

Tree-Ring Evidence for Long-Term Climatic Change: Yosemite National Park

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Summary: Tree-ring data were collected from two sites within Yosemite National Park: a western juniper stand near Juniper Ridge and a lodgepole pine stand near Gaylor Lakes. Analyses of standardized and prewhitened tree-ring indices from the two sites indicate that at both sites winter (January through March) precipitation is the factor most limiting to tree growth. Using regression analysis a model predicting winter precipitation as a function of tree growth was developed and tested. The model explains 32% of the variance of the precipitation data. While the model is statistically significant, the explanatory (and hence predictive) power of the model could be enhanced by further core collection. When the model is applied to the early portion of the tree-ring record, a reconstruction of precipitation extending back to AD 1620 is obtained. Extended droughts are common in the record and include the following periods: 1650-1648, 1700-1720, 1749-1758, 1807-1824, 1842-1851, 1885-1893, and 1911-1934. Further funding is being sought to expand the tree-ring data base allowing for more accurate climatic reconstruction and a longer temporal extent of the reconstruction.

Introduction

The management of National Park resources is often based on the assumption that the observed 20th-century climate record is an adequate measure of long-term climatic variation. Reconstructions of past climate based on tree-ring data from the White Mountains of California as well as other western North American sites indicate significant variation in both temperature and precipitation over the past 1000 years. In this project, I reconstructed winter precipitation based on variation in ring-width indices for western juniper (*Juniperus occidentalis*) and lodgepole pine (*Pinus contorta*). The reconstruction provides a preliminary estimate of long-term changes in precipitation and, as such, should prove useful in interpreting other long-term records of environmental variation (i.e., the dynamics of meadow/forest ecotones, fire frequency).

Data and Methods

During June of 1989 increment cores were extracted from two sites within Yosemite National Park. At Juniper Ridge (JR), located above Tuolumne Meadows (37°53'N, 199°22'W, 2740-2800 m.a.s.l.), two cores were extracted from each of 26 western juniper. At Gaylor Lakes (GL), immediately west of Tioga Pass (37°55'N, 119°16'W, 3050-3140 m.a.s.l.), two cores were extracted from each of 26 lodgepole pine. Cores were mounted, sanded, and cross-dated using standard techniques (Fritts 1976). Ring-width sequences were measured to the nearest 0.01 mm and the resulting series were assessed for dating and measurement accuracy using numerical techniques (Holmes 1983). Individual ring-width series were standardized to remove age-related trends in growth by fitting a horizontal line or negative exponential curves to each series and then calculating ring width indices as ratios of observed ring width to fitted curve values. The resulting index series were further transformed to remove year-to-year persistence in growth that is a result of biological processes (ex., storage of carbohydrates, multi-year needle retention) and is, therefore, unrelated to climatic trends. The persistence (or autocorrelation) in each series was modeled by fitting autoregressive-moving-average (ARMA) models to each series ('pre-whitening'; Box and Jenkins 1976). The pre-whitened ring width indices for each site were then averaged on an annual basis using robust estimation to produce the mean index chronology (Cook and Holmes 1984). Although procedures exist for re-incorporating a site-based estimate of autoregression into the final chronology (Cook and Holmes 1984), I used only the prewhitened (or 'residual') chronologies because the time series characteristics of those series were similar to those of the precipitation series analyzed. The resultant western juniper chronology extends back to AD 1248 and the lodgepole pine chronology extends

back to AD 1516. Examination of the standard error of each year's index indicates that the chronologies are adequately replicated from AD 1388 onwards for the western juniper chronology and AD 1620 onwards for the lodgepole pine chronology.

Monthly climatic data for Yosemite Valley extend back to 1906 and were used to calculate seasonal temperature averages and precipitation sums. The time series characteristics of the monthly and seasonal climatic series were assessed using autocorrelation and partial autocorrelation functions (Box and Jenkins 1976).

Scatterplots and correlation coefficients were used to investigate the relationship between monthly climatic series and each tree-ring chronology. Winter (January through March) precipitation is the most important factor governing tree-growth at both the JR and GL sites (Table 1). No significant correlation was found between growth indices and monthly or seasonal temperature data. Scatterplots indicate that the relationship between growth and winter precipitation is non-linear but can be made linear by squaring the tree-ring indices (Fig. 1). Previous work examining the climatic response of western juniper and lodgepole pine in the southern Sierra Nevada indicated that summer temperature and winter precipitation interact in governing tree-growth in subalpine environments (Graumlich 1991). I found no indication of a consistent effect of temperature on tree growth at the Yosemite sites. Extreme temperature events may explain the presence of outliers in the relationship between winter precipitation and tree-growth. Six outlier years (1919, 1922, 1935, 1942, 1977, 1984) were identified by examining scatter plots of winter precipitation vs growth. In all but one case the outlier years occurred in years with either extreme (i.e., greater than one standard deviation) summer (June through August) or January temperature conditions. The outliers were removed from the data set so that the estimates of the relationship between winter precipitation and tree growth would not be biased (Draper and Smith 1981).

Ordinary least squares regression analysis (Draper and Smith 1981) was used to develop of quantitative model predicting winter precipitation as a function of tree-growth at the GL and JR sites. The form of the model is:

$$\hat{Y}_i = b_0 + b_1X_1 + b_2X_2 \quad (1)$$

where \hat{Y}_i is the estimate of precipitation summed from January through March (cm) for the year i , X_1 is the tree-ring chronology for GL in year i , X_2 is the tree-ring chronology for JR in year i , and the b_0 , b_1 , and b_2 are regression coefficients. The

climatic record was split into two subsets (1906-1948, 1949-1988) and regression models were developed separately for each period. Cross-validation of each model was accomplished by comparing a model's estimates with observed data from the period *not* used in model calibration, thus providing an independent check of the model's validity. For the purposes of reconstructing climate, a final model was estimated using the entire observed climatic data set to ensure that the coefficients were estimated with the greatest possible precision. The residuals from the regression equation were evaluated to ensure that violations of the assumptions underlying ordinary least squares analysis had not occurred (Draper and Smith 1981).

Results and Discussion

While the regression models based on subsets of the observational data differ in their coefficients, the models are similar in estimating significant coefficients for both the JR and GL chronologies (Table 2). Correlations between observed data and estimates derived from applying the regression coefficients to the alternate subset of data provide an independent check on the model behavior. Significant correlations between observed and predicted data indicate that the model performs well when extended beyond the calibration period. The final regression equation predicting winter precipitation as a function of the squared JR and GL chronologies explains 32% of the variance of the data (Table 2). Plots of the observed vs reconstructed values indicate that both the general trends in precipitation and the timing of severe drought events are well reconstructed (Fig. 2).

The resulting precipitation reconstruction extends back to AD1620, the first year of adequate replication in the GL chronology (Fig. 3). Extended droughts are common in the record and include the following periods: 1650-1648, 1700-1720, 1749-1758, 1807-1824, 1842-1851, 1885-1893, and 1911-1934.

At present, I regard these findings as preliminary. The explained variance of the regression model is significant but is not as high as reported in other dendroclimatic reconstructions. A major limitation of the present study is the lack of replication both within and between species. Further development of the tree-ring data base within the Yosemite National Park should result in climatic reconstructions that extend farther back in time and more fully reproduce the variance of the original data. In particular, western juniper appears to be climatically sensitive and long-lived and will become an important proxy data source in the future. Towards these ends, I am in the process of seeking further funding for

this research and am hopeful that a renewed research effort may commence as early as 1991. A part of my future work is collaboration with Dr. Tom Swetnam of the Laboratory of Tree-Ring Research who is reconstructing the past occurrence of fire in Yosemite Park on the basis of fire scars in giant sequoia. By combining our results we hope to model the relationship between past climatic variation and fire frequency.

References

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Table 1. Pearson product-moment correlations between tree-growth indices and monthly precipitation data recorded at Yosemite Valley. October, November and December correlations are calculated comparing previous year's climate with current year's growth. Only values significant at $p < 0.05$ are presented.

	western juniper (JR)	lodgepole pine (GL)
October	--	--
November	--	--
December	--	--
January	--	0.243
February	0.303	0.306
March	--	0.264
April	--	0.183
May	--	--
June	0.318	--
July	--	--
August	--	-0.274
September	--	--
January through March	0.289	0.408

Table 2. Regression coefficients (b_0 , b_1 , and b_2 ; Eq. 1) and results for two subsets of data and full data set. R^2_{adj} is the square of the multiple correlation coefficient adjusted for loss of degrees of freedom. r is the Pearson correlation coefficient for the observed vs the reconstructed data. ** indicates r significant at $p < 0.01$.

Model Estimation					Cross Validation	
Period	b_0	b_1 (GL)	b_2 (JR)	R^2_{adj}	Period	r
1906-1948	-2.593	38.998	19.586	.224	1949-1988	0.434**
1949-1988	-21.958	46.317	23.440	0.399	1906-1948	0.442**
1906-1988	-12.019	40.878	23.048	0.306		

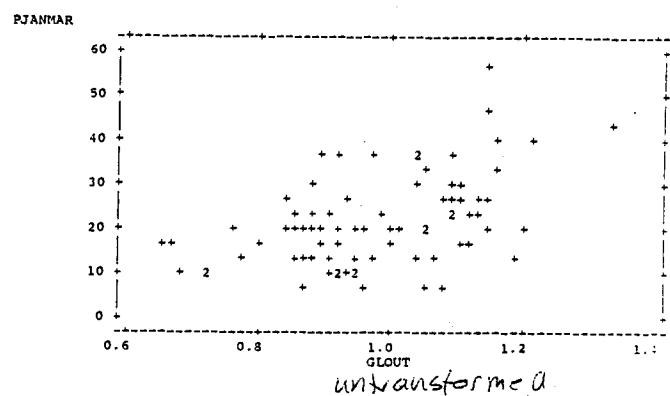
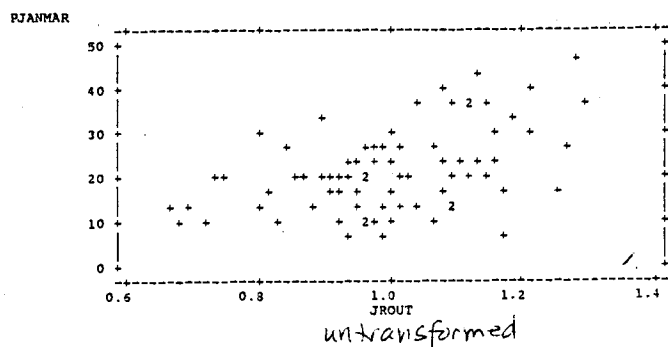
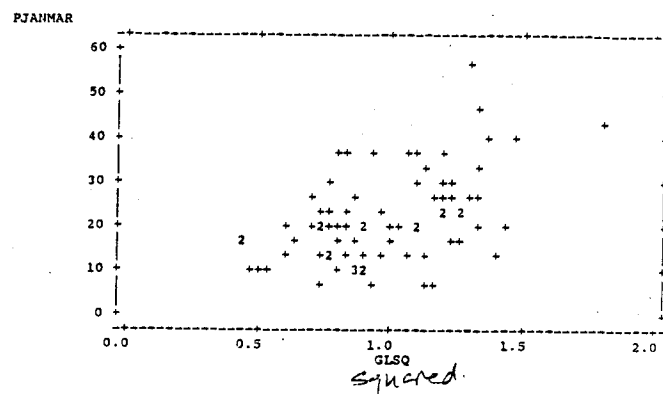
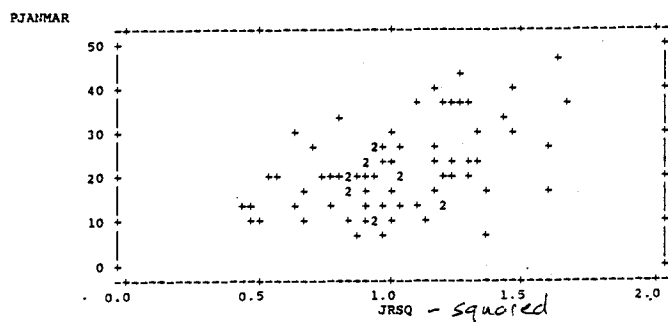


Figure 1. Scatter plots of tree-ring indices (untransformed and squared) vs winter (January through March) precipitation.

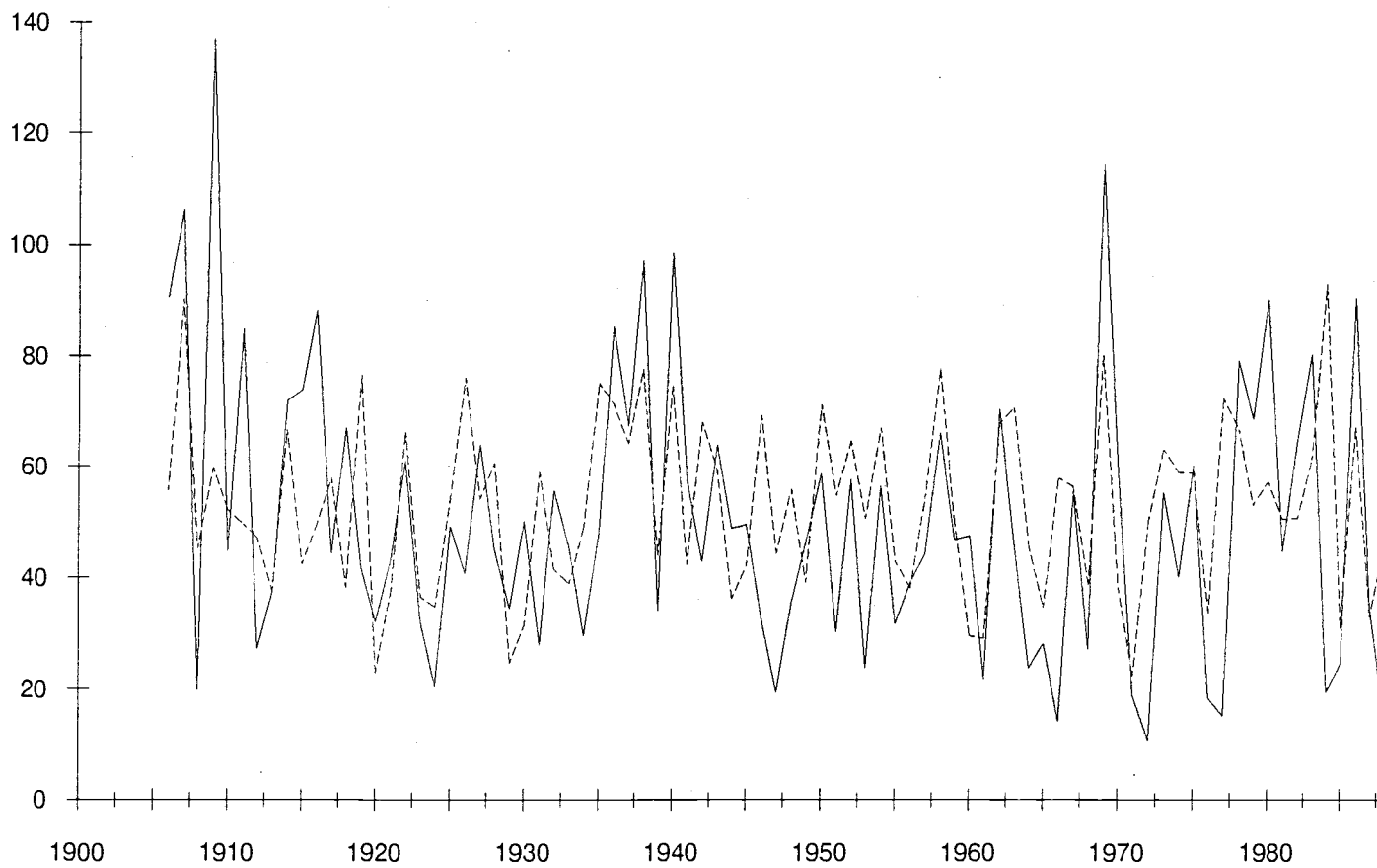


Figure 2. Observed (solid line) vs predicted (dashed line) winter precipitation for Yosemite Valley.

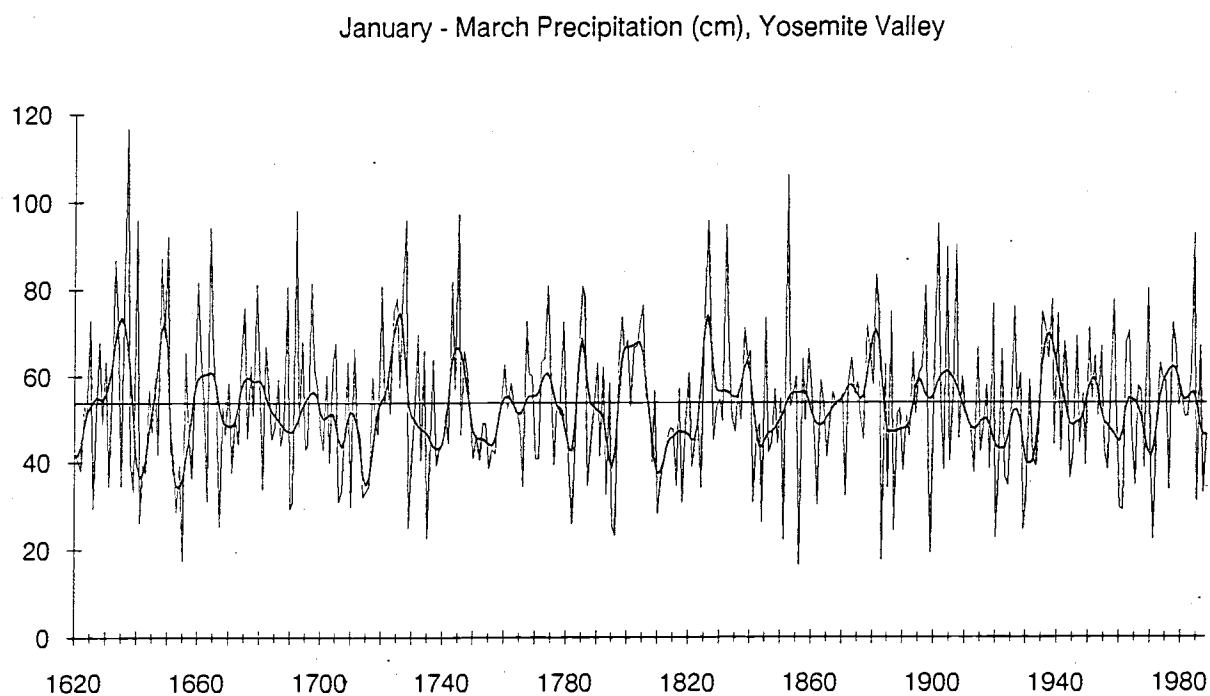


Figure 3. Reconstruction of winter precipitation for Yosemite Valley. Smoothed line represents reconstructed values filtered to emphasize low-frequency variation.