might explain why their relationship with longitude was not significant. Douglas-fir and ponderosa pine were the most widespread of the species examined, and they likely drove the relationship for the dataset overall. We speculate that the increase in *G* (west to east) might indicate a general decrease in moisture, at the continental scale, from the prevailing westerly Pacific storms, likely indicating continentality. Further explanation of the relationship between *G* and longitude could be bolstered if tree-ring data from the Pacific Northwest were available, allowing examination of the full longitudinal range of many western tree species.

The hypothesis that ring-width variability ought to decrease with increasing elevation is based on the observation that lower elevation trees receive less growing season moisture compared to high elevation trees and, as a result, have higher *G*. Because the elevation range suitable for tree species occurrence changes markedly over the range of latitude examined here, the hypothesized relationship is not straightforward. Regardless, we failed to confirm hypothesis three for the two most widespread species, Douglas-fir and ponderosa pine. Interestingly, the relationships for elevation held for common pinyon and limber pine. We suspect the relatively narrow region in which common pinyon occurs help accentuate that relationship. Limber pine, on the other hand, had limited observations ($n = 53$), so further analysis is necessary before confirming such a strong pattern across the considerable range of limber pine.

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