CLIMATE RESPONSE, AGE DISTRIBUTION, AND
FIRE HISTORY OF A CORKBARK FIR
(*ABIES LASIOCARPA* VAR. *ARIZONICA*) STAND IN THE
SANTA CATALINA MOUNTAINS, ARIZONA

by

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ABSTRACT

The southernmost known North American stand of corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) is found in the Santa Catalina Mountains just north of Tucson, Arizona. Climate response, age distribution, and fire history were studied in this small corkbark fir stand to provide baseline information for future management. Response function analysis indicated April - June precipitation from the current growing season, April - June temperature from the current growing season, November - March precipitation prior to the growing season, and August- October precipitation from the previous growing season as the most highly correlated factor with ring-width variance. Age distribution appeared to be steady state. A fire chronology developed for the corkbark fir site was used to test synchroneity of fire events with previously developed chronologies from nearby sites. Chi-squared analyses indicated significant association of fire years for all sites but not spread of fire from one site to another.

CHAPTER 1. INTRODUCTION

1.1 Purpose and Objectives

The southernmost known North American stand of corkbark fir is found in the Santa Catalina Mountains, bordering the north side of Tucson, Arizona. The elevation of the mountain range reaches 2740 m, with the corkbark fir present above 2590 m. The stand is approximately 300 m from top to bottom and 180 m side to side at its widest points. This small stand is unique because the Santa Catalinas are the only mountain range known to have a stand of corkbark fir without the typical associated species, Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.). Another unique characteristic of this stand is its distinct boundary, as opposed to a gradual mixing with other species. The stand is also distant from other stands of corkbark fir. The nearest corkbark fir stand to this one is located in the Pinaleño Mountains, southwest of Safford, Arizona, 100 km northeast of Tucson (Figure 1). The summit of the Pinaleño Mountains is at 3266 m, with the corkbark fir present from approximately 2590 m to the summit. This more extensive stand is typical of a spruce-fir forest in the Southwest (Alexander, 1974).

The purpose of this study is to evaluate some of the ecosystem processes associated with the presence of the corkbark fir stand in the Santa Catalina Mountains. Specific objectives are to examine climate response, age distribution, and fire history. There has been no previous published research on this stand. This information can be used by land managers to create plans that encourage the preservation of corkbark fir in the Santa Catalina Mountains and similar areas.
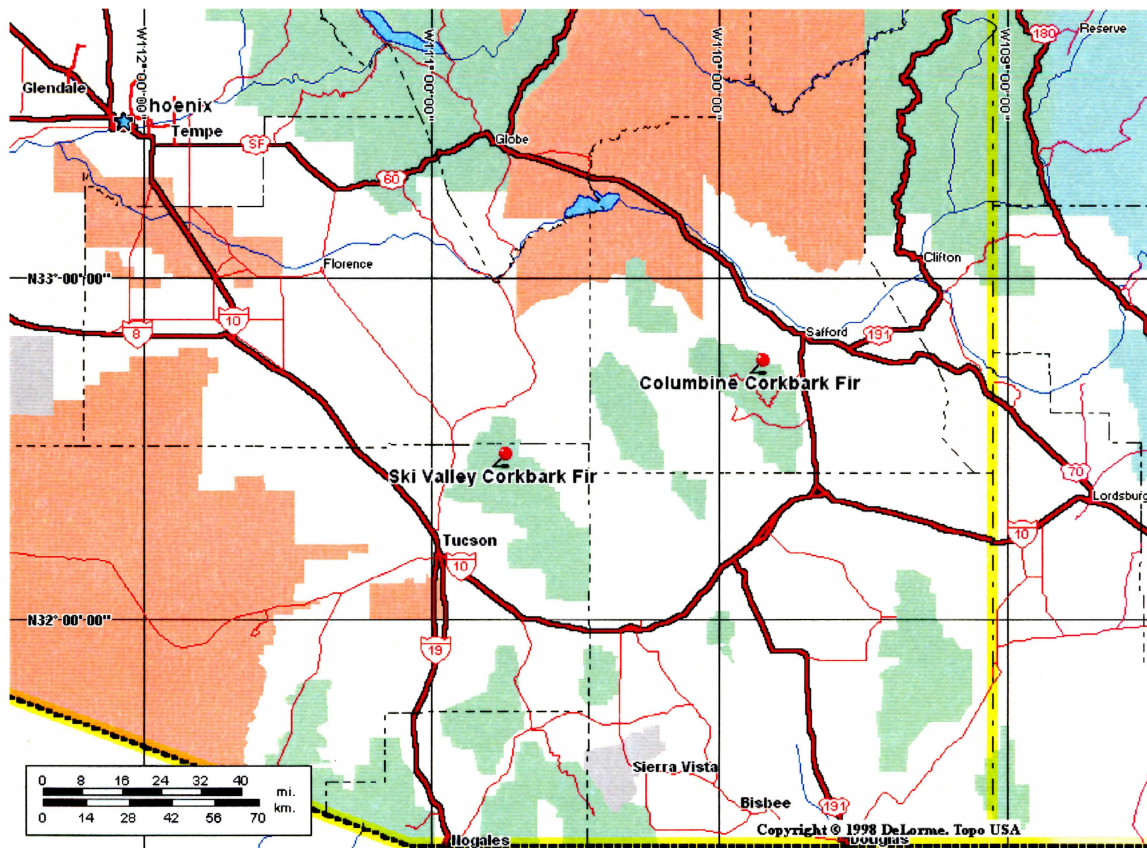
Figure 1. Map indicating locations of corkbark fir collection sites in the Santa Catalina

Mountains (Ski Valley) and Pinaleño Mountains (Columbine).

1.2 Species Characteristics

Subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) is the most widespread true fir found in the western United States (Little, 1998). Corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) is a variety of subalpine fir found in Arizona, New Mexico, and Colorado, predominantly in cool, moist spruce-fir forests (Little, 1998; Epple, 1995). Field guides by both Little (1998) and Epple (1995) report that corkbark fir can reach heights of 30 m, with a long, narrow, pointed crown (Figure 2). The needles are 2-4 cm in length and are dark, bluish-green, with two silvery lines on the undersurface. Cones are 6-10 cm in length, dark purple, and covered with pitch. The bark is a smooth, grayish-brown with a spongy texture, which differentiates corkbark fir from subalpine fir. Some taxonomists and individuals prefer to split corkbark fir into a new taxonomic classification, *Abies bifolia* (Hunt & Von Rudloff, 1983), although most literature and this study refer to corkbark fir as *Abies lasiocarpa* var. *arizonica*.

1.3 Climate Response

It is important to understand how the trees are responding to local climate factors in order to assess the possible effect of future climate change on these trees. The Pinaleño Mountains foster an extensive, thriving spruce-fir stand. In contrast, the stand of corkbark fir in the Santa Catalina Mountains is small, and is not associated with Engelmann spruce. I evaluated the response of growth indices to seasonal precipitation and temperature in both mountain ranges to determine whether the stand differences might be associated with differences in sensitivity to climatic variations.

Figure 2. Corkbark fir trees in the Santa Catalinas displaying their tall, narrow, and conical growth form.

1.4 Age Distribution

The ability of corkbark fir to successfully reproduce in the Santa Catalina Mountains can be learned by evaluating the age distribution of the trees in the stand. There is a greater chance that the trees will remain in the Santa Catalina Mountains if they are successfully reproducing. A stand is healthy when its age distribution exhibits an inverse-J curve (Hessl & Baker, 1997). This means that number of trees decrease as age class increases. The age distribution curve can also reveal information about the stand's response to external environmental processes.

1.5 Fire History

The typical fire regime in spruce-fir forests is a catastrophic, high intensity, stand replacing fire. Mixed conifer forests typically exhibit frequent, low intensity surface fires (Wright & Bailey, 1982; Dieterich, 1983; Grissino-Mayer *et al*, 1994). The corkbark fir stand in the Santa Catalina Mountains is found among a mixed conifer forest instead of a spruce-fir forest. Fire in this stand is therefore expected to occur more frequently than in other areas containing corkbark fir. Corkbark fir would either be directly killed by a fire or would die shortly after due to severe injury (U.S. Department of Agriculture, 2000). Figure 3 shows the dense understory of the corkbark fir stand in the Santa Catalina Mountains and the large fuel accumulation in the stand. The impact that fire has on this corkbark fir stand can be understood by examining the area's fire history and comparing it to surrounding areas.

Figure 3. Corkbark fir stand in the Santa Catalina Mountains showing understory characteristics and the large fuel accumulation in the stand.

CHAPTER 2. LITERATURE REVIEW

No previous published research has been done on the corkbark fir stand in the Santa Catalina Mountains, and therefore, no direct comparison with previous research is possible. However, there have been two published studies with the species corkbark fir (Grissino-Mayer *et al* 1995; Stromberg & Patten, 1991) and both of these studies were conducted in the nearby Pinaleño Mountains. Consequently, comparisons between corkbark fir on these two mountain ranges are possible. Since corkbark fir is a variety of subalpine fir, and this species has been studied in the western United States, subalpine fir comparisons are still relevant for understanding how corkbark fir may be interacting with its environment. Finally, studies of Engelmann spruce in the Pinaleños provides some additional information since this species is found with corkbark fir in this mountain range.

2.1 Climate Response

Climate response studies provide information pertaining to the correlation of annual growth indices to a given season and climatic factor, such as winter precipitation or temperature. This information allows for making reasonable predictions about the response of the trees to future climate changes. Few studies have been conducted on the climatic response of corkbark fir or other tree species in the southeastern Arizona mountain ranges.

H.C. Fritts (1976) was the first scientist to perform exhaustive quantitative studies examining the relationship between tree rings and climate using modern statistical tools. He focused on the biological response of trees to climate and included a discussion of response function analysis. Detail was devoted to procedures including principal component analysis, multiple regression analysis, and their importance in understanding the response of the growth of trees to climate variables. Guidelines established by Fritts were the basis for the multiple regression analysis used in my study.

Grissino-Mayer & Fritts (1995) discussed the way dendrochronology could be used to learn about the interactions of fauna and the environment to provide management practice guidelines. Their paper discussed the importance of climate, fire history, pollution studies, and possible interactions with endangered red squirrel populations and cone crops. Climate responses for Douglas-fir and corkbark fir in the Pinaleño Mountains were analyzed using a 14 month window starting with the previous July and ending with the current August. Douglas-fir growth was found to have a positive relationship to precipitation during the preceding autumn, preceeding winter, and current summer monsoon seasons. Corkbark fir growth had a significantly positive relationship to precipitation during the winter and summer monsoon seasons. Grissino-Mayer & Fritts (1995) also examined possible effects of climate change in the area using 1896-1940 as a calibration period. The Douglas-fir series data were modified to simulate an annual reduction in precipitation of 4%. The result was a decrease of annual growth. The data were then modified to simulate an increase of summer temperature of 10%, which resulted in an increase in annual growth. [Note: the percentages of climate change

were erroneously given as 0.04% and 0.1% in the 1995 report (Grissino-Mayer, personal communication, January 4, 2001)]. The conclusion was that reduction of precipitation and increase of temperature were not independent from one another, and since they had opposite effects on ring growth, the effects could be masked by one another. I also studied the climate response of corkbark fir in the Pinaleños to compare the response with that of corkbark fir in the Santa Catalina Mountains.

Buckley (1989) studied climatic response of Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) in southern Arizona and New Mexico at sites in the Pinaleño Mountains, Chiricahua Mountains (where Engelmann spruce is found without subalpine fir), and Sierra Blanca Mountains. At all sites, precipitation in the previous winter was the climatic variable most important to tree growth. Temperature in March of the current growing season also appeared to have a highly negative correlation with growth. The climate signals for north and south facing slopes in all three mountains were also compared. North facing slopes reflected a precipitation signal, while south facing slopes had a slightly stronger temperature signal. Therefore, I considered whether the climate response of the corkbark fir in the Santa Catalina and Pinaleño Mountains might be similar to the response of Engelmann spruce in the Pinaleño Mountains, since both species are being acted upon by a similar regional climate.

Ettl & Peterson (1995) studied the growth response of subalpine fir to climate in the Olympic Mountains, Washington. Sites across a range of elevations and annual precipitation were studied to determine the environmental factors affecting growth. The response of radial growth to precipitation was found to vary with elevation. Growth at

high elevation sites was negatively correlated with winter precipitation. Growth at low elevation, middle elevation, and dry sites was positively correlated to summer precipitation, indicating that soil moisture was partially limiting at these sites. Growth was positively correlated with current growing season temperatures at all sites. It was predicted that if climate became warmer and drier, subalpine fir growth may increase at high elevations and on wet sites, but may decrease at lower elevation, dry sites. I suspected that the corkbark fir in the Santa Catalina Mountains might have a climate response similar to that of the lower elevation dry sites in the Olympic Mountains.

2.2 Age Distribution

Climate response analysis provides information on how living trees are reacting to temperature and precipitation in the area where they are growing, but many other factors affect not only the growth but the success of reproduction of trees. One way to determine if the trees are continuously or episodically reproducing is by age distribution analysis. Research has been conducted to understand the age distribution of trees in different locations, and many of these studies have evaluated the effects of changes in climate.

Hessl & Baker (1997) studied the response of spruce and fir to climate change in the forest-tundra ecotone of Rocky Mountain National Park, Colorado. They hypothesized that recent seedling establishment was triggered by a warm wet period following the end of the Little Ice Age *ca.* A.D. 1850. Tree invasion in forest openings occurred mainly between 1951-1964, and was not balanced by mortality, suggesting more than a short-term change in the ecotone. They concluded that both high

temperatures and deep snows must occur simultaneously for several years in order to generate climatic conditions suitable for tree establishment. A warm wet situation has been present in the southern Rocky Mountain region since the end of the Little Ice Age (Hessl & Baker, 1997). These researchers speculated that the warm wet climatic conditions may be related to the tree invasion observed in forest openings with establishment dependent on both temperature and moisture conditions.

Age distribution was also discussed by Hansen (1940) who examined ring-growth and dominance in a spruce-fir association on the east slope of the Medicine Bow Range in southeastern Wyoming. He found that spruce was the most abundant tree at timberline. As elevation decreased, fir and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) became more abundant. Spruce disappeared at lower elevations, leaving a fir-pine forest. With decreasing elevation, fir disappeared and pure stands of lodgepole pine were left. Pollen analysis suggested that lodgepole pine alternated with spruce-fir in the area in the past. From ring-width measurements, spruce showed faster growth in its younger stages, while fir showed faster growth as it became older. Ring width in fir had greater annual fluctuation, while spruce ring width was more constant with trends of increase and decrease. These patterns indicated that spruce was more stable and less influenced by annual variations in climate than fir.

In addition to helping us understand the relationship between climate and age distribution of trees, dendrochronology can provide information regarding mortality and regeneration episodes. Mast & Veblen (1994) used the death dates of Engelmann spruce and subalpine fir snags in subalpine forests in the Colorado Rocky Mountains to study

tree mortality patterns. Seventy percent of the snags they sampled were crossdated successfully. A period of massive mortality of Engelmann spruce was attributed to a spruce beetle infestation in the 1940s. Although ring erosion and missing rings resulted in some imprecision of dating tree death, the crossdating procedure clearly distinguished between continuous and episodic patterns of tree mortality. Dating of tree death did not yield precise data on actual mortality rates for additional reasons. First, small trees were likely to die and disappear so that there was no record of their mortality. Second, it was not possible to core and date most logs because of decay. Third, the decay of outer rings prevented successful crossdating of all snags. Finally, because of differential root firmness of spruce versus fir, trees were not equally representative of mortality by species.

Veblen (1986) studied age and size structure of subalpine forests in the Colorado Front Range. Trees were used to reconstruct developmental patterns and regeneration dynamics of four successional and two climax stands. The dominant tree species were Engelmann spruce, subalpine fir, limber pine (*Pinus flexilis* James), and lodgepole pine. Size data were not reliable for determining stand development. On the most xeric sites, following wildfire, limber pine was the principal pioneer species, and at most sites, Engelmann spruce and subalpine fir eventually established and gradually replaced limber pine. On less xeric sites, Engelmann spruce or lodgepole pine, alone or together, acted as pioneer species and establishment of subalpine fir was coincident or occurred several decades later, eventually replacing lodgepole pine as the canopy dominants. This study also showed that variation in establishment was at least as important as mortality in

shaping age distributions in successional stands. The typically greater abundance of young subalpine fir was compensated for by the much greater longevity of Engelmann spruce. Accordingly, results of this study suggest possible reasons for the absence of spruce in the Santa Catalina corkbark fir stand.

Age structure and successional dynamics of a Colorado subalpine forest was studied by Whipple & Dix (1979). They found that among populations of old-growth Engelmann spruce, subalpine fir, and lodgepole pine: 1) five types of age structures can be recognized, 2) four different types of age structures were found in one species under different environmental or historical conditions, and 3) no species showed the same type of age structure throughout its entire range of occurrence. The three types of forest recognized were climax lodgepole, climax spruce-fir pioneered after disturbance by lodgepole, and climax spruce-fir pioneered primarily by spruce. The changes from one forest type to another began with climax lodgepole at low elevation, dry sites, followed by a forest mosaic of successional lodgepole and climax spruce-fir at both higher elevations and intermediate moisture sites. It was also found that the forest type ended with climax spruce-fir at both high elevations and on the most mesic sites. Changes in the age structure dynamics of lodgepole were important because they indicated that a species may be either successional or climax, depending on the environment, and on the presence or absence of other species, namely, spruce and fir.

2.3 Fire History

Climate response and age distribution both reveal information about the ways that trees respond to external factors. Fire is one such factor that can be studied by using scarred trees. Research has been done to understand fire frequency and its effect on different ecosystems. Grissino-Mayer *et al* (1995) reconstructed fire history at two sites in the mixed-conifer forests of the Pinaleño Mountains to understand the effects of human related disturbances. Living and dead fire scarred southwestern white pine (*Pinus strobiformis* Engelm.) and ponderosa pine trees were examined. Dendroecological techniques were used to date nearly 2,000 fire scars to their year of formation. Age structure information was also obtained for over 600 Engelmann spruce and corkbark fir in forests upslope of the mixed conifer stands with surface fire histories. Age structure dates were compared to past fires to determine which fires may have had an effect on the higher-elevation forests. The authors found that the spruce-fir forest probably established after an extensive stand-replacement fire that occurred in 1685. The study also revealed that in mixed conifer stands, prior to 1880, low-intensity surface fires occurred approximately once every four to six years, predominantly in the early portion of the growing season. After 1893, cessation of episodic fires was attributed to a combination of human-related disturbances, especially grazing and fire suppression by government agencies. This is the only other study to examine the impact of fire on corkbark fir, making the finding extremely important for my research.

Stromberg & Patten (1991) examined the Engelmann spruce-corkbark fir forests in southeastern Arizona, which are found only in the "sky island" of the Pinaleño

Mountains at elevations >2800 m. They found that the spruce-fir forests covered a limited area but many stands were old-growth. After a disturbance on high elevation or gently sloping sites, spruce colonized, followed by a reduction in further recruitment of all other species, then an abundant recruitment of corkbark fir and spruce 80 to 150 years after initial colonization. For lower elevation and steep sites, spruce or Douglas-fir were the colonizing species. Stand development was slower and corkbark fir did not establish until 150 to 250 years after initial colonization.

Three hypotheses were presented by Stromberg & Patten (1991) to explain the observed patterns. The first hypothesis, high frequency of disturbance, was of unknown importance in explaining spruce dominance in the Pinaleños. The absence of old corkbark fir in the transition zone, and presence of first-generation, old-growth stands in the spruce-fir zone suggested that fire or another catastrophic disturbance was an integral part of forest dynamics. The second hypothesis, regarding life-history, showed greater recruitment of fir but not lower mortality for spruce. The third hypothesis, regarding the explanations for the co-existence of Douglas-fir within transitional spruce-fir forests, was less complicated. Persistence of this species was a result of a large-scale disturbance and long life-span. Douglas-fir did not recruit abundantly under dense canopy in the Pinaleños or other spruce-fir areas. Spruce-fir forest findings were based on diameter of the trees, rather than dendrochronologically dated samples. They concluded that disturbance events have shaped the forests in the Pinaleños.

Subalpine fir regeneration was examined by Little *et al* (1993) following fire at two locations that burned in 1902, northeast of Mount Rainier, Washington. Tree

establishment dates were compared with local climatic records and the influence of microsite features on forest regeneration were studied. The authors found that little regeneration occurred in the first 30 years following the fires. The dominance of trees <50 cm tall at both sites indicated that trees were continuing to establish. Establishment was positively correlated with warm, dry springs with low snow accumulation, and cool, wet summers. Tree establishment following fire was greater near other trees and woody debris as well as older trees frequently observed near woody debris. Climate response indicated that regeneration depended on the magnitude and seasonality of changes in weather, especially during spring. Enhancement occurred if there was less snow accumulation and a longer growing season while warm, dry summers could result in additional moisture stress to seedlings. A warmer, drier climate in the future may produce lower fuel moisture, and subsequently, fire frequency and area burned may increase. Fires may depress the elevation of the current upper treeline. Successive fires may reduce the amount of large woody debris that promote establishment on sites. Fire in combination with different climatic conditions may produce plant communities different from those that exist today.

Veblen *et al* (1991) examined disturbance and stand development of a Colorado subalpine forest. Stand development patterns of Engelmann spruce, subalpine fir, and lodgepole pine were examined. Two old-growth stands and one *ca.* 260-year-old post-fire stand were sampled for tree sizes, ages, tree growth patterns, and replacement patterns. In the 260-year-old stand, initial colonization was by spruce and lodgepole pine, but subalpine fir became increasingly abundant over the past *ca.* 100 years. Canopy

dominance was shifting from lodgepole pine towards spruce and fir. Tree growth patterns indicated that a stand devastating fire initiated the old-growth stands. They entered a phase of development in which windthrows dominated their dynamics. Fir was the more common gap occupant but its greater rate of tree fall and the greater longevity of spruce implied that the two species would continue to codominate. Age structures and tree growth data indicated significant differences in species' response to stand-initiating fires. In contrast, spruce and fir did not differ significantly in their growth responses to small or moderate-sized windthrows. Fires eliminated the understory vegetation and exposed bare mineral soil, resulting in a substantially different type of vegetational response from that following an insect outbreak or windthrow, which primarily disturbed only the tree canopy. The type of disturbance appeared more important than the scale of disturbance in these forests.

CHAPTER 3. METHODS

Methods will be described for each of the three aspects of the study: climate response, age distribution, and fire history. Within each section, field collection procedures, dendrochronological techniques, and specific analysis utilized will be described.

3.1 Climate Response

3.1.1 Field Collection

The stand in the Santa Catalina Mountains can be reached by taking the Mt. Lemmon highway from Tucson, Arizona to Ski Valley and continuing on the service road that leads to the telescopes on top of Mt. Lemmon, for approximately 3.2 km. This road cuts directly through the corkbark fir stand, with about ¾ of the stand situated above the road, and ¼ of the stand below the road. The Engelmann spruce-corkbark fir forest in the Pinaleño Mountains is extensive at high elevations. For comparison, it was necessary to sample trees in the Pinaleños that had similar site characteristics as the stand in the Santa Catalinas. After surveying many areas in the Pinaleños, a site near the Columbine Ranger Station was chosen to be the most appropriate.

A unique ID tag number was assigned to each potential tree to be cored. Potential trees were chosen, from each site, based on apparent health and size to ensure an adequate and representative sample to compare to climate records.

Forty-five trees were successfully cored in the Santa Catalina Mountains, with the site designation SVC. Nineteen trees were successfully cored in the Pinaleño Mountains, with the site letter designation CCB. At both sites, a few additional sampled trees yielded rotten cores, which could not be analyzed in the study.

I used a 16-inch, 4.30 mm diameter, Haglof increment borer to core the trees. I found that the use of an increment borer starter tremendously assisted in initiating the increment borer into the tree. Samples were taken from the lowest possible point on the tree to obtain maximum number of rings. I estimated the location of the center of the tree in hopes of obtaining the pith, or as near to the pith as possible. The increment borer was inserted at least halfway through the tree or if possible, through the entire diameter of the tree. If the tree was too large in diameter to insert the borer all the way through, a second core was taken from the other side of the tree. Cores were taken perpendicular to the slope whenever possible to reduce the effect of reaction wood.

The core was placed in a paper straw immediately after removal from the tree. Paper straws were used instead of plastic straws to allow the cores to dry. The straw was labeled with the tree ID number using a permanent marker. A designation of "a" and "b" was used if two cores were removed from the tree. The labeled straws, containing the cores were placed in a plastic tube with air vents drilled in the side. The tube protected the cores and the air vents allowed for adequate ventilation for drying.

Identification information was collected once the core was extracted from the tree. The site letter designation was recorded followed by the previously assigned tree ID number. A metric diameter tape was used to obtain the diameter of the tree at core height

when possible. Core height was recorded for each core taken. A clinometer was used to obtain tree height when the base and top of the tree were clearly visible. Tree height was roughly estimated for all remaining trees using the value obtained with the clinometer as a comparative reference. These values were reported in meters. Other information included canopy cover (open or closed) and any other unusual identifying characteristics about the tree. This process was repeated for each tree included in the sample, for each site.

3.1.2 Dendrochronological Procedures

The cores were removed from the plastic tube following the field collection and placed in a secure location. Cores were allowed to dry for a minimum of one week.

After complete drying, a core was removed from the paper straw. If necessary, the wood was steamed, using a vaporizer, and twisted to realign the cell structure. The core was glued with the cells vertically aligned to a previously cut wood mount. String was wrapped around the entire length of the core to secure the core to the mount while the glue was drying. The ID number was written on the side of the mount. This process was repeated for each core taken.

All of the mounted cores were allowed to dry for another week. The string was then removed and the wood mounts were cut into individual sections with a single core on each section. Initial surfacing of the cores was done using a belt sander starting with 150 grit belts and finishing with 240 grit belts. A stereo zoom microscope was used to

analyze each core. Hand sanding was done when necessary, using up to 500-grit

sandpaper to obtain a clear view of the cell structure.

Each core was then skeleton plotted to accurately crossdate each ring to the year

of formation (Stokes & Smiley, 1968). The skeleton plots of the cores from the Santa

Catalina Mountains were compared to an existing Douglas-fir chronology from the Santa

Catalina Mountains. The skeleton plots of the cores from the Pinaleños were compared

to an existing ring-width index chronology from Engelmann spruce and corkbark fir from

the Pinaleño Mountains created by Henri D. Grissino-Mayer. Both of these master tree-

ring chronologies are archived in the International Tree Ring Data Bank

(http://www.ngdc.noaa.gov/paleo/ftp-treering.html).

Once each ring was crossdated to the year of formation, ring widths were

measured using a Banister Incremental Measuring Machine to the nearest hundredth mm.

The Banister Incremental Measuring Machine uses a hand cranked sliding stage

connected to a computer. All measured values are recorded on a magnetic disk.

Prior to analyzing ring-width files, each series was combined to create a new ring-

width list file using the software program Convert 5 (Grissino-Mayer, 1996). This

procedure was done for the Santa Catalina site and the Pinaleño site.

The new ring-width list files were individually analyzed with the software

program COFECHA (Holmes, 1983), which provided information pertaining to the series

intercorrelation, average mean sensitivity, and segments with possible dating or

measurement errors. The COFECHA procedure included high-pass filtering by a cubic

smoothing spline with a 50% wavelength cut-off of 32 years. Filtered segments, 50 years

in length lagged successively by 25 years, were examined to aid in identifying possible dating or measurement errors.

After dating and measurements were checked by COFECHA, necessary corrections were made in the ring-width series. The computer program ARSTAN (Cook & Holmes, 1996) was then run on the ring-width files to create a detrended and standardized chronology for each site. ARSTAN allows for user input on determining types of detrending. I used a cubic smoothing spline with a frequency response of 0.5 at a wavelength of 80% of the sample length (Cook and Peters, 1981). This allowed for long-term trends to be removed, while still retaining short-term trends. Standardized series for individual cores were combined by averaging, to create the site chronologies.

3.1.3 Additional Procedures

Monthly climatic data for total precipitation and mean temperature were obtained from the National Climatic Data Center. These data are part of the Global Historical Climate Network and have been processed specifically for studying climate variations (Patterson & Vose, 1999). Stations within 250 km of each site were selected from the database. The year-to-year climate history at the sites was estimated by inverse distance weighting of standardized monthly values at nearby stations in southeastern Arizona (Jones & Hulme, 1996). Time coverage of precipitation records used ranged from 1866 to 2000 and coverage of temperature records ranged from 1891 to 1996. Interpolated data sets were computed for each mountain range.

For a more direct measure of climate, I obtained monthly precipitation and temperature data from the Mt. Lemmon post office in the Santa Catalina Mountains, approximately 3000 m from the Santa Catalina corkbark fir site (Figure 4). Mark Hopkins, a resident of Summerhaven, collected these data for the Pima County Cooperative Storm Rainfall Network (Appendix A). These data were too short in length (6 years for temperature and 8 years for snowfall) to be compared with the tree-ring indices by rigorous statistical analysis. The much longer interpolated climatic time series for the Santa Catalina Mountains was compared with the data available from Summerhaven to verify the relevance of my interpolated data set to the climatic variations near my site in the Santa Catalina Mountains.

I performed a simple linear correlation between the residual tree-ring index derived using ARSTAN and monthly climatic data after determining that the interpolated climate records were adequate for modeling purposes. I chose four seasons for analysis by analyzing the correlations and evaluating the climate-tree growth patterns in the mountain ranges of southern Arizona. Seasonal data were analyzed by correlation and multiple linear regression analysis (MLR) for both mountain ranges. The MLR analysis consisted of regressing site chronologies (tree-ring indices) on seasonal-total precipitation and seasonal-average temperature. Cross-validation was used on both sets to validate the MLR (Michaelsen, 1987). The reduction of error statistic, or RE was used as a verification statistic (Fritts *et al*, 1990). Correlation and cross-validated MLR were performed using Matlab, a mathematical software program with a script file written by
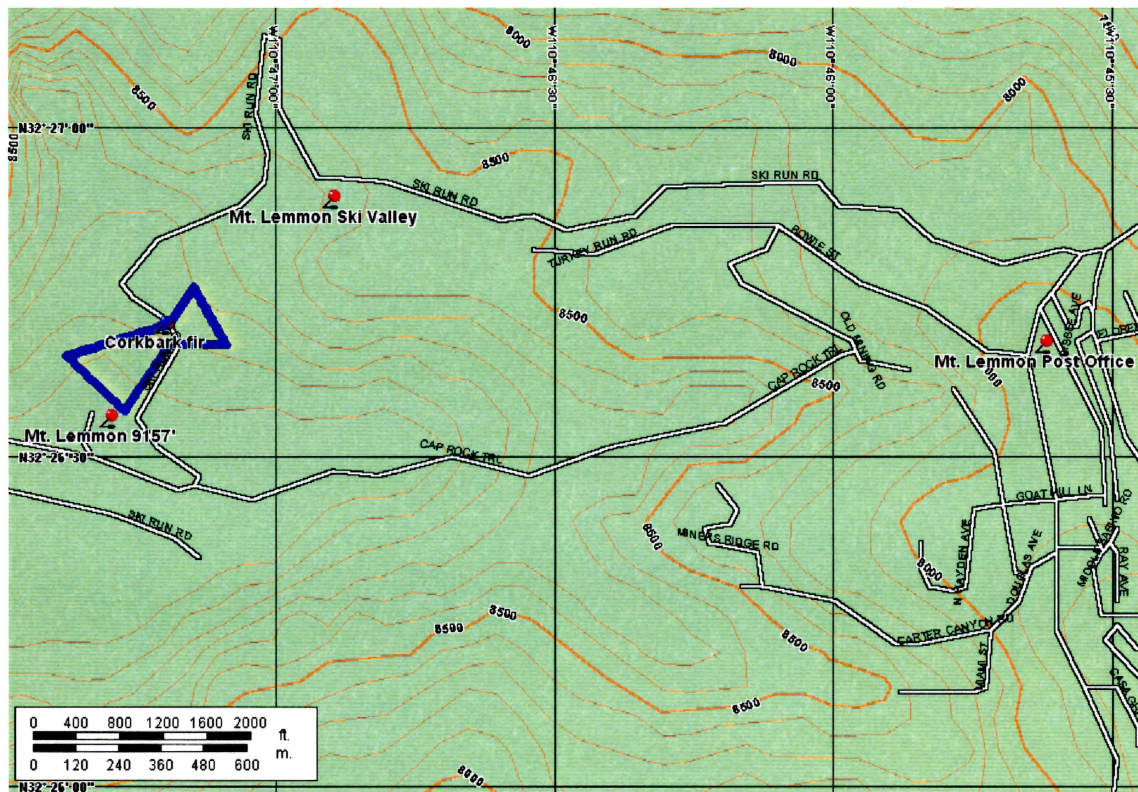
Figure 4. Map of corkbark fir stand in the Santa Catalina Mountains in relation to the Mt.

Lemmon post office.

David Meko of the Laboratory of Tree-Ring Research, University of Arizona (available on-line at www.ltrr.arizona.edu/~dmeko).

3.2 Age Distribution

3.2.1. Field Collection

Age distribution information was collected exclusively for the site in the Santa Catalina Mountains. The dimensions of the stand were approximated using Global Positioning System (GPS) coordinates. I divided the stand into five approximately evenly spaced belt transects based on this information. The uppermost corkbark fir was designated as transect 1. I ran a ground tape along the contour of the mountain from one side of the stand to the other. All corkbark fir within 5 m above or below the ground tape were sampled. Trees greater than 3 cm in diameter were cored using an increment borer, while ages of trees less than 3 cm in diameter were determined by counting branch nodes. Node counting assumes that each branch whorl represents an annual height increment and an age can be obtained by counting the branches on the sapling (Shea & Armson, 1972; LeBlanc & Leopold, 1992). An ID tag was assigned to each tree that was cored. Trees were cored and placed in labeled straws. Identification information was recorded as described in section 3.1.1.

I ran a ground tape 60 m down slope to establish transect 2. This transect was sampled identically to the procedure used for transect 1. This procedure was repeated for transect 3. Sixty meters below transect 3 was the access road, so transect 4 was placed 120 m below transect 3.

3.2.2 Dendrochronological Procedures

Samples were dried, mounted, and surfaced as described in section 3.1.2. They were then analyzed with a stereo zoom microscope and skeleton plotted as described in section 3.1.2. Pith dates for cores with visible ring curvature were approximated using a set of pith estimators (Applequist, 1958). A pith estimator is a transparent overlay based on number of rings per inch that is placed over the curved rings from a core. Pith estimation provides a more accurate age distribution plot than using the inner ring found on the core. If no pith was present, and there were no pith rings to estimate a pith date, the tree was classified as "as old as", indicating the last ring crossdated (Soule & Knapp, 2000).

3.2.3 Additional Procedures

All information collected, including inner ring and estimated pith year, were entered into a spreadsheet. If a tree had several cores with different age dates due to coring height, then the oldest core date was chosen to represent that tree's age. A new spreadsheet was then developed, reflecting the oldest age dates for all the trees. Trees were placed into categories based on establishment decades. Each category was graphed indicating the number of trees that were node counted, the number of trees designated "as old as", the number of trees with an estimated pith age, and the number of trees with a crossdated pith date. No correction was computed to account for coring height, because there was such a large variation in age for trees or cores at similar

heights. Therefore, the actual age of the trees may be slightly older than ages obtained using crossdating.

Regression analysis was performed to evaluate the strength of the age-size relationship. This regression model was plotted to graphically display the age-size relationship, including a regression line to show the predicted age, based on the regression.

3.3 Fire History

3.3.1 Field Collection

Fire scarred trees were sampled to derive fire history information. Large logs with potential buried fire scars were also sampled. A chainsaw was used to obtain wood samples (Arno & Sneck, 1977; Baisan & Swetnam, 1990; Dieterich, 1983; Dieterich & Swetnam, 1984). Information collected for each tree included: location of tree relative to other trees, species, tree type (living, snag, stump, or log), tree height, crown density, state of preservation, number of samples taken, and height of sample. Diagrams were made of each cross section and the tree.

3.3.2 Dendrochronological Procedures

Samples were brought back to the University of Arizona Laboratory of Tree-Ring Research and allowed to dry for at least one week. Some samples remained in one piece, while others broke into several pieces. When a sample was in several pieces, it was glued to a wooden board to maintain the original positioning of the pieces relative to the others.

All samples were sanded with a belt sander, starting with 40 grit and ending with 320 grit. Once surfaced, the samples were examined under a stereo zoom microscope. Additional hand sanding of the samples was difficult due to the resinous nature of the southwestern white pine and ponderosa pine. If necessary, resin was removed as best as possible with a single edged razor blade. Standard crossdating techniques (Stokes & Smiley, 1968) were employed, with the addition of visually identified fire scars noted on the skeleton plots.

3.3.3 Additional Procedures

Fire years were entered into the software program FHX2 (Grissino-Mayer, 1995) for each sample. The plotting program was used to graphically display fire events recorded by the trees and summary statistics for the site. The synchroneity of fire events at SVC and events at sites LEM and LPK (Baisan *et al*, 1998) were evaluated using FHX2. LEM and LPK are the two closest fire chronologies (Figure 5), with SVC located between them. The program tests synchroneity using both 2 x 2 and 2 x 1 contingency analyses. The 2 x 2 analysis tests for statistical independence between two fire chronologies using the chi-squared statistic. This analysis considers all years, including years when no fire events were recorded. The null hypothesis for the 2 x 2 contingency analysis states that the fire years and non-fire years are not associated between both sites. This hypothesis is rejected if the chi-squared value is significant at $p < 0.05$. The 2 x 1 analysis considers only years in which fire was recorded and tests association of these events between both chronologies. The null hypothesis for the 2 x 1 contingency analysis
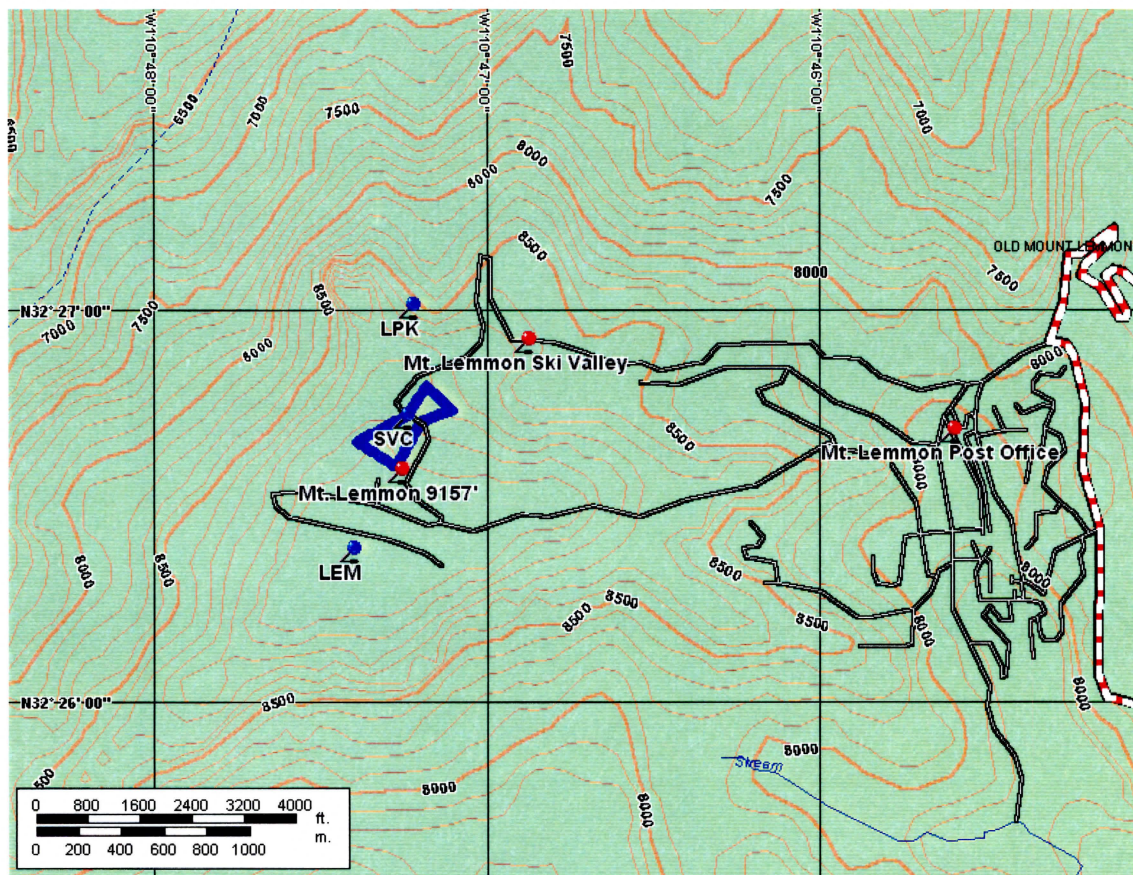
Figure 5. Location of corkbark fir site (SVC) in relation to LEM and LPK. LEM is in a meadow at top of ridge. LPK is down slope from SVC.

states that there is no association of fire dates between the sites and is rejected if chi-squared is significant at $p < 0.05$. It is more difficult to achieve statistical significance when using a 2 x 1 contingency analysis due to the smaller number of observations used to calculate the statistic (Grissino-Mayer, 1995). A non-significant chi-squared statistic calculated for sites as close as SVC, LEM, and LPK would suggest that fires probably did not spread between sites.

CHAPTER 4. RESULTS

4. 1 Climate Response

The ring-width data for the corkbark fir in the Santa Catalina Mountains was analyzed for correlation statistics using COFECHA (Holmes, 1983). Fifty-eight cores were used, representing 38 trees. These cores had a mean series intercorrelation of 0.705, indicating that the trees in this site were highly correlated, and therefore probably responded similarly to external factors. The average mean sensitivity value was 0.318. Mean sensitivity describes year-to-year variation and could theoretically range from 0 to 2. Zero indicates no variability while 2 represents every other ring missing (Fritts, 1976).

Similar results were found for the corkbark fir in the Pinaleño Mountains. Twenty-eight cores were used, representing 18 trees. These cores had a series intercorrelation of 0.679, indicating that the trees in this site were probably responding to similar external factors. The average mean sensitivity value was 0.313.

ARSTAN (Cook & Holmes, 1996) was used to create a standard and residual tree-ring chronology for the Santa Catalinas. Appendix B lists the indices for each year covered in the time series, for both the chronologies. The standard chronology is the yearly mean of the indices for all cores included in the sample. The residual chronology is the mean of the core indices after autocorrelation has been removed by autoregressive (AR) modeling. The residual chronology was used to determine climatic response since autocorrelation may obscure high frequency climate tree ring relationships (Meko, 1981).

ARSTAN was used to create both a standard and residual tree-ring chronology for the Pinaleños. Appendix C lists the indices for each year covered in the time series, for both the standard and the residual chronologies. Again, the residual chronology was used to determine climatic response.

The inverse-distance interpolated precipitation for the Santa Catalinas was correlated with the cool season precipitation data from Summerhaven for the 1992-1998 overlap period (Figure 6). The high correlation (r = 0.99) suggests that the interpolated series effectively captures the relative year-to-year variations in cool-season precipitation at the SVC site. Scatter plots representing the summer months (not shown) indicate a weaker correlation than cool season precipitation.

Monthly correlations between the Santa Catalina residual tree-ring chronology and the interpolated climate data (Figure 7) indicate that the overall response of growth to temperature is negative, i.e., corkbark fir growth responds negatively to higher temperatures. The overall response to precipitation is positive, indicating increased growth with more moisture. The most significantly correlated month is May of the current growing season for both precipitation and temperature.

Both temperature and precipitation are correlated with the Pinaleño residual tree-ring chronology (Figure 8). The overall response for temperature is negative, again indicating the tendency for corkbark fir to grow better during cooler temperatures. This response may be related to the tendency for cool conditions to be related to moist conditions. The overall response to precipitation is positive, supporting the interpretation that corkbark fir grows better in moist conditions. The most significantly correlated
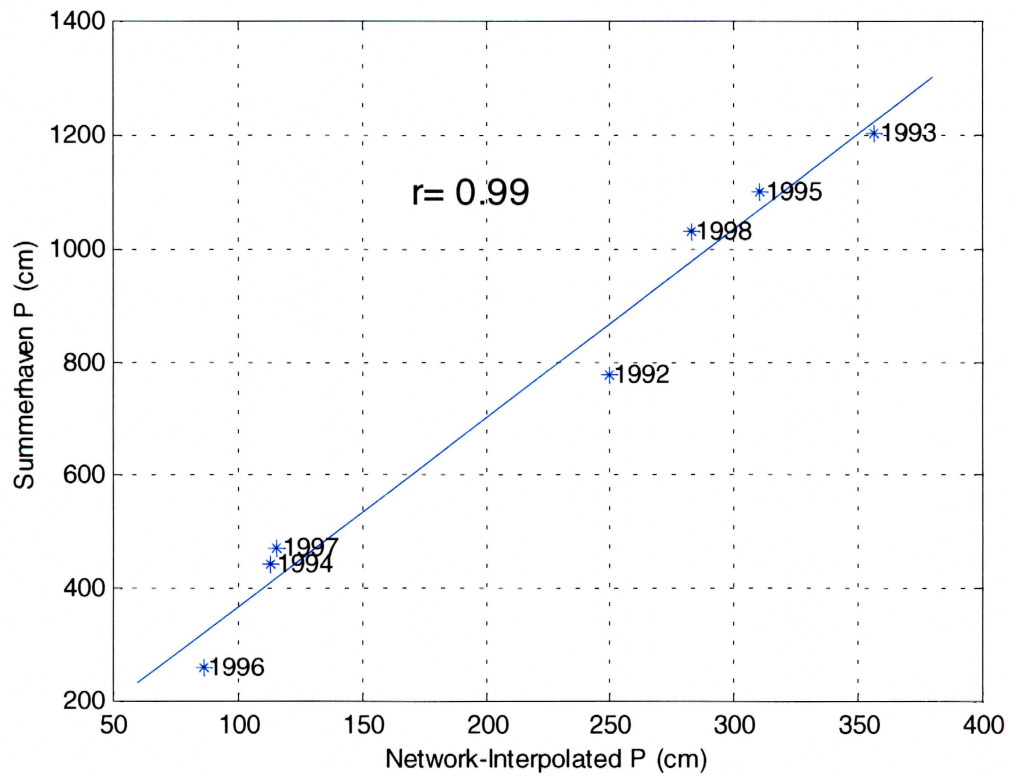
Figure 6. Correlation between cool season precipitation for Summerhaven and Network Interpolated data for the Santa Catalina Mountain range. Data were only available from 1992-1998. The correlation indicates that precipitation variation interpolated from the network of regional stations closely tracks relative variation in precipitation near the corkbark fir site (r = 0.99).
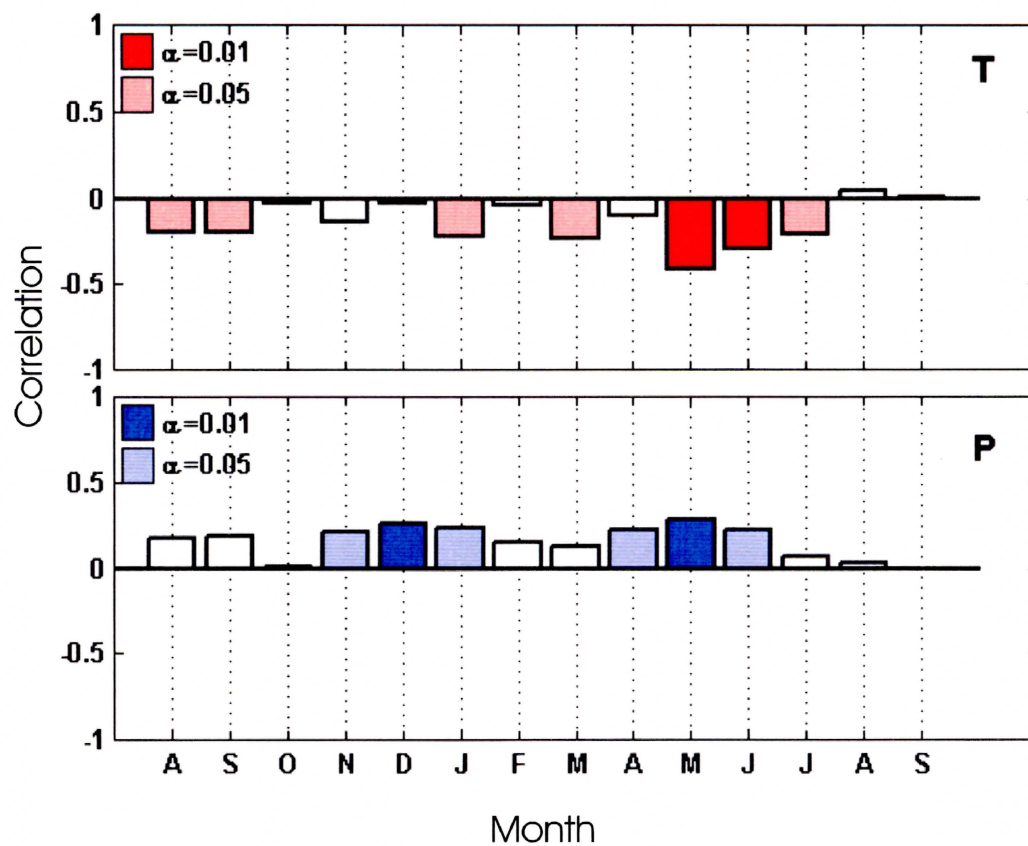
Figure 7. Monthly climate correlations of Santa Catalina Mountain corkbark fir for climate period 1887-1998. Notice the overall negative relationship with temperature (T) and positive relationship with precipitation (P).
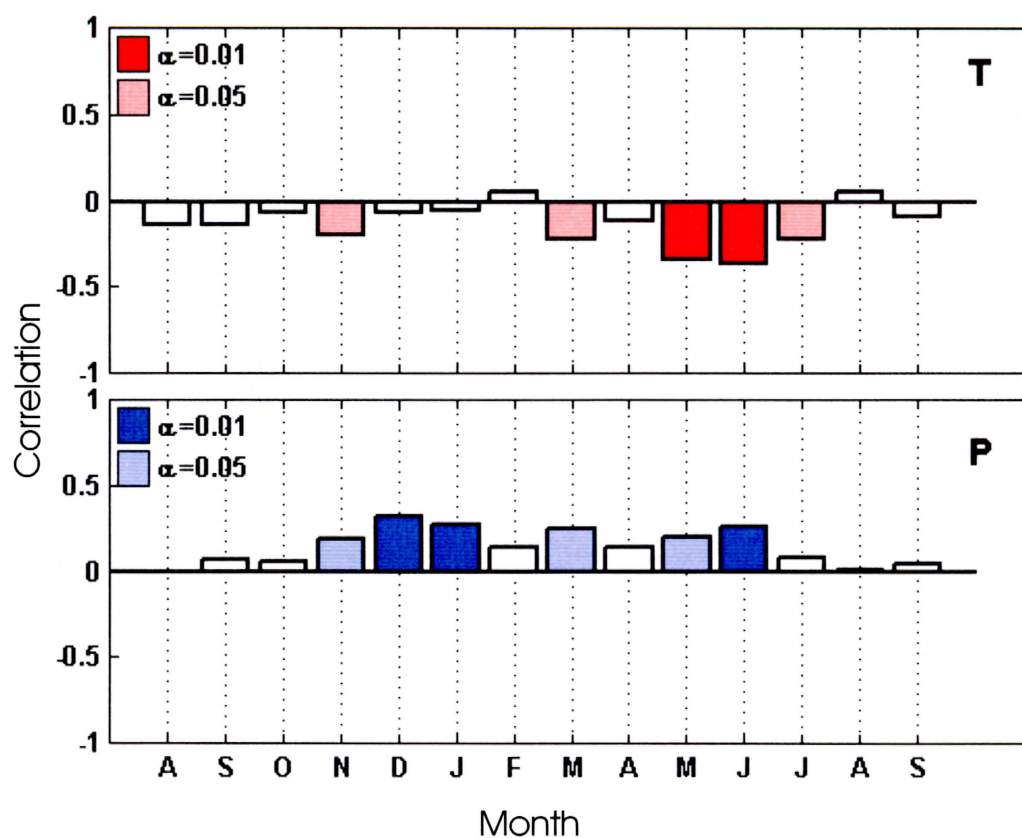
Figure 8. Monthly climate correlations of Pinaleño corkbark fir for climate period 1887-1998. Notice the overall negative relationship with temperature (T) and positive relationship with precipitation (P). This is a similar response as exhibited by the Catalina corkbark fir (Figure 7).

months for temperature are June and May, respectively. The most significantly correlated months for precipitation are June (of the current growing season), December (preceding the growing season), and January (preceding the growing season), respectively.

The months were divided into four seasons for the multiple linear regression analysis. This division was based on an understanding of the area's climate and the monthly climatic response of the trees (Figures 7 and 8). The seasons are August through October (of the preceding year), November through March (prior to the growing season), April through June (of the current growing season), and July through September (of the current growing season). This division of seasons was used for both the Santa Catalina and the Pinaleño mountains.

In step-wise multiple linear regression, the most significant variable enters the equation first. The following variables enter in decreasing order of significance. The reduction of error (RE) statistic indicates the accuracy of prediction on independent data. RE increases only as long as additional predictors add useful information. When additional variables are added and the accuracy of prediction on the independent data improves, the RE declines (Figure 9). In this regression, only the first four variables are necessary for maximum verification accuracy. The variables are: precipitation for April – June of the current growing season, temperature for April – June of the current growing season, precipitation for November – March prior to the growing season, and precipitation for August – October prior to the growing season.
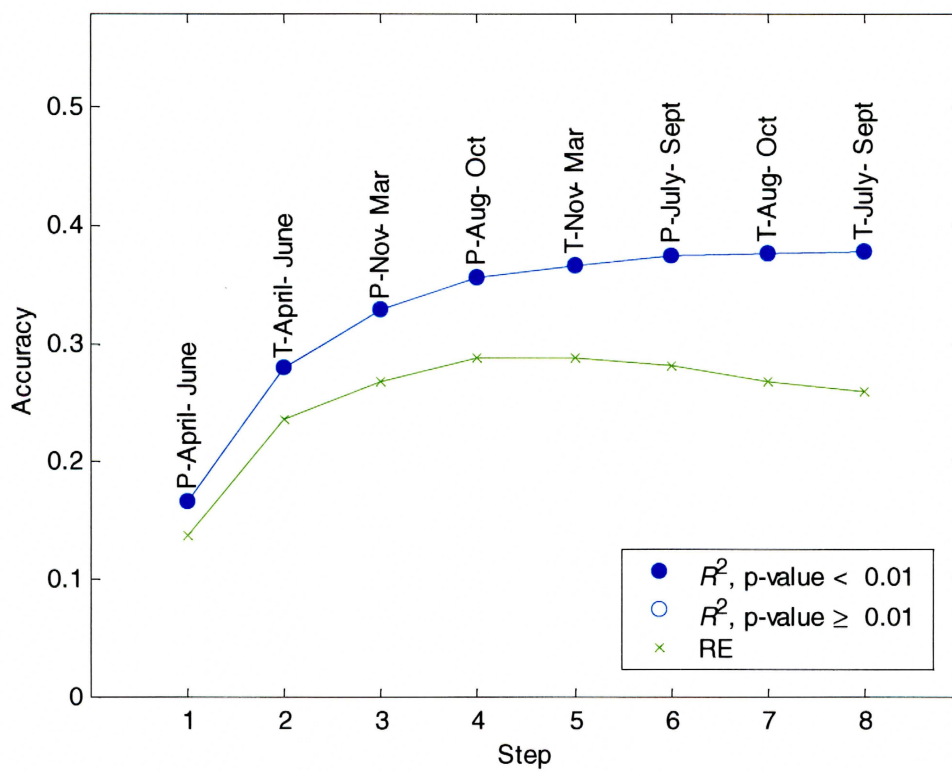
Figure 9. Cross-validated MLR for corkbark fir in the Santa Catalinas. RE shows that only the first four variables are necessary for modeling. Three of these variables are precipitation and only one is temperature.

In the cross-validated multiple linear regression for the Pinaleño corkbark fir, the RE statistic again indicates that only the first four variables are necessary (Figure 10). The variables are: precipitation for November – March prior to the growing season, temperature for April – June of the current growing season, precipitation for April – June of the current growing season, and precipitation for July - September of the current growing season.

4.2 Age Distribution

Appendix D contains identification information for all the trees sampled for the age distribution portion of this study. Field information, inner ring, estimated pith, and node count values are also included.

Establishment dates were divided into decades and graphically displayed according to the number of trees represented in that decade (Figure 11). Stacked columns were used to differentiate the method used to date the tree within each decade. The largest number of trees were established in the 1980s. The oldest tree dated to 1760, and as expected the oldest dates contained the least number of trees. There was a surge of recruitment in the 1840s -1850s, followed by a decline, a brief increase in the 1880s, and a continual decline until 1910. Establishment rate increased again in the 1920s and continued to increase. There was a slight decrease of establishment in the 1960s. However, all recruitment dates may have been earlier since cores are not corrected for coring heights due to poor correlation between age and height. As typically seen in "steady state" populations, the greatest number of trees are in the youngest age class
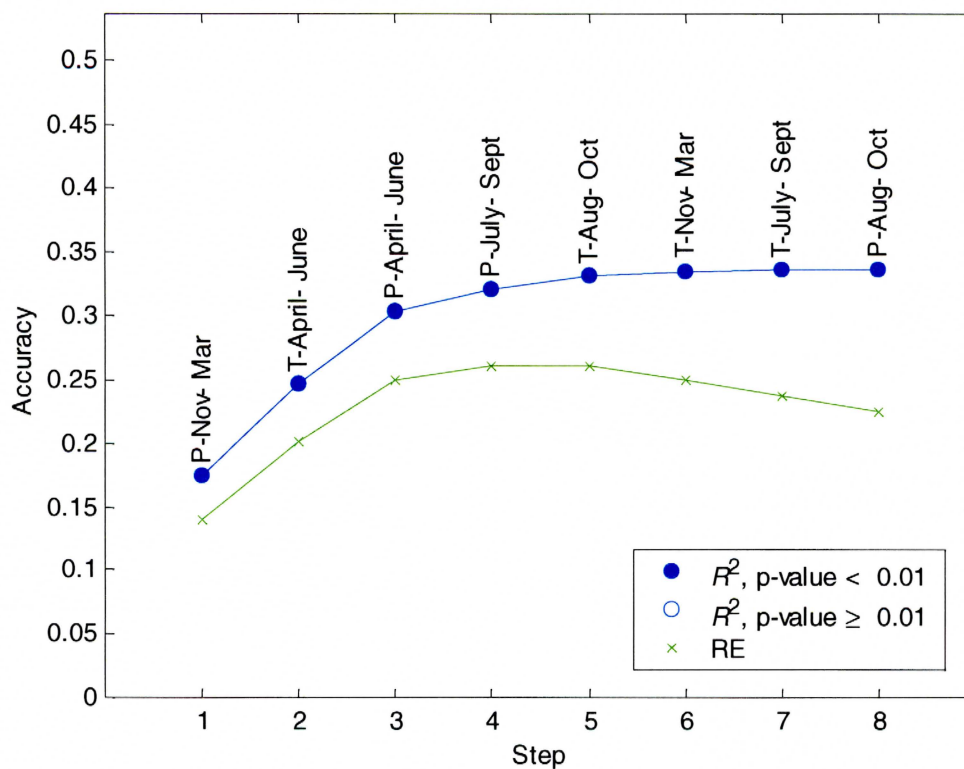
Figure 10. Cross-validated MLR for the corkbark fir in the Pinaleños. As for the Santa Catalinas, RE shows only the first four variables are needed. Three of these variables are precipitation and one is temperature. Also note that the first 3 variables are the same as the first 3 for the Santa Catalinas (Figure 9).
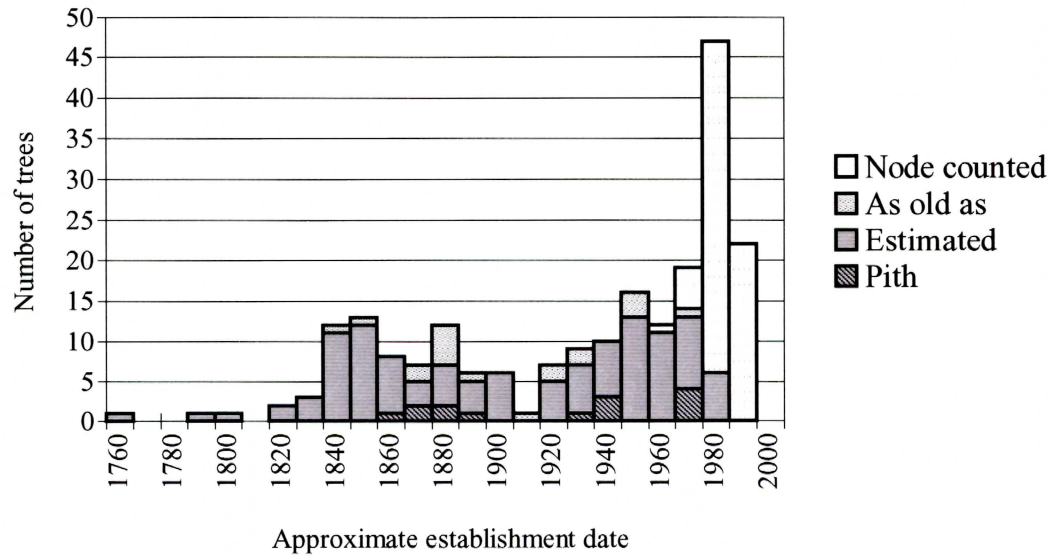
Figure 11. Age distribution of corkbark fir in the Santa Catalina Mountains. Notice the decrease of trees from 1840 - 1920 and the low recruitment of corkbark fir in the 1910 – 1919 decade.

(Whipple & Dix, 1979). Most of the dates for the 1980s and all establishment dates in the 1990s were derived by node counts. The large number of trees in younger age classes allows for seedling mortality, while still maintaining a continual transition of trees to older age classes.

Regression analysis was performed to determine the correlation between age and diameter. When all trees, including the node counted seedlings are included, the adjusted r^2 for a regression of age on diameter is 0.62. Coefficients were obtained to create a mathematical model explaining the relationship between age and size. The coefficient for the y intercept is 24.46 and the slope is 2.35. By using these coefficients, the model equation is: age = 2.35 (dbh) + 24.46, where dbh is the diameter at breast height in cm. This equation uses the dbh in cm to predict the age for each sample. Model equations are used to infer the age of a stand based on size. The equation is assumed to be a good proxy for determining age when the r^2 is high. Age can be estimated from diameter using the straight line derived by regression (Figure 12).

Regression analysis was also performed on a subset of the trees that were cored, excluding the node counted trees. The resulting r^2 from this sample set is 0.47, and the model equation is: age = 2.17 (dbh) + 41.13.
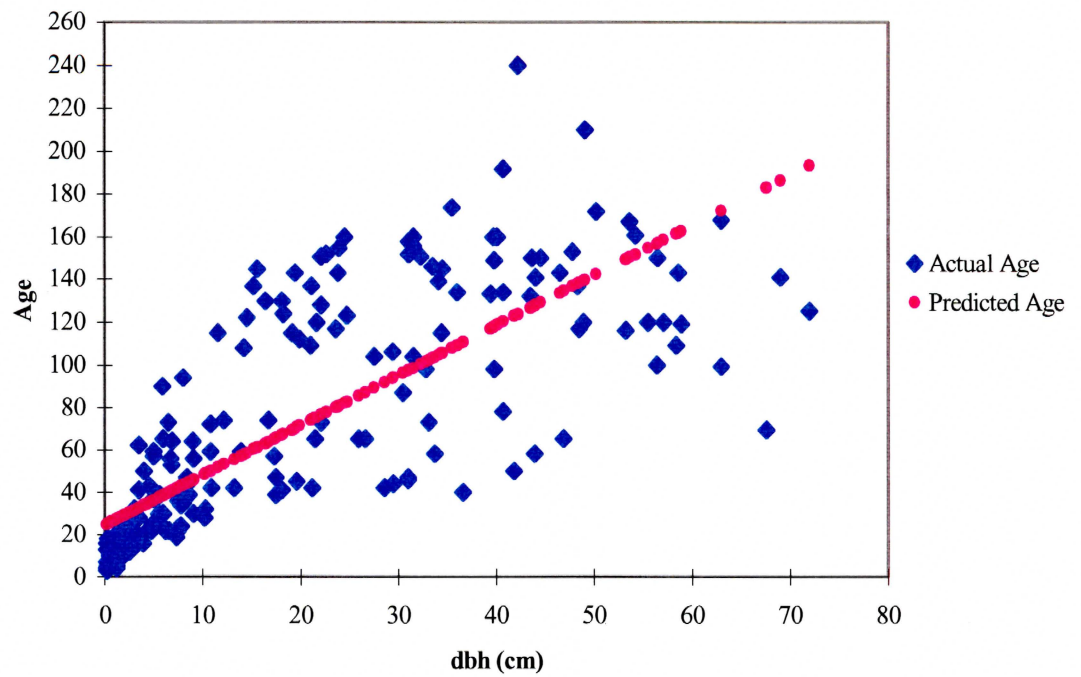
Figure 12. Age-size relationship of the corkbark fir in the Santa Catalina Mountains.

Trees with diameters less than 3 cm are all less than 25 years in age. These ages were all

obtained by node counting, indicating that corkbark fir seedlings initially grow slowly.

4.3 Fire History

Of the 11 fire history samples collected from within and surrounding the corkbark fir stand, only 5 have fire scars. These 5 were all located on the perimeter of the stand. None of the samples from within the stand have scars, but 2 samples from within the stand have charring on the outer portion of the wood, both of which contain outer rings in the 1900s.

FHX2 was used to graphically display information obtained from the fire scarred samples. Standard dendrochronological information entered into the software includes: the pith date if obtained for the sample (pith date), the inner most date for the sample if the pith was not obtained (inner date), the last year identified on the sample if bark was not present (outer date), and the last ring formed by the tree (bark date). Fire history information entered into the software includes: the year that the tree recorded a fire event (fire scar), the interval between the first year the tree was scarred by fire and the last date for the sample (recorder year), and the years prior to the first scarring event (null years). This information was entered into FHX2 to create a composite for the fire scarred trees surrounding the corkbark fir in the Santa Catalina Mountains (Figure 13). These fire years were then compared to fire years from the two surrounding sites, LEM (Figure 14) and LPK (Figure 15). The composite graph (Figure 16) compares the fire years at all 3 sites.

All 3 sites had 12 common fire years, these years were: 1725, 1735, 1748, 1752, 1772, 1785, 1803, 1810, 1819, 1836, 1851, and 1870. Trees in the SVC and LEM sites recorded fires in 1708 and 1801, while LPK shows no fires for these years. Trees in

LEGEND
● Fire Scar
├ Pith Date
└ Inner Date
┘ Outer Date
┤ Bark Date
— Recorder Years
···· Null Years

SVC001
SVC002
SVC003
SVC004
SVC005

COMPOSITE
≥25% SCARRED
MIN SCARS = 1
MIN SAMP = 1

1600   1650   1700   1750   1800   1850   1900   1950   2000
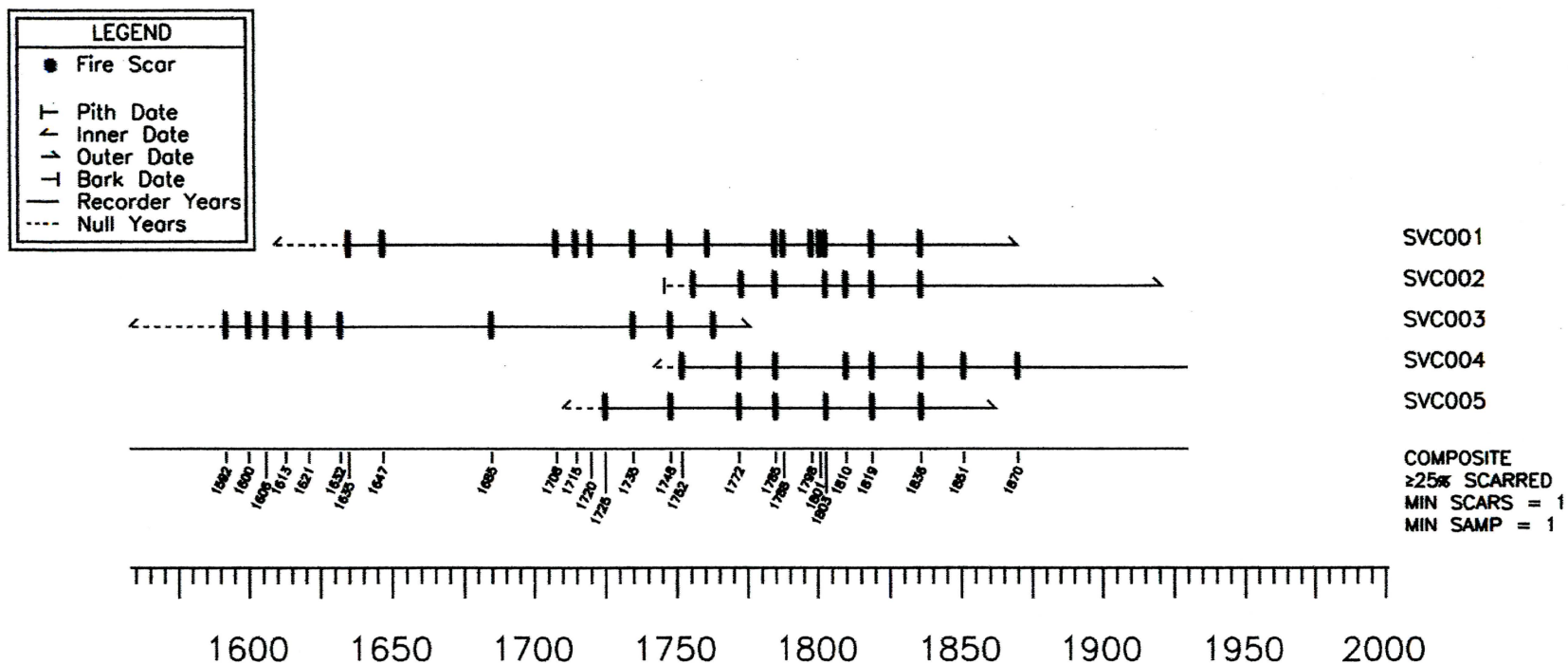
Figure 13. Fire chronology from samples directly adjacent to corkbark fir site. Dates listed on composite only when 25% of samples recorded fire event.
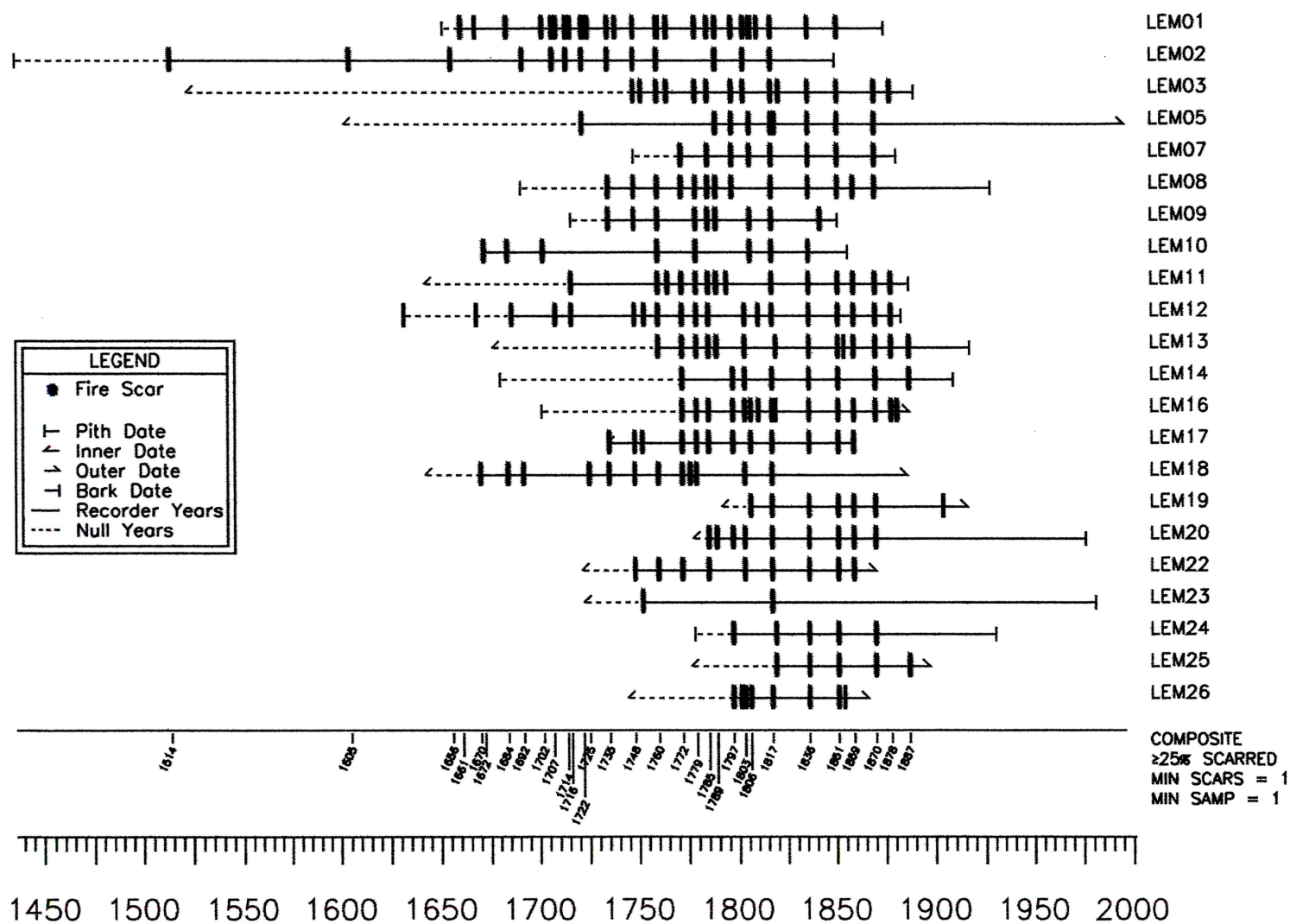
Figure 14. Fire chronology from LEM site. Dates listed on composite only when 25% of samples recorded fire event.

Figure 15. Fire chronology from LPK site. Dates listed on composite only when 25% of samples recorded fire event.
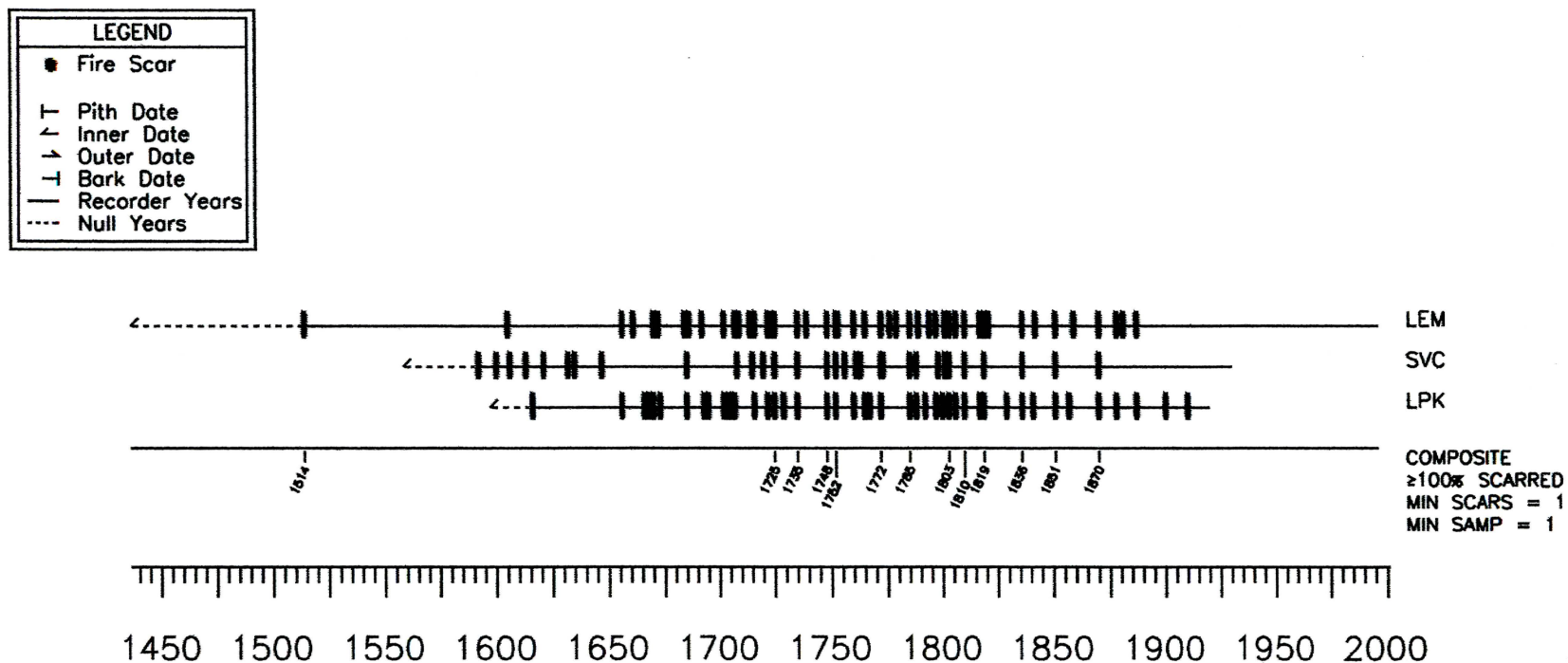
Figure 16. Composite chronology for SVC, LEM, and LPK. Composite year dates refer to years when fire was recorded at all 3 sites.

SVC and LPK sites recorded fires in 1685 and 1788, while trees in LEM did not. Thirteen fire years are in common between LEM and LPK, when no fire was recorded at SVC.

Three separate 2 x 2 contingency analyses compared the fire chronologies between SVC - LEM, SVC - LPK, and LEM - LPK. All 3 analyses result in significant chi-squared values ($p < 0.005$), indicating that the fire chronologies are associated between the sites. The 2 x 1 contingency analysis results in a non-significant chi-squared values ($p > 0.05$) when comparing SVC - LEM and SVC – LPK . This indicates that there is no association of fire dates between SVC and both the LEM and LPK sites. The 2 x 1 contingency analysis is significant ($p < 0.005$) when comparing LEM to LPK, indicating that fire dates are more synchronous than would be expected to occur by chance.

Table 1 statistics were produced by the FHX2 software (Grissino-Mayer, 1999; Grissino-Mayer, in press) to assist in analyzing the fire history of the sites. These statistics include:

- Total interval: total number of fire years minus 1.
- Mean fire interval: sum of all fire intervals divided by number of intervals. This statistic indicates that fire occurred somewhere in the area, not necessarily everywhere in the area.
- Median fire interval: the midpoint interval in an array of ordered interval data arranged from shortest fire interval to longest fire interval.

- Weibull Median fire interval: fire interval associated with the 50th percentile of the modeled Weibull distribution fit to the original fire interval data. This is a more accurate measure of central tendency in distributions that are positively skewed such as fire interval data.

- Standard deviation: the square root of the variance which measures dispersion about the mean.

- Minimum fire interval: the shortest fire interval in the original data set.

- Maximum fire interval: the longest fire interval in the original data set.

- Maximum hazard interval: the fire interval associated with the theoretical maximum fire free period an ecosystem can sustain before burning is highly probable.

Table 1. FHX2 summary statistics for SVC, LEM, and LPK for 1700-1900.

Site	SVC	LEM	LPK
Total Intervals	21	37	33
Mean Fire Interval	7.71	5	6
Median Fire Interval	7	4	5
Weibull Median Interval	6.83	4.52	5.53
Standard Deviation	5.16	3.15	3.58
Minimum Fire Interval	1	1	1
Maximum Fire Interval	19	15	13
Maximum Hazard Interval	128.2	26.82	30.01

CHAPTER 5. DISCUSSION

5.1 Climate Response

The monthly climatic response for both temperature and precipitation indicated increased growth in response to cooler temperatures and greater precipitatation, in both the Santa Catalinas and the Pinaleños. These responses are expected for corkbark fir since the species is found in cool, moist locations, and both of the mountain ranges provided these environments. It was determined that only precipitation and temperature during a limited number of climatic months were important for the growth of corkbark fir in both locations.

The most important variable in the Santa Catalinas was precipitation for April through June during the current growing season, the second most important variable was temperature for April through June of the current growing season, and the third most important variable was precipitation for November through March prior to the growing season. The order of the first and third variables in the Pinaleños was transposed relative to the Santa Catalinas.

Current growing season April through June temperature is the only temperature variable with a significant impact on the growth of the trees at both sites. This is most likely a disguised moisture response, at least in part. Moisture is lost from the soil due to evapotranspiration as temperature increases. April, May, and June are prior to the summer monsoonal season and the trees are most likely to require adequate soil moisture to fulfill their needed water uptake during these months. Soil moisture evaporates into

the atmosphere if temperatures are too warm, thereby reducing the amount of water available to the trees. A deep residual snow pack from a wet winter is also likely to favor cool conditions in April - June. Higher growth in cool April - June periods may also be favored by lower transpiration rates and internal water stress.

The fourth and final important variable was August through October prior to the growing season precipitation in the Santa Catalinas. The fourth and final important variable in the Pinaleños was also a precipitation variable, but for the months July through September during the growing season. Precipitation was still more important than temperature at both sites, even though the months were not the same. Cross-validation indicated that all four of these variables are necessary to understand the effect of climate on the trees.

Climate explained 32% of the variance in ring-width indices of the corkbark fir in the Santa Catalina Mountains when including the four variables. Climate explained 36% of the variance in ring-width indices of the corkbark fir in the Pinaleño Mountains.

5.2 Age Distribution

The 10-year age distribution plot (Figure 11) reveals that the corkbark fir in the Santa Catalinas appear to be successfully reproducing. The youngest age class has the greatest number of trees. Many trees during the 1990 decade were most likely not counted because the seedling and sapling stage for corkbark fir is indistinguishable from other species. The distribution plot indicated that the 1960s had a lower tree establishment than the 1950s. Since age was not corrected for coring height, the

establishment date could be misrepresented by as much as 10 years. This could mean that the decrease in establishment actually occurred in the 1950s, most likely a result of drought (Swetnam & Betancourt, 1998). Climate response function analysis shows that precipitation is the most important variable for growth of the corkbark fir. A higher than expected mortality rate of seedlings could be inferred if the soil moisture was not adequate in the 1950s.

The decade of 1910 through 1919 contained only one tree with an establishment date in the "as old as" category. It is possible that this tree was older, since no pith rings were visible. This absence of tree establishment during this time, and the increasing number of trees that were recruited in the period back to the 1850s, suggests some sort of disturbance event. The disturbance could be drought or human-related. It is not likely that the disturbance was fire because then both young and old trees would have been affected, since corkbark fir is highly fire intolerant. One possibility for the lack of establishment of trees during this time is livestock grazing. Grazing livestock tends to kill tree seedlings as a result of herbivory or trampling (Archer & Smeins, 1991). The surge of recruitment from the 1840's to 1850's coincides with a time of unprecedented, fire-free intervals for many Southwestern sites (Grissino-Mayer & Swetnam, 2000). This fire-free interval may have allowed for the surge of corkbark fir recruitment.

The amount of variance in age explained by diameter for the Santa Catalina corkbark fir was 0.62 when using all the trees including those that were node counted, and 0.47 when using only the trees that were cored. Both of these r^2 values are strong when compared to results from other studies of corkbark and subalpine fir, 0.13 in the

Pinaleños (Grissino-Mayer *et al.*, 1994) and between 0.18 and 0.51 in Colorado (Veblen, 1986). Even though the correlations are stronger than other studies of the species, the correlation is not adequate for use in determining age, based on size. For example, in Figure 12, when dbh is 40 cm, age can range from approximately 50-240 years. The high correlation for the Santa Catalinas corkbark fir is most likely due to the lack of competing species, such as spruce.

5.3 Fire History

The corkbark fir fire-scar collection showed that the interior of the stand boundary probably had fewer fire events than surrounding areas, at least since the germination of the corkbark fir. The lack of fire recording species such as ponderosa pine and southwestern white pine within the stand made it difficult to determine the year of the last fire event in this stand. The extreme fire intolerance of corkbark fir suggests that few fires have occurred within the stand, otherwise the corkbark fir stand would probably not be present. The fires that have occurred in the area are all on the perimeter of the stand and this may explain the distinct boundaries of the corkbark fir.

Chi-squared tests for synchroneity, using 2 x 2 contingency analyses, indicates that the fire chronologies between the sites are associated. It is easier to achieve a statistically significant value with the 2 x 2 test because it uses both fire and non-fire years. The 2 x 1 contingency analysis indicates that fire dates from the SVC site are not associated with fire dates from the surrounding sites LEM or LPK. The 2 x 1 contingency analysis that compared LEM and LPK indicates that the fire chronologies at

the 2 sites are associated. The 2 x 1 contingency analysis is meaningful when examining

ecological processes because it only includes years when the event occurred, thereby

testing the likelihood of fire to spread between sites. The LEM and LPK sites are closely

located on the landscape, while SVC is located between them. It would be expected that

the 3 sites would be statistically synchronous due to the close proximity of the 3 sites.

Since the LEM and LPK fire chronologies are associated and SVC is not associated with

either LEM or LPK, some external factor, possibly moisture in the area, may have

affected fire at the SVC site.

The climate portion of this study indicates that the corkbark fir in the Santa

Catalina Mountains grows faster with moist conditions, but moist conditions restrict the

spread of fire in an area. The north-east aspect of the stand protects it from direct

sunlight, thereby reducing moisture loss due to evaporation. There is an abrupt

topographical change of aspect on one side of the stand. The other side of the stand has a

gradual change of aspect which results in a much more open structure of the corkbark fir.

It is possible that the heat from past fires injured or killed the corkbark fir that were

growing in the area. The area still had enough moisture to facilitate the growth of

corkbark fir, but not enough moisture to restrict the fire.

Another possible explanation for the more openess of the area is grazing. The

southwestern mountains were extensively grazed starting in the late 1800s to the early

1900s (Swetnam *et al.*, in press). The livestock consumed fine fuels that previously

carried the fires. These livestock could also consume or trample tree seedlings. This has

been seen in many mountain ranges in the southwest and could have occurred in the

Santa Catalinas. The summit, located near the upper portion of the stand, has plenty of grasses and areas that could have had potentially good grazing. Since this area above the stand has such good conditions for grazing, if grazing did indeed occur in the area, it is highly likely that the livestock would have wandered into the corkbark fir stand.

CHAPTER 6. CONCLUSION

It is extremely encouraging that the Santa Catalina Mountains contain areas where the climate can support the continual growth of corkbark fir. These locations are found in the upper elevations of the mountain, in areas that are shaded from direct solar radiation. Precipitation is the most limiting climatic factor to growth of the corkbark fir. When an area is protected from direct sunlight, there is a greater chance of snow pack remaining longer and less water lost as a result of evaporation. Knowing this information, it is possible to search the mountain for similar sites, in hopes of finding other stands of corkbark fir, not previously known.

Age distribution for the corkbark fir revealed that the trees appear to be regenerating successfully. These trees are producing viable seeds to ensure continuation of the species in the mountain range.

The corkbark fir stand in the Santa Catalina Mountains response to fire is similar to a spruce-fir forest, rather than a mixed conifer forest. The amount of fuel on the ground, in addition to the length of time since the last fire in the areas surrounding the stand, should be a warning to land managers. If a fire were to burn through the area, it could be devastating. Fuel has accumulated in the corkbark fir stand for at least the past 250 years and possibly longer, and fire in the area would kill most of the corkbark fir trees in the stand.

Future research should include sampling dead trees in the stand. The number of logs and standing snags could provide further information regarding disturbances to this

stand. Trees directly on either side of the road cut could be studied to determine the impact of this opening on the forest. Many of the trees cored close to the road revealed excessive amounts of rot.

My hope is that we are able to ensure the survival of the corkbark fir in the Santa Catalina Mountains and protect similar stands in other forests.

APPENDIX A – Summerhaven Climate Data

Average monthly temperature (^{o}F)

Year	1994	1995	1996	1997	1998	1999
January	34	32	38	30	33	38
February	34	39	35	33	29	41
March	43	41	45	44	38	44
April	47	46	53	41	41	NA
May	52	52	58	59	54	NA
June	67	63	70	64	66	NA
July	67	66	68	64	66	NA
August	64	61	64	62	64	NA
September	53	56	58	60	61	NA
October	47	53	49	51	53	NA
November	37	44	47	42	43	NA
December	36	37	38	30	37	NA

Total monthly snowfall (inches)

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1986-87	2	8	24	1	75	0	0	0
1987-88	0	0	50	24	8	2	8	0
1988-89	1	7	25	22	5	50	0	0
1989-90	0	0	8	16	49	11	6	0
1990-91	6	6	39	10	10	50	4	0
1991-92	4	20	20	26	15	40	6	0
1992-93	0	3	31	42	50	16	0	1
1993-94	0	33	6	7.5	28.5	11	4	0
1994-95	2	6	15	52	3	0	18	6
1995-96	0	0	7	2	31	5	0	0
1996-97	24	7	0	47	50	0	8	0
1997-98	0	5	47	7	156	57	13	0
1998-99	0	6	14	6	1	6	NA	NA

APPENDIX B – SANTA CATALINA TREE-RING CHRONOLOGY

Standard Chronology Tree-Ring Indices

	0	1	2	3	4	5	6	7	8	9
1816							615	669	684	405
1820	569	621	1366	1127	872	872	1599	817	873	1110
1830	895	884	1468	782	1008	1017	1156	552	888	986
1840	919	427	526	652	1153	1198	1569	1187	1152	1318
1850	1070	751	761	1072	772	599	644	749	1316	945
1860	1254	1111	893	661	577	595	920	1031	1236	1291
1870	1191	1074	861	855	836	935	1079	1073	962	753
1880	769	905	913	1014	1184	1058	761	850	890	1139
1890	1179	1438	1015	826	701	910	943	897	1375	1605
1900	788	1083	700	1224	577	1005	998	1275	1457	1236
1910	676	1121	1057	1122	1372	1165	1122	1294	1183	1210
1920	1212	584	998	836	954	415	1111	1064	723	562
1930	1136	1068	1285	1160	637	1123	893	956	985	742
1940	1102	1276	1068	801	1062	999	942	769	716	915
1950	969	888	627	695	797	860	416	639	659	624
1960	966	440	907	735	847	1146	1104	1158	1028	1003
1970	969	1097	1332	1024	648	1088	1126	1132	967	1270
1980	1089	1134	1264	1063	1265	1137	878	1173	1300	908
1990	1026	1097	1407	1165	904	879	386	545	699	

Residual Chronology Tree-Ring Indices

	0	1	2	3	4	5	6	7	8	9
1817								882	869	582
1820	892	858	1576	946	816	950	1677	514	980	1188
1830	848	951	1540	548	1133	1024	1158	482	1134	1056
1840	937	480	838	911	1347	1129	1476	1044	1064	1241
1850	901	709	888	1191	744	708	1170	782	1259	701
1860	1198	1071	869	699	768	827	1105	1119	1213	1085
1870	982	970	818	903	898	986	1138	1072	943	723
1880	872	1027	994	1077	1193	988	749	946	974	1192
1890	1116	1356	855	813	769	1042	989	911	1450	1435
1900	485	1140	665	1331	517	1166	1060	1286	1326	1034
1910	543	1224	1030	1095	1329	985	1030	1219	1036	1114
1920	1109	480	1137	863	1027	449	1371	1055	688	674
1930	1328	1043	1248	1039	561	1277	849	995	1009	761
1940	1199	1257	963	770	1154	1004	945	780	841	1078
1950	1017	931	699	875	951	982	509	907	866	802
1960	1159	503	1164	829	986	1198	1093	1119	966	990
1970	987	1084	1301	855	593	1229	1103	1066	901	1261
1980	963	1050	1188	934	1222	1003	779	1220	1211	769
1990	1038	1097	1370	996	815	923	459	816	933	

APPENDIX C – PINALEÑO TREE-RING CHRONOLOGY

Standard Chronology Tree-Ring Indices

	0	1	2	3	4	5	6	7	8	9
1759										981
1760	1096	958	817	1036	1114	1221	1427	1447	1361	1093
1770	1299	1465	1442	881	769	647	1245	1660	1434	981
1780	871	872	897	676	366	639	773	1313	772	1087
1790	1134	940	1275	293	748	1223	745	639	1571	585
1800	522	846	674	1271	678	706	882	658	1029	1571
1810	1358	1361	1085	1797	1314	1385	758	1238	798	674
1820	778	528	558	965	747	1010	891	1330	1040	1023
1830	1382	1517	1900	1269	1071	1628	2265	1228	1641	798
1840	424	472	564	688	316	758	275	491	1112	1072
1850	281	879	410	776	509	957	592	1252	933	871
1860	921	841	324	648	926	831	775	932	976	1157
1870	776	753	638	821	1979	1003	693	732	1249	759
1880	1140	749	814	728	1048	529	463	743	842	1045
1890	1001	965	738	786	701	829	742	815	1282	1255
1900	652	754	695	1107	480	1010	1071	1529	1319	1136
1910	684	1161	1045	1139	1297	1098	1228	1161	981	1188
1920	1270	1068	821	1034	934	1117	1058	1237	811	831
1930	1225	1039	1069	1176	668	1066	951	1104	733	683
1940	1237	1102	940	1163	1035	856	486	773	564	1086
1950	762	663	943	797	918	799	456	1115	915	793
1960	862	546	1095	888	916	1519	1370	1259	1143	1023
1970	1076	581	929	936	726	1231	1077	1208	1057	1344
1980	1118	1084	977	1219	1038	1034	1028	993	1065	590
1990	717	1076	1421	1134	1116	1015	606	733	837	

APPENDIX C – PINALEÑO TREE-RING CHRONOLOGY (cont.)

Residual Chronology Tree-Ring Indices

	0	1	2	3	4	5	6	7	8	9
1761		917	822	1150	1146	1156	1286	1169	1019	792
1770	1164	1287	1123	532	726	806	1498	1625	1024	588
1780	777	951	1004	769	572	1066	1132	1532	667	1135
1790	1151	852	1279	166	1063	1543	695	724	1834	376
1800	605	1213	883	1490	621	816	1126	801	1248	1648
1810	1051	1031	807	1666	871	1021	478	1275	738	728
1820	1010	735	873	1327	883	1160	955	1391	897	924
1830	1365	1312	1532	662	706	1528	1917	397	1205	403
1840	376	837	999	1061	599	1209	583	947	1574	1146
1850	220	1251	662	1128	784	1283	745	1487	907	849
1860	1013	922	435	1056	1322	917	874	1093	1050	1181
1870	720	887	778	1013	2134	563	705	968	1006	876
1880	998	764	956	877	1036	995	726	736	900	1103
1890	984	962	809	894	840	999	833	965	1354	1180
1900	553	887	807	1271	434	1230	1086	1502	1091	991
1910	639	1305	1003	1155	1171	912	1159	1072	907	1166
1920	1221	982	721	1131	930	1137	1042	1192	707	884
1930	1302	986	1030	1150	591	1174	945	1137	685	774
1940	1383	1031	872	1165	970	842	534	984	689	1273
1950	791	761	1101	860	1013	843	544	1334	899	826
1960	990	635	1282	887	959	1547	1192	1086	1055	949
1970	1045	542	1062	984	766	1324	1030	1186	990	1313
1980	994	1033	925	1227	957	1008	999	985	1061	569
1990	871	1202	1390	1002	1052	959	589	863	939	

APPENDIX D – TREE IDENTIFICATION INFORMATION

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
1	001	1965	1970	PR	8	3	14.5		0
1	002	1944	1948	PR	6.7	6	11		C
1	003A	1947	1957	PR	9.1	4	14		C
1	003B	1944	1944	P.	9.1	4	24.5		C
1	004A	1943	1954	PR	17.3	7	16		C
1	004B	1943	1943	P.	17.3	7	14		C
1	005	1958	1866	PR	10.9	8	15.5		C
1	006A	1944	1950	PR	25.9	11	25		C
1	006B	1935	1939	PR	25.9	11	23		C
1	007A	-	1955	no	41.8	12	38	rot	C
1	007B	-	1950	no	41.8	12	53	rot	C
1	008	1961	1972	PR	17.5	11	19		C
1	009	1953	1967	PR	17.5	11	15		C
1	010A	-	1979	no	33.7	12	32	rot	C
1	010B	1942	1949	PR	33.7	12	72	rot	C
1	011A	-	1954	no	31	12	37	rot	C
1	011B	-	1955	no	31	12	25	rot	C
1	011C	1950	1958	PR	31	12	60	rot	C
1	012	1927	1942	PR	33.1	12	27		C
1	013	1960	1970	PR	36.6	13	17.5		C
1	014	1958	1972	PR	28.6	12	25		C
1	015A	1902	1907	PR	39.8	12	26.5		C
1	015B	1904	1926	PR	39.8	12	20.5		C
1	016A	1958	1976	PR	31	13	34.5	leaning	C
1	016B	1953	1966	PR	31	13	27.5	leaning	C
1	017A	-	1963	no	46.9	14	34		C
1	017B	1935	1949	PR	46.9	14	54		C
1	018	1936	1939	PR	9	9	10		C
1	019	1959	1965	PR	18.1	11	33		C
1	020A	1941	1963	PR	12.2	12	13		C
1	020B	1926	1938	PR	12.2	12	9		C
1	021	1964	1967	PR	7.5	9	9.5		C
1	022A	1941	1944	PR	13.9	9	22	rot	C
1	022B	-	1944	no	13.9	9	12.5	rot	C
1	023A	-	1967	no	21.2	12	39.5	rot	C
1	023B		1958	PR	21.2	12	31	rot	C
1	024	1935	1940	PR	26.6	13	24.5		C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
1	025A	-	1933	no	67.6	15	30		C
1	025B	-	1931	no	67.6	15	43		C
1	026	1961	1965	PR	5.6	2.5	11		C
1	027	1953	1956	PR	8.4	9	9.5		C
1	028	1956	1967	PR	29.5	12	20		C
1	029	1955	1974	PR	19.6	10	16	dead leader	O
2	030	1845	1854	PR	23.9	10	20		C
2	031	1892	1892	P.	14.2	8	16		C
2	032	1947	1853	PR	6.8	4	9		C
2	033A	-	1877	no	24.7	11	18	rot	C
2	033B	-	1915	no	24.7	11	110	rot	C
2	034	1849	1854	PR	32.3	11	29		C
2	035	1888	1892	PR	19.9	12	18.5		C
2	036A	1862	1885	PR	24.5	11	26		C
2	036B	1840	1864	PR	24.5	11	15		C
2	037	1863	1867	PR	21.1	11	63	hollow	C
2	038	1848	1878	PR	22.6	11	19		C
2	039A	1900	1916	PR	56.4	13	30		C
2	039B	-	1920	no	56.4	13	33		C
2	040A	1864	1880	PR	34.5	14	30		C
2	040B	1855	1870	PR	34.5	14	18		C
2	041A	-	1905	no	46.5	14	31	rot	C
2	041B	1857	1869	PR	46.5	14	45	rot	C
2	042A	1842	1847	PR	31.1	12	31		C
2	042B	-	1869	no	31.1	12	20		C
2	043	1959	1963	PR	3.5	1	4		C
2	044	1927	1982	PR	6.5	1.7	8	bent S	C
2	045	1962	1977	PR	8.1	2	9.5	base lean	C
2	046A	-	1910	no	5.9	2	8		C
2	047	1936	1942	PR	6.9	2.5	8		C
2	048A	1944	1958	PR	10.8	3	9.5		C
2	048B	1941	1951	PR	10.8	3	6.5		C
2	049	1943	1943	P.	5	1.8	7		C
2	050A	-	1970	no	6	2	7.5	rot	C
2	050B	-	1978	no	6	2	4.5	rot	C
2	051	1941	1948	PR	5	0.8	10		C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
2	052	1961	1970	PR	8.6	1.5	10		C
2	053	1968	1972	PR	10.3	2.5	10		C
2	054A	-	1881	no	40.7	14	31.5	rot	C
2	054B	1866	1884	PR	40.7	14	54	rot	C
2	055A	1850	1863	PR	56.5	16	63	flared bottom	C
2	056A	-	1961	no	34.1	14	24.5	rot, liquid	C
2	056B	1861	1865	P.	34.1	14	45	rot, liquid	C
2	057A	-	1880	no	48.9	16	29	rot	C
2	057B	-	1881	no	48.9	16	54	rot	C
2	057C	-	1884	no	48.9	16	107	rot	C
2	058	1950	1956	PR	4	1.5	6	right angle bent	C
2	059	1963	1970	PR	5	2	11	bent	C
2	060	1955	1976	PR	8.7	2.2	11		C
2	061	1977	1980	PR	6.1	1.6	10		C
2	062	1975	1981	PR	4.9	1.2	8.5		C
2	063A	-	1921	no	43.5	10	26		C
2	063B	-	1934	no	43.5	10	45		C
2	063C	1868	1898	PR	43.5	10	70		C
2	064	1826	1839	PR	35.5	11	33		C
2	065A	1906	1914	PR	8	2	10		C
2	065B	1946	1958	PR	8	2	12		C
2	066A	1900	1916	PR	58.4	11	52		C
2	066B	1891	1912	PR	58.4	11	74.5		C
2	066C	-	1917	no	58.4	11	60.5		C
2	067A	1868	1889	PR	69	12	72		C
2	067B	1859	1878	PR	69	12	40		C
2	068A	1970	1988	PR	7.8	2	10		C
2	068B	1966	1981	PR	7.8	2	30		C
2	069	1984	16	NC	3	0.8	_		C
2	070	1981	19	NC	2.5	0.8	_		C
2	071	1856	1881	PR	50.2	12	49		C
2	071B	-	1904	no	50.2	12	41		C
2	071C	1828	1844	PR	50.2	12	98		C
2	072	1957	1961	PR	4.5	1.5	14.5		C
2	073	1987	13	NC	2.5	1			C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
2	074	1972	1972	P.	3.5	1.4	8		C
2	075	1970	1977	PR	5.5	1	13		C
2		1980	20	NC	3	0.8			C
2		1988	12	NC	1.5	0.2			C
2		1985	15	NC	2.0	0.4			C
2		1991	9	NC	1.0	0.2			C
2		1984	16	NC	1.5	0.2			C
2		1983	17	NC	2.0	0.5			C
2		1984	16	NC	2.0	0.5			C
2		1988	12	NC	1.0	0.4			C
2		1994	6	NC	0.5	0.2			C
2		1984	16	NC	1.5	0.2			C
2		1986	14	NC	1.5	0.2			C
2	080A	-	1882	no	54.2	11	32	rot	C
2	080B	1885	1908	PR	54.2	11	33	rot	C
2	080C	-	1898	no	54.2	11	70	rot	C
2	080D	1839	1856	PR	54.2	11	82.5	rot	C
2		1994	6	NC	1.0	0.2			C
2		1988	12	NC	1.5	0.2			C
2		1994	6	NC	0.5	0.1			C
2		1988	12	NC	1.0	0.2			C
2		1986	14	NC	1.0	0.5			C
2		1992	8	NC	1.5	0.38			C
2		1990	10	NC	0.5	0.25			C
2		1997	3	NC	0.25	0.1			C
2		1992	8	NC	1.0	0.23			C
2		1989	11	NC	1.5	0.33			C
2	081A	-	1934	no	18.2	10	22.5	rot	C
2	081B	1876	1876	P.	18.2	10	41.5	rot	C
2	082A	-	1881	no	58.9	14	48	rot	C
2	082B	-	1886	no	58.9	14	61	rot	C
2	082C	-	1894	no	58.9	14	88	rot	C
2	083	1885	1900	PR	19.1	10	22		C
2	084	1870	1880	PR	18.1	9	14.5		C
2	085	1878	1895	PR	14.5	10	17		C
2	086	1872	1881	PR	22.1	11	24		C
2	087	1857	1863	PR	19.4	11	26		C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
2	088	1863	1887	PR	15.2	9	24		C
2	089	1926	1948	PR	16.7	9	14		C
2	090A	1866	1870	PR	36	12	25		C
2	090B	1871	1871	P.	36	12	36		C
2	091	1938	1938	P.	3.5	1	11.5		C
2	092	1867	1870	PR	39.4	11	23		C
3		1989	11	NC	1	0.26			C
3		1988	12	NC	2.5	1.12			C
3		1978	22	NC	2.0	1.28			C
3		1991	9	NC	1.5	0.24			C
3	093	1981	1985	PR	7.3	2.0	32	lean	C
3	094A	1849	1865	PR	22.1	10	23	rot	C
3	094B	1898	1905	PR	22.1	10	48		C
3	095A	-	1866	no	49.1	12	30	rot	C
3	095B	-	1851	no	49.1	12	50	rot	C
3	095C	1790	1798	PR	49.1	12	73	rot	C
3	096A	1760	1762	PR	42.2	14	50	rot	C
3		1991	9	NC	1	0.245			C
3		1987	13	NC	1.5	0.475			C
3	098	1978	1982	PR	6.6	2	13		C
3	099	1902	1917	PR	32.8	10	32.5		C
3	100	1840	1866	PR	39.7	12	30		C
3	101	1960	1965		7.2	2	19		C
3	102A	-	1871	no	63	20	40		C
3	102B	1846	1854	PR	63	20	47.5		C
3	102C	1832	1843	PR	63	20	50		C
3	103A	-	1889	no	40.1	21	46		C
3	103B	1840	1843	PR	40.1	21	46		C
3	104A	1880	1891	PR	55.5	20	50	rot	C
3	104B	-	1862	no	55.5	20	60	rot	C
3		1982	18	NC	1.9	120			C
3		1991	9	NC	0.7	15			C
3		1989	11	NC	0.6	32			C
3		1995	5	NC	0.3	12			C
3		1992	8	NC	0.7	35			C
3		1987	13	NC	1.2	62			C
3		1996	4	NC	1.2	14			C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
3		1985	15	NC	1.8	71			C
3		1995	5	NC	1.2	15			C
3		1981	19	NC	2.6	1.50			C
3		1984	16	NC	1.9	0.96			C
3		1989	11	NC	0.5	0.31			C
3		1985	15	NC	1.2	1.06			C
3		1989	11	NC	0.5	0.24			C
3		1992	8	NC	0.5	0.41			C
3		1983	17	NC	2	1.10			C
3		1973	27	NC	2.5	1.50			C
3		1986	14	NC	1	0.70		btwn 119-120	C
3		1968	32	NC	3	1.30			C
3		1978	22	NC	1.5	0.91		base 120	C
3	105	1885	1885	P.	11.6	6	29		C
3	106A	-	1941	no	23.6	12	31		C
3	106B	-	1907	no	23.6	12	63		C
3	106C	1883	1883	P.	23.6	12	40		C
3	107	1855	1877	PR	15.6	12	34	rot	C
3	108	1857	1866	PR	23.8	16	94	rot	C
3	109A	1848	1858	PR	31.1	18	45	rot	C
3	109B	1864	1886	PR	31.1	18	36	rot	C
3	110A	1894	1910	PR	29.4	19	33	rot	C
3	110B	-	1923	no	29.4	19	22	rot	C
3	111	1870	1877	PR	16.4	10	78		C
3	112A	-	1883	no	48.5	20 1	57	rot	C
3	112B	-	1910	no	48.5	20 1	54	rot	C
3	113	1851	1859	PR	39.8	20	73		O
3	114A	-	1909	no	63	23	65		O
3	114B	1901	1917	PR	63	23	31		C
3	115A	1976	1982	PR	10.8	6	24		C
3	115B	1928	1940	PR	10.8	6	83		C
3	116A	1869	1869	PR	48.3	20	63		O
3	116B	1863	1897	PR	48.3	20	47		C
3	117	1880	1897	PR	21.6	10	94	rot	C
3	118A	-	1896	no	31.5	19	44	rot	C
3	118B	-	1901	no	31.5	19	80	rot	C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
3	119A	1856	1877	PR	33.5	20	37	wound	C
3	119B	1854	1857	PR	33.5	20	37	wound	C
3	120	1844			31.5	12		749	C
3	121	1850			44.5	18		748	C
3	122	1935		no	21.5	10		747	C
3	123	1808			40.7	16		740	C
3	124	1847		no	47.8	19		742	C
3	125	1857		no	58.6	20		738	C
3	126	1840			31.5	19		739	C
3		1978	22	NC	4.8	1.0		next to 113	C
3		1982	18	NC	2.5	0.82			C
3		1985	15	NC	1.6	0.64			C
3		1987	3	NC	0.2	0.18			C
3		1990	10	NC	0.5	0.39			C
3		1993	7	NC	0.5	0.34			C
3		1985	15	NC	1.8	0.55			C
3		1993	7	NC	0.2	0.09			C
3		1980	20	NC	1.8	1.13		next to 122	C
3		1984	6	NC	0.2	0.8			C
5	134	1976	1976	P.	7.8	4	15		C
5	135	1972	1972	P.	10.2	6	17		C
5	136	1978	1978	P.	6.2	4	24		C
5	137	1978	1981	PR	4.3	3	15		C
5	138	1977	1982	PR	7.4	6	16		C
5	139	1978	1985	PR	7.5	6	16		C
5	140A	-	1884	no	53.2	20	48	rot	O
5	140B	-	1869	no	53.2	20	92	rot	C
5	141A	1859	1867	PR	44	22	44		C
5	141B	1862	1865	PR	44	22	84		C
5	142	1903	1917	PR	30.5	22	41		C
5	143A	-	1891	no	57.1	23	75		C
5	143B	-	1880	no	57.1	23	83		C
5	144A	1860	1864	PR	43.6	21	76		C

APPENDIX D – TREE IDENTIFICATION INFORMATION (cont.)

\# Pith: PR = pith rings, P = pith present, no = no pith rings, NC = node count
* Tree height is an approximate
\+ Canopy: O = open, C = closed

Transect	Core	Estimated	Inner ring	Pith #	DBH (cm)	Tree ht. (m) *	Core ht. (cm)	Comment	Canopy +
5	144B	1850	1857	PR	43.6	21	82		C
5	145A	-	1963	no	40.7	18	134	rot	C
5	145B	-	1922	no	40.7	18	35	rot	C
5	146A	-	1942	no	43.9	20	73	rot, wound	C
5	146B	-	1953	no	43.9	20	139	rot, wound	C
5	147B	-	1932	no	53.6	19	80	rot, wound	C
5		1979	21	NC	2.8	1			C
5		1981	19	NC	1.1	0.63			C
5	148A	-	1927	no	22.1	12	60	rot	C
5	148B	-	1928	no	22.1	12	121	rot	C
5		1981	19	NC	1.2	0.53			C
5		1993	7	NC	0.5	0.15			C
5		1992	8	NC	0.5	0.10			C
5		1996	4	NC	0.2	0.10			C
5	149	1896	1901	PR	27.5	8	95		C
5	150	1891	1898	PR	21	10	56	moss covered	C
5		1987	13	NC	1	0.35			C
5	151	1984	1987	PR	3.9	1.5	11	NC 25	C
5	152	1985	1988	PR	3.2	1.4	17	NC 20	C
5		1981	19	NC	1.5	0.70			C
5	153	1935			6	2	13		C
5		1982	8	NC	0.3	0.10			C
5		1983	17	NC	2.1	0.79			C
5	154	1975	1981	PR	5	3.5	25		C
5	155	1958	1970	PR	13.2	7	67		C
5	156	1970	1975	PR	9.1	6	20		C
5	157A	-	1875	no	72	22	71	rot	C
5	157B	-	1908	no	72	22	96	rot	C
5	158A	1920	1952	PR	34.4	16	77		C
5	158B	1885	1894	PR	34.4	16	79		C
5		1983	17	NC	1.8	0.74			C
5		1982	18	NC	1.5	1.0			C

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