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GIANT SEQUOIA RING-WIDTH CHRONOLOGIES FROM THE CENTRAL SIERRA NEVADA, CALIFORNIA

PETER M. BROWN, MALCOLM K. HUGHES, CHRISTOPHER H. BAISAN,
THOMAS W. SWETNAM, and ANTHONY C. CAPRIO

Laboratory of Tree-Ring Research
University of Arizona
Tucson, Arizona 85721

ABSTRACT

Giant sequoia was one of the first species that A. E. Douglass examined in his pioneering tree-ring research. Recent attention to sequoia, stimulated by fire history studies in sequoia groves, has resulted in new ring-width chronologies based on both recently collected tree-ring material and Douglass' original samples. The development and characteristics of four new multimillennial sequoia chronologies are described here. Three of these chronologies are based on tree-ring series from individual sites: Camp Six (347 B.C. to A.D. 1989), Mountain Home (1094 B.C. to A.D. 1989), and Giant Forest (1235 B.C. to A.D. 1988). The fourth is a composite chronology (1235 B.C. to A.D. 1989) that includes radii from the other three chronologies. Sequoia ring series are generally complacent with occasional narrow rings ("signature years"). Ring-width standardization was complicated by growth releases, many of which are known to have been caused by fires. Such growth releases confuse climatic interpretation of low-frequency signals in the time series. Ring-width series were detrended with cubic splines with 50% frequency response function at 40 years to de-emphasize low-frequency variation and were fit with autoregressive time series models to remove persistence. The resulting prewhitened chronologies contain primarily a high frequency climate signal and are useful for assessing the past occurrence of extreme drought events and for dating applications. The dating chronology originally developed by Douglass is confirmed and the annual nature of giant sequoia tree rings unequivocally verified.

Sequoia war eine der ersten Baumarten, die A. E. Douglass in seinen bahnbrechenden Jahrringforschungen untersuchte. Die erneute Beschäftigung mit Sequoia, angeregt durch Untersuchungen zur Brandgeschichte in Sequoia-Wäldern, hat zu neuen Jahrringchronologien geführt; sie bestehen aus neuen Holzproben sowie aus den Originalproben von Douglass. Hier sollen die Entwicklung und die Merkmale von vier neuen mehrtausendjährigen Sequoia-Chronologien beschrieben werden. Drei dieser Chronologien beruhen auf Jahrringfolgen von einzelnen Standorten: Camp Six (347 v. Chr. – 1989 n. Chr.), Mountain Home (1094 v. Chr. – 1989 n. Chr.), und Giant Forest (1235 v. Chr. – 1988 n. Chr.). Die vierten Chronologie (1235 v. Chr. – 1989 n. Chr.) ist zusammengesetzt aus den Jahrringfolgen der übrigen drei Chronologien. Sequoia-Jahrringfolgen sind allgemein wenig sensitiv mit gelegentlichen engen Jahrringen (Weiserjahre). Die Standardisierung wird durch Wachstumsschübe erschwert, von denen viele durch Waldbrände verursacht worden sind. Diese Wachstumsschübe beeinträchtigen die klimatische Interpretation von niederfrequenten Signalen in den Zeitreihen. Die Jahrringfolgen wurden mit Hilfe von kubischen Spline-Funktionen standardisiert, um so die niederfrequenten Variationen abzuschwächen; die Persistenz wurde mit Hilfe autoregressiver Zeitreihenmodelle entfernt. Die so erhaltenen sog. "prewhitened" Chronologien enthalten vor allem ein hochfrequentes Klimasignal und dienen der Abschätzung von extremen Trockenheitsereignissen in der Vergangenheit und für Datierungseinsätze. Die von Douglass ursprünglich erarbeitete Datierungs-Chronologie ist bestätigt und die Jährlichkeit der Sequoia-Baumringe eindeutig bewiesen.

Le sequoia géant fut une des premières espèces étudiées par A. E. Douglass lors de ses recherches pionnières en dendrochronologie. Cette espèce connaît un regain d'intérêt stimulé par l'étude de l'histoire des feux dans les massifs qu'elle constitue, ce qui a provoqué l'élaboration de nouvelles séries dendrochronologiques basées sur des échantillons prélevés récemment ainsi que sur le matériel original de Douglass. La construction et les caractéristiques de quatre nouvelles chronologies pluri-millénaires sont décrites dans cet article. Trois chronologies proviennent de sites définis: Camp Six (347 B.C. á 1989 A.D.), Mountain Home (1094 B.C. á 1989 A.D.), et Giant

Foret (1235 B.C. á 1988 A.D.). La quatrième (1235 B.C. à 1989 A.D.) est composite incluant des échantillons des trois autres chronologies. Les séries du Sequoia sont généralement peu réactives avec des cernes étroits occasionnels (signatures annuelles). La standardisation des cernes est compliquée par des relâchements de croissance souvent connues pour être causées par les feux. De tels phénomènes compliquent l'interprétation des signaux de basse fréquence contenus dans les séries chronologiques. Les séries de cernes ont été filtrées par l'utilisation de splines cubiques avec une fonction de réponse fréquentielle à 50% pour une périodicité de 40 ans, afin d'atténuer les variations de basse fréquence et ajustées à l'aide de modéles temporels autorégressifs pour ôter la persistance. Les chronologies préblanchies obtenues contiennent principalement un signal climatique de haute fréquence et sont utilisables pour déterminer l'occurrence dans le passé de sécheresses extrêmes ainsi que pour des applications en datation. La chronologie originale développée par Douglass est confirmée et la nature annuelle des cernes du Sequoia géant définitivement confirmée.

INTRODUCTION

Giant sequoias (*Sequoiadendron giganteum* [Lindl.] Bucholtz) are not only the largest trees in the world but also among the oldest. The great age of these trees attracted the attention of A. E. Douglass in his pioneering tree-ring work in the early part of this century. Douglass developed a 3,220 year-long record of ring widths from giant sequoia that he used in his studies of climate and cycle phenomena (Douglass 1919, 1928). However, unlike his success in relating Southwestern tree-ring series to rainfall records, Douglass was frustrated in his attempts to relate giant sequoia ring widths to climate variables. Douglass' work with sequoia never resulted in the climate record he had hoped for, due in no small part to the shortness of meteorological records that were available at that time to compare to his sequoia series (Hughes and Brown 1992).

Recently, new attention was paid to giant sequoia as an excellent recorder of past fires. Low-intensity surface fires often injured cambial tissues leaving sequences of distinctive fire scars in wood near the bases of the trees. Research into the fire history of giant sequoia groves (Swetnam et al. 1990) began by using Douglass' original ring-width record to crossdate fire-scarred tree-ring samples. This work soon led to new efforts to both improve and possibly extend Douglass' 3,220 year-long sequoia series and to reassess what climate factor or factors control sequoia radial growth (Hughes and Brown 1992; Hughes et al. 1990). Here we describe the development and tree-ring characteristics of four new giant sequoia chronologies from the central Sierra Nevada. These new chronologies incorporate ring-width series from both recently collected tree-ring samples and Douglass' original radial sections.

PREVIOUS TREE-RING RESEARCH IN GIANT SEQUOIA

Ellsworth Huntington was the first to attempt to exploit the old age of sequoia for climate reconstruction (Huntington 1914). Between 1911 and 1912, Huntington and his assistants measured the widths of 10-year increments of rings on more than 450 sequoia stumps in an effort to examine long-term changes in climate in relation to human history. Huntington was influenced by the early work of Douglass (Douglass 1909), who at that time was attempting to correlate rainfall records and tree-rings in ponderosa pine (*Pinus ponderosa*) in the American Southwest.

In 1915, Douglass made the first of several trips to the Sierra Nevada to collect samples of sequoia for his own work. Many of the sequoia groves were heavily logged between the late-1800s and the 1910s. Ironically, the cutting of these superlative trees presented a fortuitous opportunity for tree-ring research since it allowed access to the entire ring record of trees that were occasionally more than 9 meters in diameter. Douglass began his collecting in Redwood and Converse Basins, two cutover areas on the south slope of the Kings River canyon in the central Sierra Nevada. On his first trip, Douglass collected V-cut radial samples (Douglass 1941) from the tops of 15 stumps and was able to develop a 2,200 year-long ring-width chronology from a select group of these samples (Douglass 1919:119-123; 1945a). The second tree Douglass sampled, D-2, had one the most sensitive series of all the sequoias he collected. His first chronology was heavily weighted to the ring widths from this one sample. Douglass later published in the Tree-Ring Bulletin a complete set of photographs of D-2 under the title "a superior sequoia ring record" (Douglass 1949, 1950a, 1950b, 1951a, 1951b).

Douglass was pleased with the tree-ring characteristics of sequoia. In a review of trees suitable for climatic study (Douglass 1928:10), he concluded:

> ...the mountain sequoia...easily takes a leading part in company with the yellow [ponderosa] pine, for besides its great age it has a fundamental feature of greatest importance, namely, cross-identification over large areas. In this character we recognize climatic influences. The ring-growth in the big sequoia is not so sensitive as in the yellow pine, and perhaps any individual tree is a little less certain to identify with its neighbors, but yet cross-identification is very sure in that species and extends through all the mountain sequoia groves from Calaveras on the north to Springville [Mountain Home] on the south, 200 miles.

Over the next several years, Douglass made other trips to the sequoia region. Huntington had recorded three trees of more than 3,000 years in age, and in 1918 Douglass obtained radial samples from these stumps. At that point, Douglass had a total of 23 samples with which he was able to extend his previous sequoia series by more than 1,000 years. This 3,220 year-long ring-width record (1307 B.C. to A.D. 1914) was published in Douglass' first volume of *Climatic Cycles and Tree Growth* (Douglass 1919:117-123). The ring for 1307 B.C. was incomplete, and the record includes a year "AD 0." All other B.C. dates reported here are true dates with 1 B.C. followed by A.D. 1. The oldest sample Douglass collected, D-21, dated from 1307 B.C. to roughly A.D. 1890 and is still the longest-lived sequoia on record. In 1919, a special trip was made to confirm that a questionable ring between A.D. 1580 and 1581 was a true ring (Douglass 1919:58). The ring Douglass had been referring to as 1580A was present in less than half of the 23 samples collected by that time. Samples from the 1919 trip confirmed 1580A to be a true ring, the smallest in the sequoia record. Two other trips in 1924 and 1925 were made to improve the sequoia chronology and to find potential crossdating with Douglass' floating chronologies from Southwestern archaeological sites, an effort that proved unsuccessful (Douglass 1945a,b). Two other trips were made in 1931 and 1935. In articles published in 1945 and 1946 in the *Tree-Ring Bulletin* (Douglass 1945a,b, 1946), Douglass provided a summary of his sequoia trips and resulting studies, much of which set the basis for modern dendrochronology.

DEVELOPMENT OF RECENT CHRONOLOGIES

Giant sequoias occur in approximately 75 more-or-less distinct groves of from a few to several thousand trees (Rundel 1972). Local ring-width chronologies have been developed so far from three areas, two of which represent single groves and the third from two contiguous groves (Figure 1). The single grove chronologies are from Giant Forest and Mountain Home. The third chronology, known as Camp Six after a nearby early 1900s logging camp, includes trees from the Windy Gulch and Evans Groves. A fourth regional ring-width chronology was

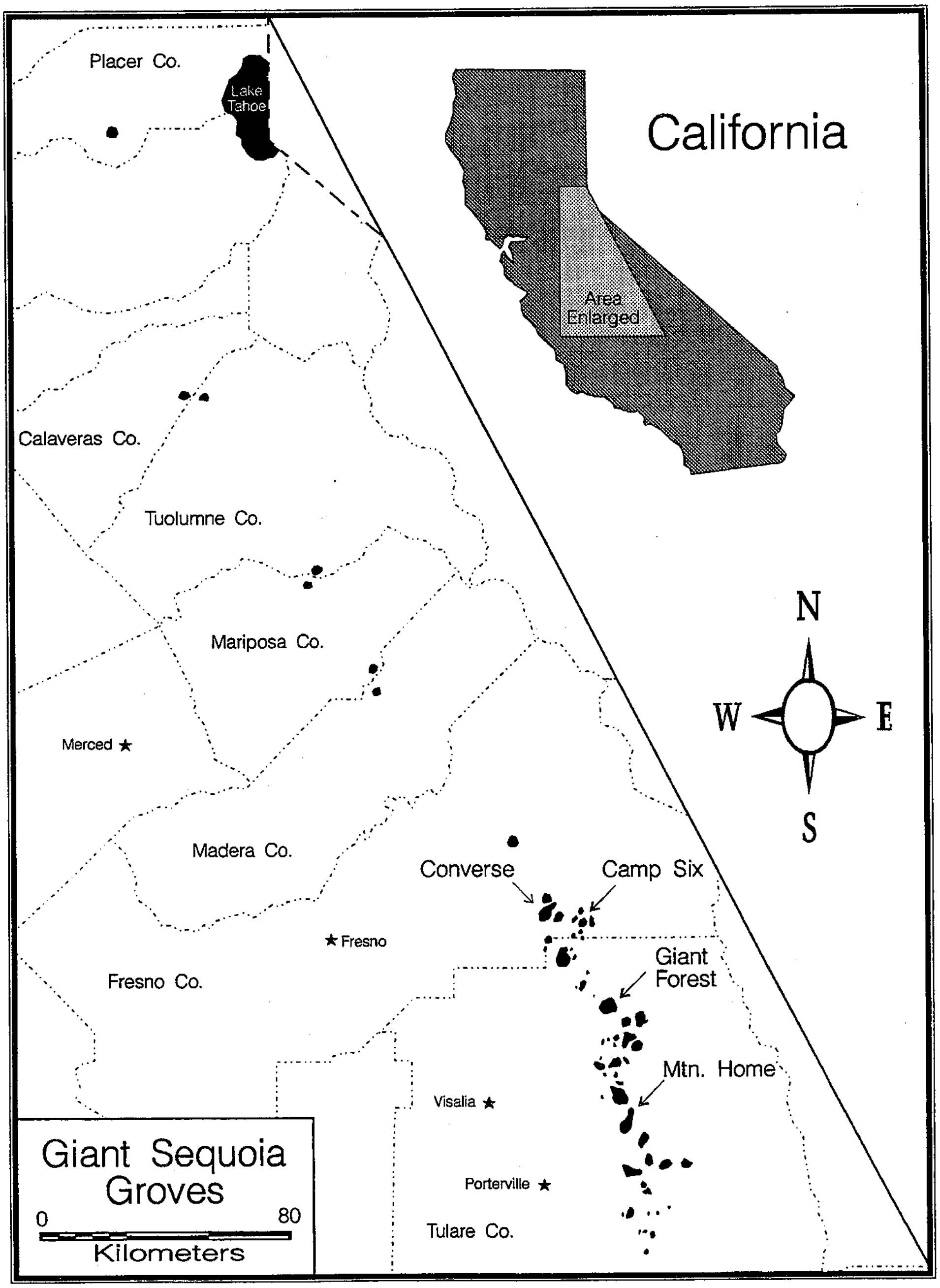

Figure 1. Locations of giant sequoia chronologies and groves mentioned in the text. Irregular black areas are giant sequoia groves.

also developed with selected radii from the three site chronologies as well as a single tree (Douglass' oldest tree, D-21) that grew in the Converse Basin Grove (Figure 1). This latter chronology is referred to as the composite sequoia chronology.

Many of the tree-ring samples that make up the chronologies were collected from remnant (dead) material in conjunction with the fire history study (Swetnam et al. 1990). Radial samples were collected from snags and logs by making plunge cuts in the sides of the main stem using a roller-tipped chainsaw with 1.3 to 2.2 meter-length bars. On stumps or the ends of cut logs, V-cuts were made with a chainsaw and radial sections removed, similar to the methods Douglass (1919) employed to collect his samples (except that he and his workers used hand saws). Samples were cut from at least two to three meters – and in some cases up to 30 meters – above ground level in order to minimize the effects of healing surges associated with fire-scarred areas at the base of a tree.

Other ring-width data included in the Camp Six, Mountain Home, and composite chronologies are from samples collected by Douglass. The Camp Six chronology includes 7 radials from Douglass' Redwood Basin collection (from the Windy Gulch Grove), and Mountain Home includes 6 radials from his Springville sequoias (collected from the Mountain Home Grove). Douglass' oldest tree, D-21, from the Converse Basin Grove, was incorporated into the composite sequoia chronology. Douglass' radials and other samples are stored at the Laboratory of Tree-Ring Research at The University of Arizona. Based on his notes about the crossdating characteristics of individual trees (Douglass 1945a and unpublished data), selected samples were removed from storage and reglued onto new mounts where new surfaces were sanded, dated, and measured. Douglass and his coworkers generally dated rings on a diagonal surface (a 35° angle to the transverse surface; Douglass 1941), which allowed a new transverse surface to be prepared and dated for the present investigation without disturbing the original crossdating marks.

In order to connect the remnant material to the present, increment borers were used to obtain cores from living trees. At Giant Forest and Mountain Home, trees in unlogged areas of the groves were sampled. At Camp Six, all of the big trees in the Windy Gulch Grove had been felled by logging. Trees in Evans Grove, an adjacent, mostly unlogged grove in a similar setting, permitted extension of the Camp Six chronology to the present. Although a 76 centimeter increment borer is no match for a 9 meter diameter sequoia, cores were obtained that overlapped the remnant material by several centuries.

All samples were crossdated and measured according to standard procedures (Robinson and Evans 1980; Stokes and Smiley 1968). Crossdating and measurements were checked using program COFECHA (Holmes 1983), which computes correlation coefficients between overlapping segments of tree-ring series. COFECHA output was also used to help select the more highly correlated series for inclusion into the final chronologies.

Sequoia ring widths often show positive growth responses to fire events, referred to as growth releases (Hughes and Brown 1992). The magnitude and duration of these growth releases ranged from very subtle to quite dramatic increases in ring widths after fire years. A singular example of a dramatic growth release was that after a fire in A.D. 1297 at Mountain Home (Stephenson et al. 1991). Ring widths in trees sampled at Mountain Home were an order of magnitude larger after 1297 than before. This growth increase persisted for several decades before gradually declining to pre-1297 widths. Abrupt growth releases following fire may be due to a number of factors, including changes in soil nutrients, pH, or moisture regimes, or reduced competitive interaction with surrounding vegetation (Hartesveldt 1964).

The presence of these fire-related disturbances complicated identification of climaterelated low-frequency fluctuations in the ring-width series. In an effort to determine if any in-common low-frequency climate signals could be seen between individual trees and sites, a series of detrending procedures, which ranged from straight line or negative exponential (Fritts et al. 1969) to increasingly flexible cubic-smoothing splines (Cook and Peters 1981), was applied to the three sets of ring-width data from Mountain Home, Camp Six, and Giant Forest. Program ARSTAN (Cook 1985; Cook and Holmes 1986) was used to detrend the ring widths and calculate mean value functions. The straight line or negative exponential detrending removed very little of the low-frequency variation, while splines removed progressively more depending inversely on the 50% frequency response function (Cook and Peters 1981). Chronologies resulting from these various detrending methods were then compared both graphically and statistically to each other and to other drought-sensitive ring-width chronologies from the western U.S. If low-frequency patterns in the chronologies were climatically-derived, they would be expected to correspond from site to site. On the other hand, if low-frequency patterns were disturbance-related, they should have been more localized and not correspond regionally to any great extent.

For the final three site chronologies, the detrending method chosen was a relatively flexible 40-year (50% frequency-response function) cubic-smoothing spline. The 40-year spline removed much of the low-frequency variance from the ring-width series (preserving only 29% of the variance on timescales of 50 years and less than 3% on timescales over 100 years). This detrending approach appeared to be the best compromise for mitigating the fire-associated disturbance signal. Negative exponential detrending or stiffer cubic splines failed to minimize the influence of the growth releases on the climate signal. Ring-width series from Mountain Home were separated into pre- and post-A.D. 1297 segments before detrending in an attempt to eliminate the effects of the growth release after the 1297 fire year. The index value for A.D. 1297 at Mountain Home was estimated using the mean of the Camp Six and Giant Forest indices for the same year.

After detrending, time series models were fit to individual series and residuals calculated. An autoregressive (AR) model (Box and Jenkins 1970; Cook 1985; Meko 1981) was selected based on the pooled autoregressive procedure in ARSTAN (Cook and Holmes 1986). The AR model selected was used to remove the effects of persistence from each set of ring-width data. This step further insured that only the high frequency signal in individual series was retained. Autoregressive-moving average (ARMA) models (Biondi and Swetnam 1987; Box and Jenkins 1970) were also applied to selected series to test the difference in effectiveness of these models. Little statistical or graphical difference was noted between AR or ARMA modeled series, and the final chronologies contain only AR modeled residuals. The prewhitened residual series were combined using a biweight robust mean (Cook 1985) for the final chronologies.

The composite sequoia chronology was developed by combining 80 of the longest and most highly correlated series from all sites. Individual ring-width series were also detrended with a 40-year spline and fit with a pooled AR model before combining into the mean value function as with the individual site chronologies.

RESULTS

The dating chronology originally developed by Douglass (1919) is confirmed without modification by this work. In addition, by crossdating of cores taken in 1988 and 1989 with Douglass' chronology ending in 1915, the annual nature of giant sequoia tree rings has been demonstrated unequivocally.

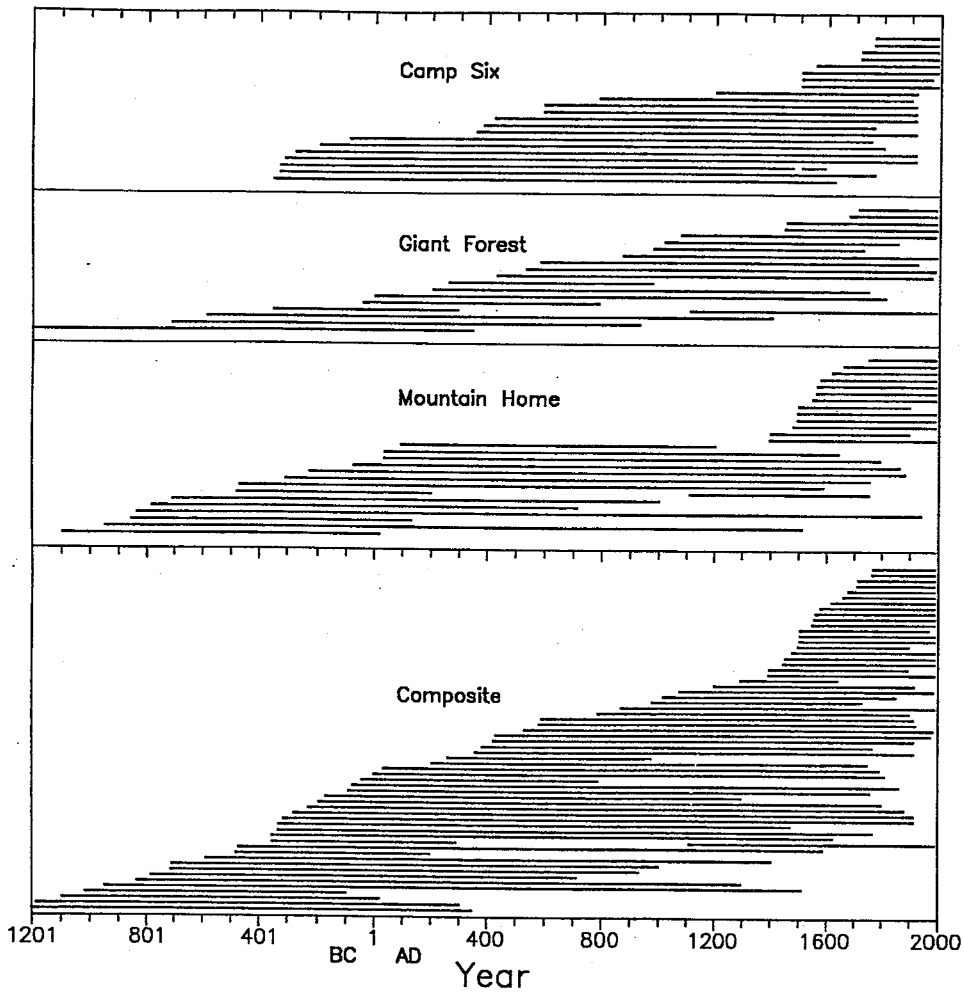

Figure 2. Time spans of individual tree-ring series for four giant sequoia chronologies.

Plots of the time spans of individual trees that make up the four chronologies are shown in Figure 2. In the composite chronology, there are 33 radii greater than 1000 years in length and 5 greater than 2000. These ring-width data, along with the chronologies, will be archived at the International Tree-Ring Data Bank at the National Geophysical Data Center in Boulder, Colorado, USA, and at the Laboratory of Tree-Ring Research.

Statistics for each chronology are summarized in Table 1. The series are generally complacent, with low mean sensitivity compared to other conifer chronologies from the western U. S. (Fritts and Shatz 1975). The chronologies are negatively skewed due to the presence of low-growth signature years in otherwise relatively uniform ring widths. A plot of a representative segment from the three site chronologies shows agreement between these low-growth years (Figure 3). Years with the 30 lowest index values in the composite chronology compared to the rankings for these same years in the three site chronologies are summarized in

Table 1. Giant sequoia chronology statistics from program ARSTAN. Statistics given are for the residual chronology, 40-year spline detrending with AR model fit by ARSTAN.

	Camp Six	Giant Forest	Mountain Home		
			pre-1297	post 1297	Composite
Time span	347 B.C to A.D. 1989	1235 B.C. to A.D. 1988	1094 B.C. to A.D. 1296	A.D. 1298 to A.D. 1989	1235 B.C. to A.D. 1989
Length in years	2336	3223	2390	692	3224
No. of series/trees	29/22	24/19	19/14	24/22	80/67
AR model	3	3	2	1	3
Mean sensitivity	0.13	0.12	0.11	0.10	0.11
Standard deviation	0.12	0.10	0.10	0.09	0.10
Skewness	-1.12	-1.01	-0.93	-1.36	-1.28
Kurtosis	4.35	3.91	3.19	6.57	5.08
Common interval[1]	597 to 1754	1113 to 1726	39 to 1296	1581 to 1861	38 to 1296
Mean Correlations[2]	0.431	0.367	0.303	0.237	0.350
Signal-to-noise ratio	7.565	3.745	3.472	3.195	8.607
Agreement w/ population chronology[3]	0.883	0.789	0.776	0.762	0.896
Percent Variance in 1st eigenvector	46.19	43.11	39.04	29.42	39.19

1 Period used in computing descriptive statistics listed below.
All dates are A.D.

2 Mean of correlation coefficients of all possible pairwise combinations of ring series in common interval.

3 Wigley et al. 1984

Table 2. Indices for A.D. 1580, the year Douglass had problems with in his original chronology, are the smallest in all chronologies.

Correlations between pairs of the three site chronologies show agreement for most of the period of record (Figure 4). Only one tree from Giant Forest extends into the 8th century B.C., and the low correlation with the Mountain Home chronology in this period may be the result of fire-related injuries in this sample. Future sampling of old trees covering this period may resolve this drop in correlation in the early part of the chronologies.

As has been noted, the detrending procedure chosen for the final chronologies was a 40-year (50% frequency response function) cubic spline. Chronologies produced by detrending with either negative exponential or straight line functions — i.e. with very little low-frequency trend removed — share some low-frequency patterns but exhibit many variations unique to each site that are most likely due to fire-associated growth releases or other disturbance-related factors in individual ring-width series. Fifty-year spline fits through the negative exponential or straight line detrended chronologies (Figure 5) illustrate these common as well as unique low-frequency variations. Note especially the unprecedented increase in growth at Giant Forest at the end of the chronology. This increase is most likely due to prescribed fires that the National Park Service has been conducting in the grove since 1978 (Mutch and Swetnam, in press). Little low-frequency agreement with other ring-width chronologies from this area was noted, although good high-frequency relationships were seen (Figure 6). Even with the fairly flexible 40-year spline detrending, the final chronologies still exhibit fire-influenced growth increases that are difficult to remove completely with a smoothing spline (Figure 7).

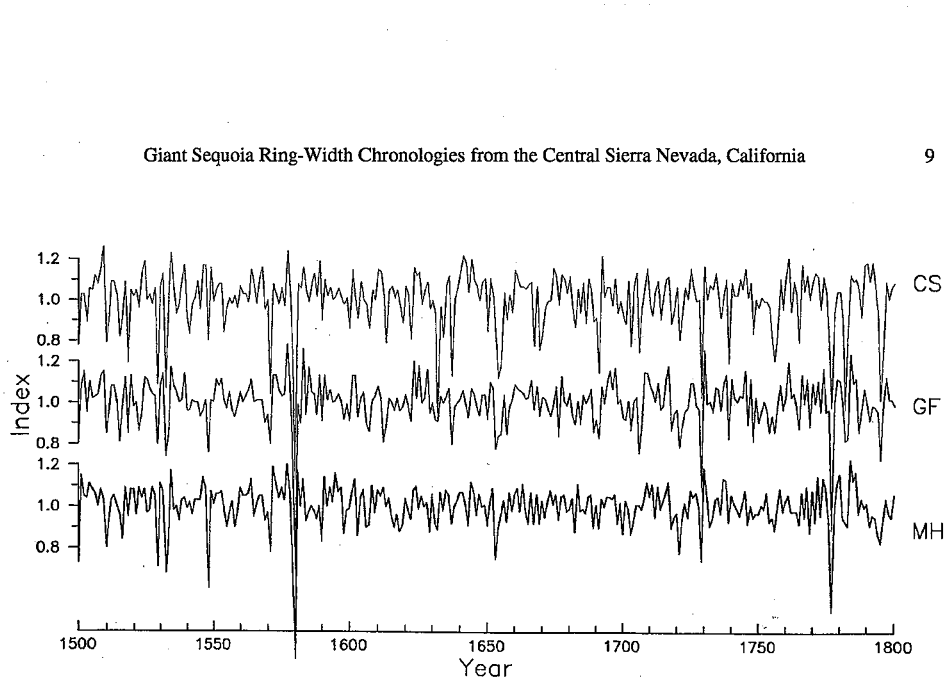

Figure 3. Ring-width indices for Camp Six (CS), Giant Forest (GF), and Mountain Home (MH) from A.D. 1500 to 1800.

DISCUSSION

The common signal in sequoia chronologies is primarily reflected in the correspondence of low-growth signature years (Figure 3). There is strong evidence that low-growth years were caused by regional-scale extreme drought events (Hughes et al. 1990), and a 2,100 year-long record of the frequency of such droughts has already been produced using the three site chronologies (Hughes and Brown 1992). Douglass' original observation of the suitability of sequoia for climate reconstruction (Douglass 1928) is supported by the co-occurrence of low-growth years both between sequoia chronologies and with other drought-sensitive tree-ring chronologies from this area of the western U.S. (Figure 6).

Periods of high correlation between pairs of site chronologies tend to occur when there are more extreme low-growth index values in common between the pair (Figure 4). Note especially the period around A.D. 1300, when correlations between Mountain Home and the other two site chronologies decrease in conjunction with a decline in correspondence of low-growth years. The decline of in-common low-growth years between Mountain Home and the other two chronologies can be attributed to the major fire in 1297 and resulting changes in stand dynamics at Mountain Home. It is probable that a substantial portion of substory trees and perhaps overstory giant sequoias were killed at Mountain Home by this fire. A change in stand density may have resulted in a reduction in competition for moisture and other resources among the surviving big trees and hence changes in growth response to moisture stress.

Fire-related disturbances present in giant sequoia ring widths also lead to problems in interpreting longer-term trends in the ring-width data. Fire years were generally low-growth years (Figure 7). Since these were predominately late season fires, occurring after latewood formation had already begun (T.W.S., unpublished data), low-growth during a fire year could not be the result of the fire itself. However, the increase in ring growth in years after fire in Figure 7 is most likely a nonclimatic signal caused by a fire-associated growth response. Even where there are low-frequency patterns that appear to be consistent between chronologies (Figure 5), this correspondence is complicated by the presence of regional-scale fire years in the fire history record (T.W.S., unpublished data). Growth releases associated with fires that

Table 2. The 30 years with the smallest index values for the sequoia composite chronology with the corresponding rank of the same year in each of the three site chronologies. These index values are the smallest for the period covered by all four chronologies from 345 B.C. to A.D. 1988. All dates are A.D. unless otherwise noted.

Composite Rank	Composite Year	Camp Six	Giant Forest	Mountain Home
1	1580	1	1	1
2	699	2	5	3
3	109	8	3	2
4	954	3	8	10
5	325 B.C.	5	6	4
6	1777	11	4	7
7	10 B.C.	46	2	8
8	1156	6	16	17
9	762	12	51	6
10	84 B.C.	21	7	9
11	553	10	23	19
12	1729	15	9	47
13	1977	19	18	25
14	554	58	41	5
15	980	37	24	13
16	1126	14	58	16
17	1532	18	47	30
18	267 B.C.	4	14	12
19	865	17	20	56
20	868	73	27	27
21	1795	13	42	108
22	1059	20	12	487
23	809	33	65	14
24	189	41	11	49
25	797	23	137	32
26	15	40	17	26
27	217 B.C.	76	54	11
28	1571	16	92	62
29	100	69	43	23
30	1352	29	21	187

occurred throughout the range of sequoias during a particular year may have resulted in site-to-site correspondence of low-frequency patterns in sequoia ring widths that were not caused directly by climate.

The recognition of disturbance signals in tree-ring series is of fundamental importance in dendroclimatic analyses (Cook 1987). The separation of ring-width data into "signal" and "noise" is a problem faced by all dendrochronologists. Sequoia chronologies have been developed to extract climate as the signal with fire-associated growth releases as a component of the noise. However, these ring-width data coupled with dates of fire events derived through analyses of fire scars could provide information about fire effects on tree growth by looking exclusively at the growth response after fire years (Mutch and Swetnam, in press). Alternatively, knowledge of fire-scar dates may provide a means of eliminating the disturbance-related component from the time series in order to obtain longer scale climatically-derived low-frequency information from the ring-width data.

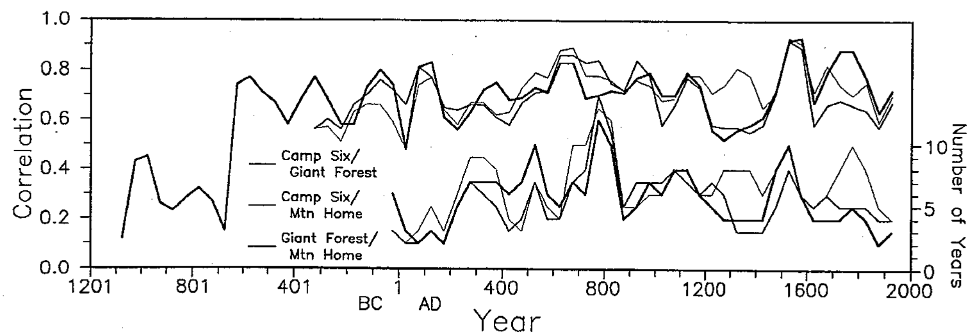

Figure 4. Correlations (top lines) and number of lowest decile years in common (lower lines) between pairs of giant sequoia site chronologies. Correlation coefficients were computed for 100 year periods lagged by 50 years. Lowest decile years were determined for each chronology for the period 101 B.C. to A.D. 1988 (Hughes and Brown 1992) and are summed over the same 100 year periods as the correlation coefficients

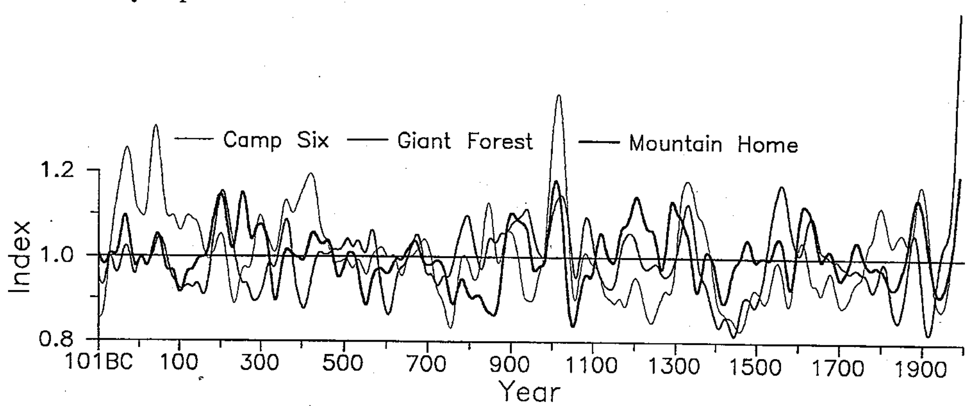

Figure 5. 50-year spline curve fits through giant sequoia site chronologies made up of ring-width series detrended with either straight line or negative exponential functions.

As Huntington and Douglass recognized, giant sequoia has much to offer for dendrochronological study. The giant sequoia chronologies described here provide some of the longest tree-ring records in the world. The rarity and importance of such records (Hughes 1989) for climatic — and, perhaps, disturbance — history make these unique resources for further study. Future chronology development will concentrate on extending the network of sequoia chronologies both spatially to other groves and temporally back in time. Further work will explore the utility of other properties of sequoia tree rings, such as density, cell dimensions, and chemical composition, as records of past environments. Much work in the coming years will be directed to examining the potential information offered by these magnificent trees.

ACKNOWLEDGMENTS

We thank Barry Richards and Richard Holmes for dating and measuring sequoia series. Sequoia/Kings Canyon National Parks, Sequoia National Forest, and Mountain Home State

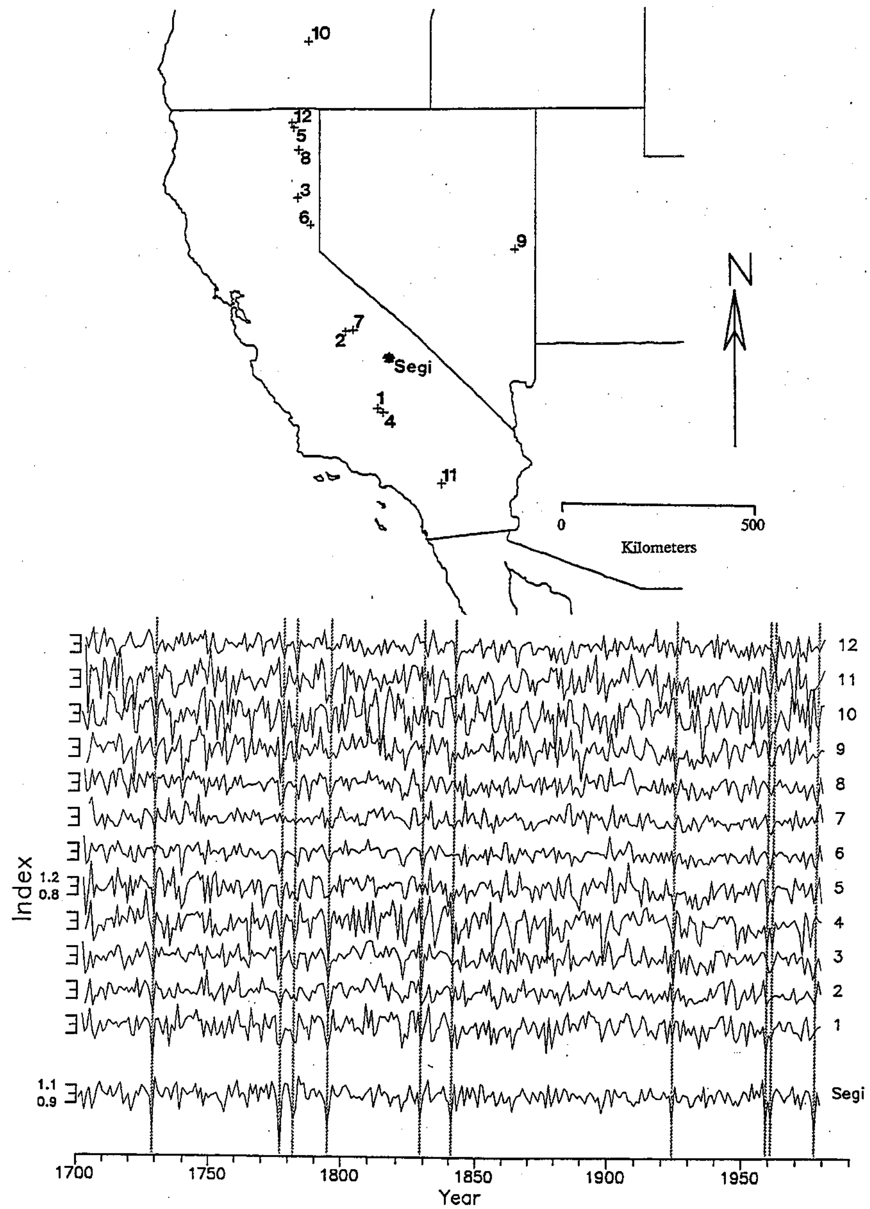

Figure 6. Locations and plots of 12 ring-width chronologies most highly correlated with the sequoia composite chronology (Segi) out of 156 western U.S chronologies checked. Years marked on time series are those during which all three sequoia site chronologies recorded a low decile year for the period 101 B.C. to A.D. 1988 (Hughes and Brown 1992). The chronologies and simple correlation with the Segi chronology are: 1, Piute Mountain (.60); 2, Black Creek (.55); 3, Lemon Canyon (.53); 4, Sorrel Peak (.50); 5, Likely Mountain (.46); 6, Antelope Lake (.44); 7, Kaiser Pass (.40); 8, Dalton Reservoir (.39); 9, Conners Pass (.38); 10, Lost Forest (.37); 11, Wellman Divide (.36); 12, Timbered Mountain (.36). All chronologies are from Holmes et al. (1986), except Conners Pass and Wellman Divide (unpublished data, Laboratory of Tree-Ring Research).

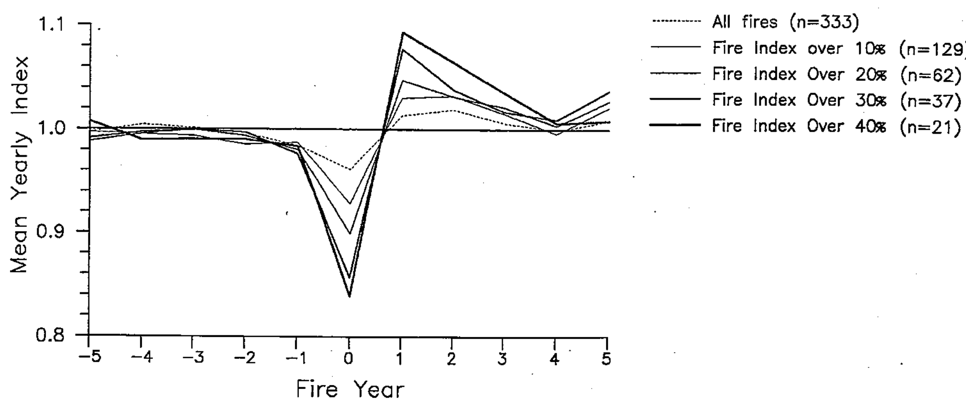

Figure 7. Average ring-width indices for five years before and five years after fire years at Giant Forest for the period A.D. 500 to 1700. Fire indices are the percentage of trees exhibiting fire scars for any given year (T.W.S., unpublished data). For example, a fire index over 40% is an average of all years in which 40% or more of sampled trees were scarred. The low index value for the year of a fire (year 0) suggests that fires occurred during low-growth (and, hence, probably dry [Hughes and Brown 1992]) years. The increase in growth after the fire year suggests that fire-caused growth releases are still present in the index chronology for Giant Forest.

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