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A TECHNIQUE FOR EXAMINING NON-CLIMATIC VARIATION IN WIDTHS OF ANNUAL TREE RINGS WITH SPECIAL REFERENCE TO AIR POLLUTION

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ABSTRACT

A new technique is developed for examining non-climatic variations in widths of annual tree rings. For each tree core, the technique involves making an adjustment for regional climate as inferred from a regional chronology based on surrounding sites. The technique is applied to two stands in Gila County, Arizona, where air pollution is potentially a limiting factor on tree-ring growth. For the stand closer to the pollution sources, a marked decrease in tree-ring widths minus climate is evident during the period 1908 to 1920. Although this decrease coincides with a period when two smelters were operating nearby, air pollution cannot be definitively identified as the cause of the decrease in ring widths.

INTRODUCTION

The fact that variations in ring widths from certain trees may be used to date wood (Douglass 1935) and to reconstruct past climates (Fritts 1971) is well established. Variables which are closely related to climate, such as stream runoff records (Stockton and Fritts 1971), may also be closely correlated with ring width variations. In addition to the information on regional climate contained in the tree-ring record, it should also be possible to glean information about the effect of local site factors on tree growth from the tree-ring record as well. It is the purpose of this article to present one technique by which the effects of non-climatic factors on tree growth may be examined after the effect of climate is removed.

This research was initially designed to examine the effects of air pollution on ponderosa pine growth in the American Southwest. Workers in Czechoslovakia (Vinš and Tesař 1969) and Indiana (Ashby and Fritts 1972) have demonstrated reductions in tree-ring size near industrial sources of air pollution. Further industrial and urban development of the Southwest may lead to substantial changes in air quality characteristics in at least some areas. To develop criteria by which further development may be planned to minimize its effects on our forest resources, it is necessary to understand how development affects the forest resources. One frequent by-product of development is air pollution which is known to have a detrimental effect on forests in some areas (Thomas 1961). Although the short-term effects (chronic and acute injury) of sulfur dioxide and ozone are well known (Jacobson and Hill 1970), the long-term (over decades) effects of air pollutants on ponderosa pine productivity is less well understood. An appropriate application of dendrochronological procedures may provide one way of assessing these long term effects.

THE STUDY AREA

Initially three Arizona and New Mexico smelter towns, Miami, Morenci, and Silver City were considered as potential study areas. Other Southwestern smelter towns are located in desert regions which are generally remote from ponderosa pine stands and consequently were not considered. Silver City was eliminated from consideration because the location of the smelter was changed by several miles and smelter operation was discontinuous. In the case of both Morenci and Silver City, good stands of ponderosa pine are only located to the north within a 30 mile radius. On the other hand, nearby stands of ponderosa pine are located both north and south of the Inspiration Copper Company smelter at Miami, Arizona. For this reason and because unpublished U.S. Forest Service reports indicate that occasional injury symptoms which resemble sulfur dioxide-induced symptoms do occur on the nearby Pinal Mountains, Miami was chosen as the study area.

We are indebted to Mr. John Woody of the Gila County Historical Society for the following information. Mining activities in the Miami area began with a small silver strike in the 1870's in Globe which is located approximately five miles east of Miami. Initially the silver was processed by a small wood burning smelter which was located on the site of the now abandoned Old Dominian Copper Smelter. With the discovery of copper ore, operations were expanded about 1890 with a new smelter which was stoked by coke. From old smelter photographs we infer that neither of the earlier smelters were large enough for their effluents to affect vegetation beyond a few hundred meters of the smelter. During the first decade of the 1900's smelting operations were again expanded with the construction of the coal-fired Old Dominian Smelter which had a 300 foot stack. In addition, at approximately the same time Phelps Dodge Corporation constructed the large smelter, which is currently run by the Inspiration Copper Company. Both of these smelters are sufficiently large that trees which are downwind from smelter effluents may potentially be injured several miles away from the smelters themselves. The Old Dominian Smelter ceased operations in 1925 as a result of the economic constraints imposed by the Depression. During the 1930's the Miami smelter operated on a reduced schedule. With the advent of World War II full scale operations at the Miami smelter were resumed about 1940 and a new natural gas fired furnace was established, replacing the older coal fired one.

Two sites in Gila County were selected for coring ponderosa pines to obtain tree-ring samples (Figure 1). The first site is located on the north and east slopes of Madera Peak in the Pinal Mountains at an elevation of approximately 1900 m. This site represents the closest ponderosa pine stand to a copper smelter in Arizona, being approximately 7 km due south of the Miami smelter and approximately 10 km ESE of the Old Dominian Smelter. The second site was located in the Sierra Ancha Experimental Forest along Arizona highway 288 on north and east slopes at approximately 1800 m. The latter site represents the closest ponderosa pine site to the north, being approximately 38 km NNW of the Miami-Globe area.

There is good evidence in support of the assumption that air pollutants are present in the Miami-Globe area. For the years 1969, 1970, and 1971, Claypool, a small town

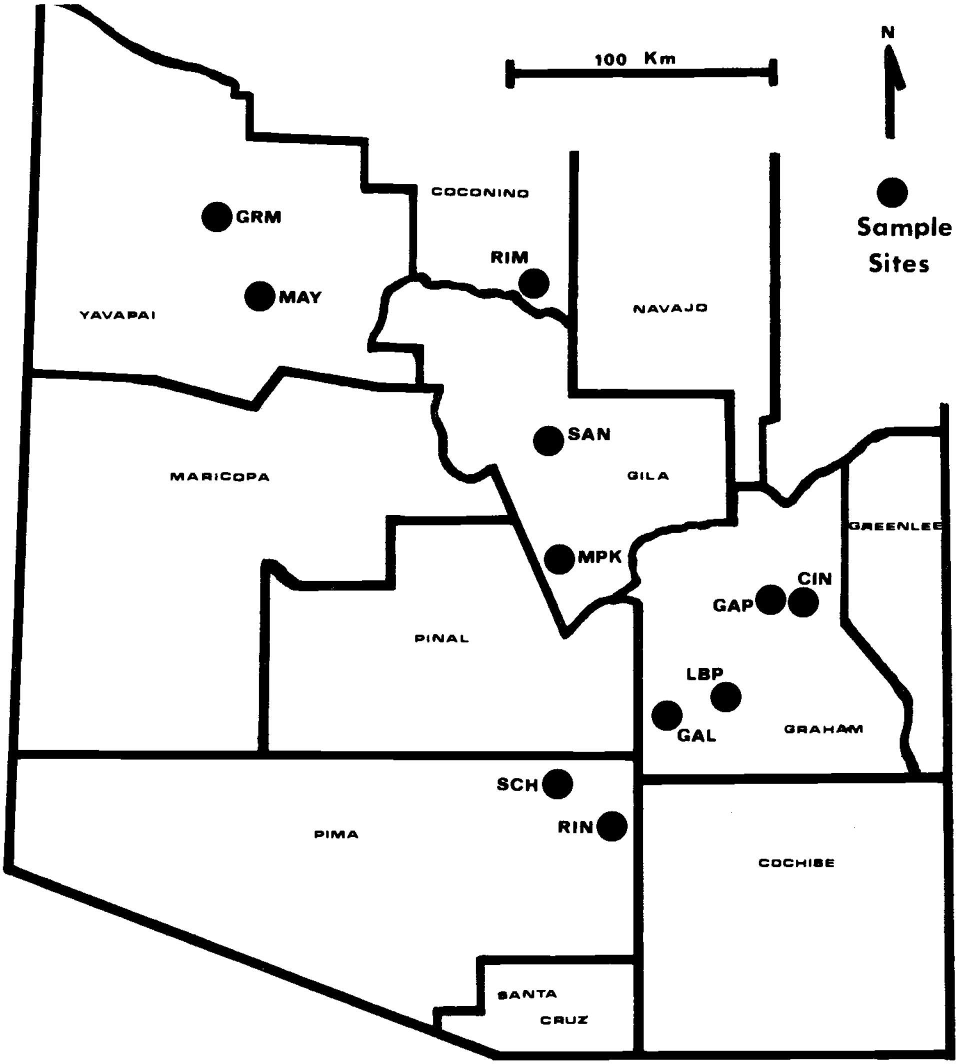

Figure 1. Geographical location of sampling sites in relation to the counties of south central Arizona. MPK stands for Madera Peak in the Pinal Mountains, the site closest to the smelters. SAN stands for Sierra Ancha. Sites employed to construct the regional climatic chronology are: GRM – Granite Mt.; MAY – Mayer; RIM – Mogollon Rim; GAP – Nantack Gap; CIN – Cienega; LBP – Lady Bug Peak; GAL – Galiuro Mts., Site A; RIN – Rincon Mts.

between Miami and Globe, consistently ranked among the top three of 22 locations for total sulfates, copper, lead, and zinc particulates (Guyton 1970 to 1971). Unfortunately the meteorological parameters of the Miami-Globe are not well documented. However, it is my personal observation, confirmed by talking with local residents and the state air pollution meteorologist, that the predominant winds blow east or west. Thus neither sampling site is likely to be regularly fumigated by effluents from the smelters. However, during periods of atmospheric stability clouds of effluents will build up over the smelter to over 2000 m. Fire watching personnel of the U.S. Forest Service has observed these clouds to occasionally expand northward, filling up the Lake Roosevelt basin adjacent to the Sierra Ancha area. Under these conditions Madera Peak may occasionally become enveloped by smelter effluents and the Sierra Ancha site may be rarely affected.

METHODS

Tree rings were sampled and analyzed according to standard procedures developed by the Laboratory of Tree-Ring Research (Fritts 1971). On the basis of sample cores taken on a preliminary reconnaisance trip, it was concluded that the tree-ring sequence exhibited sufficient sensitivity to be datable. In September, 1974, we cored more than 20 trees at each site, taking two cores per tree. Tree selection is non-random because trees growing adjacent to each other are deliberately not sampled to avoid non-climatic growth reduction associated with severe competition. The sampling procedure should thus minimize the effects of stand density on growth patterns. On the basis of measurements by the prism technique we determined the basal area at Madera Peak to be 92 sq. ft./ac. and at Sierra Ancha to be 83.5 sq. ft./ac. Because of the similarities in basal areas and in exposure and elevation, we concluded that tree-ring sequences could be legitimately compared between the sites. At this stage the planned comparisons are basically qualitative in nature, such as looking for trends within a tree-ring sequence from a tree. No attempt has been made to correct the absolute growth rate for stand density effects. Such corrections would be necessary if our results were to be translated into lost board feet (Schubert 1974).

After allowing the cores to air dry, mounting the cores on a wooden backing, and sanding the cores to clarify the ring structures, each core was examined under a binocular microscope to determine whether a crossdatable sequence of rings could be identified. In crossdating attention is generally focused on whether narrow rings consistently occur during the same years from core to core. For example, in the current study the years 1902, 1904, 1910, 1918, 1921, 1923, 1925, 1934, 1940 and 1948 were years in which tree-rings were almost always narrow. Cores which could not be accurately dated were discarded.

After successfully crossdating 31 cores from Madera Peak and 38 cores from Sierra Ancha, the width of each ring was measured to the nearest hundreth of a mm. These measurements were punched on computer cards and run through a ring width list (RWLST) program which plots a 20 year running mean and calculates the mean and mean sensitivity of the ring widths. Examination of this program output enables one to detect errors in measurement and previous interpretation. After completing this validation procedure, the ring width cards were run through the INDXA program which standardizes each core by fitting a growth curve (usually exponential or straight line) through the ring widths and subsequently dividing the ring widths by the value of the curve for each ring width measurement. These outputs of the INDXA program are referred to as tree-ring indices which are then averaged to obtain a tree chronology or stand chronology.

Numerous studies in the Southwest have demonstrated that chronologies from undisturbed stands may be closely correlated with climate (Fritts 1966, 1974; LaMarche and Fritts 1971). Broad regional climatic trends are reflected in the fact that it is frequently possible to crossdate trees which grow several hundred miles apart. The subsequent analysis proceeds on the assumption that a regional chronology, composed of the averaged stand chronologies for several stands surrounding the study area, provides an accurate index of the regional climate which affects the sampled stands. With this assumption in mind we then have devised a procedure, outlined below, by which each of the tree-ring indices may be corrected for the effect of regional climate. By multiplying the corrected indices back against the values generated by the original growth curve for each year, it is now possible to examine the variation in ring widths with the effect of climate removed. Anomalies in growth curves should then be readily apparent in plotted ring widths.

Accordingly we obtained chronologies for eight stands located to the north, east, south and west of Miami (Figure 1). These chronologies were averaged to obtain a regional chronology running from 1800 to 1968. With the regional chronology, individual tree-ring indices and core growth equations as inputs, a program (TRMCLM) was designed to generate ring widths with the effect of regional climate removed. Initially the program calculated the standard deviation (s_{TRI}) for each tree-ring index and the standard deviation (s_{RCI}) for the regional climate index corresponding to the same number of years. Then predicted residual indices (PRI) were calculated according to the following formula.

$$PRI = \frac{s_{TRI}}{s_{RCI}} \left(TRI_{i=1...n} - \bar{x}RCI\right)$$

where s_{TRI} and s_{RCI} are defined above and
TRI = tree-ring index for a given year.
The calculations are done n times where
n is the number of years of observations
and $\bar{x}_{RCI}$ is the mean of the regional chronology indices
corresponding to n years.

Each predicted residual index was then subtracted from each respective tree-ring index and the resultant corrected index was multiplied back against the value generated by the original growth equation for the year in question to generate the predicted ring width minus climate. These resultant values together with the original tree-ring measurements were then plotted by running the values through a plotting program (TRPLOT) designed by the Laboratory for Tree-Ring Research.

Cards for the original tree-ring measurements for Madera Peak and Sierra Ancha are stored at the Laboratory for Tree-Ring Research. The new program (TRMCLM) is available either through the senior author at Arizona State University or through the Laboratory for Tree-Ring Research.

RESULTS AND DISCUSSION

For comparative purposes, plots of the original ring widths are paired with plots of the predicted ring widths minus climate (Figures 2, 3, 4). Figure 2 presents the mean ring widths for all trees at both Madera Peak and Sierra Ancha. These plots should be interpreted cautiously, particularly before 1870, because the trees do not represent a uniform age class and consequently the years are not replicated in equal numbers. Figures 3 and 4 present the results for a few selected trees from both Madera Peak (site 652) and Sierra Ancha (site 653).

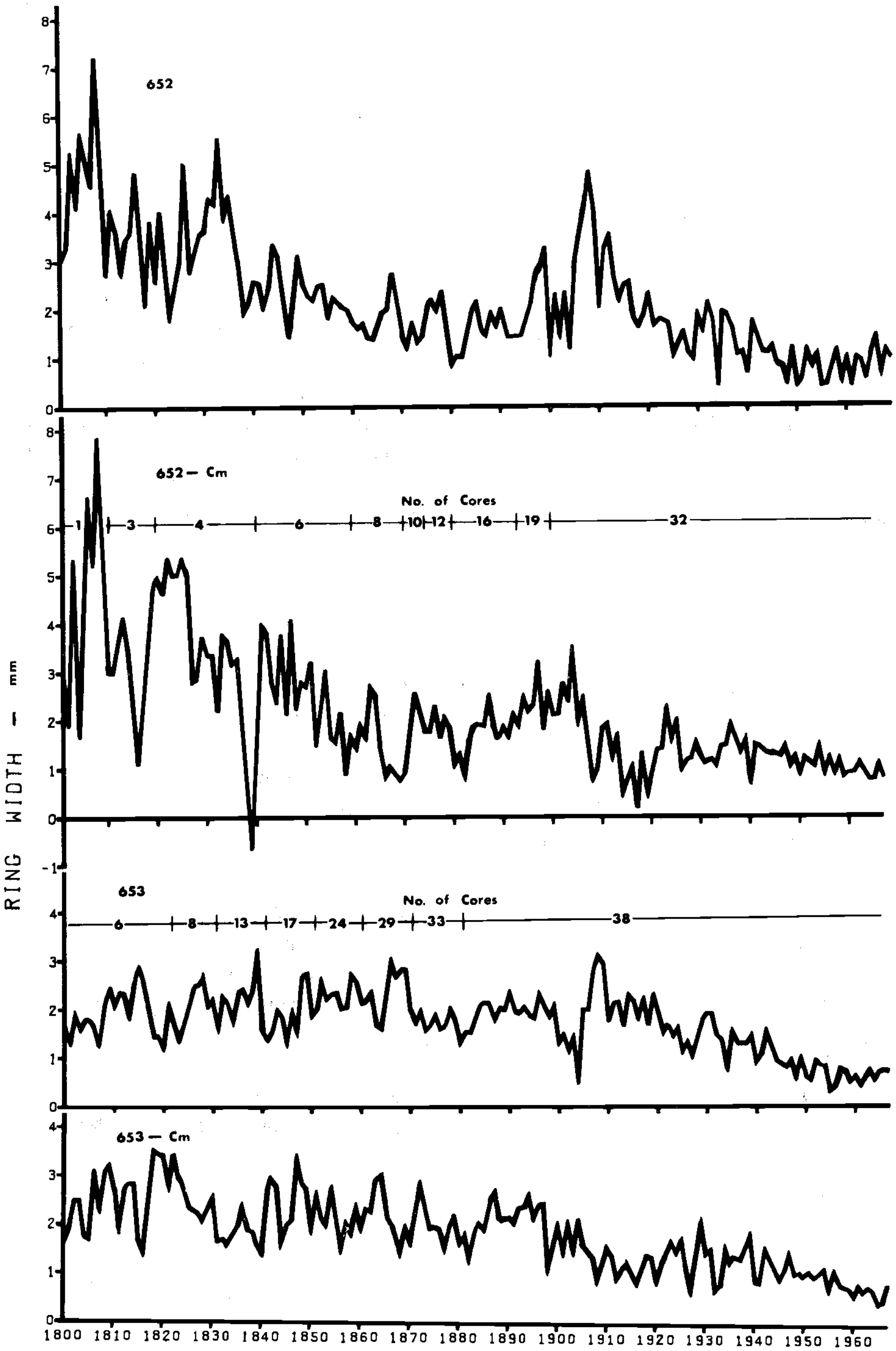

Figure 2. Average ring widths for all cores plotted versus year for sites 652 (Madera Peak) and 653 (Sierra Ancha). Reconstructed ring width series where the regional climatic effect has been removed are designated "-Cm". The number of cores per year is also designated.

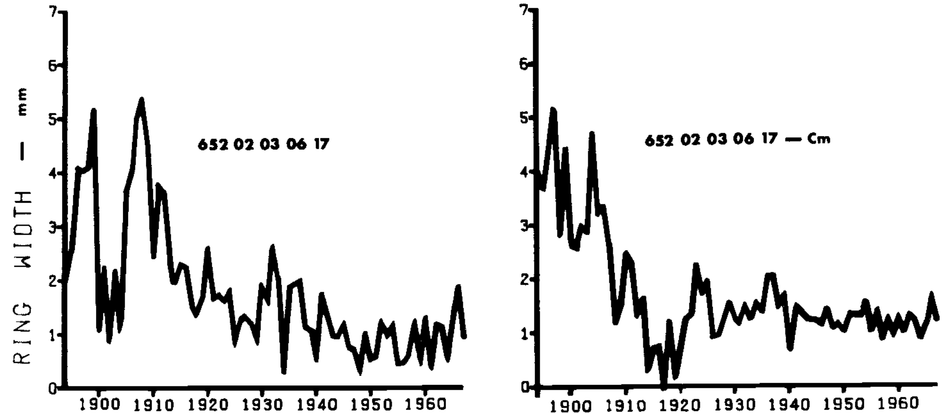

Figure 3. Average ring width and ring widths minus climate for trees 2, 3, 6 and 17 from site 652 (Madera Peak).

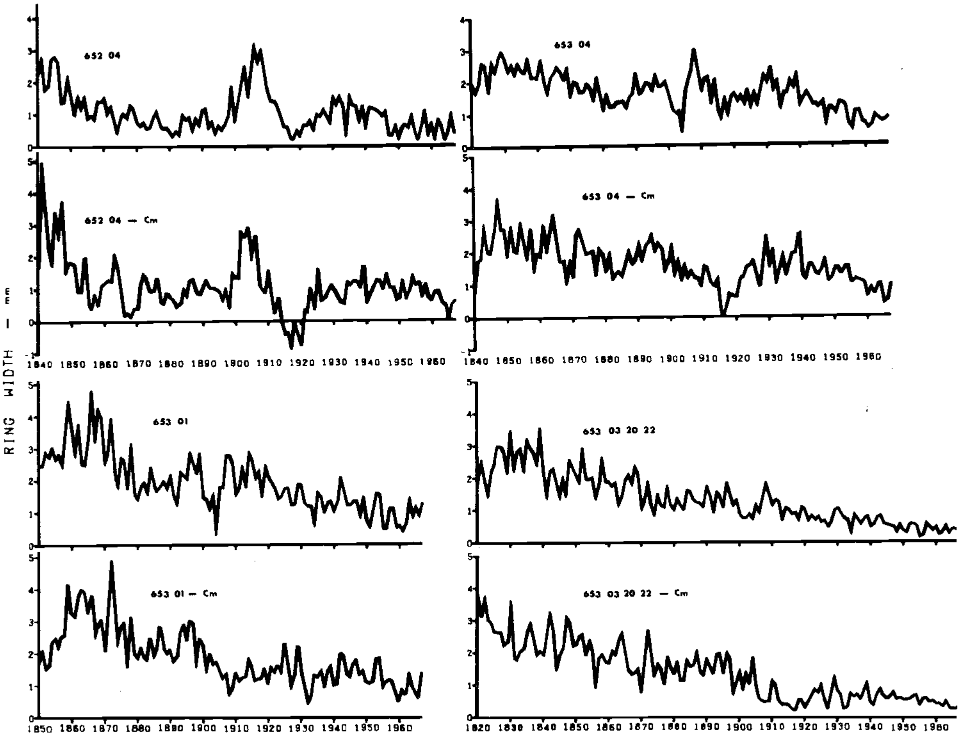

Figure 4. Average ring width and ring widths minus climate for selected cores from either site 652 (Madera Peak) or site 653 (Sierra Ancha).

One prominent result is that the years with the very narrow ring widths in the original series are removed in the adjusted ring widths where "climate" is subtracted. For example, the years 1899, 1902, and 1904, which are diagnostic markers for crossdating the original cores, no longer appear as very narrow rings in the predicted ring width minus climate series. Because these original narrow rings are known to correspond to drought periods, we interpret their removal in the predicted ring width minus climate series as validating the ability of our new program (RWMCLM) to remove the climatic signal.

It is also important that the predicted ring width minus climate series exhibit a decrease (either a straight line or exponential decay) in ring width size as the trees age. Such a decrease would be predicted in an idealized tree, where the amount of new wood added per year is constant, because of the increase in volume of the tree as the circumference increases.

Another conspicuous change between the original and predicted ring width series is the appearance of a number of years between 1908 and 1920 with very small ring widths in the predicted minus climate series. This growth anomaly is clearly present for at least some of these years for all 31 cores (from 21 trees) for Madera Peak and this fact is reflected in the mean ring width minus climate series (Figure 2). In several of these, the predicted ring width minus climate is reduced to zero (or less) which implies that growth inhibition was severe. In the Sierra Ancha material similar reductions in predicted ring width sizes occurs in less than half the trees, and where growth reduction is evident, the magnitude of the decrease is generally less than at Madera Peak (Figure 2). The most consistent small rings occur in 1908 for Sierra Ancha. It is our interpretation that such anomalies in the predicted ring widths minus climate represent the effect of local site factors, particularly at Madera Peak, which are not affecting tree-ring growth at the sites chosen to provide the regional chronology.

One reasonable interpretation is that such a site factor may correspond to the effect of effluents from the copper smelters on ponderosa pine growth. The construction of two large copper smelters in Globe and Miami during the first decade of this century establishes the possibility that the growth reduction beginning in 1908 may reflect the detrimental effect of smelter effluents. The topographic position of Madera Peak in relation to the Old Dominian Smelter is consistent with the assumption that the prevailing winds frequently carried the smelter effluents towards Madera Peak. Because of its topographic position north of Madera Peak, it is assumed that effluents from the Miami smelter would fumigate Madera Peak less frequently. The apparent growth recovery in the years after the close of the Old Dominian Smelter is consistent with this interpretation.

On the other hand, the fact that little apparent growth reduction is evident during the 1920's when the Old Dominian Smelter was still in operation is somewhat inconsistent with the above interpretation. In addition, the fact that prominent growth reductions did occur in the 1800's (Figures 2 and 4), for example 1832, before the smelters were operating, necessitates the conclusion that other site factors are also important in limiting growth. One possible factor might be the occurrence of a local drought in Gila County. Drought is known to limit tree-ring size. Other non-climatic factors which could cause a severe reduction in growth include fire and physiological drought, the latter of which occurs in winter under conditions favorable to transpiration but where the ground is frozen. Another possible factor is the effect of competition resulting from high stand densities. The tree-ring record documents that many of trees on Madera Peak belong to an age class where growth was initiated during the decade 1890 to

1900. If competition is particularly severe among trees between the years 15 and 30, then the growth reduction observed between 1908 and 1920 would be predictable. It is plausible that canopy closure may have occurred within the 15 to 30 age class. This would result in reduced growth due to competition for light as a higher percentage of the needles become shaded. In addition, tip moths are frequently active in young ponderosa pine stands (Schubert, personal communication). A severe attack by these moths would certainly reduce growth. Unfortunately there are no records of insect activity on the Pinal Mountains in the early 1900's and consequently the plausibility of an insect attack can not be evaluated.

In the future it is hoped that this new approach will be generally useful in identifying non-climatic variations in tree-ring widths. By coupling the results of these techniques with carefully documented knowledge of site factors, it should be possible to definitively identify causes of non-climatic variation in ring widths and hence tree growth.

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