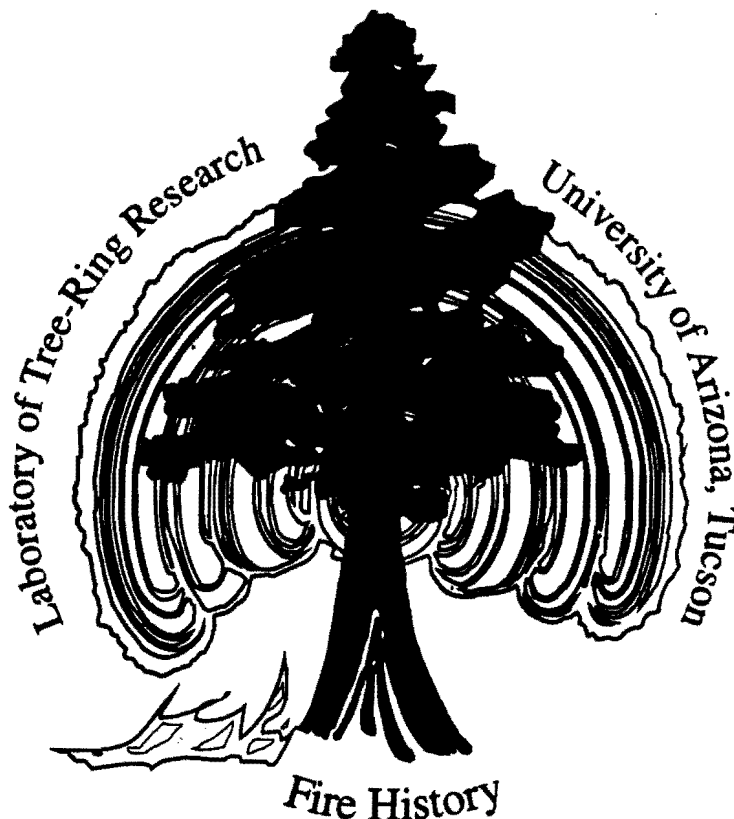


**Fire History in Ponderosa Pine  
and Mixed-Conifer Forests of the Jemez  
Mountains, Northern New Mexico**



**A Final Report Submitted to the  
USDA Forest Service, Santa Fe National Forest  
and  
USDI National Park Service, Bandelier National Monument**

**By**

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**March 20, 1995**

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## ABSTRACT

We reconstructed fire history in ponderosa pine and mixed-conifer forests across the Jemez Mountains in northern New Mexico. We collected fire-scarred samples from nine ponderosa pine areas and four mesic mixed-conifer areas. An additional collection was obtained from a bristlecone pine stand in the Sangre de Cristo Mountains. We also reconstructed December-June precipitation from ponderosa pine tree-ring indices that were developed from four different watersheds in northern New Mexico. Prior to 1900, ponderosa pine forests were characterized by high frequency, low intensity surface fire regimes. The mixed-conifer stands sustained somewhat less frequent surface fires, along with patchy crown fires. In both ponderosa pine and mixed-conifer forests precipitation was significantly reduced in the winter-spring seasons preceding fire events. In addition, winter-spring precipitation during the third year preceding major fire years in the ponderosa pine forest was significantly increased. This study provides baseline knowledge concerning the ecological role of fire in ponderosa pine and mixed-conifer forests. This information is vital to support ongoing ecosystem management efforts in the Jemez Mountains.

## INTRODUCTION

Fire has played a dominant role in controlling the formation and maintenance of species and age structure patterns in Southwestern U.S. forest communities (Weaver 1951; Dieterich 1983; Baisan and Swetnam 1990; Swetnam and Baisan - in press). In order to understand the modern landscape and to manage it effectively, fire managers require specific information about the spatial and temporal variability of past fire regimes (Allen 1994). Historical reconstructions, such as fire history analysis, provide specific information on the range and variability of the fire process, which can be a useful guide to reintroduction of fire for long-term sustainability of forests (Swanson *et al.* 1993, Kaufmann *et al.* 1994).

During the past century, the ecology of Southwestern forests, including the Jemez Mountains in northern New Mexico, has been altered by anthropogenic factors. Anthropogenic effects include intensive grazing by sheep and cattle and effective fire suppression by the U.S. Forest Service (deBuys 1985; Carlson 1969; Allen 1989; Touchan *et al.* - in press). Natural factors also have an effect on fire regimes. On a regional scale, climate causes variations in fire regimes because it has a significant influence on fire frequency, extent, and intensity. On a local scale, topography, aspect, and elevation have site specific influences on fire regimes.

In this study we investigate the past fire regimes of ponderosa pine, and mixed-conifer forest types in the Jemez Mountains, and a bristlecone pine (*Pinus aristata*) stand in the Pecos Wilderness (Round Mountain), Sangre de Cristo Mountains. We also employ dendrochronological methods to determine exact fire dates and approximate establishment dates of aspen stands. Fire history data, observations of site characteristics, and independent

dendroclimatic reconstructions are used to assess associations between fire regimes and environmental factors (Baisan and Swetnam 1990; Swetnam and Betancourt 1990; Swetnam 1993).

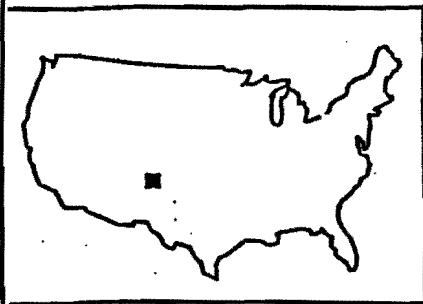
## STUDY AREA

The Jemez Mountains are located in north-central New Mexico (Figure 1). Elevations range from 1,590 m at the Rio Grande to 3,526 m at the summit of Tschicoma Peak (the highest point in the Jemez Mountains), with a geologic boundary enclosing about 543,522 ha (Smith *et al* 1976). The elevation of the sampled area varies between 2,250 m and 3,000 m (Table 1). Soil parent material varies from rhyolites and andesites with some dacites and latites, to tuff and pumice on the plateaus and basalt near the Rio Grande (Nyhan *et al* 1978).

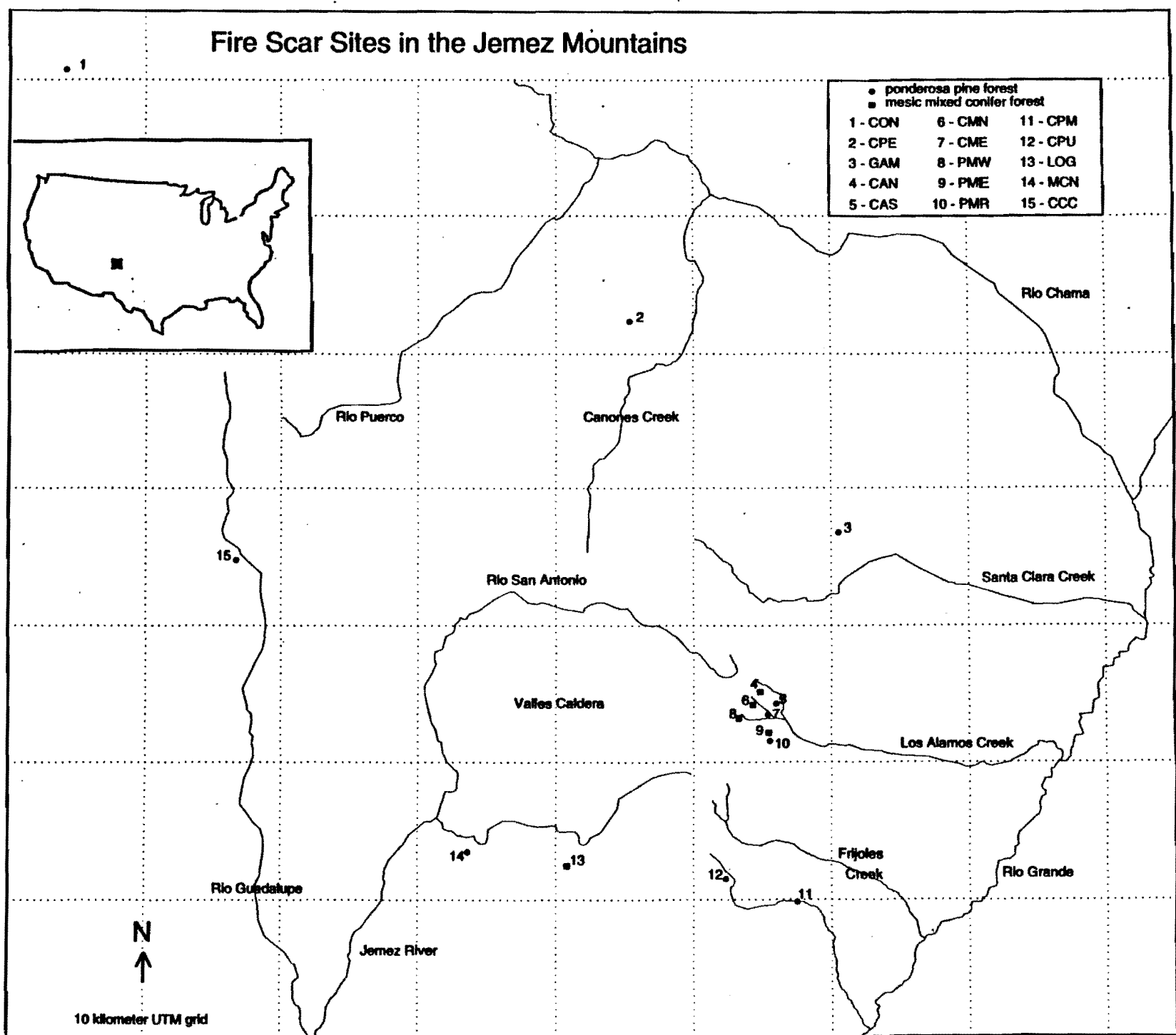
The length of the frost-free growing season in Los Alamos is 157 days, or around five months (Bowen 1989). July is the warmest month at Los Alamos, with a mean temperature of 28° C, and January is the coldest month, with a mean temperature of -1.6° C. Annual precipitation ranges from about 30 cm at the lower elevations to about 90 cm at higher elevations. Yearly precipitation is bimodal, with maxima in winter (December-January) and summer (July-August). Winter precipitation falls primarily as snow, with average accumulations of about 130 cm. This moisture typically originates in eastern-moving storms from the Pacific Ocean. Summer precipitation often results from a southeasterly wind pattern that transports moisture from the Gulf of Mexico to New Mexico. This moisture, combined with strong heating, produces an unstable atmosphere that leads to convective storms. Forty percent of the

Figure 1. Locations of fire history sites in the Jemez Mountains, northern New Mexico.

# Fire Scar Sites in the Jemez Mountains



● ponderosa pine forest	■ mesic mixed conifer forest	
1 - CON	6 - CMN	11 - CPM
2 - CPE	7 - CME	12 - CPU
3 - GAM	8 - PMW	13 - LOG
4 - CAN	9 - PME	14 - MCN
5 - CAS	10 - PMR	15 - CCC



10 kilometer UTM grid

Table 1. Jemez Mountains fire-scar site locations. The area of each study site was estimated within the perimeter of an area defined by the sampled trees. Sites are listed by forest type (PIPO = ponderosa pine, PIPO/MC = ponderosa pine/mixed conifer, MC/PIPO= Mixed conifer/ponderosa pine, MC = mixed conifer, and PIAR= Bristlecone pine).

Name of Site	Ranger District/Park	Latitude	Longitude	Veg. Type	Area (ha)	Elevation (m)	No. of Samples
Monument Canyon Natural Area	Jemez RD	35° 48' 12" N	106° 37' 3" W	PIPO	259	2,600	30
Pajarito Mountain Ridge	Española RD	35°53'04"N	106° 22' 49" W	PIPO	3.5	2,985	26
Cerro Pedernal	Coyote RD.	36°9'43"N	106°30'12"W	PIPO	16	2,865	26
Continental Divide	Cuba RD	36° 18' 42" N	106° 57' 30" W	PIPO	27	2,300	27
Clear Creek Campground	Cuba RD	36° N	106° 49' 4" W	PIPO	130	2,500	20
Capulin Canyon	Bandelier NM	35° 47' 12" N	106° 24' 2" W	PIPO/MC	103	2,250	23
Gallina Mesa	Espanola RD	36° 1' 26" N	106° 19' 42" W	PIPO/MC	285	2,700	25
Cañada Bonito South	Española RD	35°54'25"N	106°22'22"W	PIPO/MC	2	2,800	31
Camp May East	Española RD	35°54'N	106° 22' 57" W	PIPO/MC	1.3	2,710	6
Los Griegos Mountain	Jemez RD	35°55'24"N	106°32'12"W	MC/PIPO	4	2,835	19
Pajarito Mountain North East	Española RD	35° 53' 09" N	106° 22' 09" W	MC	7.6	2,925	14
Pajarito Mountain North West	Española RD	35°53'13"N	106°24'14"W	MC	7	3,000	11
Camp May North	Española RD	35°54'25"N	106°23'53"W	MC	8	3,000	20
Cañada Bonito North	Española RD	35°54'56"N	106°23'15"W	MC	4.8	2,980	28
Round Mountain	Pecos RD	35°52'20"	105°38'15"	PIAR	1	3,270	19

total annual precipitation falls in July and August during the height of the summer rainy season.

In a summary of forest fire statistics for the period 1960 to 1975, Barrows (1978) found that 80% of New Mexico fires were ignited by lightning, and about 20% were anthropogenic fires. Foxx and Potter (1978) and Allen (1984) found that 86% of the fires recorded at Bandelier were ignited by lightning, with a peak in July and smaller peaks in June and August. Generally all local fires occurred between April and September. Barrows (1978) found that this seasonal pattern of ignitions occurred throughout the Southwest, but fires that start in June cause the greatest area burned. For example, approximately 72% of the area burned in New Mexico was due to lightning fires which started in June.

The overstory in sampled forests range from pure ponderosa pine (*Pinus ponderosa*) stands to high elevation, mesic, mixed-conifer forests (Table 1, Figure 1), to pure bristlecone pine forest. Five of the sampled sites occur in ponderosa pine forests, including Monument Canyon Research Natural Area (MCN), Pajarito Mountain Ridge (PMR), Cerro Pedernal (CPE), Clear Creek Campground (CCC), and Continental Divide (CON). CON includes three adjacent sub-sites called Laguna Jaquez (LJA), Laguna Gurule (LGU), and Continental Divide (CON). The sampled mixed-conifer forests are dominated by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), Englemann spruce (*Picea engelmannii*), and quaking aspen (*Populus tremuloides*). The four mixed-conifer sample sites are Pajarito Mountain North (PMN), which includes two sub-sites called Pajarito Mountain East (PME) and Pajarito Mountain West (PMW), and Camp May North (CMN) and Cañada Bonito North (CAN). Two sites (Capulin Canyon (CCP) and Gallina Mesa (GAM)) were sampled in transitional situations where mixed-conifer species were co-dominants with ponderosa pine. Capulin Canyon includes two sub-sites located

in the upper and middle reaches of the canyon, respectively. One site was sampled in a transitional situation where ponderosa pine species was co-dominant with mixed-conifer. At two other transitional sites, Camp May East (CME) and Cañada Bonito South (CAS), ponderosa pine shared dominance with limber pine (*Pinus flexilis*). Finally, the overstory in the bristlecone pine (*Pinus aristada*) site in the Pecos Wilderness (ROM) was dominated by this species.

## METHODS

### Fire-Scar Sampling and Analyses

During 1988 to 1993 we collected fire-scarred samples from a total of 15 sites (Table 1). Full or partial cross-sections were cut with a chainsaw from fire-scarred boles of downed logs, snags, and stumps. Partial sections were also taken from living trees as described by Arno and Sneek (1977). One criterion for sample tree selection within study areas was the presence of a maximum number of well preserved scars showing evidence of fire by the number of healing ridges observed on the scarred surface ("cat face") (Dieterich and Swetnam 1984, Baisan and Swetnam 1990). Samples were also selected in areas widely dispersed as possible within selected stands. Although the stand (or patch) size of selected sample areas varied considerably, as well as did the areas over which samples were obtained, in general, the sampled areas for each site encompassed approximately 10 and 100 ha.

In addition to collecting fire-scarred samples in the mixed-conifer sites, we cored 202 quaking aspen, since this species often sprouts abundantly after fire disturbance in mixed-conifer forests (Jones and DeByle 1985). We sampled dominant and codominant aspen trees in aspen stands which were adjacent to the old-growth mixed-conifer stands that we sampled for fire

scars. Hence, we determined both fire dates and tree recruitment dates to reconstruct fire and stand development histories.

In the laboratory, samples were fine-sanded and crossdated using standard dendrochronological techniques (Stokes and Smiley 1968; Swetnam *et al.* 1985). In some cases, the aspen growth was very suppressed after 1979 because of a tent caterpillar outbreak that occurred in the early 1980's (Allen 1984). Because of this growth suppression the tree rings on some cores were difficult or impossible to crossdate during this period. If a particular core was near to but did not contain the pith, then Applequist's (1958) method was used to estimate the pith dates.

We identified the intra-ring position of fire scars to infer approximate timing of individual fires relative to the growing season of the trees (Dieterich and Swetnam 1984, Baisan and Swetnam 1990, Touchan and Swetnam 1991). All fire-scar dates from individual trees within each site were compiled into master chronologies to examine both temporal and spatial patterns of past fire occurrence. The FIRE2 fire history analysis program was used to compute descriptive statistics (Grissino-Mayer *et al.* 1994). These included fire frequency (number of fires per time period), fire-scar index ( $[\text{number of trees scarred per fire event} / \text{number of trees sampled}] \times 100$ ), Weibull median probability intervals (WMPI), maximum and minimum fire interval (Max. FI and Min. FI), and standard deviation (STD) of fire intervals. These statistics were computed separately for (1) all fire dates, (2) fires recorded by 10% or more and (3) fires recorded by 25% or more of the sampled trees. Because sampled fire-scarred trees were generally spatially dispersed throughout the sites, we infer that the  $\Rightarrow 10\%$  and  $\Rightarrow 25\%$  categories generally estimated the fire regime patterns of relatively larger, more widespread fires

within the sites (Swetnam and Baisan - in press).

The WMPI is calculated using the Weibull distribution, a very flexible distributional model that may be fitted to a variety of negatively and positively skewed distributions. The Weibull distribution often provides a superior fit to fire interval data than does the normal distribution (Johnson 1992; Baker 1992; Grissino-Mayer *et al.*, 1994). The WMPI is used here in addition to the Mean Fire Interval (MFI) because fire interval data are usually positively skewed (Baker 1992; Grissino-Mayer *et al.* 1994), hence in these cases, simple averages (e.g. mean fire intervals) provide a less robust estimate of the central tendency of the fire interval distribution. Here we report the fire interval associated with the 50% exceedance probability of the WMPI, which is the interval (in years) at which there was a 50% probability of fire intervals exceeding or being less than this interval (Grissino-Mayer *et al.* 1994).

Changes in fire frequency through time were graphically examined by computing and plotting moving-period fire frequencies. The moving periods were overlapping time periods of different lengths (50 and 25 years), during which the total number of recorded fires were summed. Each sequential value was the sum of fire events in the time period lagged one year forward from the previous period. The fire frequencies in these moving periods were plotted on the central-year of the period (i.e., 25th and 12th years respectively).

The computation of WMPI, MFI, Max. and Min. FI, and STD were based on a time span we termed the "period of reliability". This is the number of years that included a minimum number of fire scar samples deemed sufficient to reliably estimate fire regime parameters. Generally this period included at least three to four samples recording the fire events (Table 2). This was a somewhat subjective determination, but given the degree of replication of fire dates

Table 2. Time spans of fire-scar chronologies. Period of reliability is the period when the number of samples was deemed sufficient to reliably estimate presuppression fire regime characteristics. Generally this was the period during which at least three or four samples recorded fire events. Sites are listed by forest types (PIPO = ponderosa pine, PIPO/MC = ponderosa pine /mixed conifer, MC/PIPO= Mixed conifer/ ponderosa pine, MC = mixed conifer, PIAR= Bristlecone pine).

Site Name	Site Code	Veg. Type	Tree-Ring Date		Earliest Fire-Scar Date	Latest Fire-Scar Date	No. of Fire-Events (Years)	Period of Reliability	
			Earliest	Latest				Beginning Date	Ending Date
Monument Canyon Natural	MCN	PIPO	1408	1972	1493	1909	57	1648	1892
Pajarito Mountain Ridge	PMR	PIPO	1626	1993	1632	1912	39	1685	1875
Cerro Pedernal	CPE	PIPO	1380	1993	1522	1959	30	1598	1873
Continental Divide	CON	PIPO	1387	1979	1601	1899	54	1654	1870
Clear Creek Campground	CCC	PIPO	1538	1978	1548	1881	45	1664	1860
Capulin Canyon	CCP	PIPO/MC	1554	1990	1624	1955	44	1664	1893
Gallina Mesa	GAM	PIPO/MC	1531	1979	1558	1921	66	1663	1870
Cañada Bonito South	CAS	PIPO/MC	1378	1993	1480	1966	33	1672	1893
Camp May East	CME	PIPO/MC	1660	1993	1709	1880	11	1709	1879
Los Griegos Mountain	LOG	MC/PIPO	1534	1993	1573	1925	23	1664	1892
Pajarito Mountain North-East	PME	MC	1702	1993	1773	1949	13	1801	1879
Pajarito Mountain North-West	PMW	MC	1617	1993	1669	1925	10	1841	1879
Camp May North	CMN	MC	1683	1993	1729	1880	7	1847	1879
Cañada Bonito North	CAN	MC	1655	1993	1685	1914	12	1801	1893
Round Mountain	ROM	PIAR	843	1993	1404	1948	16	1580	1873

among the sampled trees, and relatively small size of the study sites, we are confident that these are reasonable time periods to confidently base our descriptive analyses.

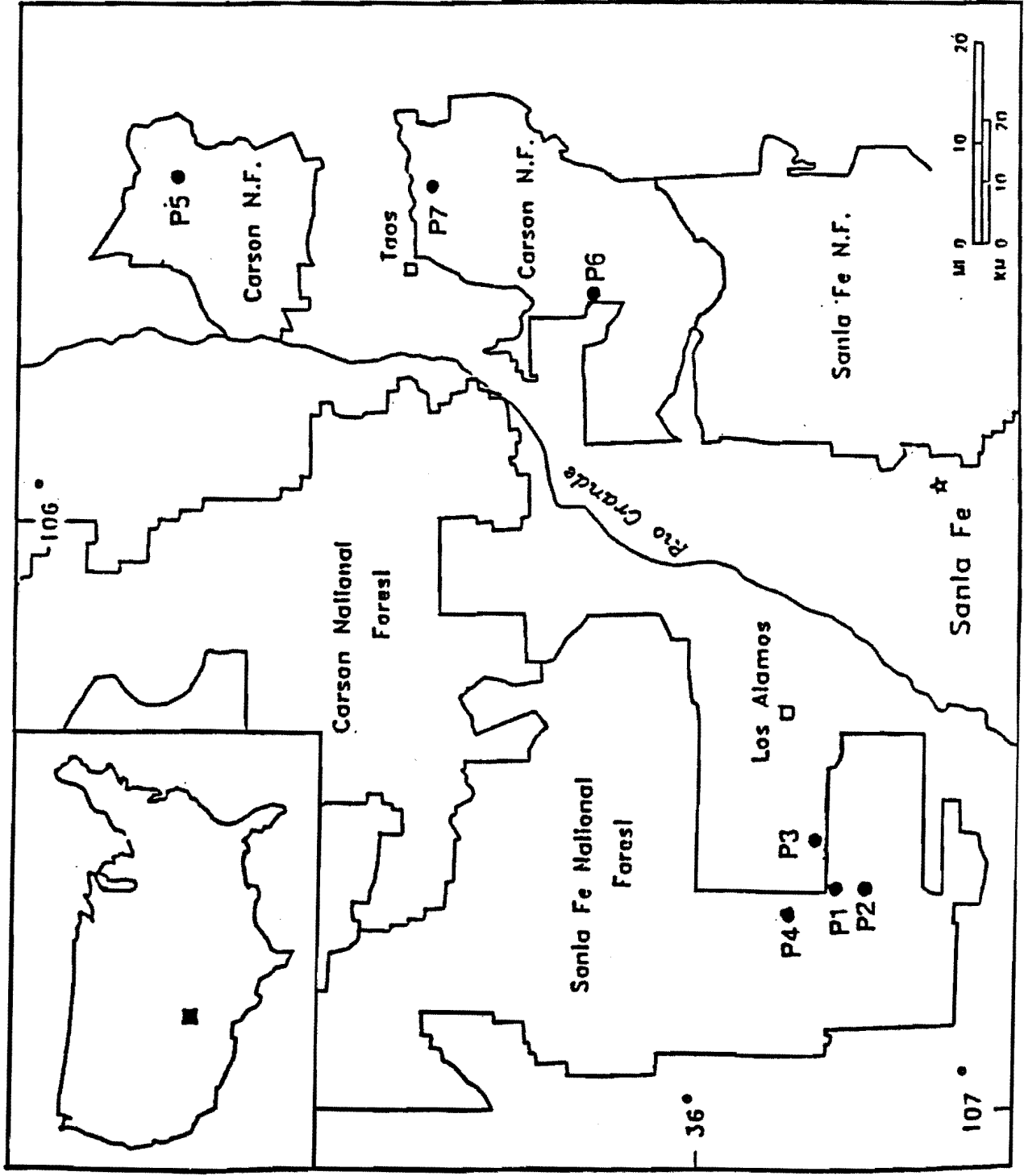
### Dendroclimatic Reconstruction

We developed a paleoclimatic reconstruction for the Jemez Mountains from a network of ponderosa pine tree-ring width chronologies that were originally developed as climatic controls in a tree-ring reconstruction of western spruce budworm history (Swetnam and Lynch 1993) (Figure 2). The watersheds included in this network were Jemez River, Red River, Rio Pueblo, and Rio de Taos.

We used response function analysis to identify the strongest and most statistically significant relationships between each chronology and monthly and seasonal climatic parameters of temperature and precipitation of Division Four (South West Mountains) (Fritts 1976, 1991). We determined that total precipitation during the December to June period was the most appropriate predictand for reconstruction.

We performed principal components analysis on the seven tree-ring chronologies prior to developing a regression equation to reconstruct precipitation. This transformation produced uncorrelated, predictor time series that contained the common variance in the original chronologies (Fritts 1976, Kutzbach and Guetter 1980, D'Arrigo and Jacoby 1991). The first, fourth, and seventh principal components from the PCA (based on the common interval AD 1653-1986) were used as predictors. The first component accounted for 75% of the common variance in the untransformed tree-ring data.

Figure 2. Locations of seven ponderosa pine chronologies in northern New Mexico used for reconstructing December-June precipitation. These chronologies were taken from four different watersheds: Jemez River (Abouselman P1; Cat Mesa P2; Baca P3; and Fenton Lake P4). Red River (Elephant Rock P5), Rio Pueblo (Rio Pueblo P6), Rio de Taos (Capulyn Canyon Pine P7).



Following standard dendroclimatic procedure (Fritts 1976), all tree-ring and climatic data during the period of historical record were divided into a "calibration period", which was used to develop the original regression equation, and a "verification period", in which data were withheld to verify the original regression equation (Fritts 1976). In this study, the calibration period spanned 1941 to 1986 and the verification period spanned from 1896 to 1940. Verification tests included the correlation coefficient between predicted and actual precipitation values, the reduction of error statistic (RE), and the product-means test (Fritts 1976, Fritts 1991).

### Fire-Climate Analyses

Finally, we used superposed-epoch analyses (Baisan and Swetnam 1990; Swetnam 1993; Swetnam and Baisan-in press) to compute the mean climate conditions before, during, and after sets of fire years in both the ponderosa pine and mixed-conifer forests. In this analysis, fire years were "superposed" on the independent tree-ring reconstructed winter-spring precipitation for the period 1653 to 1986. The winter-spring seasonal precipitation values used in this analysis were assigned to the calendar year corresponding with the spring months. Mean precipitation values (expressed as departures from the long term mean) were computed for the set of fire years and lagged years and then plotted. We conducted 1,000 Monte Carlo simulations of the same number of randomly selected dates to estimate confidence intervals for the mean departures of the fire dates at the 95% and 99% probability levels based on the normal approximation and percentile-rank methods (Mooney and Duval 1993).

## RESULTS

### Ponderosa Pine Fire Regimes

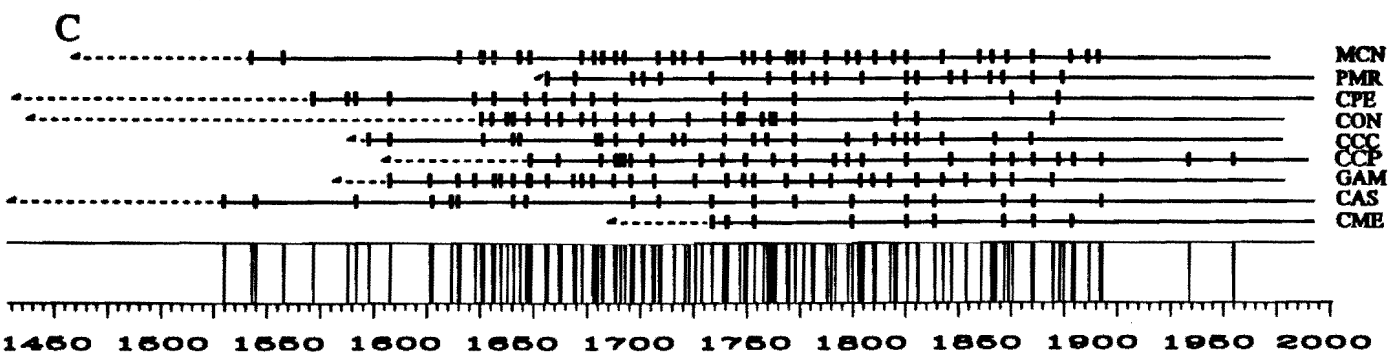
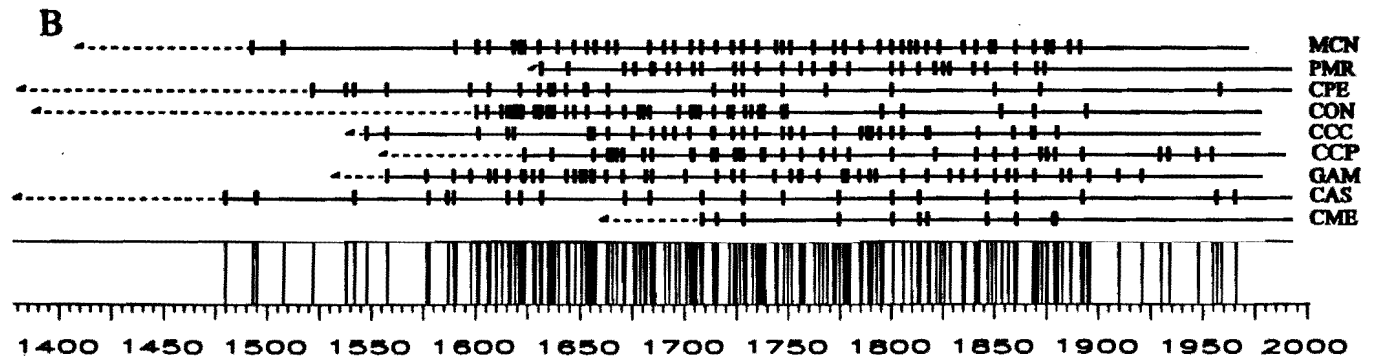
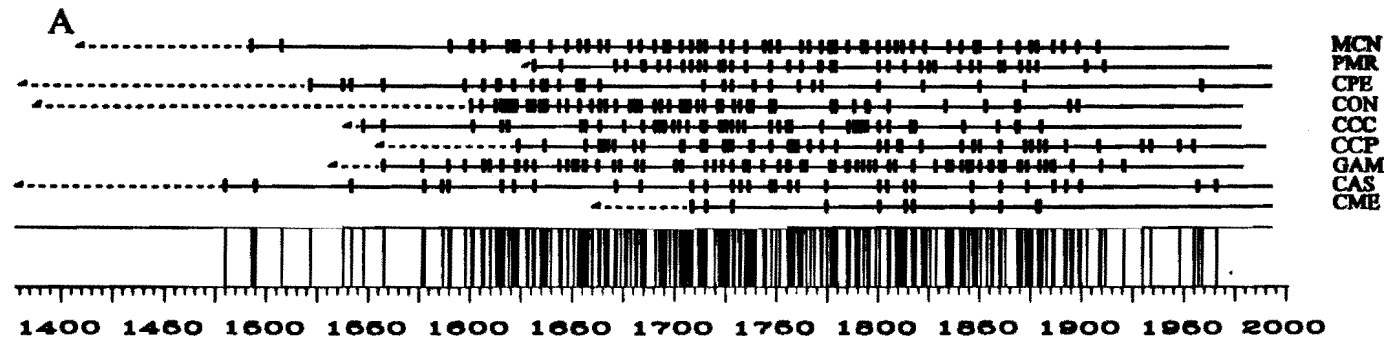
The fire-scarred samples in the ponderosa pine and transitional forests contained abundant and well preserved fire history records. We identified 1,652 fire events representing 383 separate fire years between AD 1380 and 1993 (Figure 3, Table 2). The average, maximum, and minimum number of fire scars per tree was 8, 28, and 1 respectively. Long-lived specimens extended the record to more than 600 years before present in a few sites, but most of the samples began consistently recording fires after about AD 1600. Major widespread surface fires ceased after the 1890s.

The pre-1900 WMPI varied at each site for the three different percentage scarred classes were examined (Table 3). For example, the WMPI for major fire years (at least 10% of the trees scarred) ranged from 6.5 to 22.1 years. At CME and CAS the WMPI values for major fire years were much higher than at the other ponderosa pine sites.

Fire intervals varied considerably among the sites. The minimum fire intervals (Min. FI) for major fires ranged from 1 to 12 years (Table 3). The maximum fire intervals (Max. FI) for major fires ranged from 16 to 51 years. Unusually long maximum fire intervals were recorded at CPE and CON during the 18th and 19th centuries.

The WMPI for all fires, regardless of percentage of trees scarred, was slightly lower in most cases than the MFI values derived from the arithmetic mean (Table 3). The MFI overestimate was due to a few longer fire intervals, which skew the distribution (Grissino-Mayer *et al.* 1994). During the pre-settlement period, the differences between the MFI and the WMPI for major fire events ranged from zero (i.e., no difference) at CAS to 3.9 years at CPE. Most of

Figure 3. Composite fire history chart for A all fires, B at least 10% of trees scarred, and C at least 25% trees scarred for the ponderosa pine and transitional forests. Horizontal lines are maximum life span of trees within each site. Vertical lines are composite fire dates recorded by the trees within each site.



LEGEND	
	Fire Scar
∇	Other Injury
T	Pith Date
▲	Inner Date
△	Outer Date
↓	Bark Date
-	Recorder Years
-	Null Years

Table 3.

Summary of fire interval statistics for different sites in the Jemez Mountains for the period of reliability. Weibull median probability interval (WMPI), Mean Fire Interval (MFI), Standard deviation (STD), and maximum and minimum fire interval for all trees scarred and at least 10%, and 25% of all trees scarred. All values are expressed in years. Sites are listed by forest type (PIPO = ponderosa pine, PIPO/MC = ponderosa pine/mixed conifer, MC/PIPO= mixed conifer/ponderosa pine, MC = mixed conifer, and PIAR= Bristlecone pine).

Site Name (Veg. Type)	Site Code	WMPI			MFI			STD			Max. Fire Interval			Min. Fire Interval		
		All Fires	10% Trees Scarred	25% Trees Scarred	All Fires	10% Trees Scarred	25% Trees Scarred	All Fires	10% Trees Scarred	25% Trees Scarred	All Fires	10% Trees Scarred	25% Trees Scarred	All Fires	10% Trees Scarred	25% Trees Scarred
Monument Canyon Natural Area (PIPO)	MCN	5.4	6.5	8.1	5.5	6.6	8.4	2.5	2.9	4.3	12	16	18	1	2	3
Pajarito Mountain Ridge (PIPO)	PMR	5.6	7.0	13.0	6.1	7.6	13.6	4.0	4.7	6.9	21	21	27	1	1	5
Cerro Pedernal (PIPO)	CPE	8.8	12.3	20.1	11.5	16.2	22.9	11.5	15.2	17.8	51	51	53	1	1	9
Continental Divide (PIPO)	CON	4.7	6.9	11.3	6.2	9.8	15.4	6.8	12.7	18.0	28	48	64	1	2	2
Clear Creek Campground (PIPO)	CCC	4.3	7.2	12.6	5.6	8.2	13.1	5.5	5.6	6.5	24	24	25	1	1	5
Capulin Canyon (PIPO/MC)	CCP	5.4	6.8	10.6	6.5	8.2	11.5	5.3	6.2	6.4	21	21	23	1	1	2
Gallina Mesa (PIPO/MC)	GAM	4.6	7.5	11.5	5.0	8.0	11.5	3.4	4.2	4.0	16	16	19	1	1	5
Cañada Bonito South (PIPO/MC)	CAS	9.8	22.1	22.1	11.1	22.1	22.1	7.8	7.7	7.7	29	33	33	2	12	12
Camp May East (PIPO/MC)	CME	17.1	17.1	20.0	18.9	18.9	21.3	13.0	13.0	13.0	46	46	46	4	4	7
Los Griegos Mountain (MC/PIPO)	LOG	12.9	12.9	16.3	15.2	15.2	20.7	9.7	9.7	13.4	33	33	45	1	1	1
Pajarito Mountain North-East (MC)	PME	9.7	9.7	19.9	11.1	11.1	19.5	8.1	8.1	4.7	22	22	25	3	3	14
Pajarito Mountain North-West (MC)	PMW	12.6	12.6	10.0	12.7	12.7	10.0	6.1	6.1	5.7	18	18	14	6	6	6
Camp May North (MC)	CMN	10.2	10.2	16.0	10.7	10.7	16.0	7.0	7.0	2.8	18	18	18	4	4	14
Cañada Bonito North (MC)	CAN	14.0	14.0	20.4	15.3	15.3	20.0	10.1	10.1	5.6	32	32	25	4	4	14
Round Mountain (PIAR)	ROM	27.5	28.0	86.5	29.3	32.6	97.7	17.2	29.9	72.3	58	105	166	9	9	22

the differences were between 1 and 2 years. Thus, although WMPI was a more statistically robust estimation of central tendency, it only differed appreciably from MFI when the distributions were highly skewed.

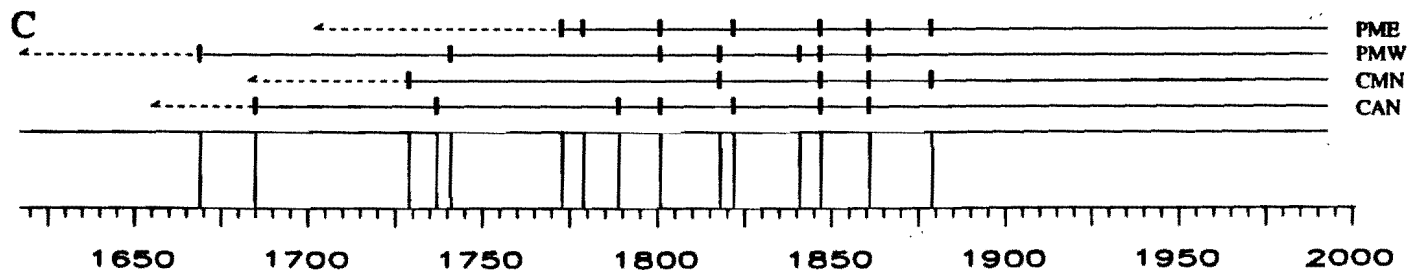
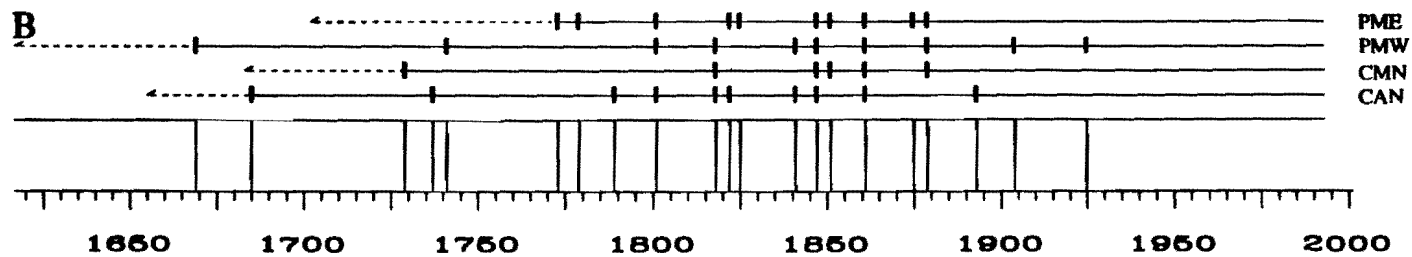
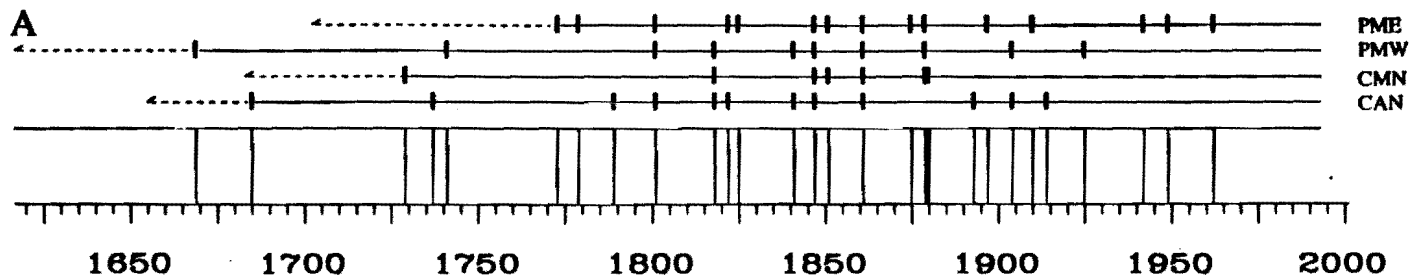
### Mixed-Conifer Fire Regimes

Samples collected from the mixed-conifer sites were not as well preserved as the samples from the ponderosa pine sites. For example, at Cañada Bonito North (CAN), 33 fire-scarred samples were collected, but due to advanced decay five samples could not be dated. Most of these samples were fire-scarred Douglas-fir and white fir, which were generally less resinous than ponderosa pine and seemed to have decayed more rapidly following scarring. The composite of master fire chronologies for the four sites yielded a total of 113 individual fire scars representing 44 separate fire years from AD 1617 to 1993 (Figure 4).

The mixed-conifer sites yielded a shorter tree-ring record than the ponderosa pine sites, extending to a maximum of 377 years before present *versus* over 600 years at some ponderosa pine sites (Table 2). Moreover, the period of reliability was relatively short for all of the mixed-conifer sites, ranging from only 38 years to 92 years, *versus* over 200 years for most ponderosa pine sites.

The pre-1900 WMPI for major fire events (at least 10% of trees scarred) ranged from 9.7 to 14 years (Table 3). The Max. FI and Min. FI for all percentage classes varied between sites. The Max. FI for major fire events ranged from 18 to 32 years. The Min. FI for major fire events ranged from 4 to 6 years. Although samples were obtained at the Los Griegos site results will not be included here because we believe the sample depth was too low to derive accurate or

Figure 4. Composite fire history chart for A all fires, B at least 10% of trees scarred, and C at least 25% trees scarred for the mixed-conifer forests. Horizontal lines are maximum life span of trees within each site. Vertical lines are composite fire dates recorded by the trees within each site.



LEGEND	
┆	Fire Scar
▼	Other Injury
┆	Pith Date
←	Inner Date
→	Outer Date
┆	Bark Date
—	Recorder Years
---	Null Years

complete estimates of fire regime variations. Additional samples are needed from this site.

#### Bristlecone Pine Fire Regime:

The collected samples from this site were well preserved and long-lived. We developed an incomplete fire record that extends approximately 600 years before present, and 1,110 years before present in one of the seven samples (Table 2 and 3). This is one of the oldest stands of living trees in the Southwest (Swetnam and Brown 1992). The oldest tree (ROM7) had an inside date of AD 843 and an outside date was AD 1953. The number of fire-scars for individual trees was low (Appendix B15). One tree recorded one fire event, and two trees recorded three fire events. Some samples recorded additional unspecified injuries after the fire event. This may be because trees in high elevation sites are more susceptible to climatic events (frost, sun scalding, etc.) after a fire event. Fire-scar dates were not synchronous among most trees except for the 1873 fire. This may be because the sample depth is very low. Therefore, The results from this site will not be discussed in this report. More samples would help us to document the fire history in this bristlecone pine site. In addition, a new collection effort would enable us to maximize the length of tree-ring records by selecting the oldest trees which contain more information on past variations in rainfall, temperature, forest fires, and many other aspects of the past environment.

### Aspen Age Distributions

The age distributions for the sampled quaking aspen showed tree recruitment occurred sporadically from 1795 to 1918, but most of the regeneration was concentrated in the period between 1850 to 1910 (Figure 5). Some recruitment episodes correspond to fire dates obtained near the stands, but others do not. We hypothesize that most recruitment episodes in the late 1800's correspond to relatively intense, patchy, stand opening fires.

### Seasonality of Past Fires

We determined intra-ring position for 66.5 percent of the scars examined from the 15 sites (including the sub-sites) in northern New Mexico (Figure 6). The 33.5 percent were not classified because of decayed wood, insect damage (e.g., beetles galleries), or narrowness of the rings in the scar area. Of the classified scars, 27.4 percent were identified as dormant season scars, 33.5 percent were identified as early-earlywood scars, 27.1 percent were identified as mid-earlywood scars, 11.2 percent were identified as late-earlywood scars, and 0.8 percent were identified as latewood scars. Based upon these position data and recent observations of cambial phenology in the Jemez Mountains (Allen, unpublished data on file at Bandelier National Monument), we believe that the peak burning period extended from about mid-April to early July. This interpretation of the seasonal timing of past fires corresponds closely to modern monthly patterns of lightning fire ignition in this area (Barrows 1978).

Figure 5. Distribution of estimated aspen ages. Fire events are indicated with vertical arrows.

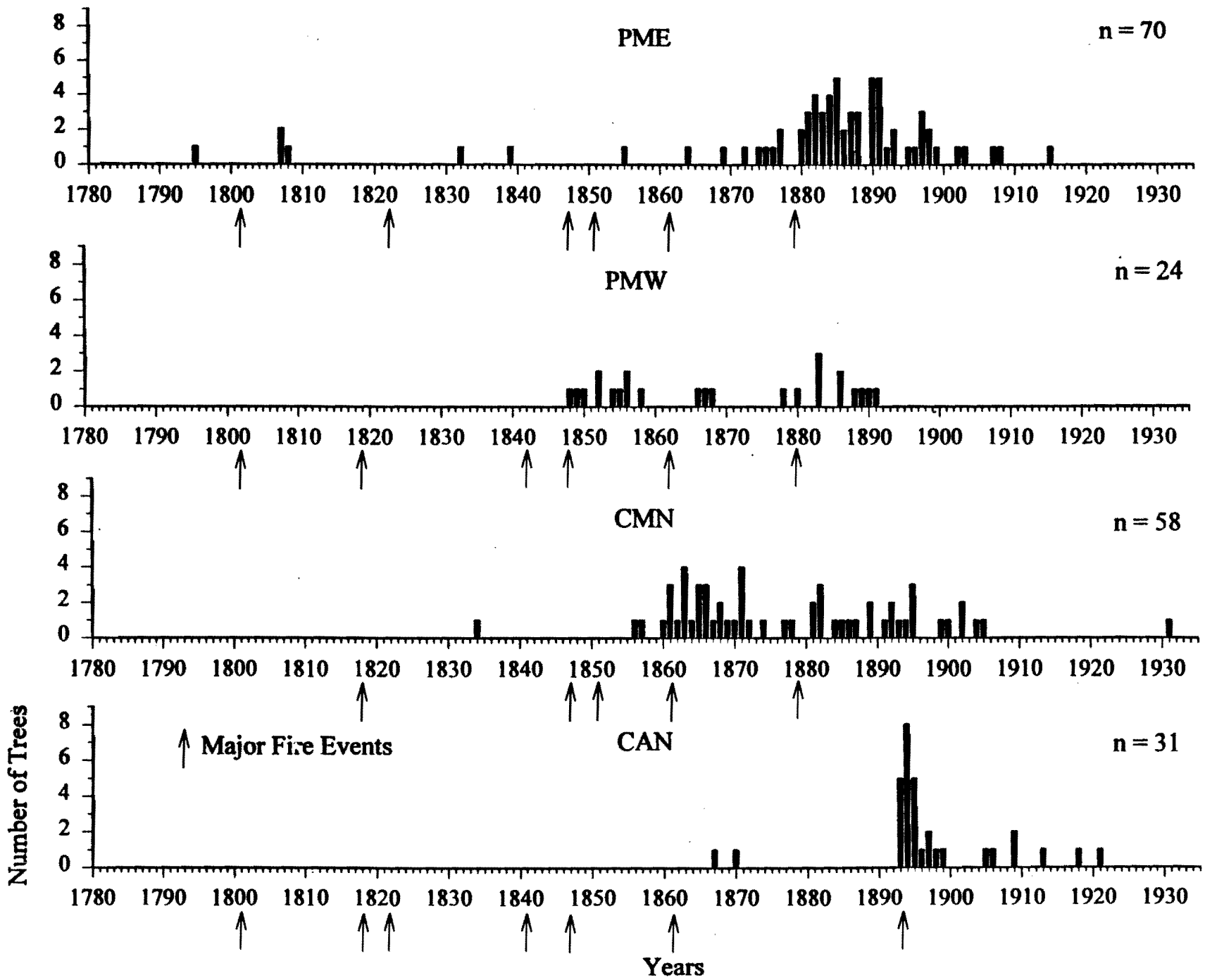
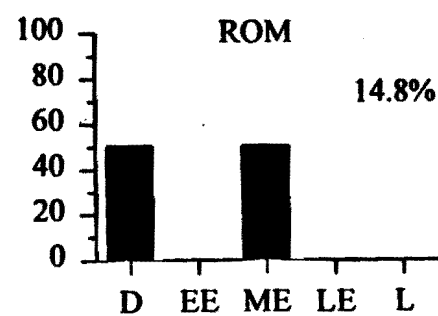
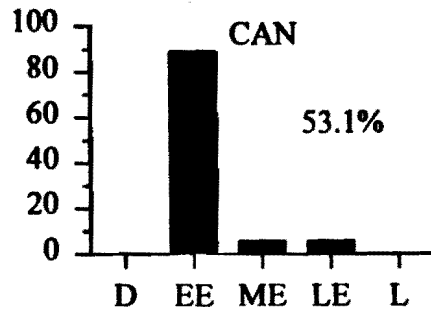
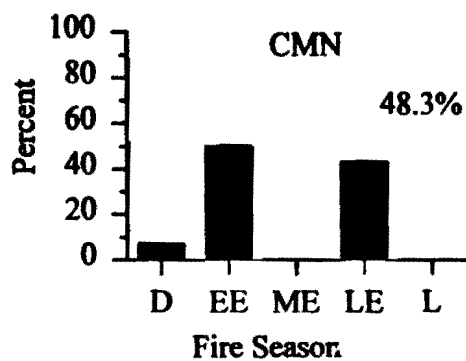
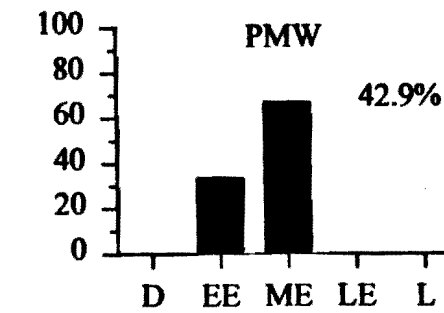
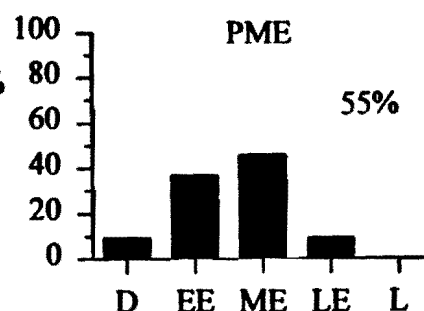
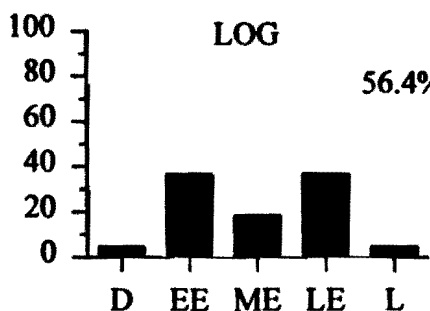
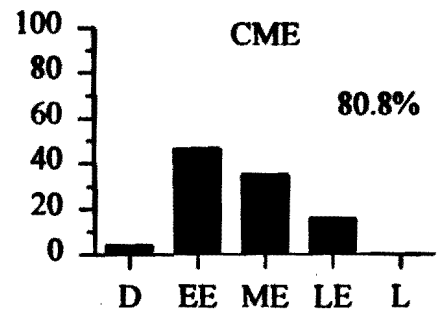
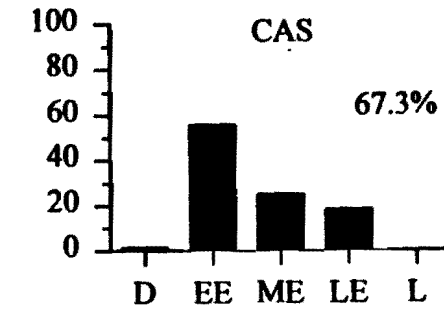
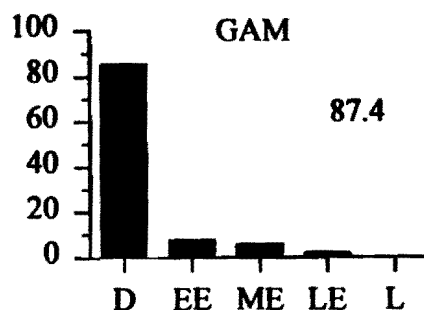
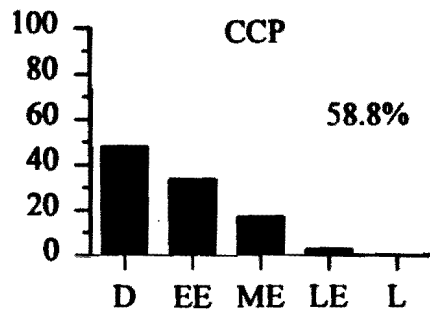
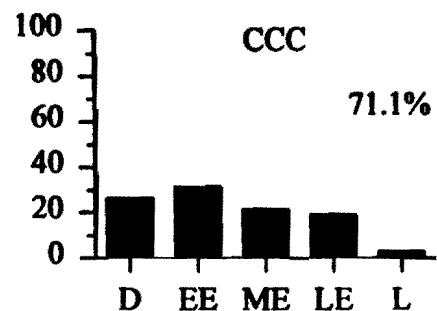
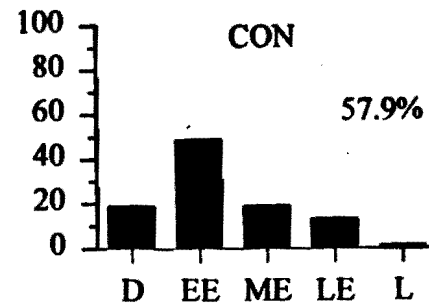
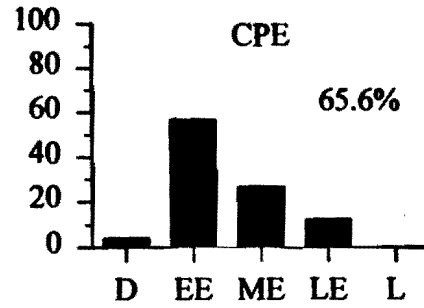
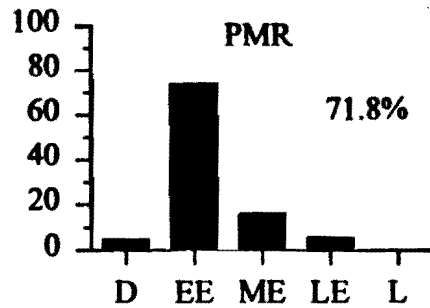
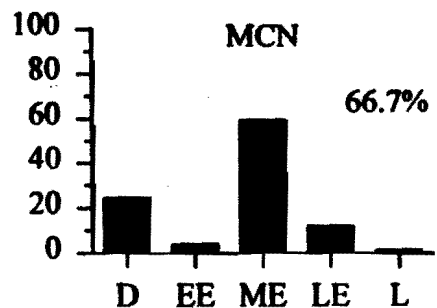


Figure 6. Distribution of fire-scar positions within annual rings for 1,109 fire scars. Percentages are amount of fire scars successfully classified in each site.



Fire Season

## Dendroclimatic Reconstruction

The final regression obtained between the transformed tree-ring data (predictors) and precipitation (predictand) was highly significant ( $F = 25.5$ ,  $p < 0.0001$ ). The predictor variables accounted for 63% (adjusted for loss of degrees of freedom) of the variance in the precipitation data. Parameter estimates derived from the final equation and their associated probabilities are listed in Table 4, while the relationships between actual and predicted values from 1896 to 1986 are shown in Figure 7. All verification statistics were highly significant. The correlation between predicted and the actual precipitation values was 0.65 ( $p < 0.05$ ), The RE statistic was 0.25 ( $p < 0.05$ , and the product-means test had a t-value of 6.3 ( $p < 0.05$ ) (Table 5). The regression equation was therefore deemed appropriate for reconstruction back to AD 1653. In comparison with other dendroclimatic reconstructions from the Southwest (e.g. Fritts 1991) these statistical results are considered excellent.

## Fire-Climate Analyses

The superposed epoch analysis revealed that both mixed-conifer and the ponderosa pine forest types exhibited significantly negative (dry) mean winter-spring precipitation departures during fire years (Figure 8). For example, in the mixed-conifer forests the mean precipitation departure during the fire years was -1.48 inches; in the ponderosa pine forests the mean precipitation departure during the fire year was -1.07 inches. In the ponderosa pine forests, the second and the third years prior to the fire year were noticeably wet, with the third year significantly wetter than normal at the 95% confidence level.

**Table 4. Regression coefficients for predicting December through June precipitation for northern New Mexico with an adjusted  $R^2=0.63$ ,  $F=25.54$ , and  $\text{Prob}>F=0.0001$**

Variable	DF	Parameter Estimate	Standard Error	T for Ho: Parameter=0	Prob> T
Intercept	1	6.873854	0.21553177	31.893	0.0001
Factor 1	1	1.497215	0.18846181	7.944	0.0001
Factor 4	1	0.788854	0.26322667	2.997	0.0046
Factor 7	1	-1.039552	0.27672256	-3.757	0.0005

**Table 5. Verification statistics for regression model for the period 1896-1940**

Correlation	Reduction of Error(RE)	T-Value
0.6488	0.2466	6.2926

All values are significant at the 0.05 level.

Figure 7. Comparison between actual and estimated December through June precipitation for northern New Mexico from AD 1896-1986.

Jemez and Sangre de Cristo Mountains, New Mexico

PPT Reconstruction from Ponderosa Pine

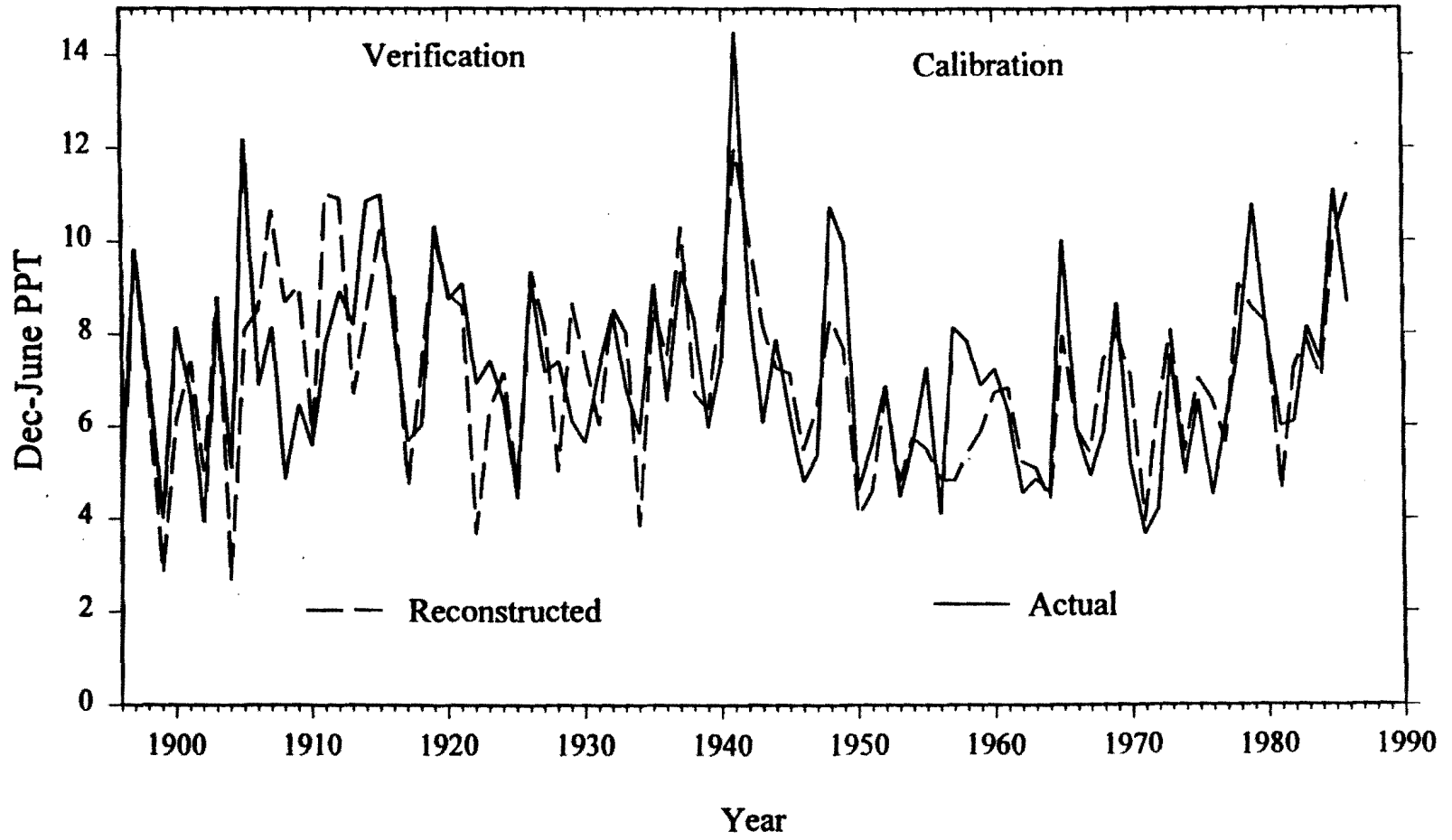
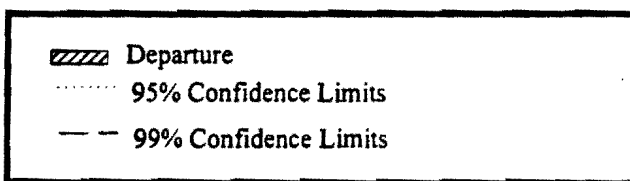
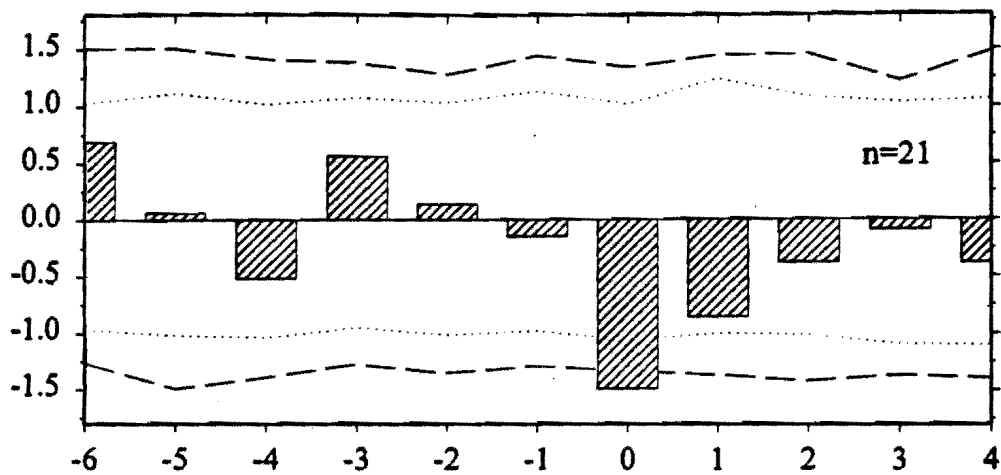
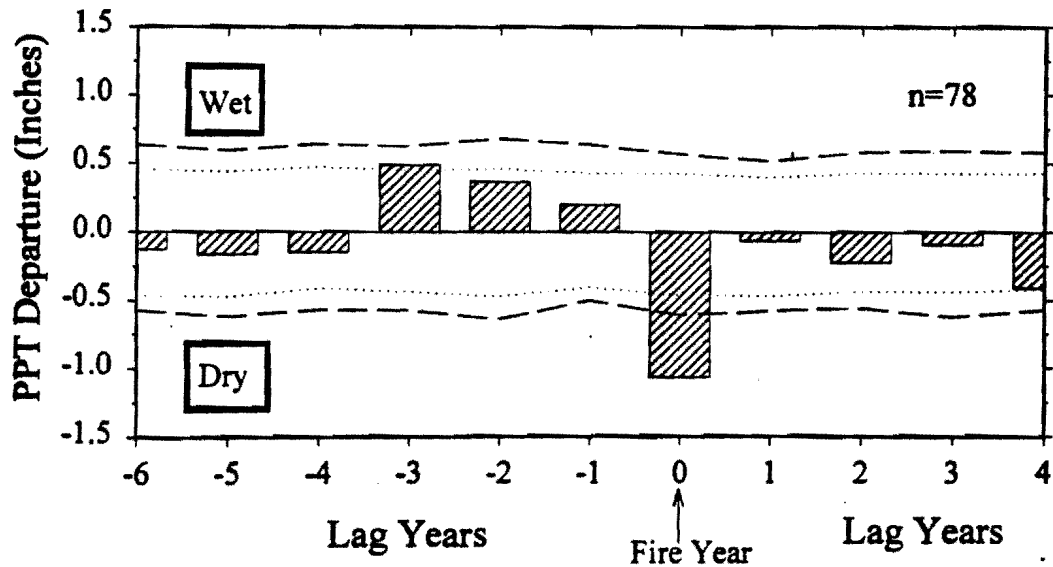


Figure 8. The superposed-epoch analysis for both the mixed-conifer (all fire dates) and the ponderosa pine forests (fire dates based on at least 10% trees scarred) for the period 1653-1986. The precipitation time series used was based on a tree-ring reconstruction of December-June precipitation. Departures were computed as the difference between the long-term mean precipitation level (1653-1986) and the observed mean precipitation during the fire years and lagged years. The "n" value is the number of fire years used the calculations.

### Mixed-Conifer Forest



### Ponderosa Pine Forest



## DISCUSSION

Prior to 1900, fire regimes in ponderosa pine forests were characterized by high frequency, low intensity surface fires (Figure 9 and 10). At the ponderosa pine sites, the WMPIs for major fire years generally falls within the range found in other Southwestern ponderosa pine forests (6.5 to 22.1 years, Table 3) which ranged from about 6 to 21 years (Swetnam and Baisan - in press).

Variations in fire intervals between sites and through time were probably due to differences in topographic situation, site-specific histories of intensive livestock grazing, and climatic variability (Figure 10). Each of these factors are discussed below.

The CON sub-sites all show high fire frequency in the 1600's and early 1700's, with a clear reduction in fire frequency after 1752 and early cessation of major fires (Figure 3). These early reductions in fire frequency could be due to early sheep grazing by Navajo communities at CON (Touchan *et. al* - in press). Intensive livestock grazing removes grasses and herbs necessary for the spread of fire in high frequency fire regimes. Trails created by the herding of animals would also disrupt fuel continuity, and hence fire spread patterns. Baydo (1970) and Bailey (1980) reported that early grazing of sheep and other livestock by the Navajo began in northern New Mexico in the mid 18th century. Savage and Swetnam (1991) documented an early decline in fire frequency beginning around the mid 1800s in ponderosa pine forests in the Chuska Mountains of Arizona (about 195 km to the east of the Jemez Mountains), and hypothesized that this change in fire regime was due to the rise of intensive sheep herding by the Navajo in this area.

Figure 9. Fire frequency (number of fires/period, based on all fires date) for both (A) mixed-conifer and (B) ponderosa pine forests. Moving periods of 50 and 20-years length were used for computing the fire frequencies and are plotted on the central year of the moving period. Decline in frequency before ca. 1700 in A and Ca. 1600 in B is due primarily to decreasing number of sampled trees before these times.

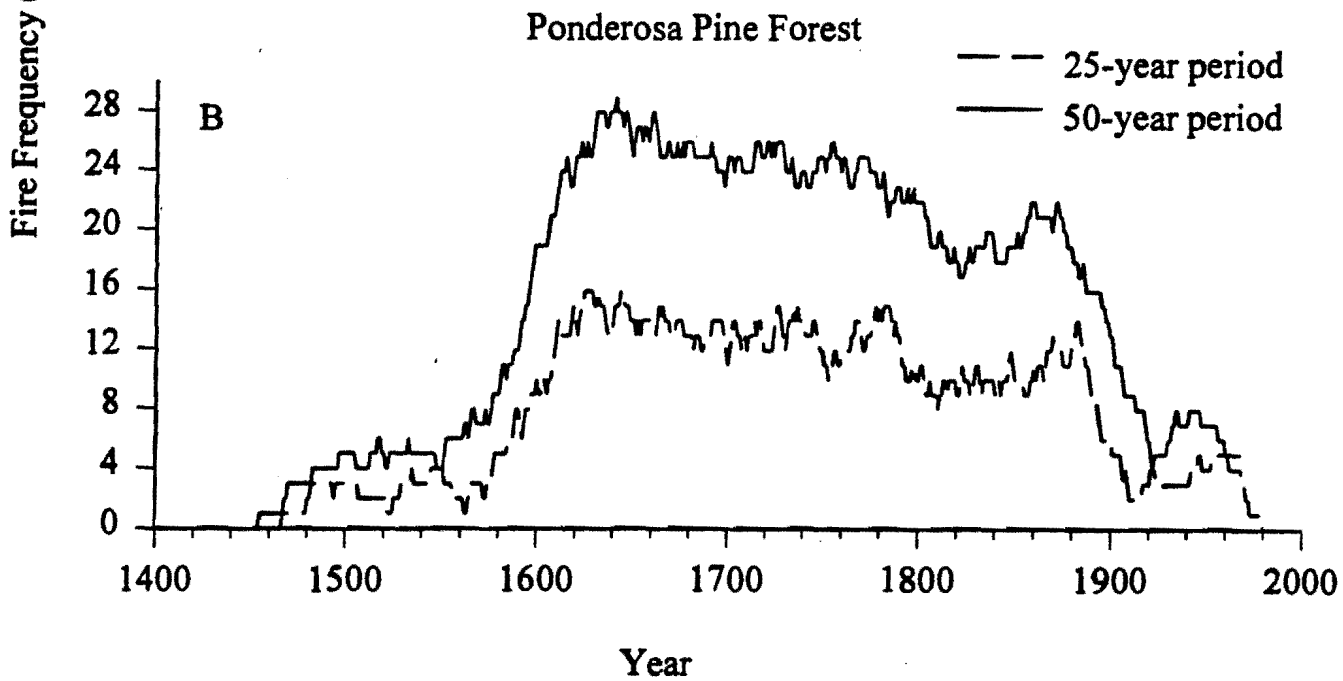
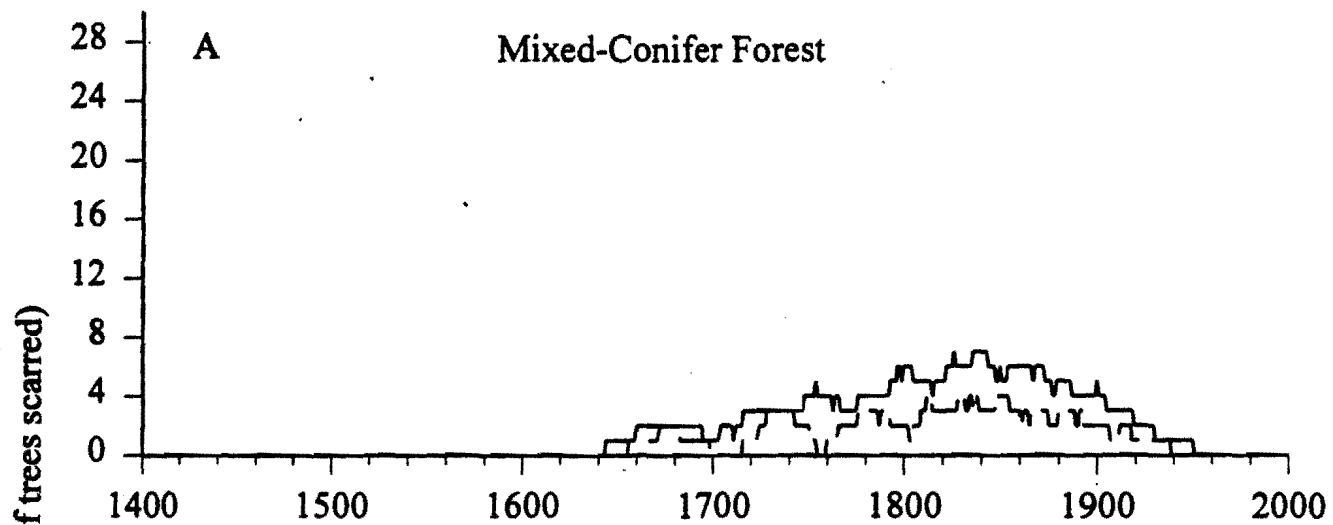
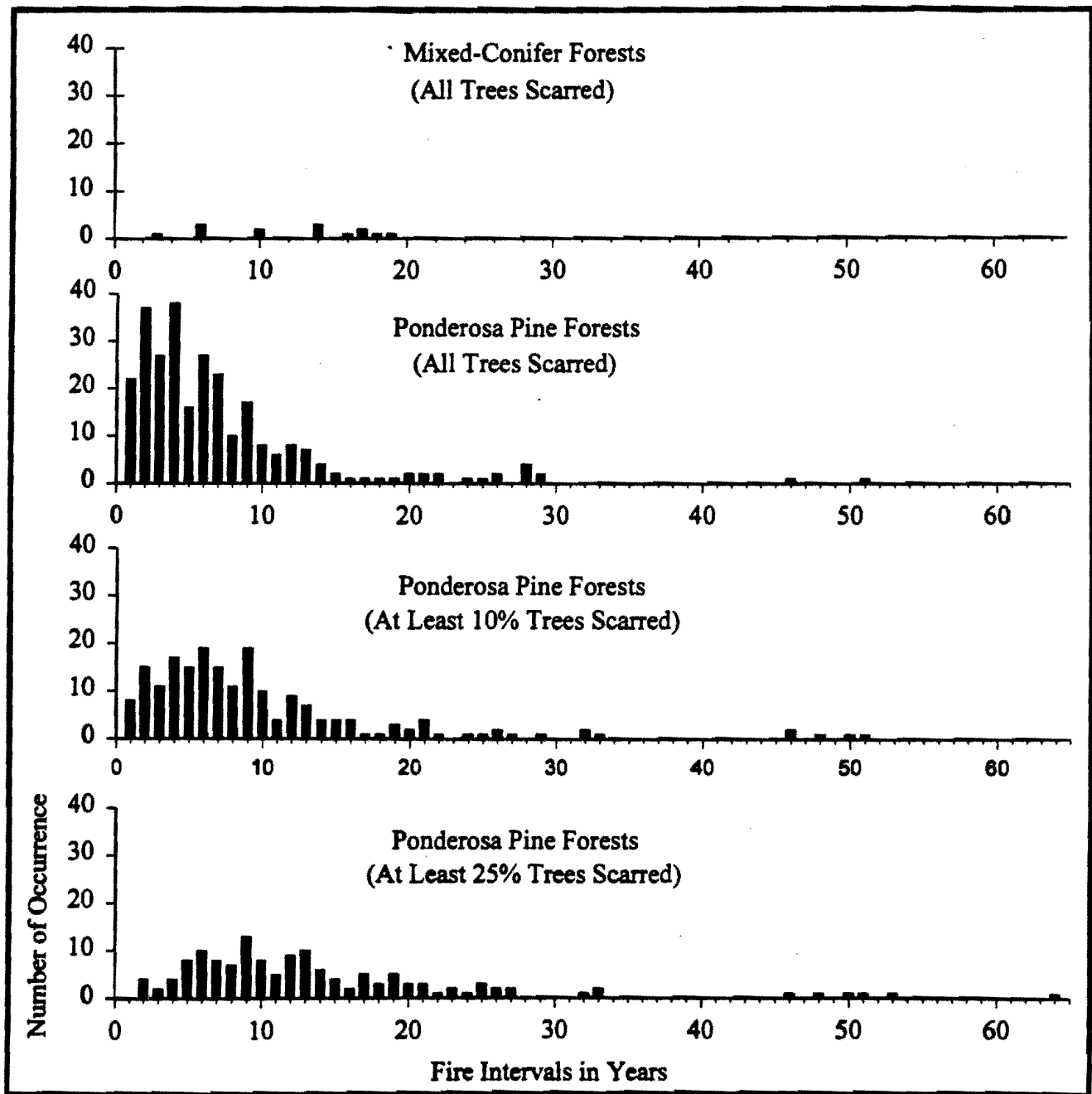


Figure 10. Distribution of fire intervals for mixed-conifer forests (all fires) and ponderosa pine forests (all fires and at least 10% and 25% of all trees scarred).



The Cerro Pedernal site (CPE) also sustained high frequency fire regimes during most of the 1600s and early 1700s. An obvious reduction in fire frequency occurred after 1748 and a complete cessation of major fires by 1873 (Figure 3). Portions of the CPE area were grazed by Hispanic/genizaro peoples since the 1720s, and the initial Spanish land grant for Cañones (immediately northeast of CPE) was established in 1731 (Van Ness 1987). These lines of evidence suggest Hispanic grazing practices might have caused the reduction in fire frequency which is apparent after ca. 1748 in this area.

CPE sustained an unusually long, 51-year gap without any recorded fires between 1664 and 1715. This long fire interval may be due to utilization of the CPE area for livestock husbandry and fuelwood gathering by Tewa Native Americans during the unsettled years immediately before and after the 1680 Pueblo Revolt, as indicated by Piedra Lumbre phase archeological sites in the adjoining Chama River Valley (Wosniak 1992, Kermer 1992) and historic documentation of Tewa puebloans taking refuge from the Spanish reconquest in 1696-1697 "at the foot of Cerro de los Pedernals" (Wozniak 1992:59-60). Potential explanations for this odd, long fire interval must remain speculative until additional historical information and comparative fire history data are gathered and analyzed for this locality.

The CAS and CME sites had much lower fire frequencies than the other ponderosa pine sites, and their Max. and Min. FI's were also relatively high (Table 3). Both stands were at relatively high elevations and were partially isolated by unvegetated, steep, rocky cliffs. The adjoining north-facing slopes of these two mountains are quite mesic and are dominated by mixed-conifer forests, which had somewhat lower fire frequencies than most ponderosa pine forests. Consequently, we suggest that topographic isolation from more extensive ponderosa

pine stands (and their spreading fires), combined with the lower frequency of fire in the mixed-conifer forests on the adjoining north-facing slopes, led to lowered fire frequencies with these two sites.

There was a clear cessation in widespread fire occurrence at all sites after ca. 1893 (Figure 3). The end of the frequent and extensive fires coincided with the onset of the documented period of intensive livestock grazing across northern New Mexico (Wootton 1908, Allen 1989:145-148), which reduced the continuity of herbaceous fine fuels (e.g., grasses) and hence the ability of fires to spread. Because the buildup of livestock numbers in the late 1800s was also a regional phenomenon, concurrent and similarly sharp declines in fire frequency were documented in most other southwestern fire-scar studies (Weaver 1951, Dieterich 1980, Allen 1989, Swetnam 1990, Swetnam and Baisan - in press). However, fire histories show earlier cessation of fires at sites with earlier periods of intense grazing (e.g. Savage and Swetnam 1991, Touchan *et al.* 1993), and conversely high frequency fire regimes have persisted well into the 20th Century at a few sites where grazing and fire suppression were limited (e.g., Dieterich 1983, Baisan and Swetnam 1995, and Grissino-Mayer and Swetnam - in press).

Another factor that could have been important in the decline of fire occurrence after the late 1800s was the change in the climate conditions after ca. 1875. Our climate reconstruction, which will be discussed later in this report, indicates that a very wet period occurred from 1875 to 1930. Therefore, intensive grazing and this decadal climatic shift could have been complementary factors that caused the initial decline in fire frequency. By the 1920s the US Forest Service had established an efficient fire detection and suppression organization in northern New Mexico (Allen 1984).

Our results indicate that fire during the pre-settlement period was less usually frequent in the mesic mixed-conifer forests in the Jemez Mountains than in the ponderosa pine forests (Figure 9). This conforms to expectations that pre-settlement fire frequency decreased with increasing elevation due to the cooler and wetter conditions that prevail at higher elevations (Wright and Bailey 1982). Although this general pattern was observed, fire frequencies for major fires in the Jemez mixed-conifer forests varied considerably between sites. Overall, the range of variation was similar to that found in other southwestern mixed-conifer forests where the MFIs were estimated to vary between about 7 and 22 years (Dieterich 1983; Ahlstrand 1980; Baisan and Swetnam 1990). However, Grissino-Mayer *et al.* (1994) have recently reported that the MFI on Mount Graham in the Pinaleños Mountains in southeastern Arizona (3,267 m), was considerably lower than in other mixed-conifer forests (the WMPI for at least 25% of all trees scarred was 8.7 years). This indicates that large variability in past fire regimes existed among mixed-conifer forests in the Southwest and that a linear model of fire frequency variation as a function of elevation is too simplistic.

Our results for the age structure of aspen stands in Jemez Mountains mesic mixed-conifer forests suggests that major episodes of aspen regeneration were the result of patchy crown fires, particularly in the late 1800s. For example, at CAN a pulse of aspen regeneration in the 1890s suggests that the widespread 1893 fire recorded in the adjacent forest probably crowned across much of this slope (Figure 5). Other fire dates recorded on nearby conifer trees do not obviously correspond temporally with recruitment surges. We conclude that a combination of surface and crown fires occurred in these mixed-conifer forests. A large proportion of existing aspen stands in the Los Alamos area originated from intense fires in the late 1800s, but, smaller patches and

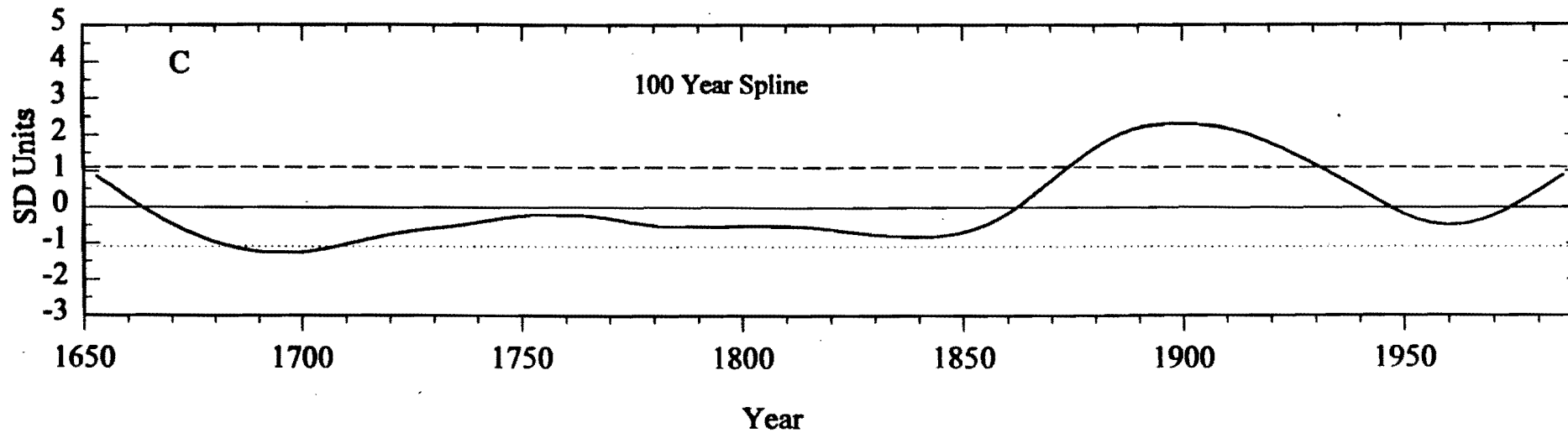
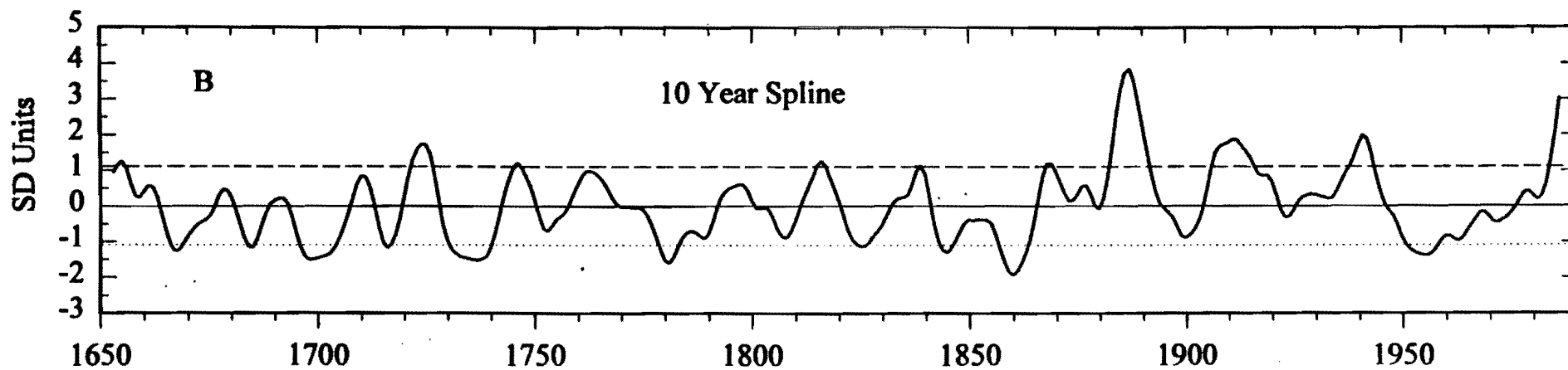
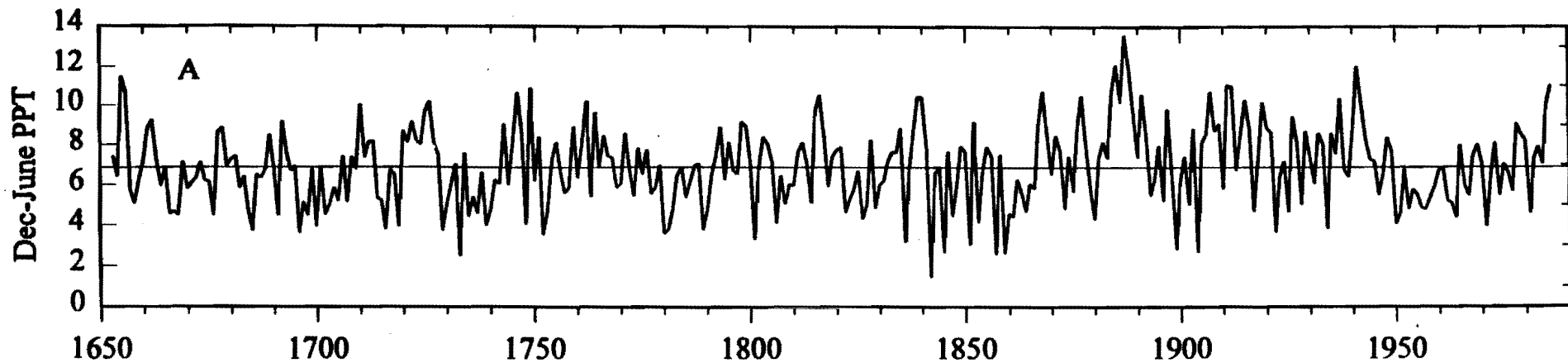
older individuals and stands probably developed from more localized burns.

During the past century, both the ponderosa pine and mesic mixed-conifer forests throughout the Southwest sustained changes in species composition and stand structure. For example, changes in the ponderosa pine forest include the formation of dog-hair thickets, decreased understory cover, and increased fuel-loading (Covington and Moore 1994). Evidence of such changes are very obvious at the MCN site (Moir and Dieterich 1988). These changes are most likely a result of natural and anthropogenic factors such as grazing, good seed crop years, and fire suppression (deBuys 1985; Carlson 1969; Allen 1989; Touchan *et al.*, in press). In the mesic mixed-conifer forests, these anthropogenic changes have favored the establishment of the shade tolerant, less fire resistant white fir within many portions of these stands (Allen 1984:70-75). As in ponderosa pine forests, fire suppression accompanied with a very wet period over the past century has allowed the development of a densely stocked, younger, understory ("doghair thickets") that would previously have been thinned by repeated surface fires (Harrington and Sackett 1990). These changes in forest structure and species composition have increased the probability of high intensity fires. In addition, these structural changes have probably resulted in other kinds of disturbance regime changes in the Jemez Mountains, such as increased synchrony and severity of regional spruce budworm outbreaks (Swetnam and Lynch 1993).

### Dendroclimatic Reconstruction

To evaluate the most severe of the short-term droughts, we converted yearly values obtained from 10-year and 100-year splines fit through the reconstruction into standard deviation units by first subtracting the series mean then dividing by the standard deviation (Figure 11).

Figure 11. Variations in tree-ring based reconstruction of precipitation. Curve A shows the annual values of the final reconstruction for December-June precipitation for the period from 1653-1986. Curve B shows a 10-yr cubic spline fit through the reconstruction to emphasize short-term decadal-scale climate episodes. Curve C represents 100-yr spline fit through the reconstruction to emphasize the long-term climate episodes.



Following Dean (1988) we identified extreme drought or wet periods as those that surpassed the -1.1 or 1.1 standard deviation threshold levels.

A multi-century period of winter-spring below average rainfall occurred during the period between 1674-1862. Grissino-Mayer (in press) found evidence in western-central New Mexico for a long term trend of below average rainfall that began ca. 1400 and lasted to 1790. Although this period was interrupted by single years and sub-decadal periods of increased moisture, overall it was the longest multidecadal dry period in the past 1,000 years (Grissino-Mayer in press).

Our climate reconstruction showed nine short-term droughts during 1666-1669, 1684-1685, 1696-1704, 1716-1717, 1731-1740, 1779-1783, 1824-1827, 1857-1863, and 1951-1958. It also showed seven short very wet periods during 1722-1726, 1745-1746, 1815-1817, 1883-1891, 1906-1916, and 1938-1943. The wettest period in our reconstruction was between 1883-1891.

Many recent tree-ring studies have identified relations between tree growth and ENSO (El Niño-Southern Oscillation), particularly between wetness caused by El Niño events (Lough and Fritts 1985, D'Arrigo and Jacoby 1991, Stahle and Cleaveland 1993). We compared the frequency of El Niños during 1883-1891 to other periods using Quinn and Neal's (1992) list of events derived from archive documents. The number of El Niño events of this period was not different from other ten year periods, and in some cases it was lower. We also compared the same period to Grissino-Mayer's (in press) reconstruction and found that the surge of high growth in our reconstruction was not obvious in his reconstruction. Furthermore, we compared our reconstruction to both the Santa Fe and Wolf Canyon winter-spring precipitation data back to 1850. According to these data this period was not especially wet, therefore, these results do not

give unequivocal indication that a decadal-scale climate shift was responsible for the enhanced growth during the period of 1883-1891. Further investigation is needed to determine what climatic factors may have contributed to this period of high reconstructed precipitation.

An alternative hypothesis to a climatic cause, is that the high values in 1880s tree growth were due to indirect effects caused by intense livestock grazing. These indirect effects could have operated through grazing induced changes in nutrient dynamics and water balance in the ponderosa pine forests that we sampled for developing the tree-ring width chronologies. The high intensity of grazing by sheep and cattle in the mid-1800s certainly caused a decline in the grass cover, and probably reduced the competition for soil moisture and nutrients between grasses and the overstory. These conditions may have allowed the trees access to more nutrients and water, thus allowing the trees to grow more vigorously. Following the initial pulse of herbage-derived nutrients into the soils and recruitment of new tree seedlings into the understories in the early 1900s, declines in tree growth may have occurred due to increased nutrient and moisture competition.

Archer (1994) reported that reductions in leaf area, root biomass and root activity associated with livestock grazing can increase surficial soil moisture. Increased surficial soil moisture encourages the establishment and growth of woody seedlings characterized by shallow roots. It also increases the depth of water penetration and improves both the conditions of the established woody species with deep root systems, and the nutrient availability to the woody vegetation. The increase in nutrient availability could result from the following: input from dung and urine (Archer and Smeins (1991) or enhanced microbial activity combined with higher soil temperature and moisture (Parton and Risser 1980). Furthermore, Archer (1994),

Archer and Smeins (1991), Madany and West (1983), and Wright (1974) considered livestock grazing to be a primary agent in the 20th century increase in forest density and extent, because grazing reduced the competition from grasses, thus allowing tree seedlings to establish.

#### Fire-Climate Analyses

Climatic variation has an important influence on fire regimes in the Southwestern United States. On a regional basis fires are more likely to occur in years of below average moisture. For example, the regional drought years of 1748 and 1879 show up repeatedly as fire dates in fire history studies across the Southwest (Swetnam 1990, Swetnam and Betancourt 1990, Swetnam and Baisan - in press). A factor that may play a role in regional fire occurrence is the influence of winter-spring precipitation on the accumulation and moisture content of the fuels. A dry spring may be followed by numerous lightning strikes at the onset of the summer precipitation season, which ignites accumulated, dry fuels (Baisan and Swetnam 1990). In contrast, wet springs result in high fuel moisture which may persist into the early fire season inhibiting fire spread.

In our study, we found that, during the pre-settlement era, the winter-spring season immediately preceding the fire season (late spring through summer) was significantly drier than normal in both the ponderosa pine and mixed-conifer forests (Figure 8). In ponderosa pine forests, winter-spring seasons several years prior to fires tended to have above average precipitation, but only the third year prior to the fire was statistically significant, i.e., wetter than average at the 95% confidence limit. This general pattern suggests that during wet years the build up of fine fuels is an important pre-condition for fire ignition and spread. This pattern has

also been observed in other mountain range-scale studies (Baisan and Swetnam 1990) and at the regional scale (Swetnam and Baisan- in press).

Our analysis of climate/fire relationships in mixed-conifer forests of the Jemez Mountains suggests that the winter-spring season immediately preceding the fire season was much drier than normal, but we found no significant relationships with preceding years (Figure 5) in contrast to ponderosa pine forests, fine fuel accumulation resulting from plant growth in preceding years was less important. A consequence of the normally mesic, relatively productive conditions and lower fire frequencies on north facing slopes is that fuel is usually available in the mixed-conifer forests. Therefore, we suggest that fuel moisture was the most important factor determining fire spread in these mesic forests. If fuels were dry enough, then there was a high probability of the spread of fire in this forest type.

An unusually long fire-free interval in the 1820's and 1830's occurred at almost all of the Jemez sites (Figure 2). A similar decrease in fire occurrence during approximately the same period has been noted in several other southwestern fire history studies (Swetnam 1983; Swetnam and Dieterich 1985; Swetnam *et al.* 1989; Baisan and Swetnam 1990; Grissino-Mayer *et al.* 1994). Swetnam and Dieterich (1985) hypothesized that the lack of fire during this period may have been due to regional climate changes during this period. Fritts' (1991) regional precipitation reconstruction for the western US shows that the 1830s was the wettest decade since 1602 A.D. Our winter-spring reconstruction for the Jemez Mountains showed that the four years from 1824 to 1827 was very dry, followed by a wet period in the 1830s. Grissino-Mayer *et al.* (1994) also found that a severe drought was followed by a very wet episode during the 1810s in southeastern Arizona. They hypothesized that this drought resulted in a decline in the

herbaceous vegetation, and that the average to wet conditions that followed reduced both successful ignitions and the spread of fire. Hence, a combination of extreme drought followed by a wet episode is one plausible explanation of this regional scale, anomalously long fire-free interval. The extensiveness of this pattern across the Southwest also argues for a climatic, rather than an anthropogenic explanation.

### CONCLUSIONS

Our data show that pre-1900 fire regimes in ponderosa pine forests were characterized by high frequency, low intensity fires. Fire regimes in the mixed-conifer forests were characterized by somewhat lower fire frequencies than in the ponderosa pine forest. Patchy crown fires within a matrix of surface fire also occurred during some years in the mixed-conifer forests. The site-to-site history and variability of fire documented in both the mixed-conifer and the ponderosa pine forest was probably caused by three main factors. First, intense livestock grazing, initially reduced fine fuels necessary for the spread of fire in the high frequency fire regimes. This historical factor was probably the initial cause of the alteration or elimination of surface fire regimes in the Jemez during the 1700s or late 1800s (depending on the site). Overall, one of the most important anthropogenic disturbances in the Jemez Mountains in the last century was organized fire suppression by land management agencies. Fire suppression allowed changes in species composition and stand structure in both the ponderosa pine and the mixed-conifer forests. Fire suppression resulted in both the build-up of dead woody and herbaceous fuels and the increase in living vegetation, such as the formation of densely overstocked understory pine thickets. These factors have also contributed to the decline of native grasses, due to the

increased shading and accumulation of thick mats of pine needle litter. If a policy of total fire suppression is continued, without other fuel treatment strategies, then further fuel buildups will occur in both forest types, threatening modern forests with high-intensity conflagrations such as the La Mesa Fire of 1977 (Foxy and Potter 1978).

Second, on a local scale, topography and moist north facing slopes played an important role in lowering the frequency of fire in some ponderosa pine sites. Hence, study shows that forest type and elevation were sometimes less important than topographic features in determining historic fire regimes. In particular, isolation of sites due to cliff and talus slopes or other barriers to fire spread may result in reduced fire frequency.

Third, on a regional scale, climate played an important role in the fire regimes in both the ponderosa pine and the mixed-conifer forests. Major fire years in both forest types tended to be significantly drier than normal. Moreover, our analysis of climate/fire relationships suggests that production of fine-textured surface fuels due to prior year wet conditions was important in controlling occurrence and spread of fires in ponderosa pine forests. Similar patterns have been observed in modern fire occurrence patterns; e.g., the 1994 fire season was particularly extensive in the southern portion of the Southwest. The summer of 1994 was dry and it followed three years of herbaceous and needle litter fuel buildup during the wet conditions of 1991, 1992, and 1993. In mixed-conifer forests fuel moisture was probably more important than fine fuel availability in determining fire occurrence. Unusually long intervals between fires in many sites across the Southwest could have been important in synchronizing forest structures across the region since these were probably periods when many trees successfully germinated and established.

This study provides a baseline for planning and justifying ecosystem management programs. For example, documentation and improved understanding of the pre-settlement fire regimes for specific areas can be used to justify and design the appropriate prescribed burning plan to affect ecosystem dynamics in a fashion similar to the natural fire regimes that sustained southwestern forests for many centuries. Such management plans may not be designed to strictly mimic the historical pre-settlement fire regime, but rather to meet ecological objectives by bringing the range of landscape processes and structures to within the historical, or "natural" range of variability. This natural range of conditions, as defined by the pre-settlement, historical patterns, may not be desirable or practical to achieve in some portions of forest landscapes. On the other hand, in many cases the natural range of variability is probably the best template we have for longer-term sustainable conditions (Allen 1994, Swanson *et al.* 1993).

In summary, this study demonstrates that the past fire regimes in the Jemez Mountains were the result of complex interactions between combinations of anthropogenic and natural factors, and regional as well as local factors. These data provide understanding of patterns and processes that are useful for explaining ecosystem structure and dynamics that we observe today. It is our hope that insights deriving from our studies of these historical patterns and processes will lead to the knowledge necessary for "retrodicting" and predicting past and future fire regimes, respectively, for use in ecosystem management planning.

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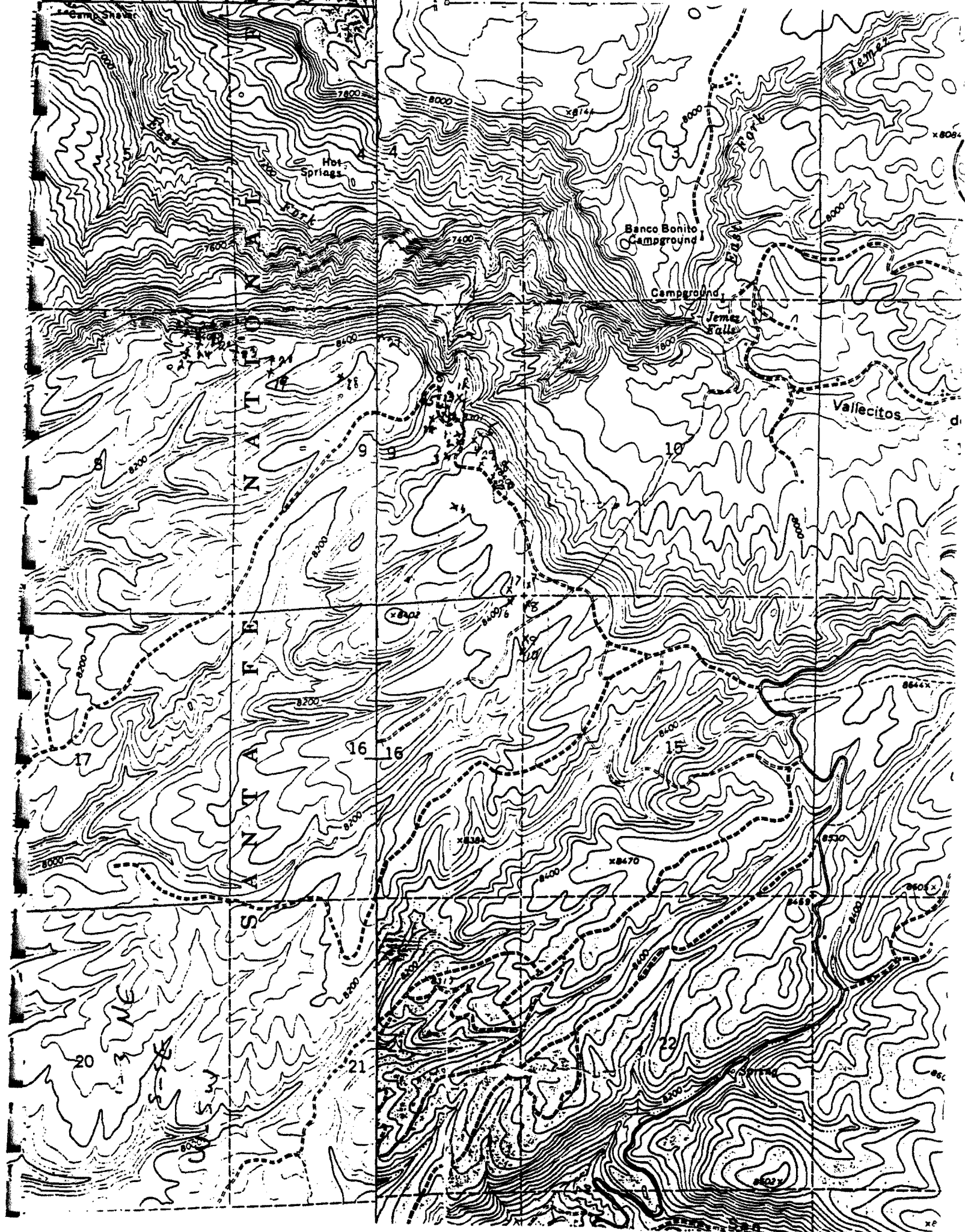
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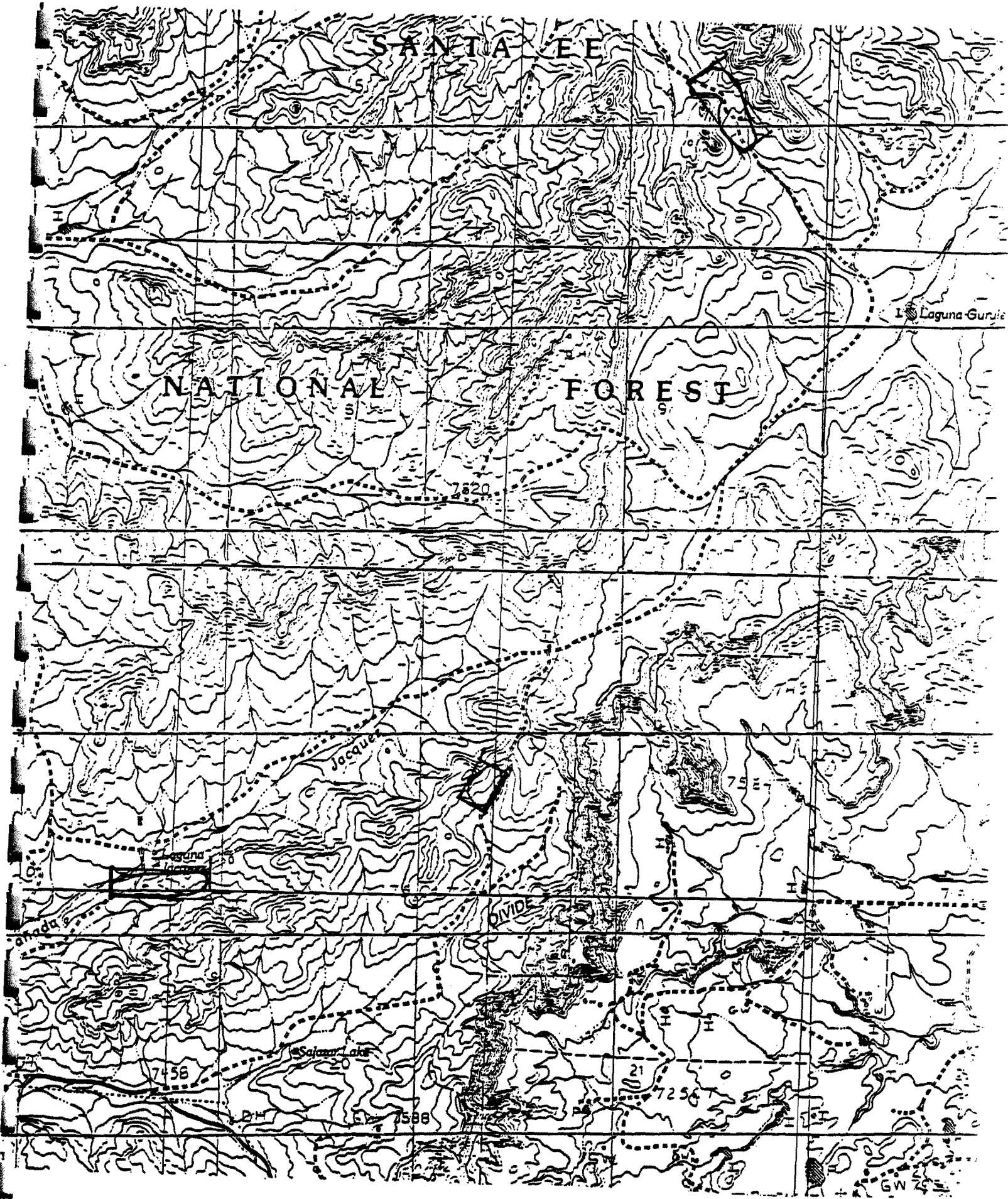
## APPENDIX A

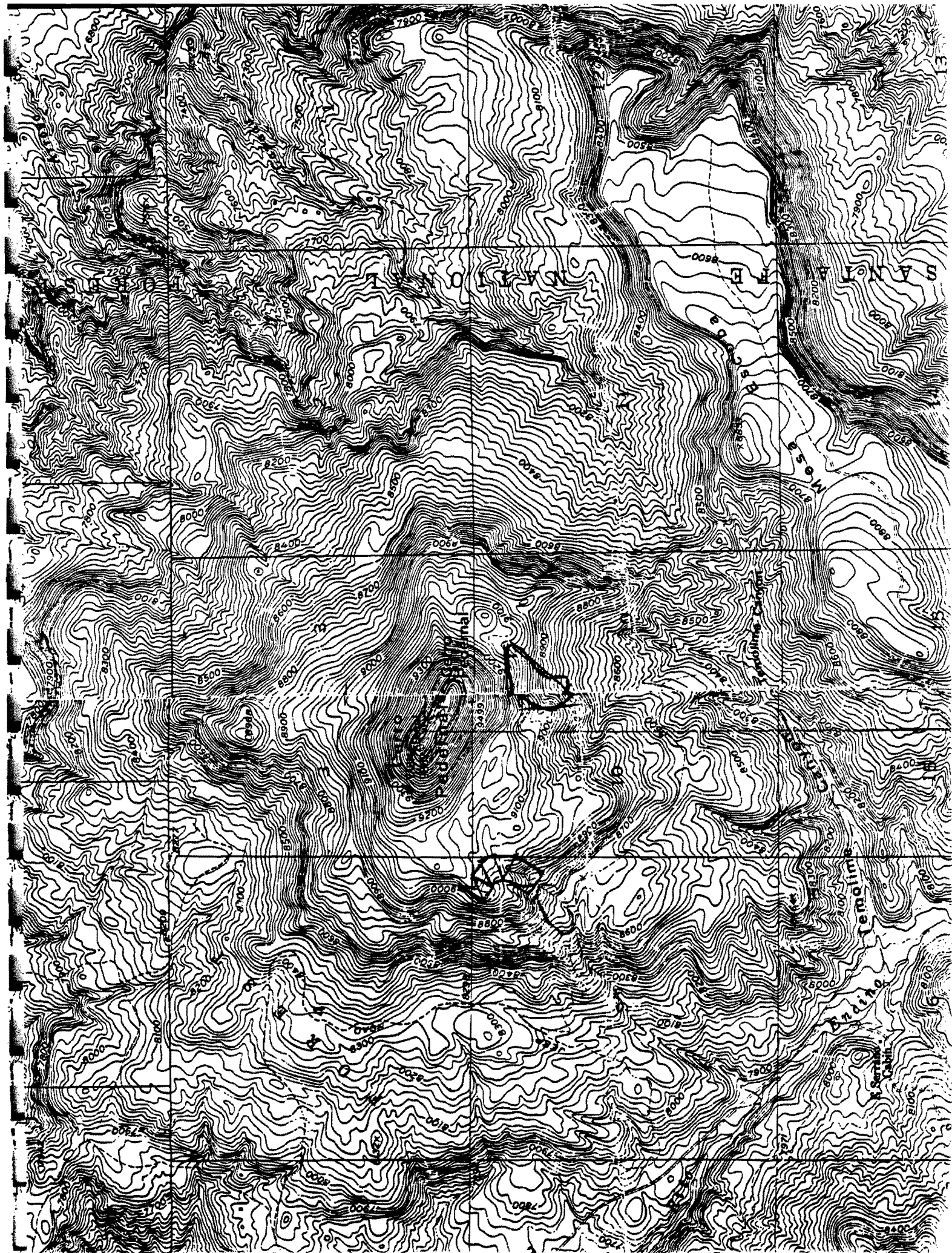
1. Map for Monument Canyon Natural site (MCN).
2. Map for Pajarito Mountain Ridge (PMR), Pajarito Mountain North-East (PME), Pajarito Mountain North-West (PMW), Camp May East (CME), Camp May North (CMN), Cañada Bonito South (CAS), and Cañada Bonito North (CAN) site.
3. Map for Cerro Pedernal (CPE) site.
4. Map for Continental Divide (CON) site.
5. Map for Clear Creek Campground (CCC) site.
6. Map for Capulin Canyon Upper (CPU) site.
7. Map for Capulin Canyon Middle (CPM) site.
8. Map for Gallina Mesa (GAM) site.
9. Map for Los Griegos Mountain (LOG) site.

10. Round Mountain (ROM) site.









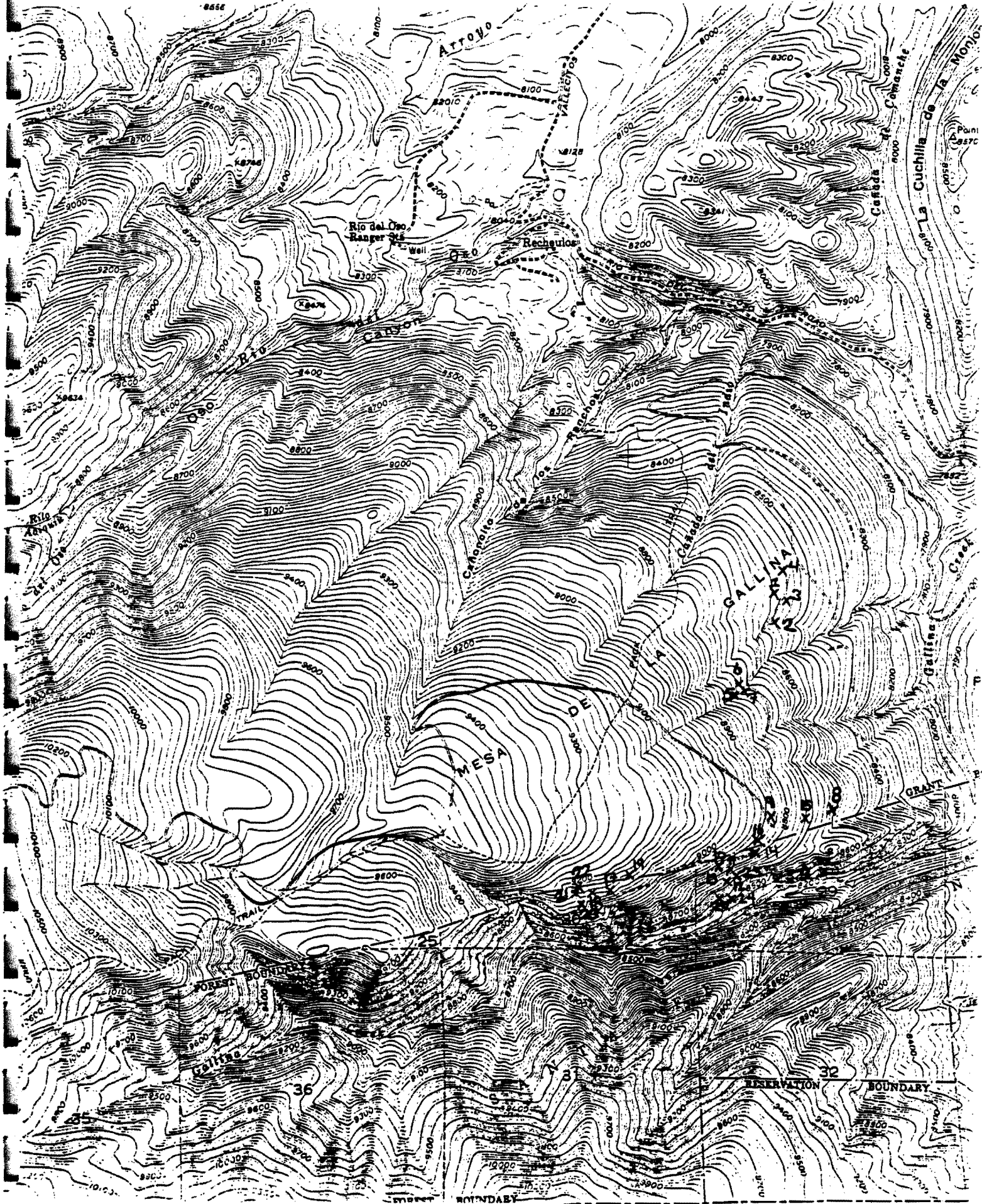


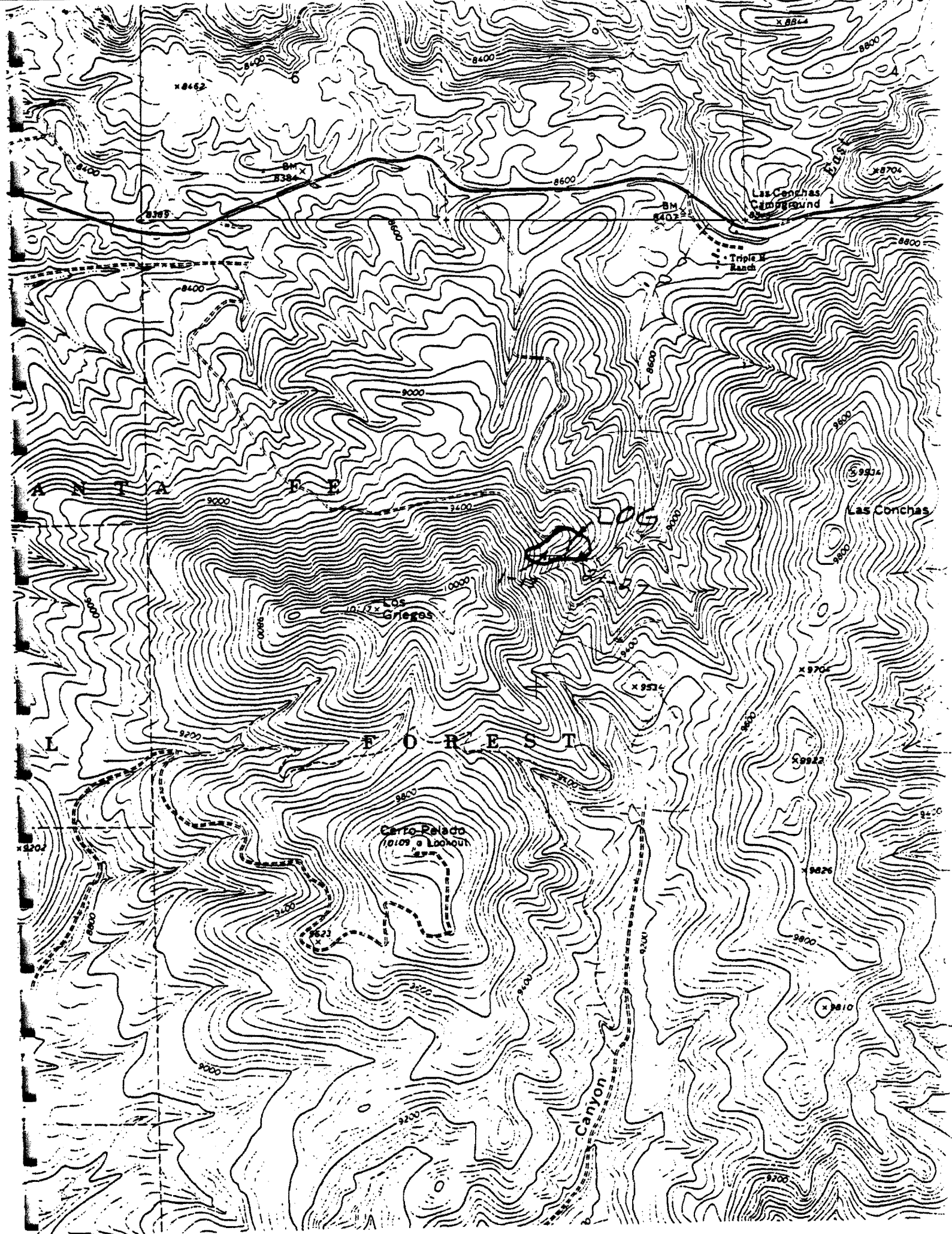


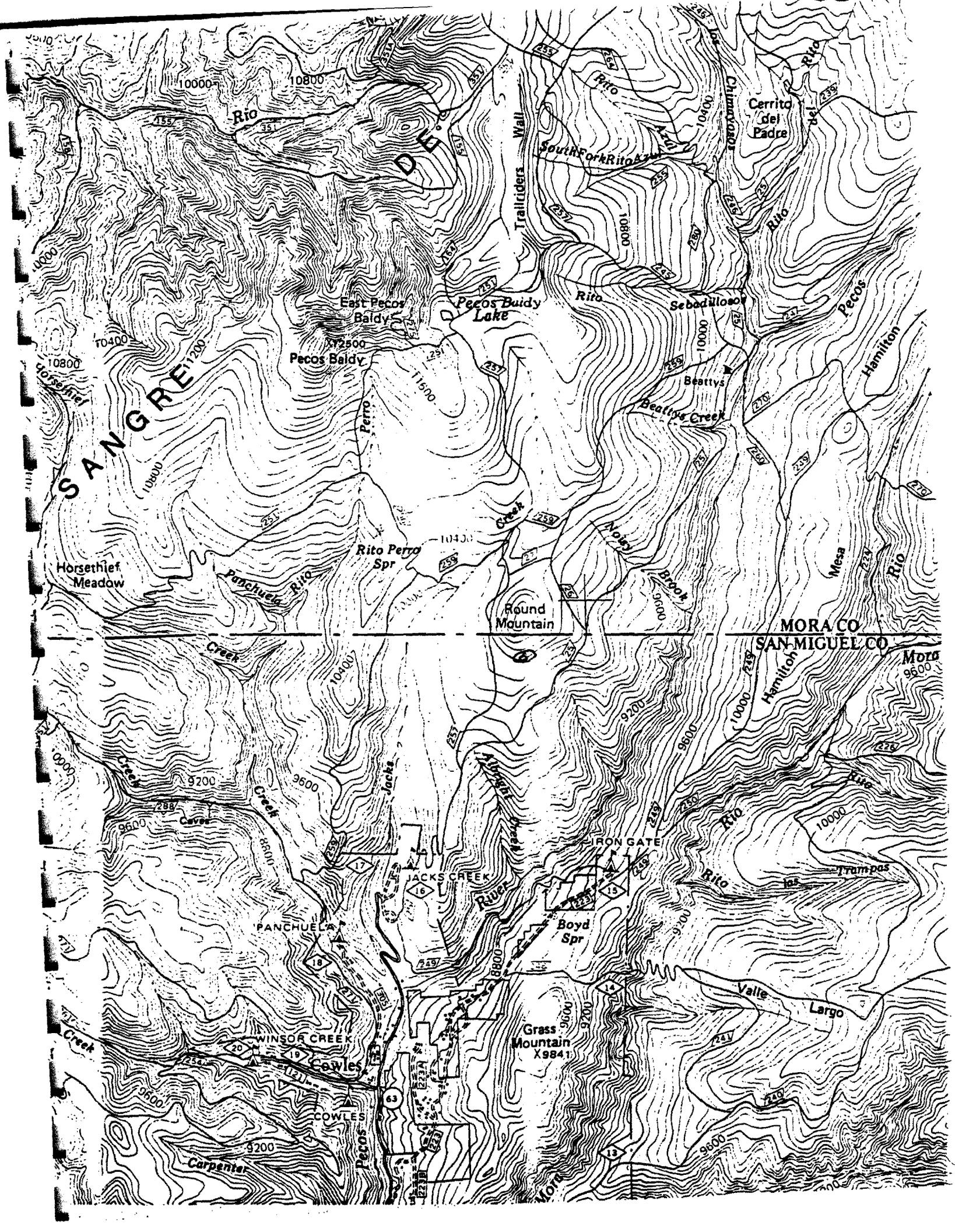


# GAM SITE

# JEMEZ NEW MEXICO







SANGRE DE CRISTO

MORA CO  
SAN MIGUEL CO

East Pecos Baldy  
12500  
Pecos Baldy

Pecos Buidy Lake

Horsethief Meadow

Round Mountain

IRON GATE

Grass Mountain  
X9841

PANCHUELA

WINSOR CREEK

COWLES

COWLES

Carpenter

Valle Largo

Trampas

Mora  
9600

MORA CO  
SAN MIGUEL CO

## APPENDIX B

1. Master fire chronology for the Monument Canyon Natural site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
2. Master fire chronology for the Pajarito Mountain Ridge site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
3. Master fire chronology for the Cerro Pedernal site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
4. Master fire chronology for the Continental Divide site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
5. Master fire chronology for the Clear Creek Campground site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
6. Master fire chronology for the Capulin Canyon site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.
7. Master fire chronology for the Gallina Mesa site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

8. Master fire chronology for the Cañada Bonito South site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

9. Master fire chronology for the Camp May East site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

10. Master fire chronology for the Los Griegos site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

11. Master fire chronology for the Pajarito Mountain North-East site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

12. Master fire chronology for the Pajarito Mountain North-West site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

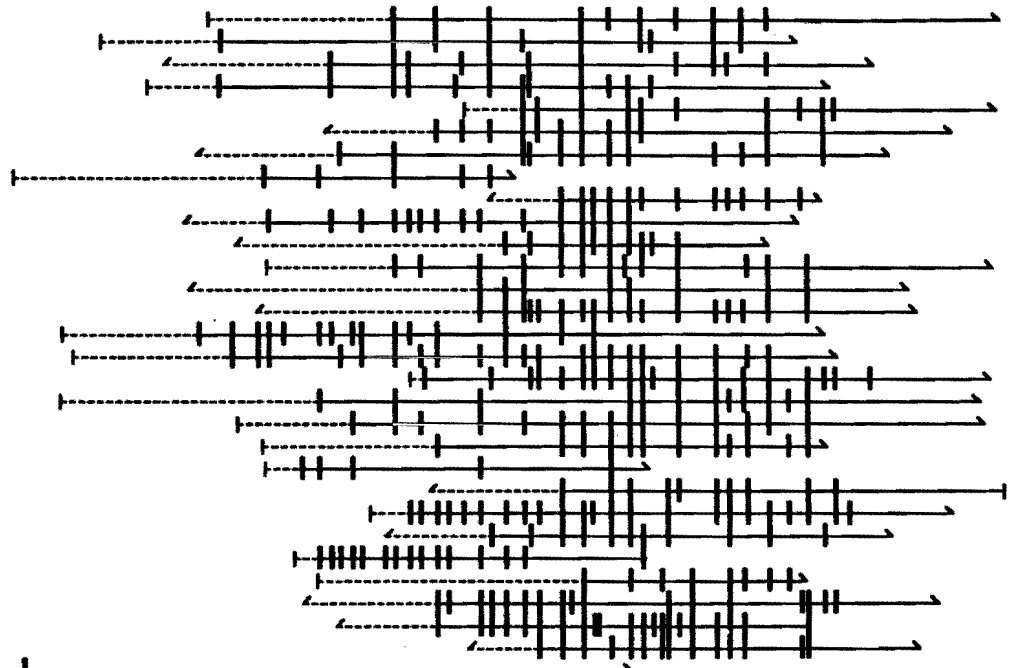
13. Master fire chronology for the Camp May North site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

14. Master fire chronology for the Cañada Bonito North site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

15. Master fire chronology for the Round Mountain site. Horizontal lines are sampled life spans of individual trees. Vertical lines are fire scar dates.

**LEGEND**

- ↓ Fire Scar
- ↓ Other Injury
- ┆ Pith Dots
- ┆ Inner Dots
- ┆ Outer Dots
- ┆ Bark Dots
- ┆ Recorder Years
- ┆ Null Years



MCN25  
 MCN28  
 MCN22  
 MCN24  
 MCN27  
 MCN23  
 MCN20  
 MCN19  
 MCN21  
 MCN15  
 MCN13  
 MCN11  
 MCN12  
 MCN14  
 MCN01  
 MCN02  
 MCN03  
 MCN04  
 MCN05  
 MCN29  
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 MCN18

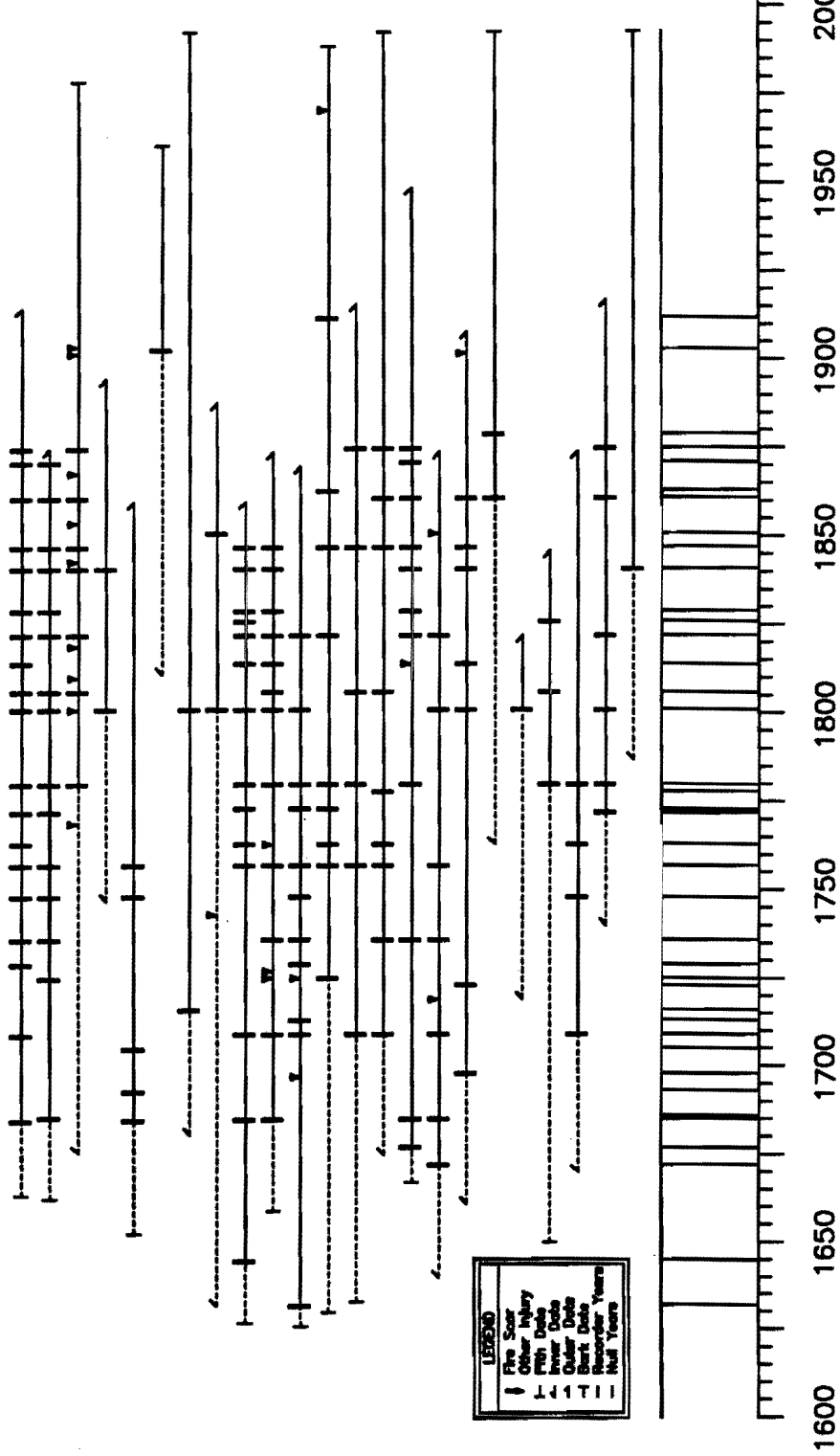
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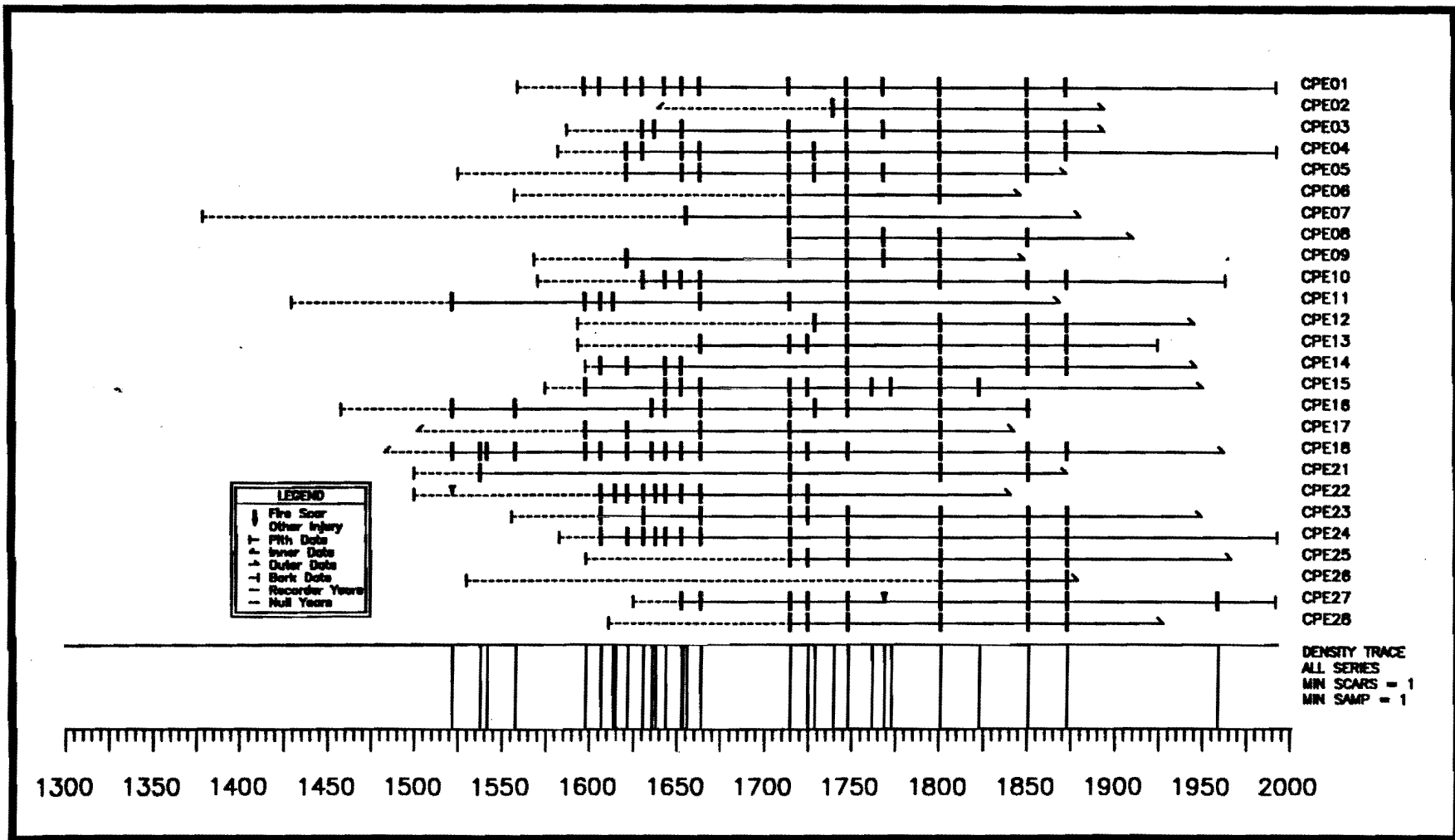
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 PMR03  
 PMR05  
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 PMR09  
 PMR10  
 PMR11  
 PMR12  
 PMR13  
 PMR14  
 PMR15  
 PMR16  
 PMR17  
 PMR18  
 PMR21  
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 PMR27

DENSITY TRACE  
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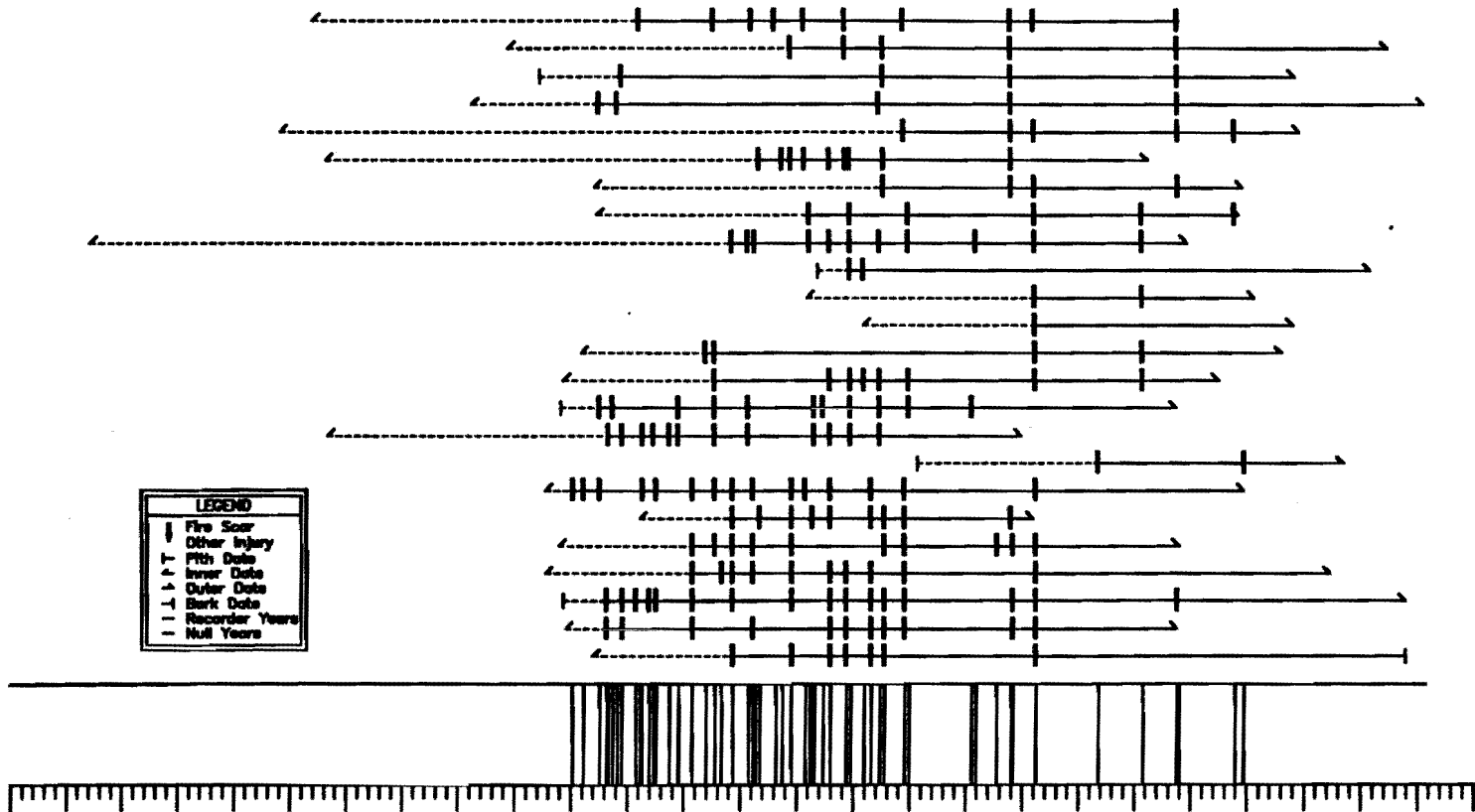


LEGEND  
 ↓ Fire Scar  
 - - - Other Injury  
 ┌─ Path Damage  
 └─ Insect Damage  
 ┌─ Quail Damage  
 └─ Bark Damage  
 ┌─ Responder Years  
 └─ Null Years



**LEGEND**

- | Fire Scar
- | Other Injury
- | Pith Date
- | Inner Date
- | Outer Date
- | Bark Date
- | Recorder Years
- | Null Years



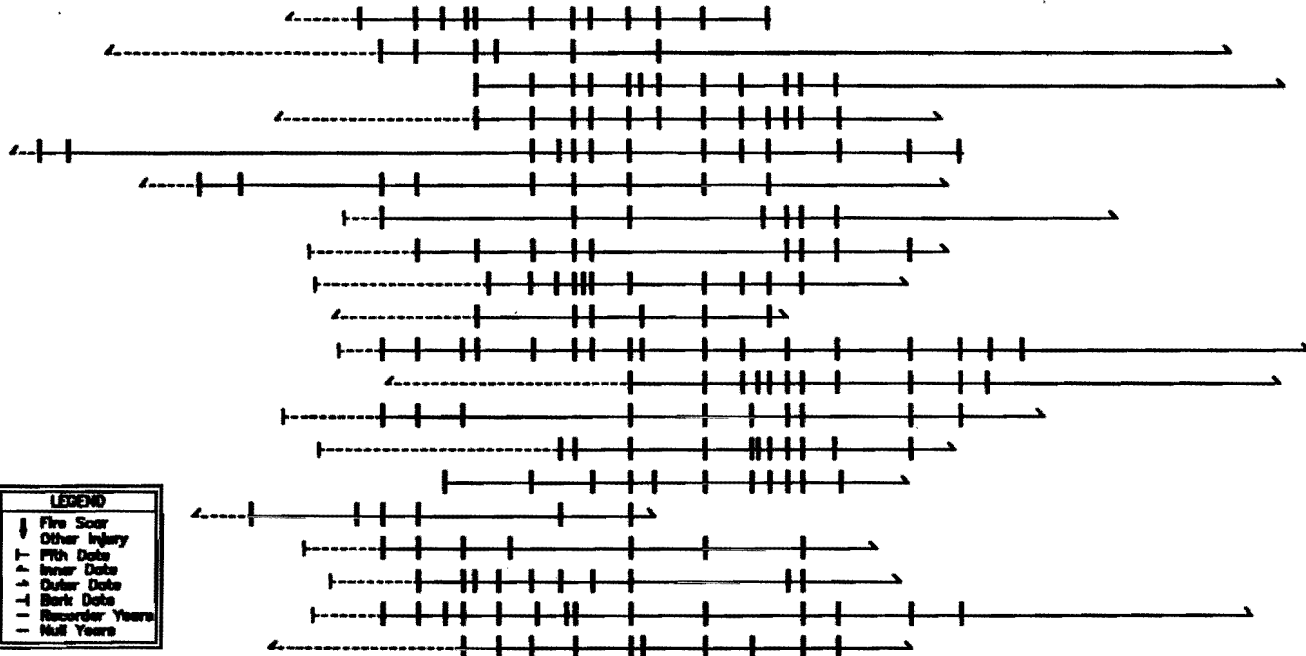
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 LGU02  
 LGU03  
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 LGU05  
 LGU06  
 LGU10  
 LGU11  
 LGU12  
 LGU13  
 CON01  
 CON02  
 CON04  
 CON05  
 CON06  
 CON07  
 CON08

DENSITY TRACE  
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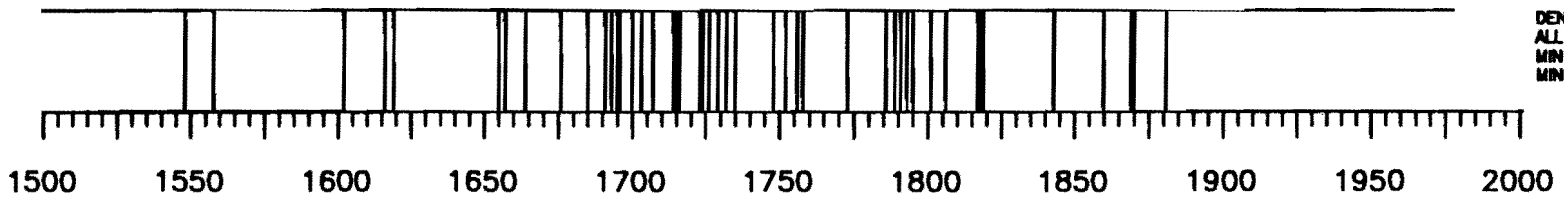
**LEGEND**

- ↓ Fire Scar
- Other Injury
- ┆ Pith Date
- ▲ Inner Date
- △ Outer Date
- ┆ Bark Date
- Recorder Years
- Null Years



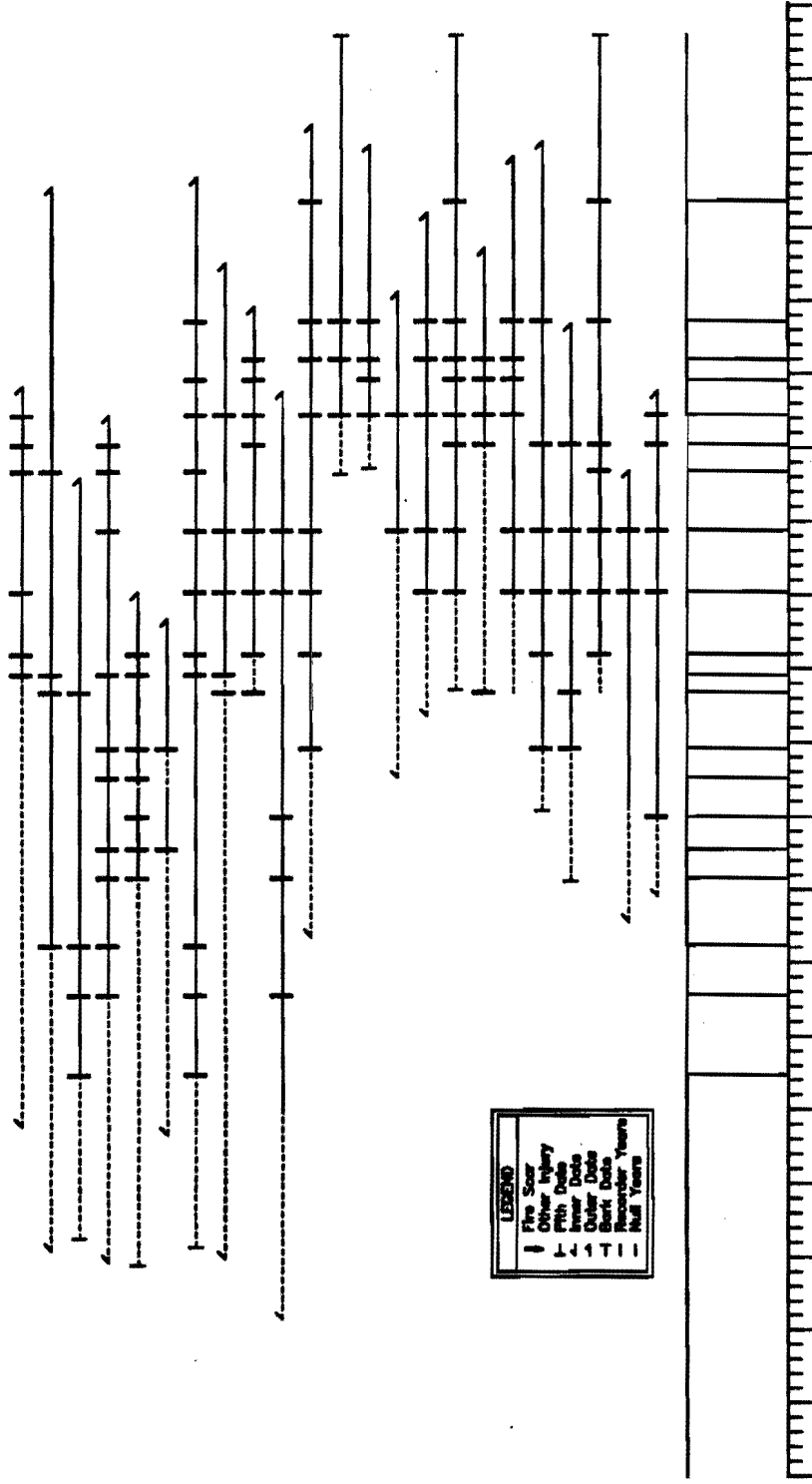
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 CCC13  
 CCC14  
 CCC15  
 CCC16  
 CCC17  
 CCC18  
 CCC18  
 CCC19  
 CCC20

DENSITY TRACE  
 ALL SERIES  
 MIN SCARS = 1  
 MIN SAMP = 1



1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

CPU01  
 CPU02  
 CPU03  
 CPU05  
 CPU07  
 CPU08  
 CPU09  
 CPU10  
 CPM17  
 CPM01  
 CPM02  
 CPM03  
 CPM04  
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 CPM14

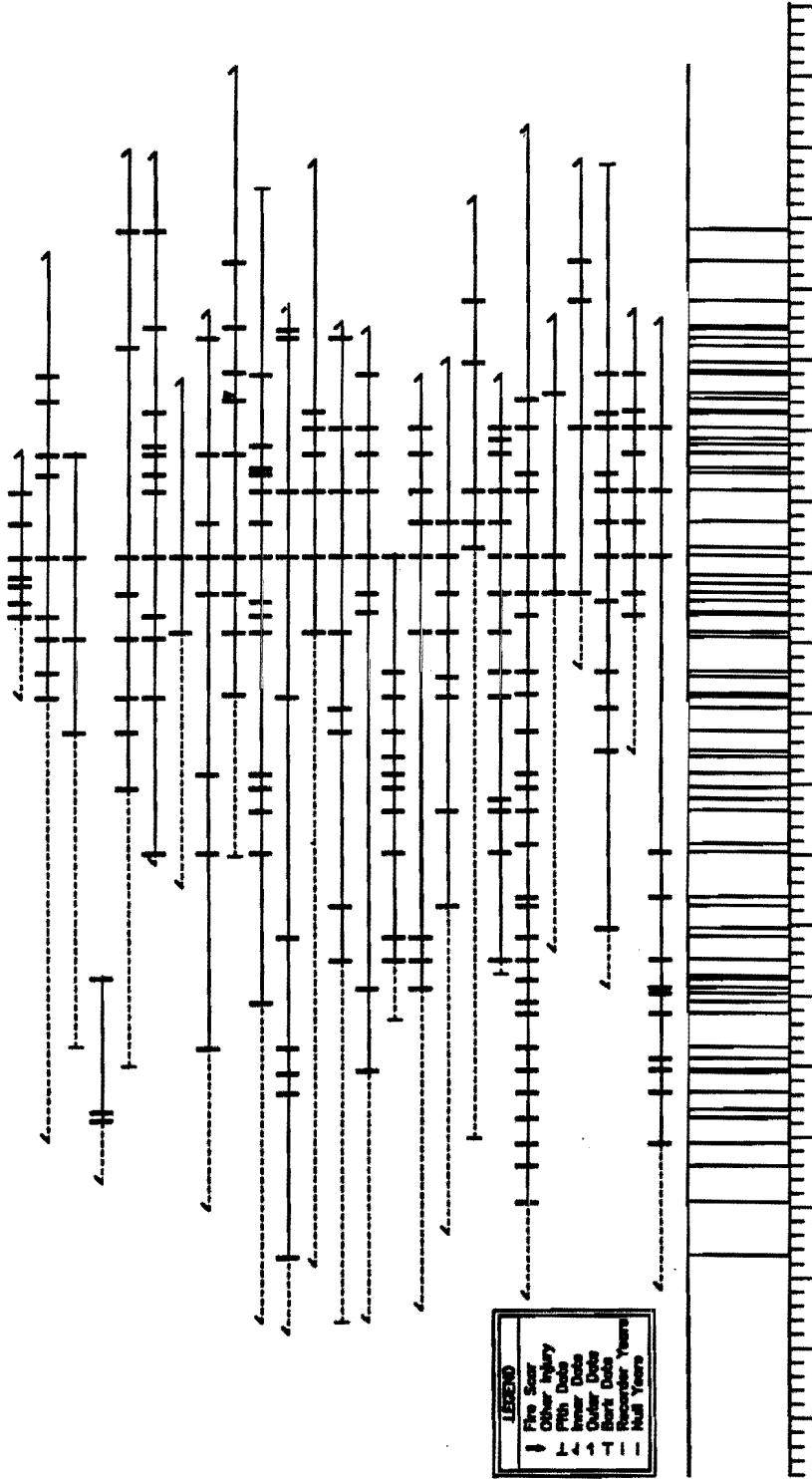


**LEGEND**  
 | Fire  
 | Other  
 | Injury  
 | Pith  
 | Dots  
 | Inner  
 | Outer  
 | Bark  
 | Responder  
 | Years

1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

GAM01  
 GAM02  
 GAM03  
 GAM04  
 GAM05  
 GAM06  
 GAM07  
 GAM08  
 GAM09  
 GAM10  
 GAM11  
 GAM12  
 GAM13  
 GAM14  
 GAM15  
 GAM16  
 GAM17  
 GAM18  
 GAM19  
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 GAM25

DENSITY TRACE  
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 MIN SAMP = 1

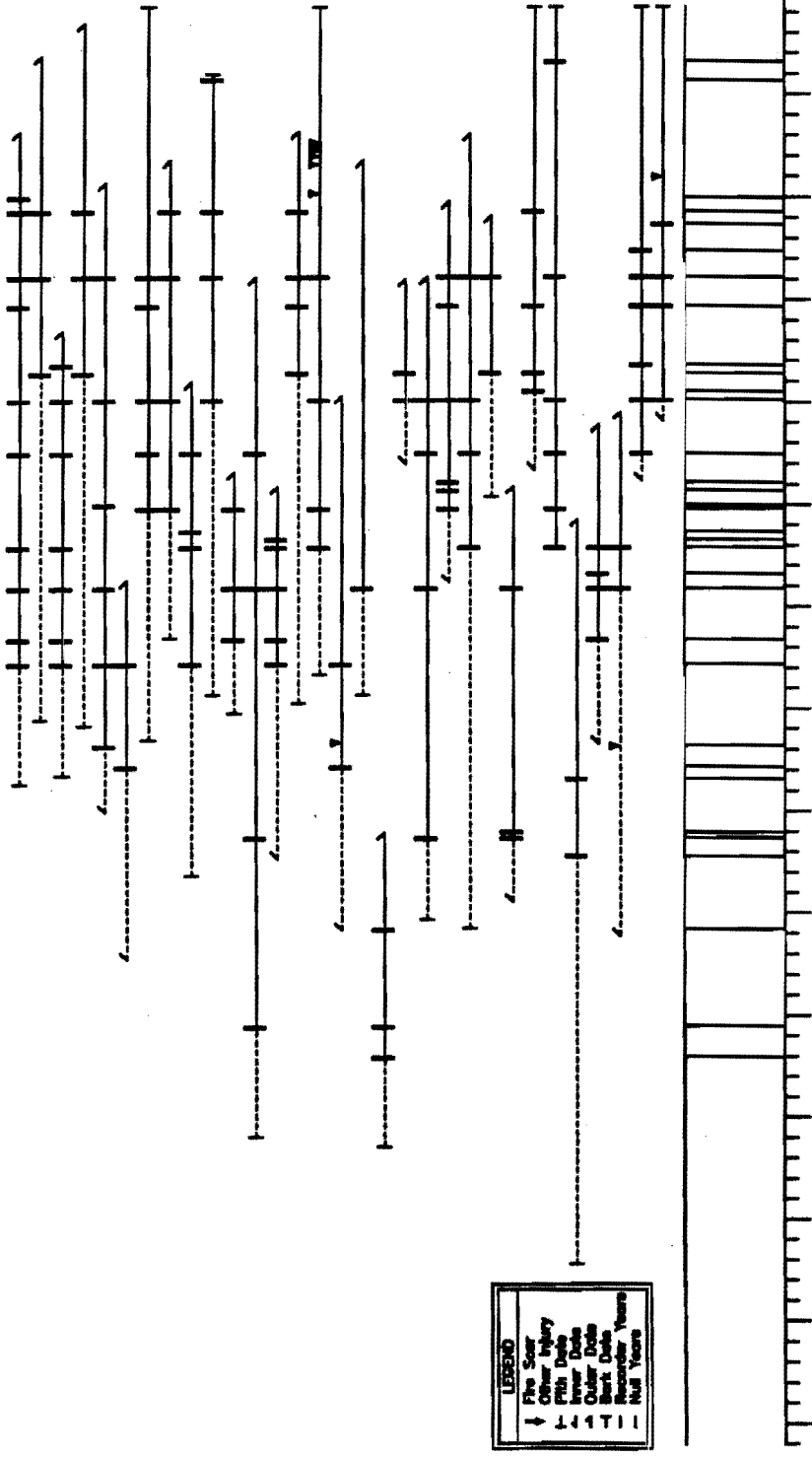


**LEGEND**  
 | Fire Scar  
 | Other Injury  
 | Pith Death  
 | Inner Death  
 | Outer Death  
 | Bark Death  
 | Rescuer Years  
 | Kill Years

1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

CAS01  
 CAS02  
 CAS03  
 CAS04  
 CAS05  
 CAS06  
 CAS07  
 CAS08  
 CAS09  
 CAS10  
 CAS11  
 CAS12  
 CAS13  
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 CAS18  
 CAS19  
 CAS20  
 CAS21  
 CAS22  
 CAS23  
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 CAS25  
 CAS26  
 CAS27  
 CAS28  
 CAS29  
 CAS30  
 CAS31

DENSITY TRACE  
 ALL SERIES  
 MIN SCARS = 1  
 MIN SAMP = 1



**LEGEND**  
 ↓ Fish Scar  
 ↓ Other Injury  
 - Fish Dents  
 - Inner Dents  
 - Outer Dents  
 - Bent Dents  
 - Rescued Years  
 - Hull Years

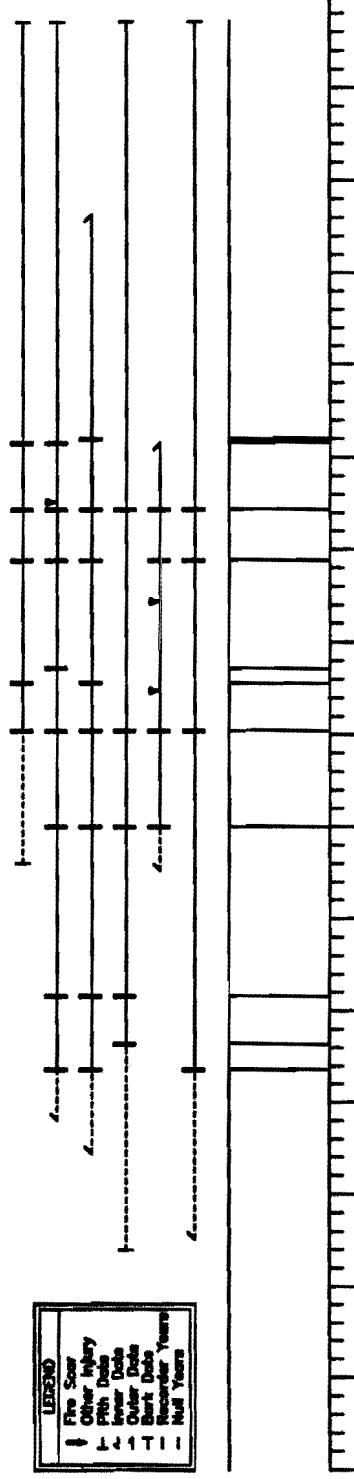
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CME05  
CME06

DENSITY TRACE  
ALL SERIES  
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MIN SAMP = 1

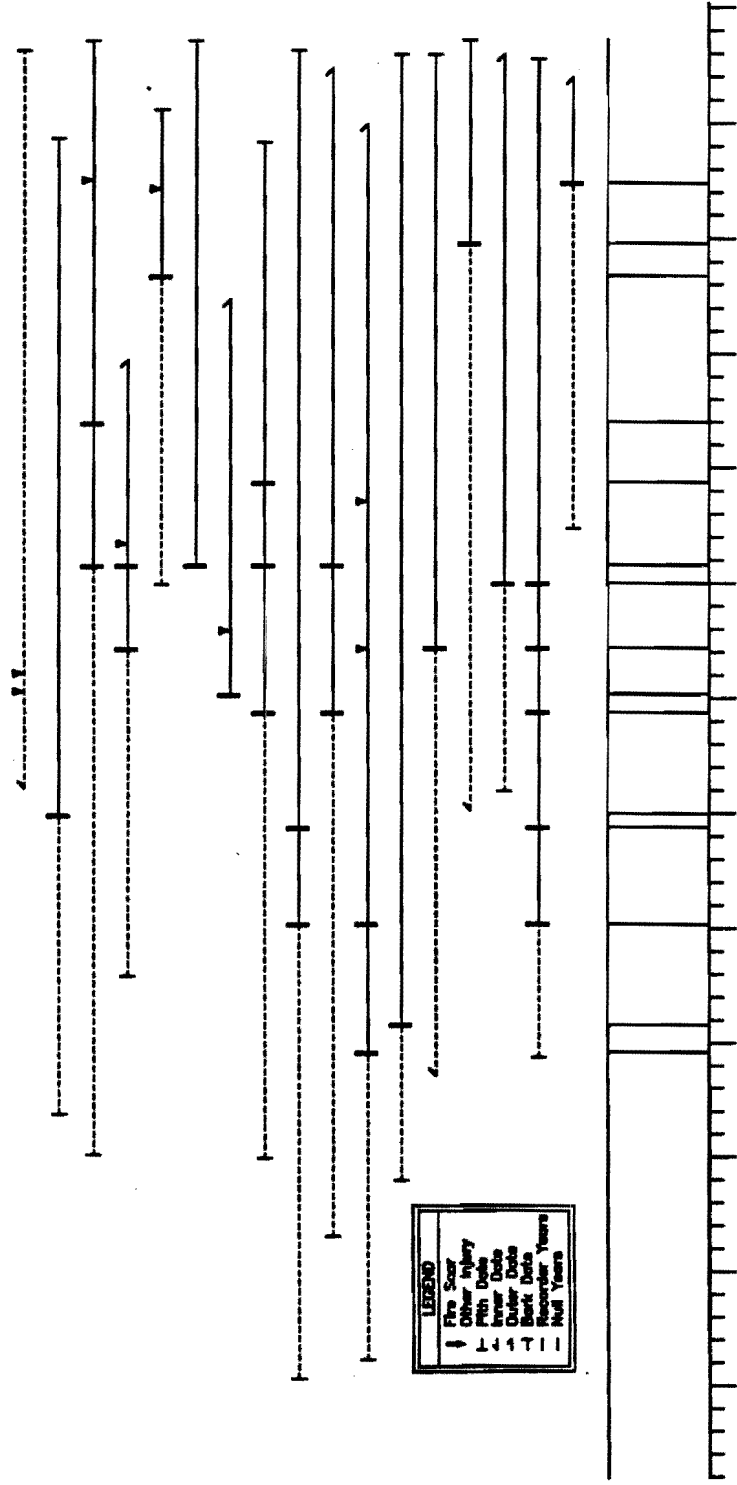
LEGEND  
P - Scar  
I - Other Injury  
F - Fish Dots  
L - Inner Dots  
O - Outer Dots  
B - Bark Dots  
N - Recorder Years  
H - Hull Years

1600 1650 1700 1750 1800 1850 1900 1950 2000

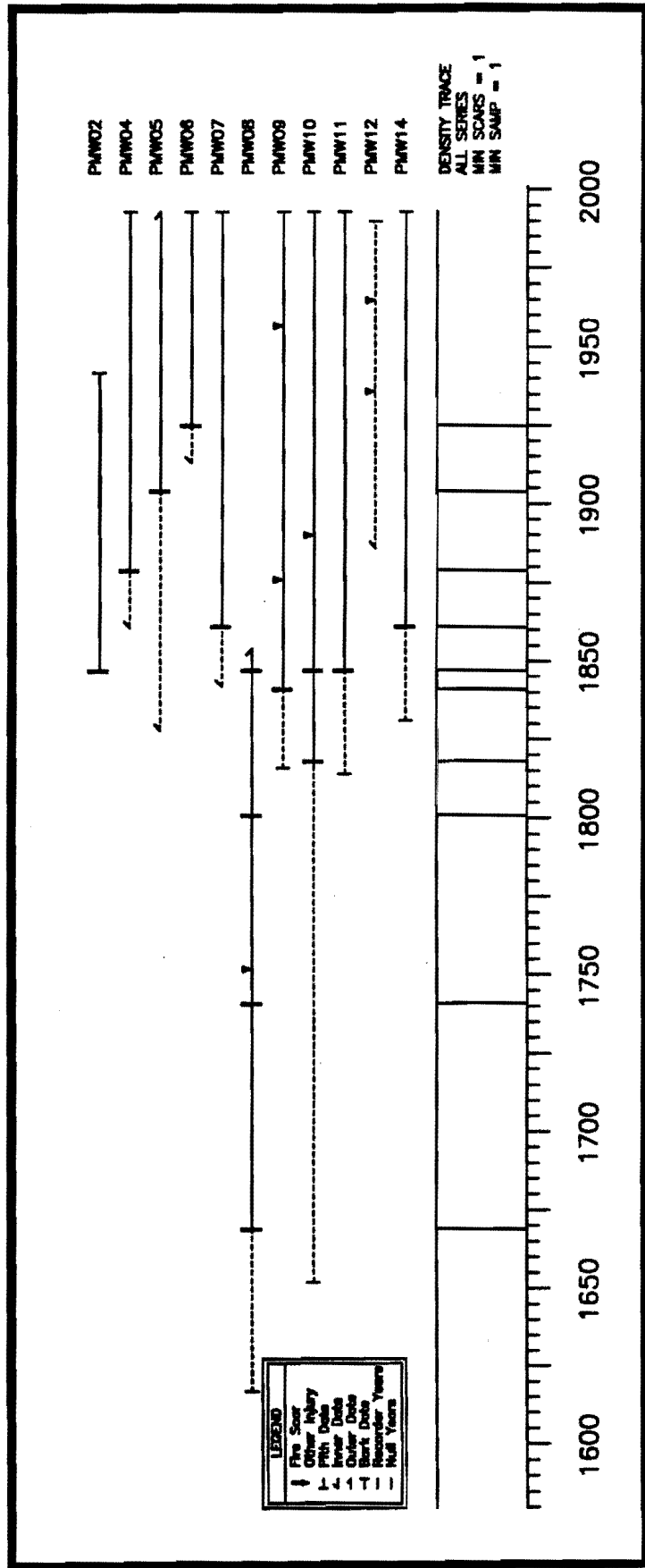


PME01  
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 PME04  
 PME05  
 PME06  
 PME08  
 PME09  
 PME10  
 PME11  
 PME12  
 PME13  
 PME15  
 PME16  
 PME17  
 PME18  
 PME19

DENSITY TRACE  
 ALL SERIES  
 MIN SCARS = 1  
 MIN SAMP = 1



1700 1750 1800 1850 1900 1950 2000



P1M102  
 P1M104  
 P1M105  
 P1M106  
 P1M107  
 P1M108  
 P1M109  
 P1M110  
 P1M111  
 P1M112  
 P1M114

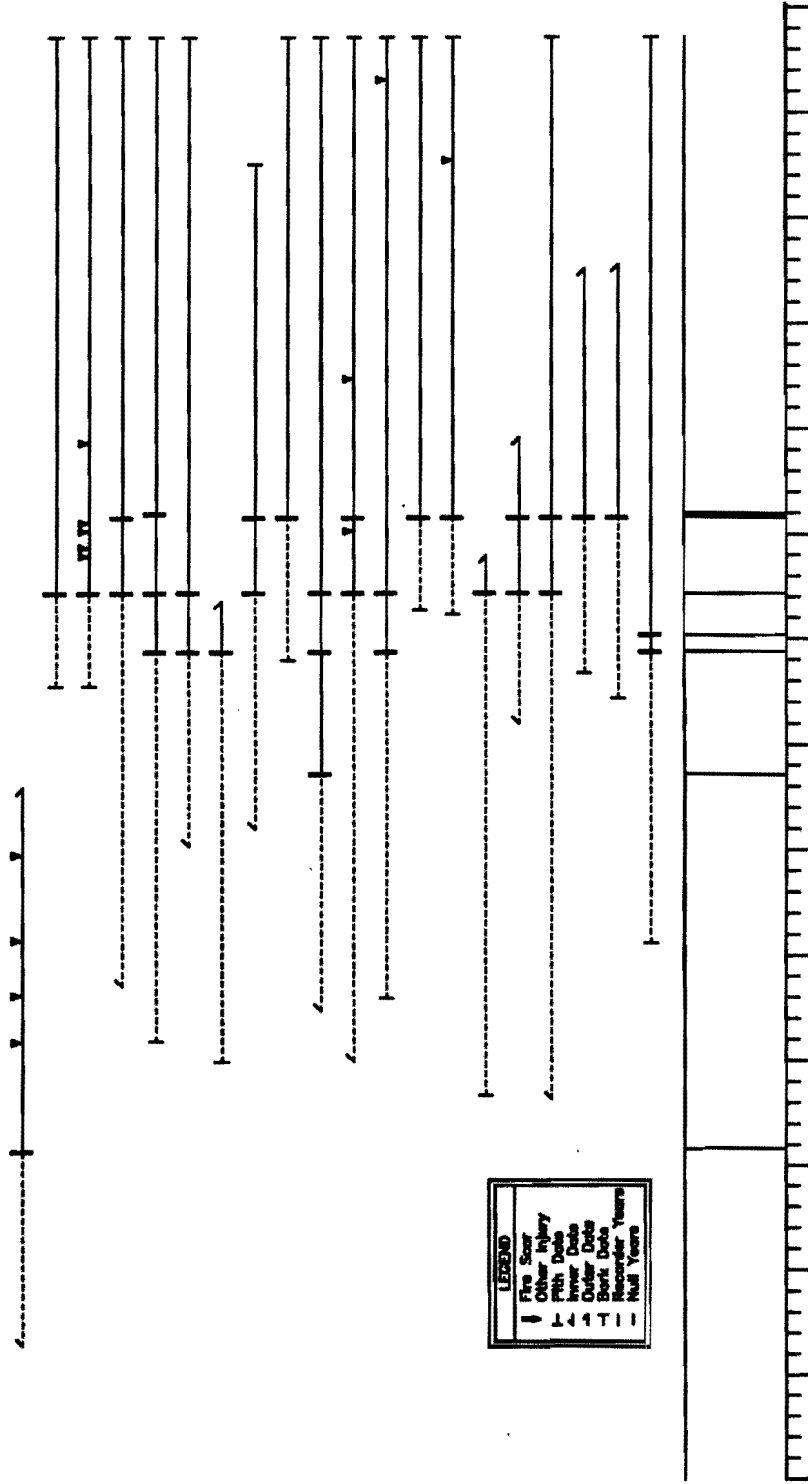
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 MIN SAMP = 1

1600 1650 1700 1750 1800 1850 1900 1950 2000

LEGEND  
 | Fire Scar  
 - Other Injury  
 - Frith Date  
 - Other Date  
 - Bark Date  
 - Heart Date  
 - Root Date  
 - Half Years

CMIN03  
 CMIN04  
 CMIN05  
 CMIN07  
 CMIN09  
 CMIN10  
 CMIN11  
 CMIN12  
 CMIN13  
 CMIN14  
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 CMIN31

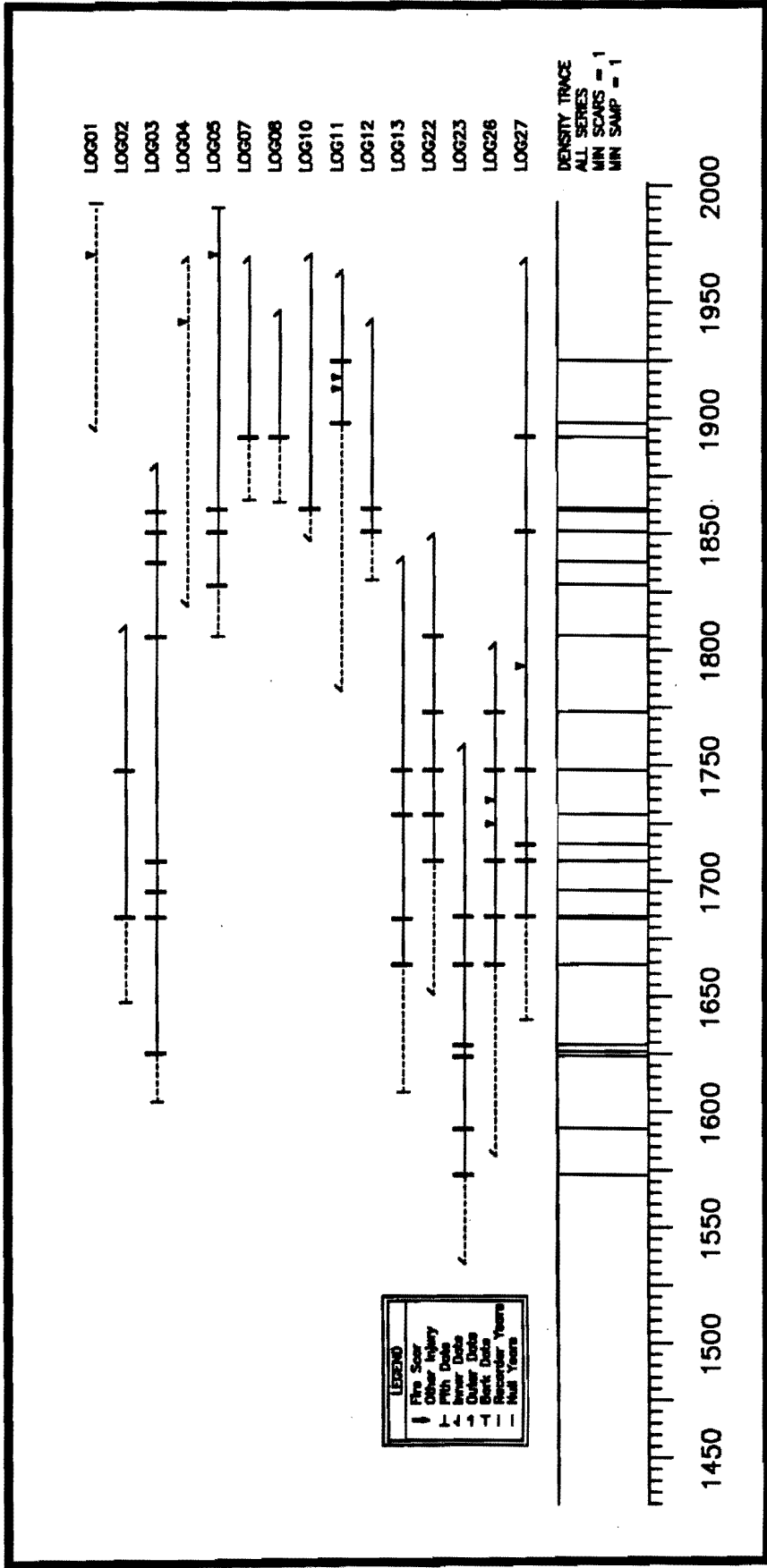
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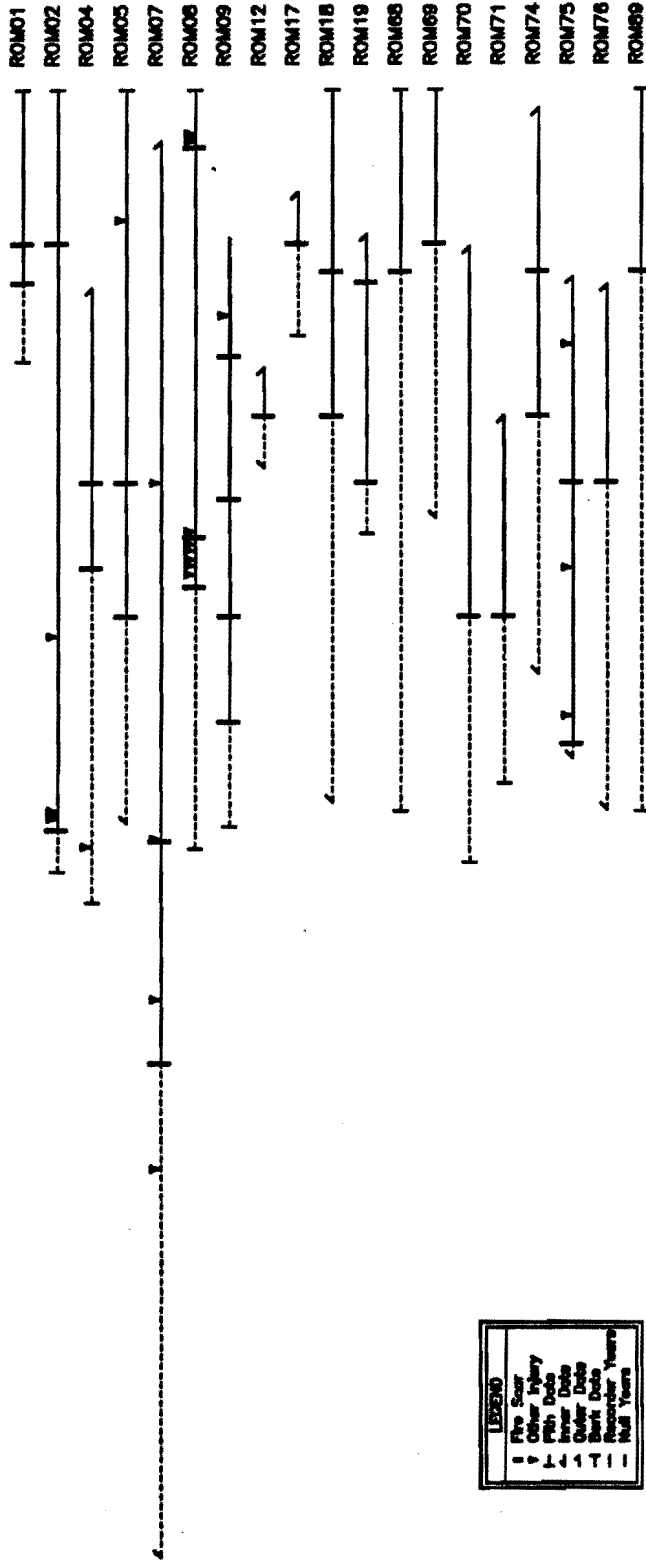


**LEGEND**  
 | Fine Scar  
 | Outer Injury  
 | Outer Disk  
 | Inner Disk  
 | Outer Disk  
 | Bark Disk  
 | Resiniferous Yarns  
 | Null Years

1650      1700      1750      1800      1850      1900      1950      2000

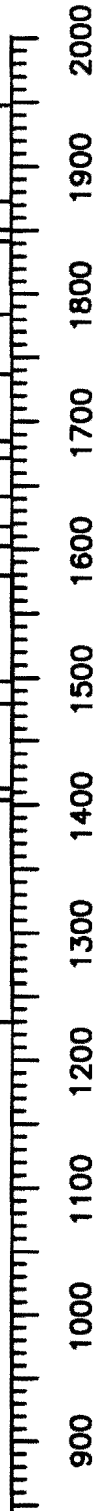






LEGEND  
 □ Fire Scar  
 △ Other Injury  
 + Fish Die  
 - Inver Die  
 △ Outer Die  
 - Bark Die  
 - Reservoir Years  
 - Half Years

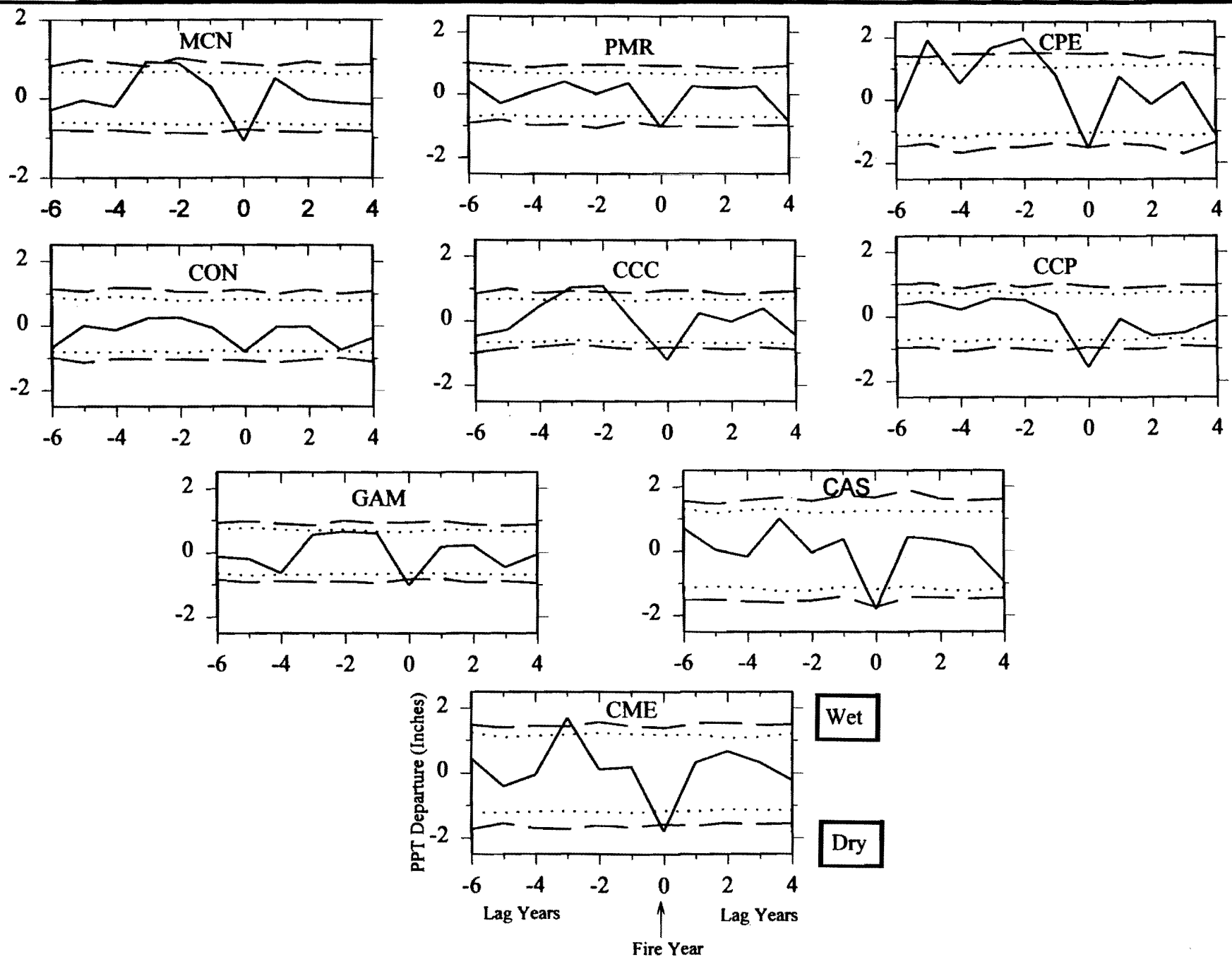
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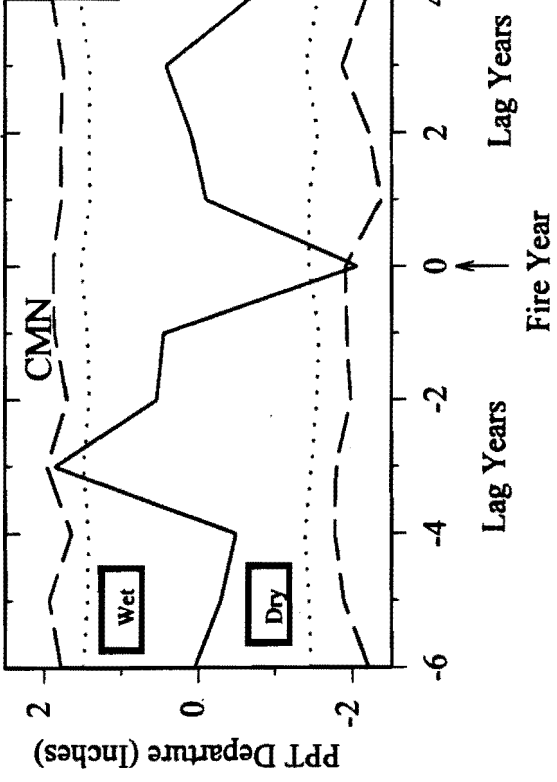
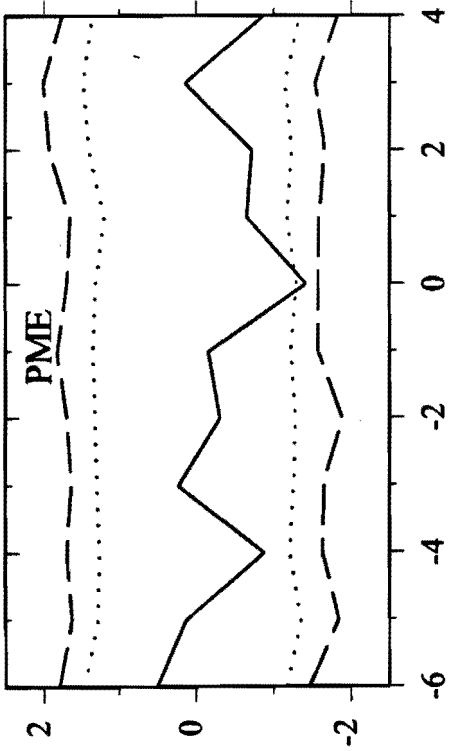
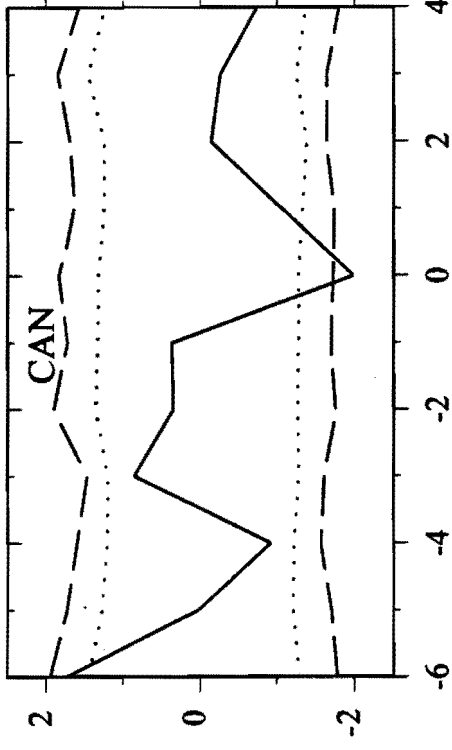
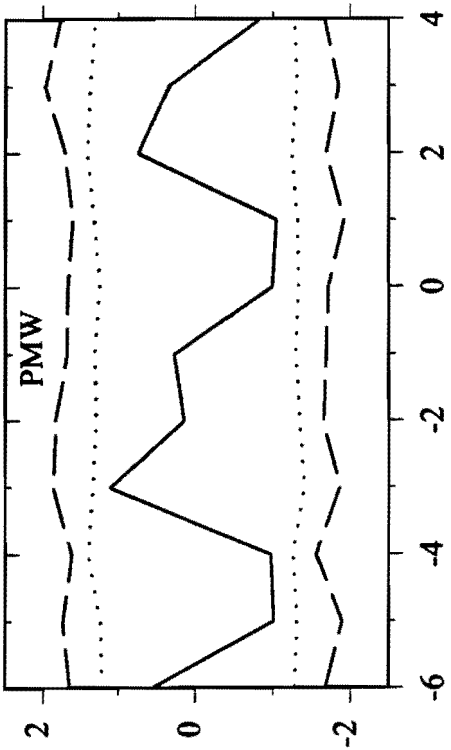


## APPENDIX C

1. The superposed-epoch analysis for each of the ponderosa pine site (fire dates based on at least 10% trees scarred) for the period 1653-1986. The precipitation time series used was based on a tree-ring reconstruction of December-June precipitation. Departures were computed as the difference between the long-term mean precipitation level (1653-1986) and the observed mean precipitation during the fire years and lagged years.

2. The superposed-epoch analysis for each of the mixed-conifer site (fire dates based on at least 10% trees scarred) for the period 1653-1986. The precipitation time series used was based on a tree-ring reconstruction of December-June precipitation. Departures were computed as the difference between the long-term mean precipitation level (1653-1986) and the observed mean precipitation during the fire years and lagged years.





PPT Departure (Inches)

Lag Years

Lag Years

Fire Year