# Interactions Between Climatic Variables Controlling Subalpine Tree Growth: Implications for Climatic History of the Sierra Nevada, California

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**ABSTRACT**: Tree-ring records from foxtail pine *(Pinus balfouriana)* and western juniper *(Juniperus occidentalis)* growing near tree line in the eastern Sierra Nevada, California, show strong correlations with summer temperature and winter precipitation. Response surfaces portraying tree growth as a function of summer temperature and winter precipitation indicate a strong interaction between these variables in controlling growth. In both species, growth response to summer temperature is positive when precipitation is above normal. When precipitation is below average, growth shows a curvilinear relationship with temperature for foxtail pine and a negative relationship with temperature for western juniper. Above average growth for both foxtail pine and western juniper from AD 1480 to 1570 can be interpreted as indicating an extended period of warm, moist conditions unequalled during the 20th century.

## INTRODUCTION

Tree-ring records from trees growing at elevational tree line have long been recognized as a source of proxy climatic data. Long-period variation in such records has been interpreted as reflecting variation in temperature (LaMarche, 1974, 1978; Scuderi, 1987). In addition, precipitation may play an important role in controlling high-frequency variation in growth at tree line (LaMarche and Stockton, 1974; Graumlich and Brubaker, 1986). Understanding the relative role of different climatic variables in controlling growth is a critical preliminary step before either qualitative inferences or quantitative reconstructions of climate based on tree-ring data can be made.

In this paper I describe how temperature and precipitation variables interact in controlling growth of two long-lived subalpine conifers, foxtail pine *(Pinus balfouriana)* and western juniper *(Juniperus occidentalis)*, growing along the eastern crest of the Sierra Nevada. I then discuss how the differences in growth response between these two species can be used to elucidate climatic conditions associated with periods of above average tree growth previous to the 20th century.

## DATA AND METHODS

Two increment cores were extracted from 20 to 25 individual foxtail pines at each of three sites located on the easternmost crest of the Sierra Nevada between Kearsarge Pass and Mt. Whitney (Table 1). All cores were processed, cross-dated, and measured using standard methods (Swetnam et al., 1985). Cores proving difficult to cross-date or having visible indication of damage were removed from the analysis.

Table 1. Site and chronology characteristics of tree-ring data.

| Site | Species | Lat. (°N) | Long. (°W) | Elev. (m) |
|---|---|---|---|---|
| West Tyndall | Foxtail pine | 36°39' | 118°23' | 3450 |
| Bighorn | Foxtail pine | 36°36' | 118°22' | 3430 |
| Crabtree | Foxtail pine | 36°35' | 118°22' | 3350 |
| Kaiser Pass | Western juniper | 37°17' | 119°05' | 2700 |

Age-related trends in core measurements were removed by fitting negative exponential growth curves to individual measurement series. Site chronologies were then developed by averaging standardized measurements within each site (Graumlich, in prep). The western juniper "standard" chronology from Kaiser Pass was developed by Richard Holmes of the University of Arizona using similar techniques (Table 1; Holmes et al., 1986).

Monthly temperature and precipitation data used for the foxtail pine analyses are from Giant Forest (1927-1968; 36°34'N, 118°46'W, 1943 m) and from Grant Grove (1944-1986; 36°46'N, 118°58'W, 2012 m). Regression equations were used to predict Grant Grove monthly temperature and precipitation from the corresponding Giant Forest data and thus extend the Grant Grove record. During the 25-year period of overlap, the regression equations accounted for 41-97% of the variance of the Grant Grove data (Graumlich, in prep). The predictive power of the Giant Forest/Grant Grove calibration equations was high for the summer temperature and winter precipitation variables discussed below ($R^2 = 85\%$ and 93%, respectively). Climate data used for the western juniper analyses are from Yosemite Park Headquarters (1906-1981; 37°45'N, 119°35'W, 1236 m).

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Response surfaces portraying graphically annual tree growth as a function of two climatic variables were constructed by:

- Using an inverse distance weighting algorithm to interpolate between observed data points, resulting in a regularly spaced grid of tree-ring data, and
- Smoothing the resultant grid by averaging adjacent points with a center-weighted smoothing matrix.

The resulting response surfaces show general trends of growth response to climatic variation and can be interpreted to indicate the presence of nonlinearities or interactions between two variables as they influence tree growth (Graumlich, in prep; Graumlich and Brubaker, 1986).

In the analyses presented here, total winter (previous October to current June) precipitation and average summer (July to August) temperature were selected for the response surface analysis based on preliminary analyses of scatter plots between climate and tree-ring variables. The low correlation between summer temperature and winter precipitation results in a wide scatter of values over the X-Y plane formed by these two variables and thus allows a response surface to be calculated over the entire range of both variables. Standardized values of the climatic variables were used to facilitate comparisons between response surfaces.

## GROWTH RESPONSE TO CLIMATE

The response surface for the West Tyndall foxtail pine site (Figure 1a) is typical of the foxtail pine response surfaces in indicating that growth is maximized when both summer temperatures and winter precipitation values are high. The response surface is also typical of those for this species in indicating that summer temperature and winter precipitation interact in controlling tree growth. For example, when precipitation is above average, the response to summer temperature is positive; when precipitation is below average, the response to summer temperature is depressed under both very cool or very warm conditions. A positive response to temperature in these subalpine conifers thus depends on the availability of adequate moisture supplies, a result that is not surprising given the coarse soils, warm temperatures, and low precipitation totals on the lee side of the Sierra Nevada.

The response surface for the Kaiser Pass western juniper site (Figure 1b) is similar to that of the foxtail pine sites in indicating maximum growth under conditions of high summer temperatures and high winter precipitation. The previously observed interactions between temperature and precipitation in controlling tree growth can also be seen in the change from a positive response to temperature when precipitation is above average to a negative response to temperature when precipitation is below average. The response surface for western juniper displays a higher degree of non-linearity than does the foxtail response surface. Without additional western juniper sites, it is difficult to determine if the climatic response surface derived for Kaiser Pass is typical of western juniper. Analysis of recently collected western juniper cores from similar tree-line sites in the Sierra Nevada will allow such a determination.

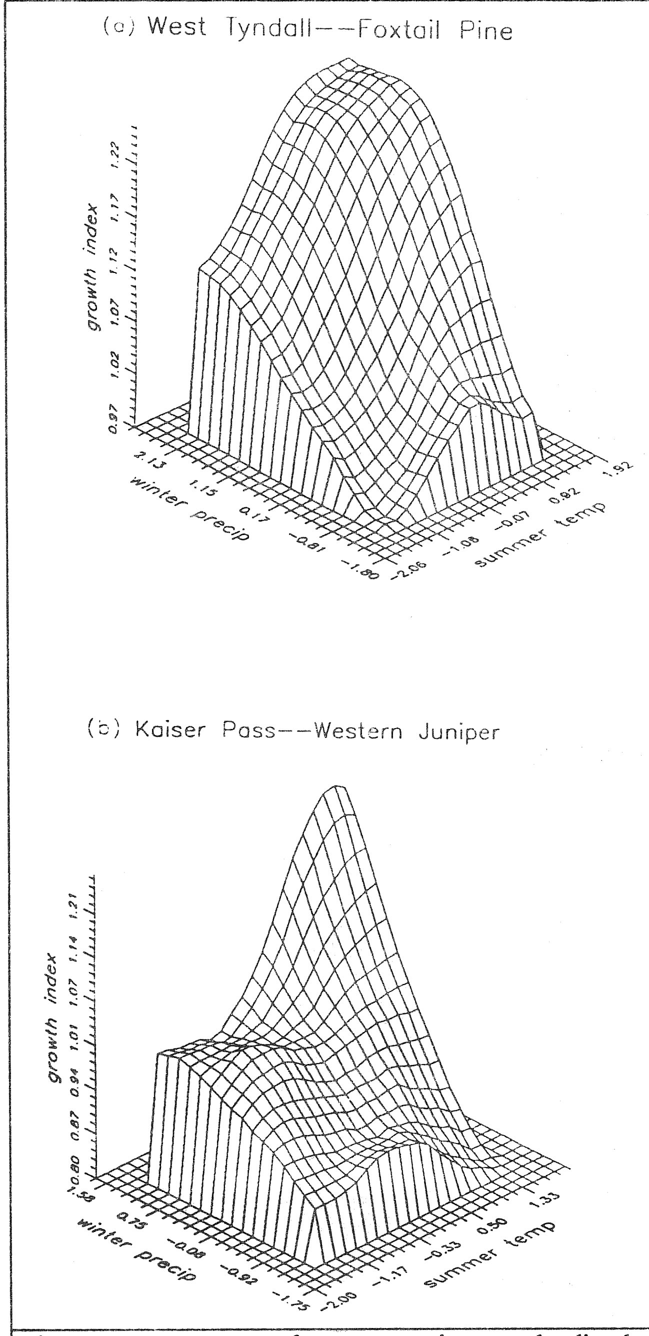


Figure 1. Response surfaces portraying standardized tree growth indices of (a) foxtail pine and (b) western juniper as a function of standardized values of average summer (July to August) temperature and total winter (previous October to current June) precipitation.

## LONG-TERM GROWTH TRENDS

Growth trends at the three foxtail pine sites and one western juniper site are strongly coherent over time at both high and low frequencies (Figure 2). Particularly intriguing are the extended periods of above average growth for foxtail pine from AD 1400 to 1450 and from AD 1480 to 1570. If climatic inferences were to be drawn from the foxtail pine record, one would conclude that the periods from 1400 to 1450 and from 1480 to 1570 were long warm, moist episodes during the 20th century (e.g., 1951-1952, 1969-1970, 1978, 1980).

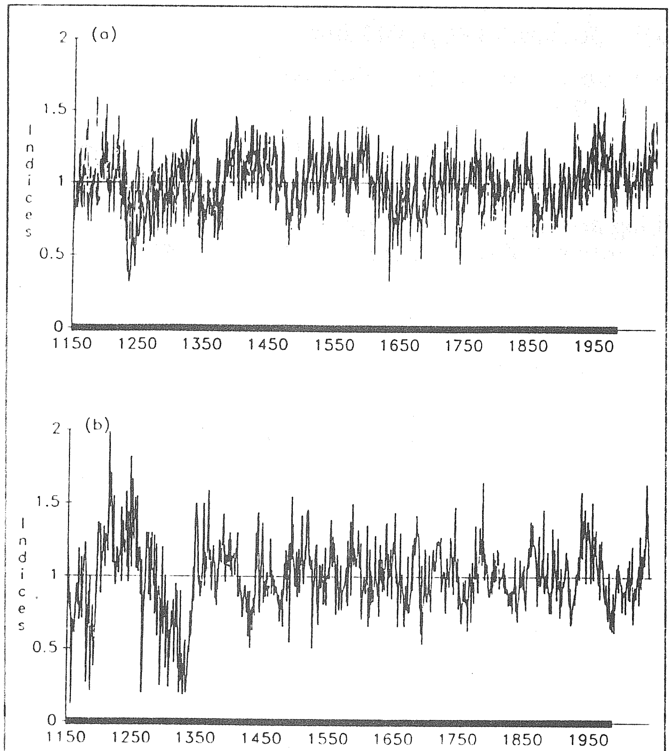


Figure 2. Tree-ring indices for (a) three foxtail pine sites (West Tyndall, Bighorn, and Crabtree) and (b) one western juniper site (Kaiser Pass).

When a detailed comparison is made between foxtail pine and western juniper growth (Figure 3), the previous interpretation of climatic significance of a portion of the AD 1400 to 1570 period breaks down. If conditions were uniformly warm and moist, then we would expect to observe greater than average values of both foxtail pine and western juniper. While the two species vary coherently from 1480 onward, from AD 1400 to 1450, levels of foxtail pine growth are substantially higher than those of western juniper.

There are several possible interpretations of the differing growth patterns observed between the two species from AD 1400 to 1450. One could argue that the response surfaces indicate the greatest contrast in growth between the two species when temperatures are below average and precipitation is above average and that growth during the period in question could reflect such a climatic scenario. Alternatively, climatic conditions during the period from 1400 to 1450 might not have analogs during the period of observed climate, and our inferences based on analogy are thus inadequate. Finally, sample size of the western juniper chronology during this period is small enough ($n = 6$) that non-climatic factors could be responsible for the low frequency variation in the early part of the chronology.

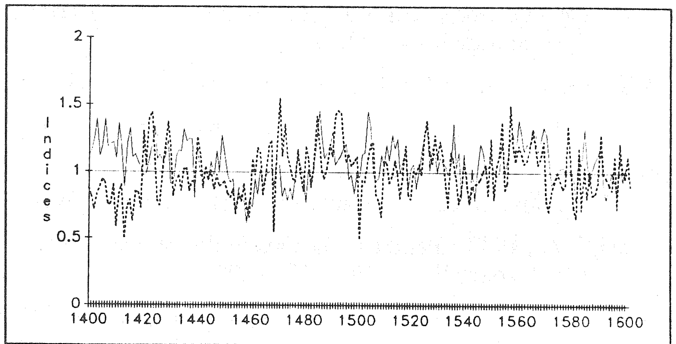


Figure 3. Tree-ring indices for foxtail pine at West Tyndall site (solid line) and western juniper at Kaiser Pass site (dashed line).

Ongoing work, including further sampling of subalpine conifers, investigation of the possibility of no-analog climatic conditions in the past (Graumlich and Brubaker, 1986), and development of maximum likelihood approaches to reconstructing climate directly from response surfaces (Bartlein et al., in prep) should resolve these and similar questions.

## CONCLUSIONS

Analyses of foxtail pine and western juniper chronologies from the Sierra Nevada clearly indicate that:

- Both summer temperature and winter precipitation are important factors governing subalpine tree growth in the Sierra Nevada;
- Summer temperature and winter precipitation interact strongly in controlling growth in these subalpine environments; and
- Given the complex nature of the growth response to climate, use of alternative reconstruction strategies involving response surfaces from multiple species will be necessary to reconstruct quantitatively climate from subalpine tree-ring chronologies in this region.


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