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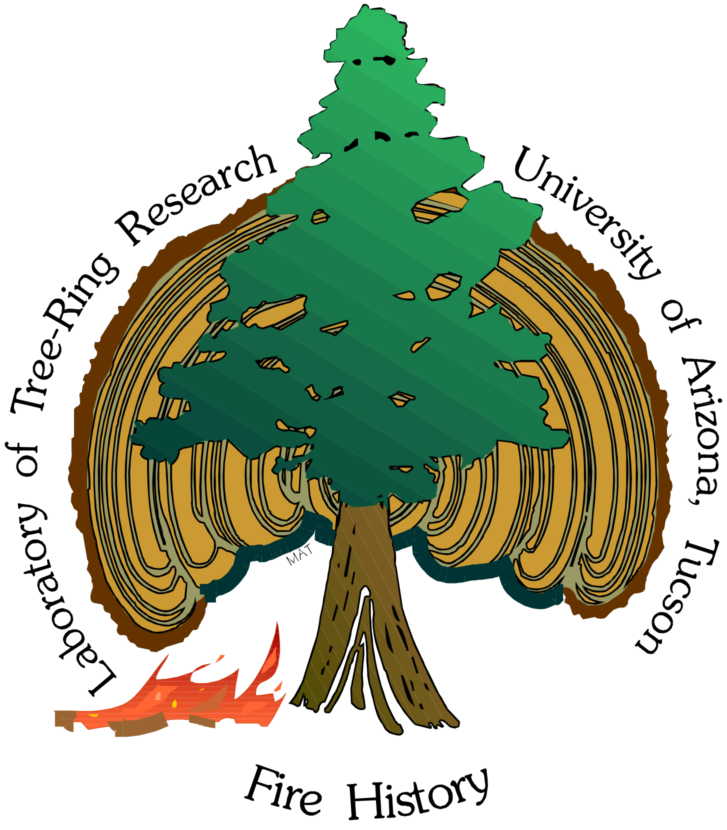

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TEMPORAL AND SPATIAL PATTERNS OF GIANT SEQUOIA RADIAL GROWTH RESPONSE TO A HIGH SEVERITY FIRE IN A.D. 1297

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ABSTRACT

Fire was a dominant disturbance process in the development and maintenance of most Sierra Nevadan forests, including the many unique giant sequoias groves. Individual severe fire events had important impacts on both the short-term dynamics and the long-term history of these forest stands. In the Mountain Home Grove of giant sequoias we observed that a fire in A.D. 1297, recorded as scars on many trees, was followed by a growth release of unusually large magnitude and duration. The number of scarred trees and a growth release of this size suggested this fire event was of unusually high severity, not equaled over the last 2,000 years. We hypothesize that this event was associated with mortality of most non-sequoia tree species and a considerable number of giant sequoias. In this study we examined the spatial extent of this event throughout the grove and the temporal response of the growth release by comparing ring-width series from samples from within the grove to a regional "control" tree-ring chronology. These findings were also compared to results from another recent study relating growth releases following contemporary prescribed burns and logging to impact severity (Mutch 1994).

Using the magnitude of the growth release as a proxy of fire severity, we found that the spatial distribution of the 1297 fire impacts indicated the fire was most severe in the northern and central portions of the grove. Sequoia trees in peripheral areas had a smaller post-fire growth release. The post-fire growth release at Mountain Home was apparent for about 100 years (to ~1400) when pre-burn average growth was again equaled. The release was often proceeded by a short period of suppressed growth in many trees, that we attributed to the severity of the burn. Our comparison of the growth release to the regional "control" chronology showed significantly greater growth at Mountain Home during much of the release period. The comparison was somewhat confounded by the fact that there was an apparent growth increase at several of the individual "control" sites that may also have been associated with fire. Time series of precipitation, reconstructed from tree-rings, showed that a long drought occurred between 1292 and 1296. Hence, regional fire events may have occurred during this period and could have affected the "control" sites. The comparison of the 1297 event to modern disturbances showed that most recent prescribed burns were of much smaller impact, although a few may have responses that exceeded the effects of the 1297 event. Comparison to a logged area suggested that although there are some similar post-impact growth responses there may also be some differences.

INTRODUCTION

In the process of reconstructing a 3,000-year fire history for the Mountain Home Grove of giant sequoias (***Sequoiadendron giganteum***) (Swetnam et al. 1992; Swetnam 1993), we discovered an unusual fire event in the year AD 1297 (Swetnam and Baisan 1988; Stephenson et al. 1991; Swetnam 1991). Most sequoia trees which survived this fire had a pronounced post-fire growth increase (Fig. 1). This dramatic increase in ring widths (often following a slight suppression immediately after the event), lasted from three to ten decades before returning to approximately mean pre-fire ring-width levels. Additionally, evidence from the stand structure of the grove, based on data collected by E. Huntington (1914) and A.E. Douglass (1919), also suggested that an unusually large cohort of sequoias established within a short period following this event (Swetnam and Baisan 1988; Stephenson et al. 1991). We hypothesized that the 1297 fire was of unusually high severity and that the stand density was greatly reduced, with the growth release a result of reduced inter- and intraspecific competition and an accompanying nutrient release. The period of enhanced sequoia recruitment was probably associated with the opening of the stand and the creation of a suitable seedbed through the exposure of large areas of mineral soil, which is important for seedling survival (Harvey et al. 1980; Mutch 1994).

The fire history of any particular site has strong influences on the subsequent vegetation structure and composition, and the fire regime of the area (Fox and Fox 1987). Thus, the 1297 event probably had a distinct influence on the structure and dynamics of the Mountain Home Grove, with effects that persisted for centuries following the event. Although such extreme events seem to be rare in the fire record from sequoia groves (Swetnam et al. 1992), they may have important consequences on the life history of giant sequoias and for grove structure. However, because of effective and continuing fire suppression in Sierra Nevada forests for the last 80 to 90 years, fuels are accumulating within groves (Biswell 1989; Kilgore and Sando 1975; Vankat and Major 1978; Parsons and DeBenedetti 1979), increasing the likelihood of such a severe event recurring.

Tree-ring research has been conducted on giant sequoias for many years (Huntington 1914; Douglass 1919, 1920, 1928; Hughes and Brown 1991; Swetnam et al. 1992; Swetnam 1993; Mutch 1994; Stephenson in press; Brown et al. in press). The great age of giant sequoias was documented by E. Huntington (1914) during his early work investigating climate dynamics, in which he determined the ages of 358 stumps (47 in Mountain Home Grove) in areas that had been recently cut-over. Huntington directed A.E. Douglass to the oldest stumps, and Douglass subsequently developed a 3,220 year crossdated tree-ring chronology (Douglass 1919, 1920). Today, this is one of the longest tree-ring chronologies ever constructed, and at has been recently updated to extend to the present by Brown et al. (in press).

The objectives of the research were to investigate spatial and temporal patterns of the 1297 AD fire event, and through comparison with known modern disturbances, to suggest probable severities for the burn. Methods included making a survey of the approximate areal extent of the 1297 event by examining stump tops, and by collecting specimens from groups of stumps and snags over a range of locations throughout the grove. The severity of the event and the magnitude of the growth release were also studied and compared to a regional set of giant sequoia chronologies. For comparison, we also investigated growth patterns following recent disturbances in areas 1) harvested for timber, 2) burned with prescribed fires, and 3) nearby control sites that were not disturbed by recent events. Many of the methods and findings of a recent dendroecological study of giant sequoia growth responses to prescribed fire (Mutch 1994) were used in this study. These included most of our data on recent disturbances. This permitted us to make judgements on the severity of the burns because the growth responses were compared to fire impacts at each specific tree sampled. This comparison of the 1297 event with recent events will help in assessing the severity of past fires recorded in the tree-ring record. Additionally, the magnitude of the 1297 growth release, based on these techniques was compared to the growth release categories used in the fire history study of the grove (Swetnam et al. 1992).

STUDY AREA

Mountain Home State Forest - Mountain Home State Forest (MHSF) is located on the west slope of the south-central portion of the Sierra Nevada in California (Fig. 2). It is approximately 40 kilometers east of Porterville, California, on the Balch Park Road (Fig. 3). The state forest (established in 1946) and Balch Park County Park encompass much of the Mountain Home Grove of giant sequoias. The grove is situated on a broad nearly u-shaped ridge that surrounds Bear Creek and drops into the Wishon Fork to the east and the North Fork of the Tule River to the south. To the north the ridge is bordered by a steep slope rising to the south flank of Moses Mountain (2800m). Elevations on the ridge generally vary between 1760 and 2200 m (5800 - 7200 ft).

Vegetation of the area is composed of a highly productive mixed-conifer forest dominated by giant sequoias within the sequoia grove boundaries. Other common tree species include, ponderosa pine (***Pinus ponderosa***), sugar pine (***P. lambertiana***), Jeffrey pine (***P. jeffreyi***), white fir (***Abies concolor***), red fir (***A. magnifica***), incense cedar (***Callocedrus decurrens***), and black oak (***Quercus kelloggii***). Understory vegetation, depending on the area, is dominated by mountain misery (***Chamaebatia foliolosa***), manzanita (***Arctostaphylos*** spp.), mountain whitethorn (***Ceanothus cordulatus***), other Ceanothus species (***Ceanothus*** spp.), chinquapin (***Castanopsis sempervirens***) and graminoids. Climate is strongly Mediterranean with most precipitation falling as winter snowfall. Winters are mild and wet and summers warm and dry with only slight convective storm activity.

Extensive selective logging of giant sequoias took place in this grove around the turn of the century, and then continued intermittently until the 1950's (Otter 1963). Many large, old trees remain, including some of the largest known sequoias - Genesis Tree and Adam Tree (Flint 1987). Most of the stumps from logging activity are still in existence today and in sound condition because of the decay resistant nature of sequoia heartwood. Sapwood was decayed or missing from most of these stumps. Stumps have provided the main source of samples for dendrochronological studies in the area. Harvesting of pines, firs and incense-cedar has continued up to the present.

Mountain Home - 1297 Sites - The sampled sites were located throughout the state forest over a range of elevations (Fig. 3). The lowest elevation sites (1680 m) were on the west side of the park in the Coburn Creek and Rancheria Creek drainages. Slightly higher sites were located on both the east and west side the forest, in the area of Brownie Meadow and Happy

Camp to the west, and on the east side of the Wishon Fork of the Tule River to the east. The highest sites were located in the area of Tube Flat on the south flank of Moses Mountain. Samples originally collected during the fire history study in 1987 and 1988 came from the Enterprize Millsite and from the Frasier Mill Campground (Fig. 4).

Sequoia Regional "Control" Sites - The chronologies used as a regional "control" for sequoia growth came from five groves (Brown et al. in press; Hughes unpublished data) located both north and south of MHSF (Fig. 2). Sites located to the north were Camp Six and Converse Basin, situated on the south side of the Kings River Canyon in Sequoia National Forest, and Giant Forest, located in the Kaweah drainage in Sequoia National Park. Sites to the south were Black Mountain and Parker Peak, located in Sequoia National Forest.

Mountain Home - Logged Site - We sampled one site in MHSF that had been selectively logged in 1956 and salvage logged in 1966 (Fig. 3). The salvage logging occurred primarily near the paved road at the lower end of the site (Dave Dulitz, personal communication). The site was not extensively slash-burned after the logging operations (Malcolm Harris, personal communication). The logged area was located approximately ½ mile up the road (to the northeast) from the Frasier Mill Campground. It was an area 32 hectares (80 acres) in size located just to the north of the main road. The center point UTM coordinates were 4011^{900}N, 348^{500}E. The site was in the southwest quarter of section 25, T28S, R30E. The elevation ranges from 1,902 to 2,000 meters (6,240 to 6,560 feet). The aspect was variable but primarily southwest, and the slope ranged from 5 to 26°. The average slope was 13 degrees.

Mostly whitewoods were logged at this site, but some large giant sequoias were also cut. The site had a very open appearance and a dense growth of whitethorn occupies much of the area underneath remaining trees. Sequoia reproduction occurred in many locations on the site, as well as a small amount of fir and pine reproduction.

Mountain Home - Control Site - This site, used as a control for the logged area, was located just to the west of Bogus Meadow on a primarily east-facing slope and extending up to a ridgetop. Centerpoint UTM coordinates are 4012^{000}N, 347^{600}E (Fig. 3). The elevation ranges from 2,000 to 2,048 meters (6,560 to 6,720 feet) and slope from 6 to 32°. The average slope was 19 degrees. This area has not been disturbed by recent fire or logging (for approximately 100 years).

METHODS

Sampling and Crossdating

We examined stump tops of giant sequoias in areas that had been cut 40-100 years ago for the presence of unique, large magnitude, growth releases that would indicate the occurrence of the 1297 burn. All such releases were recorded. Our field and lab experience, based on the samples from Enterprize Millsite fire history collections, suggested that the 1297 release may be visually distinguishable from most other events to be identified on stump tops. In addition, using chainsaws, we removed radial v-cuts from stump tops or radials by making plunge cuts into the sides of logs. Crossdating of these samples in the laboratory permitted a check of the growth releases observed on stump tops. Field sampling was designed to obtain collections from small clumps of trees from a wide variety of locations around MHSF. The collection of multiple samples from a specific area was important in obtaining replicated material to confirm tree response. Additionally, because samples from some sites were complacent, and difficult or impossible to crossdate, samples from different trees within an area was frequently required to obtain one or two that could be crossdated. Core samples were taken from a few trees. We sought to obtain specimens that contained tree rings for the period from about 1100 to 1500 AD as a minimum. These collections were returned to Tucson, stabilized by attaching to plywood strips and prepared for crossdating. Preparation entailed sectioning the samples with a band saw, and sanding with progressively finer grits (80-400 grit) until a very finely sanded surface was produced (individual cells were clearly distinguishable).

The material sampled in 1991/1992 was augmented by previous collections obtained for the fire history study in 1987 and 1988 (Swetnam et al. 1992) in the areas of the Frasier Mill Campground and the Enterprize Millsite (Fig. 4), and for A.E. Douglass' studies during the first half of this century (Douglass 1919). Data for the prescribed burn sites in Sequoia and Kings Canyon National Parks and from the logged and unlogged sites in MHSF were provided through recent research by Linda Mutch (1994).

All chronologies and samples from Mountain Home were crossdated using the skeleton-plot technique (Stokes and Smiley 1968), or measured and processed through the program COFECHA.. All dates obtained from COFECHA were verified by reexamining specimens. The purpose of crossdating was to assign each ring to the actual calendar year in which it was formed during tree growth. This provided exact dates of tree rings and fire events. All measured series were checked for dating errors and internal agreement using the program COFECHA (Holmes 1994). Crossdating of the samples was based on the original chronology constructed by Douglass (1919) and the updated and expanded chronologies developed by Brown et al. (in press).

When samples were crossdated all growth releases or suppressions in the period around 1297 were noted and rated. The rating or magnitude of a release or suppression was recorded using a numeric category from -5 to +5, with negative values indicating a growth suppression and positive values a growth release. Specific criteria used in assigning these categories, based on an evaluation of the tree-ring sequence on a cross-section possessing the 1297 event, are given in Appendix 1. These criteria were also used when categorizing growth releases associated with the dating of fire scar samples during the previously developed fire history from the Enterprize Millsite (Swetnam et al. 1992). This permitted a comparison of the growth release information from the two groups of data.

Tree-Ring Analysis

Selection of Regional "Control" Series - We obtained a set of ring-width data from giant sequoias sampled at five sites: Camp Six, Converse Basin, Giant Forest, Black Mountain, and Parker Peak. These data were obtained from Brown et al. (in press) and from recent collections by Malcolm Hughes, Peter Brown, Rex Adams, and Ramzi Touchan (unpublished data, Laboratory of Tree-Ring Research), who sampled these sites to construct giant sequoia chronologies for climate analyses. Ring-width series that overlapped the period from 1100 to 1500 AD were utilized to create a regional "control" chronology to represent the mean growth response to climate for this time period. Although we cannot rule out the presence of fire disturbance at some of these individual sites, the averaging of many ring-width series from five different groves should have the effect of removing disturbance related growth pulses that occurred within individual sites. Following are the sites and numbers of ring-width series included in the regional "control" chronology:

Site	**Number of Series**	**Elevation**	**Location**
Camp Six (CSX)	14	2100 m	36° 46’ lat, 118° 49’ lon.
Converse Basin (CBR)	13	1900 m	36° 48’ lat, 118° 58’ lon.
Giant Forest (GF)	12	2100 m	36° 33’ lat, 118° 45’ lon.
Black Mountain (BMG)	21	1925 m	36° 06’ lat, 118° 39’ lon.
Parker Peak (PPG)	18	1810 m	35° 59’ lat, 118° 40’ lon.

Each site was standardized using the program ARSTAN (Holmes 1994) to remove age trend from the individual series. Negative exponential or trend lines were fit to each series that represented the expected growth trend. The ring-width values were then divided by this expected growth curve to obtain a set of dimensionless indices for each ring-width series. Standardization resulted in indices with a mean of 1.00 so that fast-growing trees did not dominate slow-growing trees when individual series were averaged together to produce a mean site chronology. The five individual site chronologies obtained after standardization were then averaged together to produce the regional "control" chronology.

Mountain Home 1297 Chronology - Ring-width series were measured for 36 of the trees sampled in Mountain Home in 1991/92. Twenty-eight of these were standardized with ARSTAN using the same standardization procedure described for the "control" ring-width series. All individual tree indices were then averaged together to produce a mean site chronology, which we will refer to as the Mountain Home 1297 chronology. The period from 1100 to 1500 AD was used in the analysis since this brackets the 1297 event by approximately 200-years. In several instances a subset of series from these samples were sorted for comparison with other groups of data. For example, trees whose growth response indicated a moderate-to-high severity impact were separated and compared to modern fire events. This permitted a more realistic comparison of higher severity events from the different sites, versus comparing higher severities from one site to an average of different severities from a second site.

T-tests - We conducted t-tests to compare mean growth between "control" and burn chronologies for a 10-yr pre-burn period and 10-yr post-burn period and for successive 20-yr periods beginning twenty years prior to 1297 and extending 140 years after 1297. We used t-tests that did not adjust the effective sample size and degrees of freedom to account for autocorrelation because this persistence may be a biological reality that incorporates much of the growth release signal, so accounting for it may be removing much of the response that is of interest. A more rigorous justification for this approach is provided by LeBlanc et al. (1992).

IMPACT Program - The IMPACT program (Holmes 1994) was used to calculate percent growth changes between pre- and post-burn periods for each individual tree as well as for the mean growth change for burn and "control" chronologies. The output gave growth following a known or hypothesized impact as a percentage of the pre-impact growth for a specified length of time (both pre- and post-impact). The program also provided mean growth values for each year during the specified time period and the percent of each annual value relative to the mean pre-impact growth. The IMPACT program required input of individual tree-ring widths or indices, the disturbance date (1297 AD), and a length of time to compare in both the pre- and post-disturbance periods. We compared mean growth changes between burn and "control" series for various length pre- and post-burn periods. These time periods compared equal lengths of time for both pre- and post-burn periods (5-, 10-, 20-, 30-, 40-, and 50-year periods).

The percent change from the 10-year IMPACT comparison for the Mountain Home 1297 burn chronology was used to categorize the strength of the difference between the pre- and post-burn periods. Applying the findings of Mutch (1994) allowed us to separate trees into groups that sustained low severity fire (no post-burn increase or very low post-burn increase), moderate to high severity fire (moderate to large growth post-burn growth increase), or very high severity fire (post-burn growth suppression). Numerically, these severity categories were defined as follows; low, 80 to 120% change, moderately high, >120% increase in radial growth, and very high, <80% increase.

We also used the IMPACT program to evaluate the impacts of several recent prescribed burns of differing severities on giant sequoias, and to compare these effects to both the 1297 event, and to the growth responses of giant sequoias in an unlogged and logged area (harvested in 1956). This evaluation was done by calculating the percent growth changes for the Mt. Home logged and control sites, and for three recent prescribed burns and control sites in Sequoia and Kings Canyon National Parks (Mutch 1994). For all of these events, a 10-yr pre-disturbance period was compared to the 10-yr post-disturbance period.

These data were compared to the release value categories that were assigned by visually examining the same samples using criteria given in Appendix 1 (information recorded for the fire history reconstruction from five sequoia groves (Swetnam et al. 1992)). This was important in our evaluation of the relationship between the two sets of criteria and will help us interpret the release category data.

Difference or Residual Indices - To compare index series from disturbance events that occurred at different dates, we removed (or minimized) the growth response due to climate, since climate has variable effects on growth for the different pre- and post-disturbance time periods. To remove climate effects on growth from the burn or logged site chronologies, we subtracted the respective control series (representative of growth response due to climate) from the disturbance chronologies. The difference or residual series that result, represent essentially the growth response due to the disturbance. A similar approach has been used in studying air pollution and insect defoliation effects on tree growth (Nash et al. 1975; Swetnam et al. 1985; Swetnam and Lynch 1993). We calculated the residual indices from five tree-ring series; 1297 burn (all samples), 1297 burn (moderate and high severity), MHSF logged site, and recent low severity burns. The pre- and post-fire impact responses of these residual series were then evaluated.

RESULTS AND DISCUSSION

"Control" and Disturbance Impact Chronologies

During 1991/1992 we collected samples from 73 trees in MHSF (Appendix 2). Of these, 53 were crossdated but nine could not be used to evaluate the 1297 event because they did not overlap this time period (their outside ring being too early or inside ring starting after 1297). The remaining 20 trees could not be crossdated, and were usually complacent individuals (often from trees in mesic sites), samples with too few rings to date (not enough key marker years), or trees that were suppressed or injured. The crossdated samples were used to produce the Mountain Home 1297 chronology (Fig. 5, upper plot).

The five regional "control" chronologies and the Mountain Home 1297 chronology all agree well among themselves (Fig. 6), with significant correlations between all chronology series (Table 1). Key low growth years: 1126, 1152, 1154, 1183, 1227, 1276, 1352, 1377, and 1500, were important in the dating of the samples and appear as the smallest ring widths on the chronology plots. Important low growth years for the chronologies from recently disturbed areas were 1777, 1795, 1841, 1924, 1932, and 1977. Most low growth years are closely associated with periods of extreme drought (Hughes and Brown 1991). Trees growing in more mesic conditions often did not respond consistently to drought, resulting in very complacent ring-width series which sometimes could not be crossdated.

Three of the five chronologies - Parker Peak, Camp Six, and Giant Forest - showed an a 1300s growth increase, somewhat similar to the post 1297 increase at MHSF. This increase was also present in the composite regional "control" chronology developed from these five sites, but was less pronounced due to inclusion of the Black Mountain and Converse Basin chronologies which do not show a growth increase during this period. This period of positive growth may be a result of a general climate trend throughout the region, such as increased soil moisture at sites where growth was limited by this factor. Alternatively, the growth increases could have been due to regional occurrence of fires just prior to 1300 at a number of sites (resulting in reduced competition or nutrient releases), or a combination of both fires and climate trends. Climatologically, the years from 1292 to 1296 was one of the most persistent droughts for the period from 1100 to 1500, based on reconstructed precipitation for the Giant Forest (Fig. 7) by Graumlich (1993) and Graybill(1993). Four-year running means show that either four or five of these means for the decade from 1290 to 1300 were within the lowest 15 means for the period from 1100 to 1500 (Table 2). Thus, because this drought was regional in extent and dry periods were strongly associated with regional fire occurrence in sequoia groves (Swetnam 1993) it is quite possible that high severity fires occurred in many sequoia groves during this period. Such a release has been observed at the Redwood Mountain Grove in Kings Canyon National Park.

The 1297 release appear at MHSF may appear smaller and less significant than it actually might have been. When comparing residual series, one assumes that the "control" indices represent the growth response to climate with little effects of large-scale disturbance present. An ideal "control" chronology would have been obtained from groves where fire had not occurred, similar to sampling non-host trees when comparing residual indices for insect defoliation (Swetnam et al. 1985), however this was not possible because fires were probably frequent in all sequoia groves (Swetnam 1993). The post-1300 growth increase at MHSF was greater than the increase observed in the regional chronology (Fig. 8) since the regional "control" may have included the effects of regional fires.

Both the Mountain Home logged site and control site chronologies showed good agreement between the two series up to the point when the 1950s logging took place (Fig. 9). They each had a pronounced dip in growth for the period from around 1905 until the mid-1950s and a somewhat similar, but less obvious period of decreasing growth during the mid-1800s with an intermediate period of higher growth during the late 1800s. The cause of these growth change was unknown but could be climatic or a result of local effects within the grove. The pre-1950s growth changes do not appear to be associated with logging since neither sequoias nor whitewoods were previously harvested in the control area.

The 1297 Event

Visually identifying the presence of the 1297 fire event from stump tops proved difficult in nearly all cases. In only a few instances were we successful in correctly identifying the 1297 growth release in the field using this method. We concluded that this was an impractical method for ascertaining the spatial extent of this fire. This problem, was noted soon after we began our fieldwork and was confirmed in the lab when samples were crossdated. The presence of the 1297 release usually could not be detected, because the magnitude was low or because other releases were also present. Additionally, to obtain a wider spatial coverage of the grove we often needed to sample downed logs in areas where stumps were not available. Trees also frequently had very small rings with the release not clearly visible on the cut surface of a stump top. Due to these problems we found it necessary to collect samples from all localities and transport them to the laboratory for sanding, crossdating, and measuring.

A map displaying the magnitude of the growth release categories (see Appendix 1) for these trees showed large releases in the northern and central portion of the grove and on the ridges north and east of Coburn and Bear Creeks (Fig. 10). Areas outside this portion of the grove exhibited smaller growth releases or none at all.

The master fire chronology plot for all the fire scarred trees sampled in 1987/1988 in the Enterprize Millsite area showed a very strong 1297 impact on the trees (Fig. 5). Of the 15 trees sampled here, nine had fire scars in 1297, all had some kind of injury visible within the 1297 ring, and all had growth releases at this date. The average value for the 1297 release category was 4.5. No other year in the in the period between 1100 and 1500 AD had a value greater than 3.1. Mapping the pattern of the magnitude of these release values (Fig. 11) suggested the impact of the 1297 event was severe over most of the Enterprize Millsite area sampled.

A composite map (Fig. 12) of the growth releases from both collections showed a pattern similar to that described for Figure 10. The spatial pattern apparent from these maps suggested that the fire was severe and had an impact over a relatively large area, from 16 ha (Enterprize Millsite samples) to several square kilometers in size. This pattern contrasts with the low severity fires with localized high severity impacts usually observed in modern prescribed burns which is also inferred to be a typical pattern of presettlement burns (Stephenson et al. 1991; Stephenson in press). The distribution of the fire impacts also suggested that the 1297 fire may have spread into the grove from lower elevation areas to the west. The spread of fire from lower to higher elevations is also indicated by fire history reconstructions along elevation transects for the period from 1600 to the present in Sequoia National Park (Caprio and Swetnam in press) and MHSF (Caprio and Swetnam 1994).

The extensiveness of high intensity fire within sequoia groves probably had important influences on the spatial patterns of post-fire recruitment. Groves in which widespread high severity fire occurred should have a spatially extensive cohort (i.e. large areas with similar-aged individuals), whereas groves where high severity fires occurred in localized areas should have smaller groups of even-aged individuals. Based on these patterns, we hypothesize that groves that have not sustained widespread high severity fire, such as the 1297 event, should have a stand structure with many different even-aged groups of individuals scattered throughout the grove, whereas groves that sustained one or more severe widespread fires should have a distinct tree cohorts distributed over large areas of the grove.

An estimated impact severity of the 1297 burn was determined for each measured MHSF tree-ring series using the percent growth change between 10-year periods pre- and post-fire, output from the program IMPACT (Table 3). The severity categories were based on criteria about post-fire tree-ring growth responses established by Mutch (1994) when investigating the relationship between burn severities and post-fire growth responses after recent prescribed burns. The map of these severity ratings provided a view of the spatial pattern of the burn impacts over the grove (Fig. 13). Although the pattern was somewhat different from that for release categories (Fig. 12), it had an overall similarity, with higher severities in the central and north-central portion of the grove and lower severities in grove boundary areas. The differences were possibly a result of how fire impacts were grouped by the two sets of criteria that were not exactly equivalent. The severity criteria had a grouping of moderate to high severity, that would have been similar to combining release categories two through five, and the inclusion of a very high severity rating, that defined an additional impact not recognized in the release criteria. The very high severity criteria defined an impact for trees that showed a delayed growth release (1-6 years). The moderate-to-high severity rating on the map (Fig. 17) was similar to values greater than two on the release map (Fig. 12), although there were differences in how individual trees were categorized by each set of criteria (Table 3).

Comparison of 1297 Event to Regional "Control" Chronology

The results from the IMPACT program, comparing mean growth indices from the Mountain Home 1297 chronology against the regional "control" chronologies for 5, 10, 20, 30, 40, and 50 year pre- and post-1297 impact periods, showed nearly equivalent growth increases (~21%) at five years (Table 4). A rapid increase then occurred in the Mountain Home 1297 chronology up to 20-years post-impact, with a slower increase persisting up to 40-years post-impact when a peak of ~54% relative growth increase was attained. During these periods, growth increases of the "control" chronology were between 112% and 115%.

The t-tests used to compare mean growth between the "control" chronology and the Mountain Home 1297 chronology for a 10-year pre-burn (1287-1296) and 10-year post-burn period (1298-1307) (Appendix 3) showed there were no significant differences between the two chronologies during either of these periods (Table 5). While we expected this for the pre-burn period, it was intuitively unexpected for the post-1297 period because there was such a striking growth release apparent on many MHSF trees. However, the lack of a statistically significant difference for this 10-year period following the 1297 event could be due to at least two factors. First, many of the most severely injured trees suffered growth suppressions immediately post-fire, lasting one to six years, which may have reduced the mean difference between the "control" chronology and the Mountain Home 1297 chronology. Secondly, the Mountain Home 1297 chronology was composed of an average of all trees measured, with some trees having large increases and others none at all, which would produce greater variance.

A plot of the ring-width series from the Mountain Home 1297 chronology, divided into the low, moderate-to-high, and very high severities series, as classified in Table 3, showed differing patterns of post-fire response depending on the estimated fire severity (Fig. 14). Although sample size was limited for some subgroups, there was little apparent difference between trees sustaining low severity impacts and the regional "control", while growth response of trees in the moderate-to-high severity was immediate and much greater than the regional "control". In contrast, the few trees that showed a very high severity impact (N=4) showed a sharp reduction in growth followed by a long period of delayed recovery before growth returned to levels similar to the regional "control". This same pattern was still present when the residual indices, adjusting the tree-ring indices for regional climate, for the three severity categories were plotted (Fig. 15), with the delay lasting 15-20 years. This differs from the post-fire response that Mutch (1994) observed in the 1977 Partin Burn in Kings Canyon National Park, where trees categorized as being severely impacted also had a delayed growth increase but which lasted only 5-6 years (Fig. 16). The different responses of the impact severity categories appears to be a result of the amount of foliage damage that tree suffered when they were scorched during intense fires (Fig. 17) (Mutch 1994).

The persistence of the 1297 growth increase, relative to the regional "control" chronology, was evaluated using t-tests on progressive 20-year periods from 1298 to 1437 (140 years post-impact), in addition to a single 20-year pre-impact period (1277-1296). The greater length of period used in the first post-burn period (1298-1317), versus the previous 10-year period, still showed no significant pre-burn differences, but did show that growth at MHSF was significantly greater than growth in the regional "control" chronology (Table 6). Repeated t-tests on consecutive 20-year periods, showed that the growth increase was significantly greater than the regional "control" for about 100 years following the 1297 event (1378-1397), after which we detected no differences. A growth release of this magnitude that persisted for this length of time on trees throughout a grove has not been observed during any other time period, although individual trees do exhibit releases of this magnitude (Swetnam et al. 1992).

The relationship between the 1297 event and the post-fire ecological or environmental factors that produced this persistent growth response are largely unknown and without a modern analog. However, several processes may be surmised. These include: 1) a release from competition due to fire caused mortality of whitewood species and also some giant sequoias, 2) fire induced nutrient releases, 3) an interaction of these and subsequent fires, and 4) the influence of climate. The simplest answer, if the growth responses of the regional chronologies were due solely to climate, would be that the growth increase was a result of an extremely severe fire event that occurrence just prior to a period of advantageous climate conditions that allowed a period of very positive growth to occur. More complex processes might involve several interacting factors. For example, the severe fires might have decreased competition by reducing stand density while also generating a nutrient pulse from the burned biomass. Secondarily, such a stand might have developed an understory dominated by ***Ceanothus*** species that persisted on the site for many years, possibly due the effects of subsequent fires, that provided a long term nitrogen input into the ecosystem before an overstory reestablished. A possible role for ***Ceanothus*** species is also suggested as an influence on the dramatic post-fire growth increase in sequoias following the recent Partin burn in Kings Canyon National Park (Mutch 1994).

Comparison of 1297 to Recent Burns and Logging

We compared 10-year pre- and post-burn growth indices from 1297 to indices from similar length periods following contemporary disturbances by prescribed burns of different severities and by logging. This analysis permitted assessment of the relative effects of these different disturbances on giant sequoia growth patterns (Table 7). We observed post-impact growth increases at all sites (Fig 18), although the magnitude of these releases varied from site-to-site and the type of impact. At recent low-to-moderate severity burn sites (Moro and Grant burns) the increase was only slightly greater than the increase seen in the control sites (16 and 11% greater respectively). The logged area also had an obvious but not pronounced growth increase, and was comparable to low-to-moderate severity fires, and to the growth increase following the 1297 event. The most striking growth release observed in this analysis was the release following the high severity Partin (Redwood Mountain, Kings Canyon National Park) burn that shows a very rapid strong release (~52% greater than the control) soon after the 1977 burn. The post-fire response of the 1297 event showed a short period of decreased growth followed by a moderate increase during this 10-year post-fire period

In general, for the immediate post-fire periods, the recent prescribed burns showed a more immediate, higher magnitude release than the 1297 burn (Fig. 18). This could be due to injuries sustained by trees during the 1297 fire, which produced a delay in the positive growth response. The peak in the post-fire growth release in these trees was not experienced until 20-years post-fire. This impact of the 1297 event provided evidence for its severity and would account for the lack of significant statistical differences between the severe 1297 event and much less severe recent prescribed burns.

Additionally, the comparison of the series from the recent disturbances to the 1297 chronology was somewhat misleading because of the way the Mountain Home 1297 chronology was constructed. The lack of a strong release for the 1297 event shown by this data may have been a result of the chronology construction process, in which all measured tree-ring series from MHSF were included in the averaged 1297 chronology, whether they exhibited a release or not. Though this provided us with an overall MHSF chronology with reliable sample depth, it also had the effect of reducing the average magnitude of the release. As a way of overcoming this problem a subset of tree-ring series from MHSF, those that exhibited post-fire growth features similar to patterns seen following modern high severity fire (Mutch 1994), were selected and again compared to the regional chronology and the recently disturbed sites. This subset of series might be more equivalent to trees sampled at recent sites with high severity impacts and may provide a more realistic comparison. However, although the selection of these severity groups was inferred from the growth responses, rather than actual measures of site impacts, the classification of these responses was based post-fire responses of sequoias following recent fires.

In this analysis, we separated trees into three subgroups and averaged them into new chronologies, corresponding to low, moderate-high, and very high severity categories. The time series of the residual indices (disturbance indices minus control indices) from these chronologies were then again compared to the recent fire and logging disturbance. We then compared disturbances, using the mean of the 1297 residual series for only those trees that had moderate-to-high increases, to the recent disturbances (prescribed burns and logging) over several impact periods (Table 9). For the 10-year period, these results suggested that the response to the logging impact was similar to the low-to-moderate burns, as was the combined grouping of all MHSF trees for the 1297 event (Fig. 18). However, the subset of trees with a large 1297 growth increase was intermediate between the low-to-moderate prescribed burns (Moro and Grant) and the high severity Partin Burn, with a suggestion that the logged site had a slightly delayed response (Fig. 19). When longer impact time periods were looked at (because the prescribed burns occurred recently these could not be evaluated for these effects), 20 and 30-year periods, the growth response of the trees in the logged site increased and was nearly equivalent to the subset of 1297 trees with a large increase. This suggested there may be biological differences in the way sequoias responded to these different disturbances. However, this was not entirely clear, due to subsequent cutting and other factors discussed above.

Our comparison of the growth indices from the MHSF logged site to the nearby uncut control site, that used 5, 10, 20, and 30-year impact periods, showed there was a continuous increase in the percent growth release (relative to the pre-burn period) in both the logged and the control sites for the 30-years following 1956, but with a greater increase in the logged area (Table 8). This greater increase at the logged site seemed to be a result of the logging, but the long period of increase may be due to several additional confounding factors that occurred at this site which make the results difficult to interpret. This site was unusual in several respects, with a somewhat complicated history. Following the initial cut in 1956, a second salvage cut was made in the stand in 1966, that produced a second disturbance at the site and may have further emphasized the earlier growth release (Fig. 20). Although our sampling took place 26 years after the last cutting, adults and reproduction of whitewood species were nearly absent from this site, which has resulted in very open stand conditions over an extended period of time. This indicated there has been little competition from whitewood species in the area. Additionally, because of the open character of the stand much of the understory shrub cover has been dominated by whitethorn which is an important nitrogen fixer in Sierran ecosystems and may have provided a longer term nutrient source to the remaining sequoias.

SUMMARY

The 1297 fire event in the Mountain Home Grove of giant sequoias was an extremely unusual fire event in the reconstructed fire history of the grove. Evidence for the unusual severity comes from both the post-fire tree-ring growth response and the establishment of a cohort of sequoias following the fire. It had important long lasting effects on both stand structure and grove history that persisted for centuries. The 1297 fire followed the most persistent drought (1292-1296) observed in the record of reconstructed precipitation between AD 1100 and 1500.

Because growth releases were observed in other sequoia groves at this time there may have been regional scale disturbances from severe fires due to this drought. Fire severity was estimated for each measured sequoia sample based on a comparison between post-fire growth releases characteristics in 1297 relative to recent prescribed burns on which fire severity was measured (Mutch 1994). The magnitude of the growth release was probably associated with mortality of mixed-conifer species and some giant sequoias within the grove and an accompanying post-fire nutrient release. The spatial pattern of the growth releases suggested the fire impact was sustained over an unusually large area, up to several square kilometers. The impact was most severe in the central and northern portion of Mountain Home Grove and lesser in peripheral areas to the east and south. Temporally, the growth release was of unusually long duration that appeared to be unprecedented in the tree-ring record which does not have a specific modern analog. Comparisons of the event to recent prescribed burns and a logged area were also made. The post-fire response of sequoias to the 1297 event differed from their response to most recent disturbances. However, while the data showed a much stronger post-fire growth release following the 1977 Partin burn in Kings Canyon National Park than what we observed following the Mountain Home 1297 event, this may be a result of the 1297 event being more severe and causing a growth suppression for 10-15 years in many trees prior to a consistent release occurring. The results also suggested there may be some differences in how giant sequoias respond to different types of disturbances, in our case the differences between burns of differing severities and between burns and logging. These finding indicate that further research is needed to better quantify the affects of the different types of disturbances if they are to be better understood as processes in ecosystems of the Sierra Nevada. However, such disturbances have been a common component of the giant sequoia ecosystem, and are a process to which this species is well adapted, with some life history characteristics that take advantage of such impacts.

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APPENDICES

Appendix 1. Categorical values used in defining the magnitude of growth release or suppression in samples. Positive values indicate a growth release and negative values a growth suppression in the tree-ring series. For the first three categories a fire scar or injury must be present to record a value.

0.0 **-** Fire scar/injury present, no growth increase/decrease apparent in ring widths.

1.0 **-** Fire scar/injury present, growth increase/decrease present only at site of scar as a healing curl.

1.5 **-** Fire scar/injury present, growth increase/decrease persists away from site of scar for 1-2 rings only.

2.0 **-** An increase/decrease in growth is apparent which persists for 2-5 rings and is not confined to the site of scarring or injury when present, but may diminish in magnitude or duration away from injury.

2.5 **-** Increase/decrease persists for 3-10 rings an is present away from site of scarring when scar is present (does not diminish a in magnitude or duration away from site of injury). From this it follows that when a scar or injury site is not present, a value of at least 2.5 will be assigned unless only 2 rings are involved.

3.0 **-** Increase/decrease persists for 11-15 rings without diminishing in magnitude or duration away from site of injury, or across piece when no obvious injury is present.

3.5 **-** Increase/decrease persists for 16-20 rings without diminishing in magnitude or duration away from site of injury, or across piece when no obvious injury is present.

4.0 **-** Increase/decrease persists for 21-30 rings without diminishing in magnitude or duration away from site of injury, or across piece when no obvious injury is present.

5.0 **-** Increase/decrease persists for 31 or more rings without diminishing in magnitude or duration away from site of injury, or across piece when no obvious injury is present.

Appendix 2. Listing of all trees sampled during 1991/1992. Tree identifications were based on the location of a tree within each quarter section of a specific section with the exception of RRJ 1 and 2.. For example tree "M1SE2" would be tree number two located in the southeast quarter section of section number 1 for the sections that make up the state forest. Trees without an inner or outer date (undated) were coded as -9999, whereas trees for which the release value is not known was given a release value of 9.0 (release values only cover the range from -5 to 5).

Ident.	Inside Date	Outside Date	Release Value
M01NW1	89	1808	4.0
M01SW1	1209	1620	9.0
M01SW2	-9999	-9999	9.0
M01SW3	1007	1803	0.0
M01SW4	1169	1943	0.0
M01SE1	1200	1400	0.0
M01SE2	411	1283	-9.0
M01SE3	521	1681	1.0
M01SE4	-9999	-9999	9.0
M06NW1	600	1573	0.0
M06NW2	1320	1811	-9.0
M06NW3	572	1817	4.0
M06NW4	795	1679	0.0
M06NW5	1330	1920	-9.0
M12NW1	1335	1735	-9.0
M18SW1	650	1711	0.0
M18SW2	316	1600	0.0
M18SW3	834	1833	2.0
M18SW4	1097	1397	0.0
M18SW5	200	1500	0.0
M19SE1	-9999	-9999	9.0
M19SE2	945	1410	2.5
M23SW1	850	1707	5.0
M23SW2	-9999	-9999	9.0
M25NW1	-104	1367	5.0
M25NW2	-9999	-9999	9.0
M25NE1	-9999	-9999	9.0
M25NE2	786	1822	3.0
M25SE1	1214	1500	4.0
M26SE1	-9999	-9999	9.0
M26SE2	-9999	-9999	9.0
M26SE3	-9999	-9999	9.0
M26SE4	1100	1343	5.0
M26-2A	1100	1382	0.0
M26NW1	605	1005	-9.0
M26NW2	623	1408	4.5
M26NE1	300	1858	4.0
M26NE2	929	1329	4.5
M26NE3	-9999	-9999	9.0
M26NE4	-9999	-9999	9.0

Ident.	Inside Date	Outside Date	Release Value
M26NE5	500	1650	4.0
M26NE6	1097	1397	4.0
M30SW3	1076	1735	2.0
M30SW4	-266	1496	2.0
M30SW5	-9999	-9999	9.0
M30SW20	-40	1560	0.0
M30SW21	-500	1720	3.0
M30SW2	1097	1499	9.0
M30SW1	1100	1308	5.0
M31NW1	389	1797	2.0
M31SW1	1521	1937	-9.0
M34NE1	1100	1461	5.0
M34NE2	-9999	-9999	9.0
M34NE3	-9999	-9999	9.0
M34NE4	-9999	-9999	9.0
M35NE1	1124	1722	5.0
M35NE2	-9999	-9999	9.0
M35NE3	-9999	-9999	9.0
M35NE4	1043	1883	3.0
M35SE1	-9999	-9999	9.0
M35SE2	1371	1771	-9.0
M35SE3	1403	1803	-9.0
M35SE4	1095	1719	4.0
M35NW1	450	1720	3.0
M36SW1	818	1937	0.0
M36NW1	-9999	-9999	9.0
M30SW6	1187	1355	4.0
M#U	-9999	-9999	9.0
D49	-9999	-9999	4.0
NO ID	-9999	-9999	0.0
Unknown	1264	1505	3.0
RRJ2	-459	1943	5.0
RRJ6	-58	1750	4.5

Appendix 3. Output of IMPACT program for the Mountain Home 1297 burn and the regional control series, with the percent change from pre- to post-fire ring-width size, assumed to be due to the fire. These data were used in the t-test analysis. Also listed are the mean ring-widths for the 10-years pre-burn and 10-year post-burn periods.

Output of IMPACT program--Mountain Home 1297 trees

First year of impacted growth:	1297		
Comparison of prior growth:	1287	1296	10 years
with growth from the impact year:	1297	1306	10 years

Series	**Mean growth**		**Percent**
Identification	**Before**	**After**	**After/Before**
M18SW1	Short series 1309 1500, rejected		
1 M18SW4	1.354	1.045	77.18
2 M18SW5	1.016	1.030	101.38
3 M1NW1	0.805	1.523	189.19
4 M1SE1A	1.016	1.113	109.55
5 M1SE3A	0.944	1.042	110.38
6 M1SW3B	0.783	1.137	145.21
7 M1SW4	0.923	0.978	105.96
8 M25NW1	0.704	1.097	155.82
9 M25SE1	0.811	1.432	176.57
10 M262A	1.173	0.662	56.44
11 M26NE2A	0.779	1.209	155.20
12 M26NE6	1.241	1.665	134.17
13 M26NW2A	1.022	0.636	62.23
14 M26SE4	0.924	1.035	112.01
15 M30SW1C	0.807	2.107	261.09
16 M30SW21	1.150	1.268	110.26
17 M30SW3B	1.038	1.202	115.80
18 M30SW4	0.800	1.033	129.13
19 M31NW1	1.370	0.832	60.73
20 M34NE1	0.591	0.814	137.73
21 M35NE1A	0.595	1.886	316.97
22 M35NW1U	0.756	1.098	145.24
23 M35SW4A	1.180	2.598	220.17
24 M36SW1	0.773	1.155	149.42
25 M6NW3B	0.379	0.726	191.56
26 M6NW4	0.429	0.446	103.96
27 MOSES1C	0.690	1.179	170.87

MEAN BEFORE AND AFTER IMPACT YEAR 1297--MOUNTAIN HOME 1297 BURN

BEFORE: mean = 0.891

Year	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296
	0.920	0.803	0.874	0.969	0.930	0.677	0.940	1.010	0.953	0.833
	0.303	0.266	0.279	0.314	0.306	0.284	0.289	0.328	0.333	0.327
% of mean before	103.23	90.18	98.12	108.76	104.35	75.96	105.48	113.37	107.01	93.54

AFTER: mean = 1.183, equal to 132.82 percent of mean before

Year	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306
	0.946	0.916	1.096	1.280	1.150	1.264	1.211	1.300	1.301	1.369
	0.489	0.696	0.826	0.686	0.518	0.555	0.453	0.547	0.429	0.632
% of mean before	106.22	102.77	123.02	143.72	129.05	141.89	135.91	145.89	146.05	153.70

Output of IMPACT program--Regional Control trees

First year of impacted growth:	1297		
Comparison of prior growth:	1287	1296	10 years
with growth from the impact year:	1297	1306	10 years

Series	Mean growth		Percent
Identification	**Before**	**After**	**After/Before**
BMG040	Short series 1295 1500, rejected		
1 BMG120	0.850	1.044	122.72
2 BMR010	0.824	1.130	137.15
3 BMR020	0.694	0.664	95.72
4 BMR030	0.856	0.828	96.73
5 BMR040	1.031	1.298	125.88
6 BMR050	1.141	1.126	98.67
7 BMR060	0.714	0.867	121.42
8 BMR070	0.878	1.051	119.70
9 BMR080	1.074	1.167	108.68
10 BMR090	1.051	1.938	184.31
11 BMR100	1.152	1.236	107.31
12 BMR110	1.154	1.195	103.54
13 BMR120	1.067	1.546	144.88
14 BMR200	0.950	0.000	0.00
15 BMR220	0.749	1.079	144.13
16 BMR230	0.765	0.801	104.80
17 BMR240	0.531	0.546	102.90
18 BMR250	0.897	1.336	148.84
19 CBR010	1.471	1.578	107.31
20 CBR020	0.988	1.050	106.35
21 CBR030	0.846	0.805	95.18
22 CBR040	0.825	0.972	117.81
23 CBR050	1.073	1.136	105.87
24 CBR060	1.100	1.153	104.81
25 CBR100	0.856	1.070	125.06
26 CBR130	0.980	0.894	91.18
27 CBR140	0.910	1.028	113.00
28 CBR150	0.634	0.711	112.12
29 CBR210	1.447	1.449	100.14
30 CSX020	0.773	0.750	97.04
31 CSX030	1.260	1.179	93.51
32 CSX040	0.882	1.076	121.91
33 CSX050	1.073	1.154	107.50
34 CSX080	1.002	0.989	98.68
35 CSX100	1.001	1.109	110.76
36 DSQ010	0.893	1.011	113.22
37 DSQ020	1.225	1.163	94.93

Series	Mean growth		Percent
Identification	Before	After	After/Before
38 DSQ030	0.929	1.192	128.25
39 DSQ040	0.956	1.085	113.54
40 DSQ050	0.690	0.864	125.12
41 DSQ070	0.744	0.818	109.89
42 DSQ100	0.753	1.207	160.32
43 RWB010	0.985	0.955	96.88
44 CMC040	0.948	1.227	129.43
45 CMW060	1.020	0.898	88.04
46 GFCT10	0.977	1.238	126.71
47 GFI480	0.888	0.928	104.50
48 GFI500	1.638	1.801	109.95
49 HMW040	0.900	0.928	103.11
50 HMW1E0	0.804	1.036	128.86
51 LME030	0.615	0.969	157.56
52 LME2C0	0.866	0.888	102.54
53 LME4C0	1.416	1.186	83.76
PPG030	Short series 1295 1500, rejected		
54 PPG100	0.783	0.850	108.56
55 PPG110	0.814	1.195	146.81
56 PPG200	1.121	1.456	129.88
57 PPG250	0.783	1.081	138.06
PPG290	Short series 1293 1500, rejected		
58 PPR010	0.708	1.025	144.77
59 PPR020	0.963	1.216	126.27
60 PPR030	1.044	1.309	125.38

IMPACT output--Regional Control, 10-year period

```
MEAN BEFORE AND AFTER IMPACT YEAR 1297

 BEFORE: mean =   0.949
 Year              1287     1288     1289     1290     1291     1292     1293     1294     1295     1296
 Mean growth      1.081    0.921    0.957    1.092    1.070    0.784    0.927    1.022    0.884    0.757
 Std dev          0.294    0.196    0.207    0.301    0.261    0.255    0.231    0.292    0.271    0.285
 % of mean       113.83    96.96   100.81   115.02   112.67    82.60    97.62   107.62    93.08    79.79
before

 AFTER:  mean =   1.075, equal to  113.19 percent of mean before
 Year              1297     1298     1299     1300     1301     1302     1303     1304     1305     1306
 Mean growth      1.018    1.037    1.136    1.088    1.023    1.064    1.010    1.109    1.126    1.137
 Std dev          0.327    0.366    0.386    0.391    0.353    0.334    0.317    0.310    0.323    0.333
% of mean before 107.27   109.22   119.64   114.59   107.76   112.02   106.35   116.77    118.6   119.73
```

CAPTIONS

Fig. 1) Example of the 1297 growth release at Mountain Home on a sanded cross-section of giant sequoia.

Fig. 2) Location of Mountain Home Grove and other sequoia groves used in the regional control chronology in the central and southern Sierra Nevada.

Fig. 3) Locations of all trees sampled throughout Mountain Home State Forest. Tree identifications were based on the location of a tree within each quarter section of a specific section with the exception of RRJ 1 and 2.. For example tree "M1SE2" would be tree number two located in the southeast quarter section of section number 1 for the sections that make up the state forest. Locations of the logged and unlogged "control" sites are also shown (medium shading). The inset area (light shading) indicates the area sampled in 1987/1988, which is shown in larger scale in figure 3.

Fig. 4) Location of all samples collected in 1987/1988 from which growth release information was used that supplements the 1991/1992 collections.

Fig. 5) The unusual features of the 1297 event were noticeable across several types of tree-ring records. Composite plot showing the fire record from each individual tree from the 1987/1988 collection, with fire scars or other fire indicators displayed (lower plots), a bar plot of the average value from the growth release category (middle plot), and the tree-ring series from standardized Mountain Home 1297 chronology (upper plot). A few recently crossdated samples (8) were not included in this chronology.

Fig. 6) Detrended ring-width plots for the five control chronologies (five upper plots) that were averaged to produce the single regional control chronology (lower plots).

Fig. 7) The five-year drought proceding 1297 was the most severe dry winter period between AD 1100 and 1500, based on precipitation reconstructions by Graumlich (1993) and Graybill (1993). Although the 1292 to 1296 period does not have the lowest reconstructed values for the four-hundred year period shown it stands out as having generally low precipitation with no large values. Inset shows four-year running means (centered on last year) from 1280 to 1310 which also shows the strenght of the drought.

Fig. 8) Comparative plot of the regional control chronology and the Mountain Home 1297 chronology for the period from 1100 to 1500 AD. Lower plots shows the number of samples that were averaged into the chronology through time.

Fig. 9) Comparative plot of the chronologies from the Mountain Home logged site and the unlogged site for the period from 1700 to 1991. Sample depth for cores that went into building these chronologies is shown at bottom.

Fig. 10) Spatial distribution of the growth release values from trees collected in 1991/1992 throughout Mountain Home State Forest.

Fig. 11) Spatial distribution of the growth release values from trees collected in 1987/1988 at the Enterprize Millsite and Frasier Mill Campground.

Fig. 12) Composite map of the spatial distribution of all the growth release values from throughout MHSF.

Fig. 13) Spatial pattern of 1297 impact severities across MHSF

Fig. 14) Time series of standardized ring-width indices for the 1297 chronology separated into low, moderate-to-high, and very high severity categories plotted with the regional control chronology.

Fig. 15) Residual indices (corrected for climate using the regional control chronology) for the three severity categories showing the impact of the 1297 event on the different categories.

Fig. 16) Residual indices from Kings Canyon National Park recent burn sites (Grant and Partin) showing the post-fire response of trees in four impact severity categories.

Fig. 17) Post-fire growth response of trees with no foliage damage (amount of crown foliage scorched and killed), <50% damage, and >50% damage.

Fig. 18) Residual indices comparing the impact of the MHSF 1297 burn to a recent high severity burn, a recent low severity burn, and a recently logged site.

Fig. 19) Residual indices comparing the impact of the MHSF 1297 burn, using only a subset of trees that showed a moderate-to-high severity impact, to a recent high severity burn, a recent low severity burn, and a recently logged site.

Fig. 20) Residual indices for the MHSF logged area showing the dates of the logging disturbance and the post fire growth response of the trees following each of these events.

Figure 1.

Figure 2.

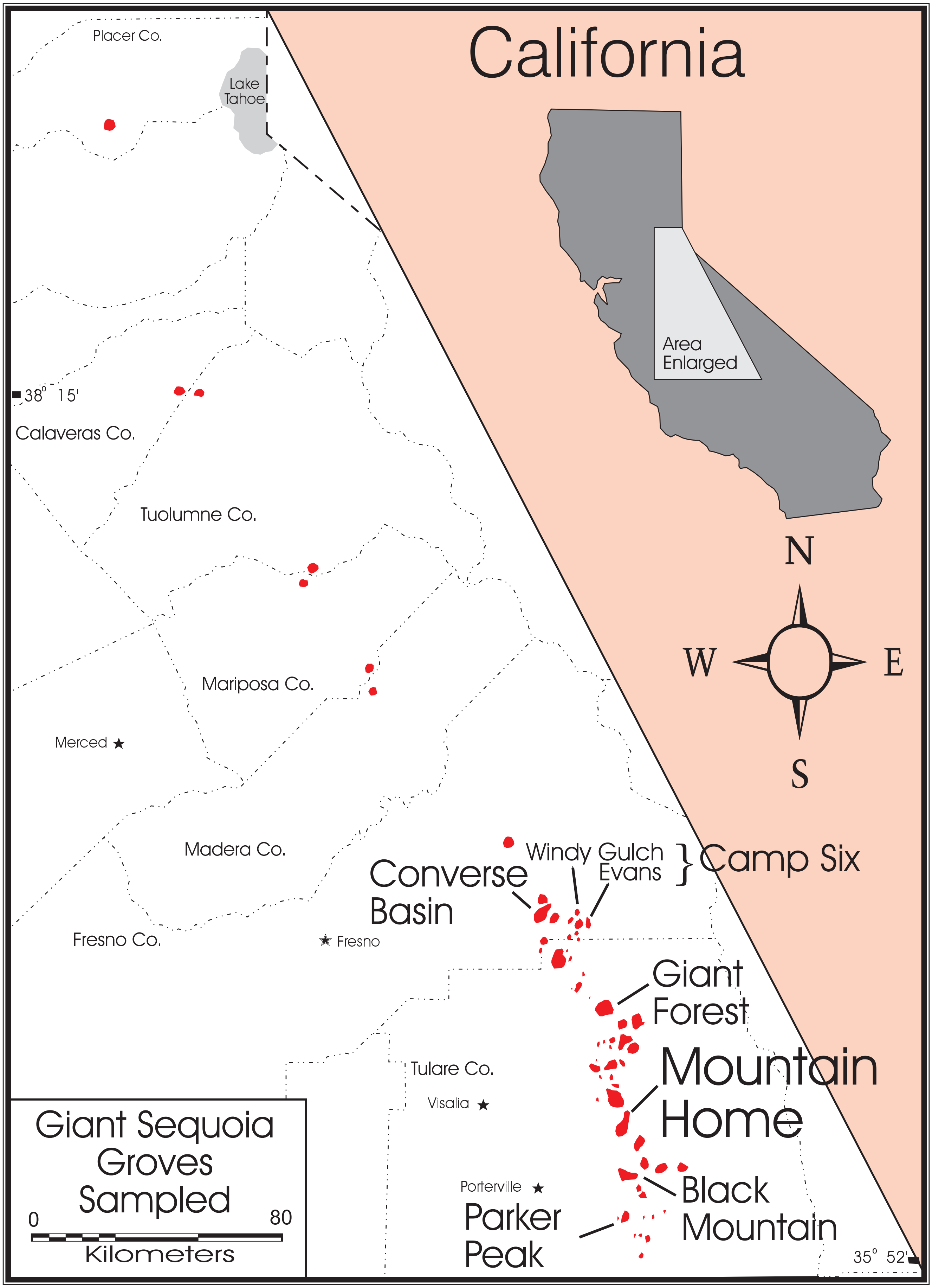

California
Area Enlarged
N
W
E
S
Placer Co.
Lake Tahoe
38° 15'
Calaveras Co.
Tuolumne Co.
Mariposa Co.
Merced
Madera Co.
Fresno Co.
Fresno
Windy Gulch
Evans
Camp Six
Converse Basin
Giant Forest
Mountain Home
Tulare Co.
Visalia
Porterville
Black Mountain
Parker Peak
35° 52'
Giant Sequoia Groves Sampled
0
80
Kilometers

Figure 3.

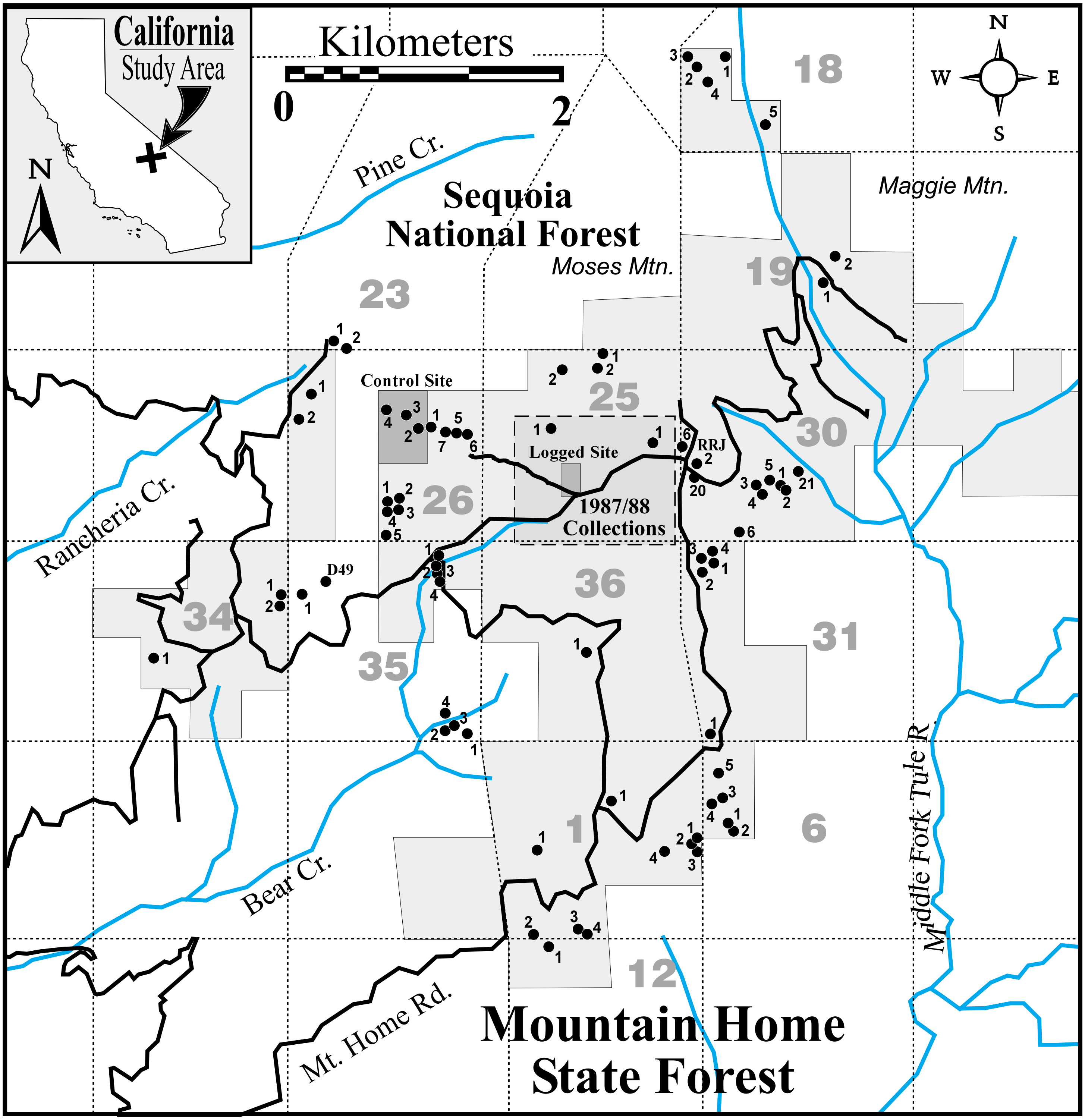

California
Study Area
N
Kilometers
0
2
N
W
E
S
Pine Cr.
Sequoia
National Forest
Moses Mtn.
Maggie Mtn.
18
19
23
25
26
30
31
34
35
36
1
6
12
Control Site
Logged Site
1987/88
Collections
RRJ
D49
Rancheria Cr.
Bear Cr.
Mt. Home Rd.
Middle Fork Tule R.
Mountain Home
State Forest

Figure 4.

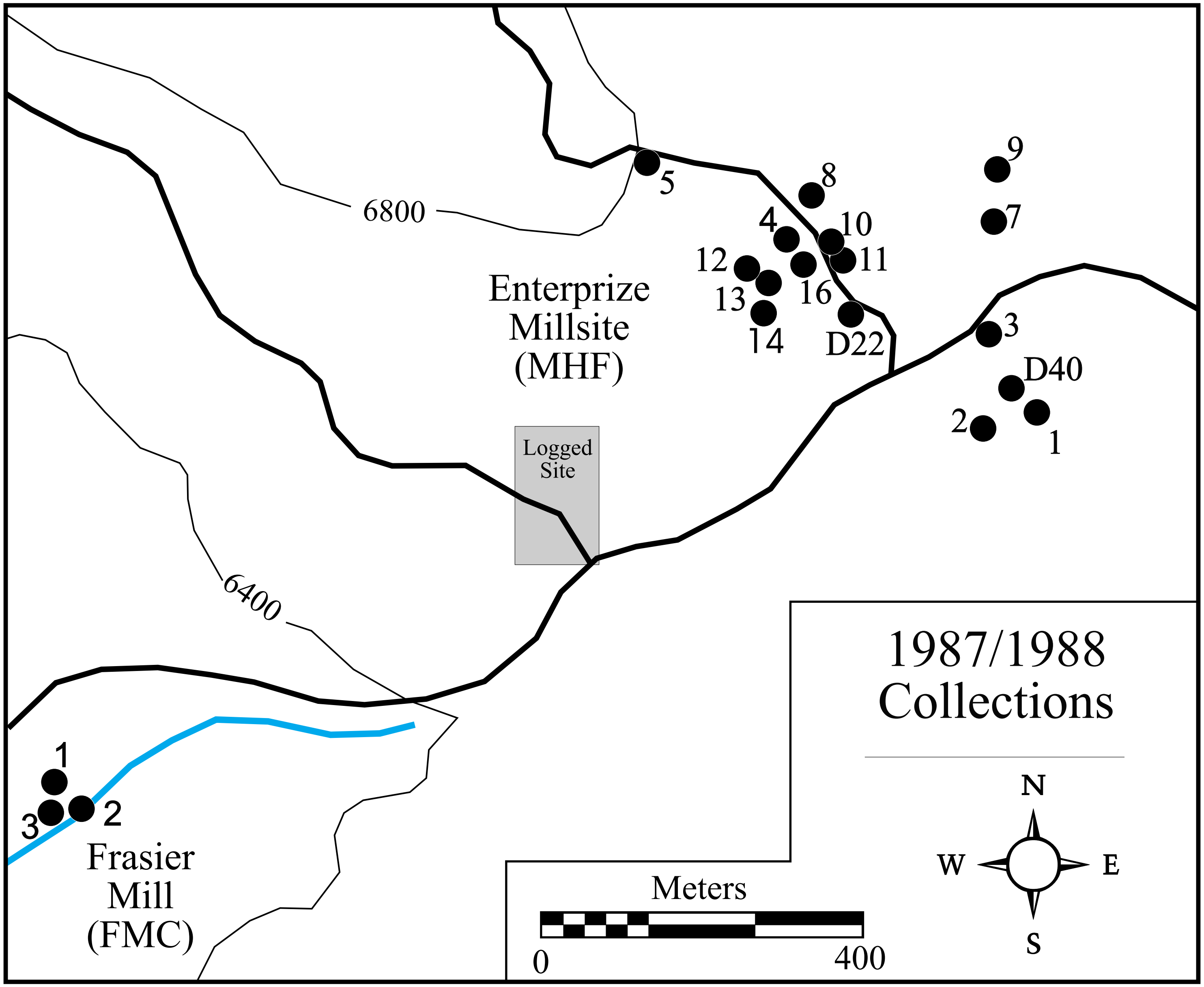
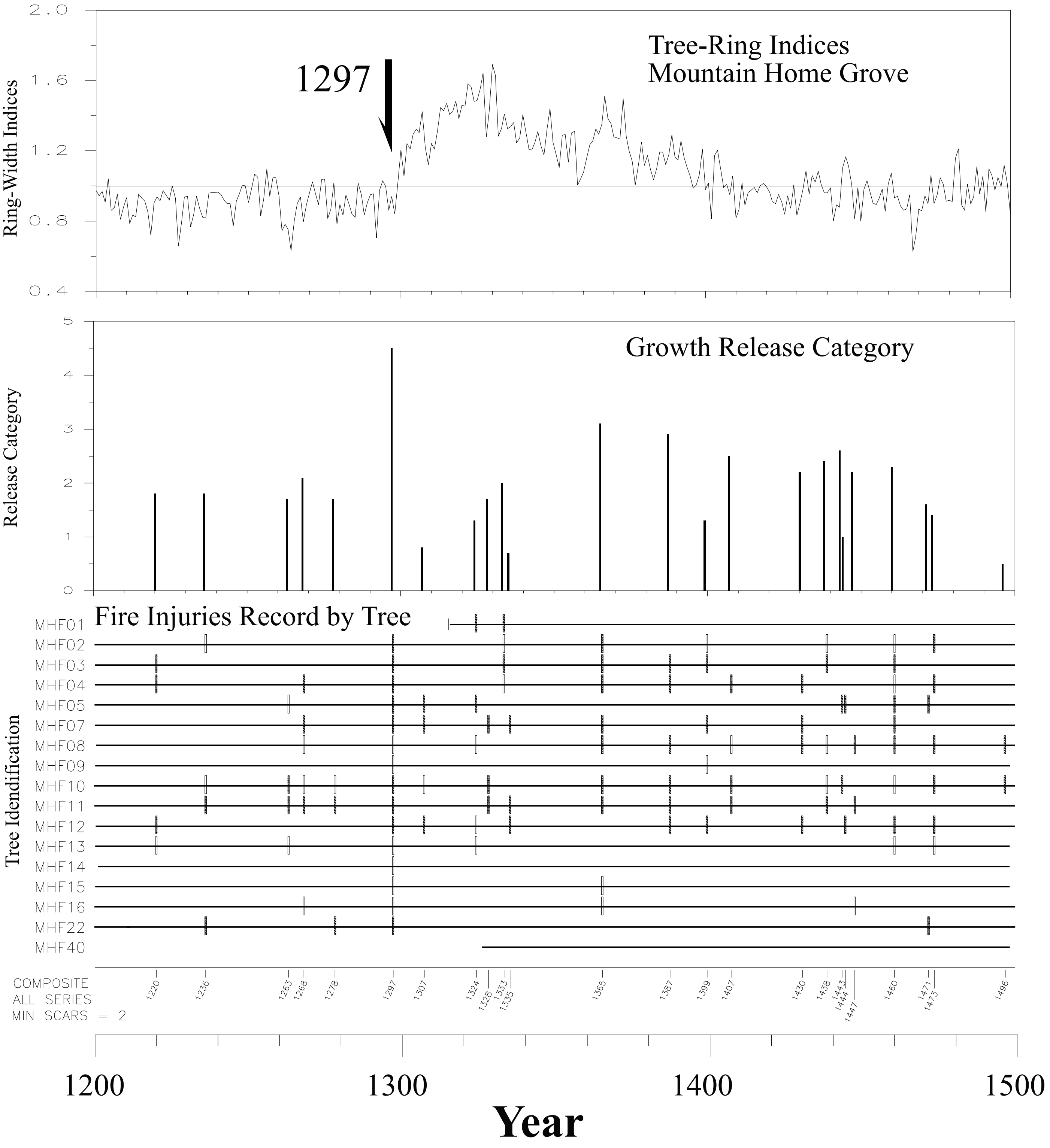

6800
5
8
9
7
4
10
11
12
16
13
14
D22
3
D40
2
1
Enterprize Millsite (MHF)
Logged Site
6400
1
3
2
Frasier Mill (FMC)
Meters
0
400
1987/1988 Collections
N
W
E
S

Figure 5.



Tree-Ring Indices
Mountain Home Grove
1297
Ring-Width Indices
2.0
1.6
1.2
0.8
0.4
Growth Release Category
Release Category
5
4
3
2
1
0
Fire Injuries Record by Tree
Tree Idendification
MHF01
MHF02
MHF03
MHF04
MHF05
MHF07
MHF08
MHF09
MHF10
MHF11
MHF12
MHF13
MHF14
MHF15
MHF16
MHF22
MHF40
COMPOSITE
ALL SERIES
MIN SCARS = 2
1220
1236
1263
1268
1278
1297
1307
1324
1328
1333
1335
1365
1387
1399
1407
1430
1438
1443
1444
1447
1460
1471
1473
1496
1200
1300
1400
1500
Year

Figure 6.

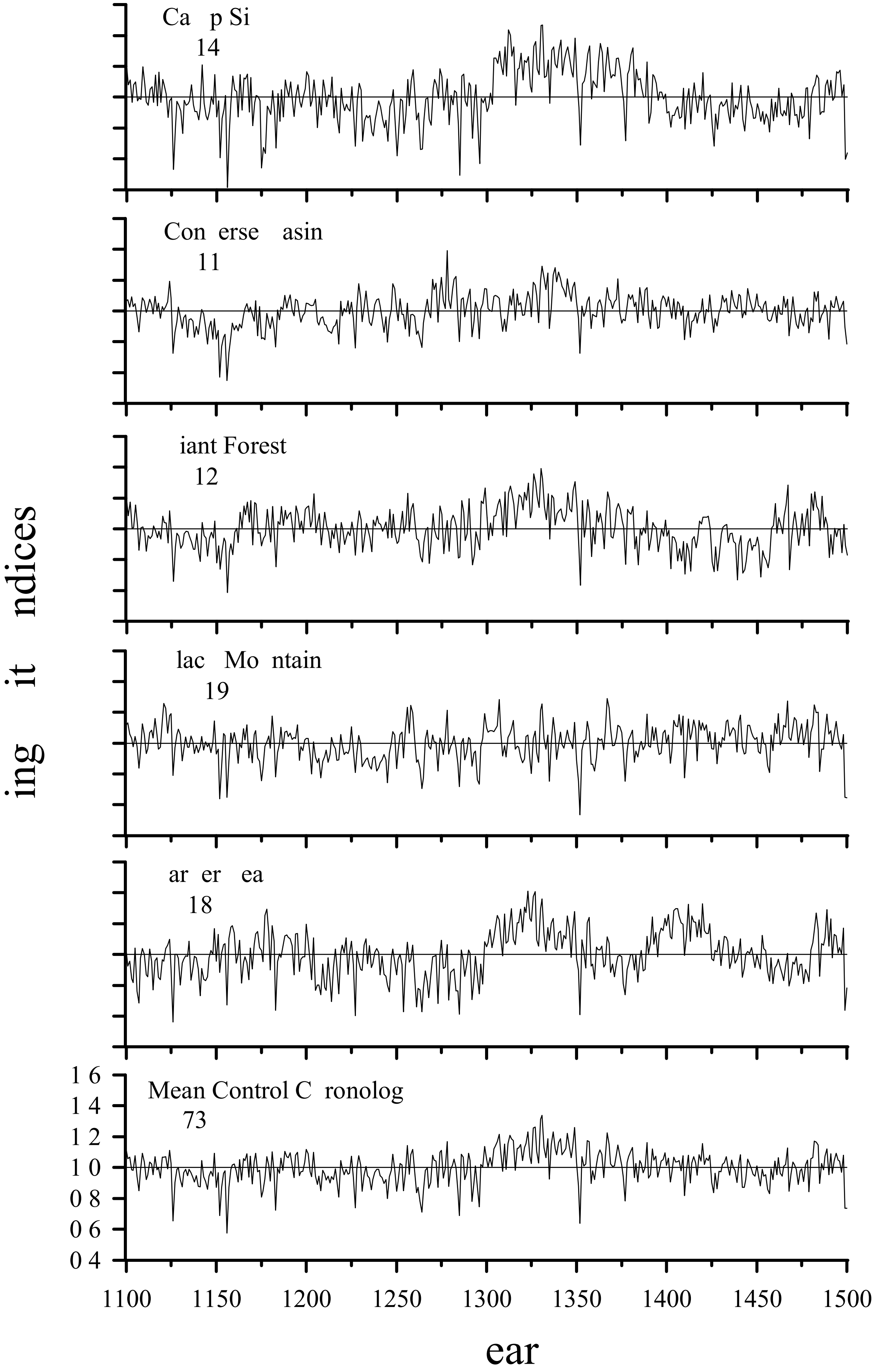
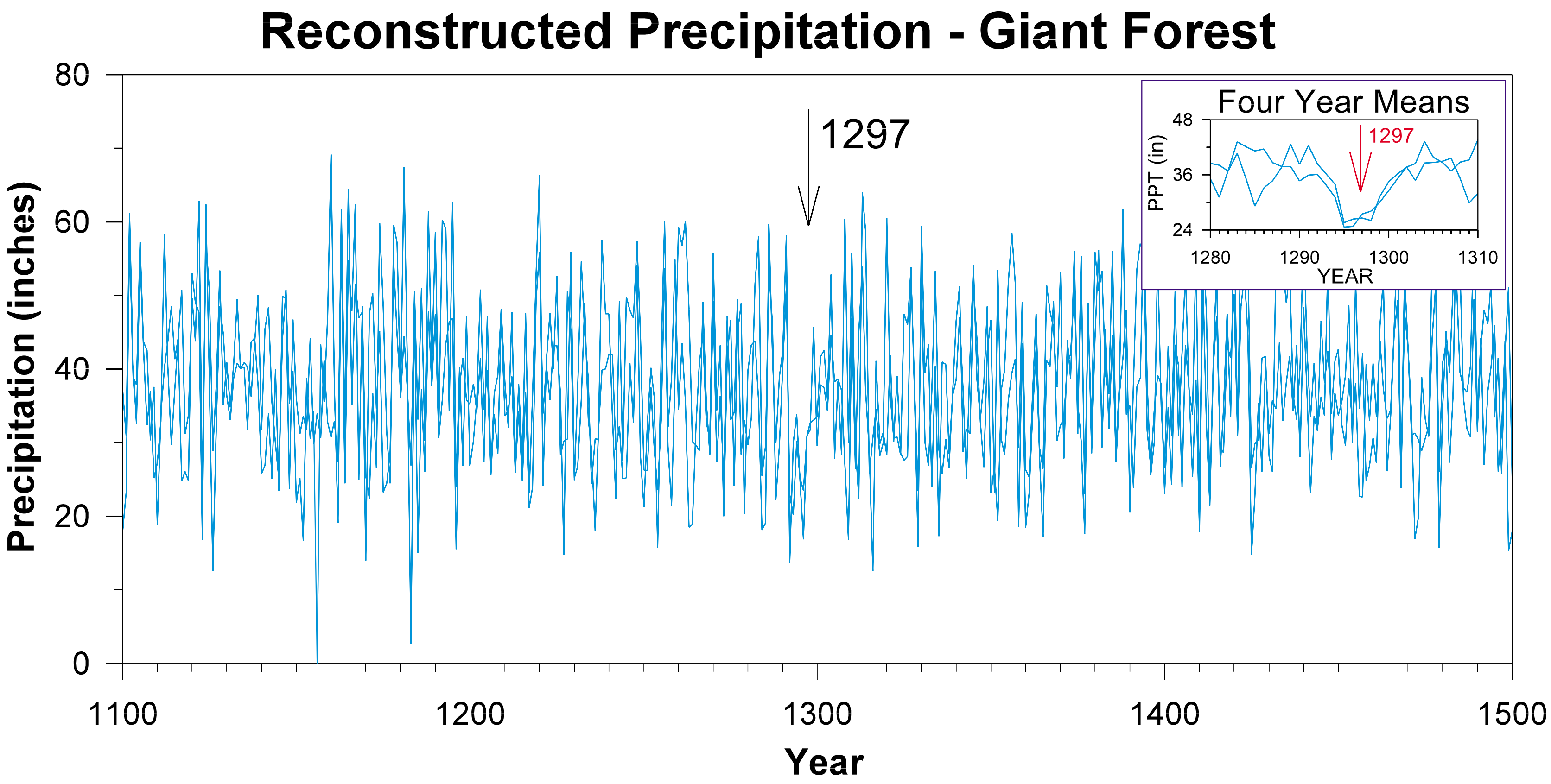

Ca p Si
14
Con erse asin
11
iant Forest
12
lac Mo ntain
19
ar er ea
18
Mean Control C ronolog
73
ing it ndices
1 6
1 4
1 2
1 0
0 8
0 6
0 4
1100
1150
1200
1250
1300
1350
1400
1450
1500
ear

Fig. 7



Reconstructed Precipitation - Giant Forest
Precipitation (inches)
80
60
40
20
0
1100
1200
1300
1400
1500
Year
1297
Four Year Means
PPT (in)
48
36
24
1280
1290
1300
1310
YEAR
1297

Figure 8.

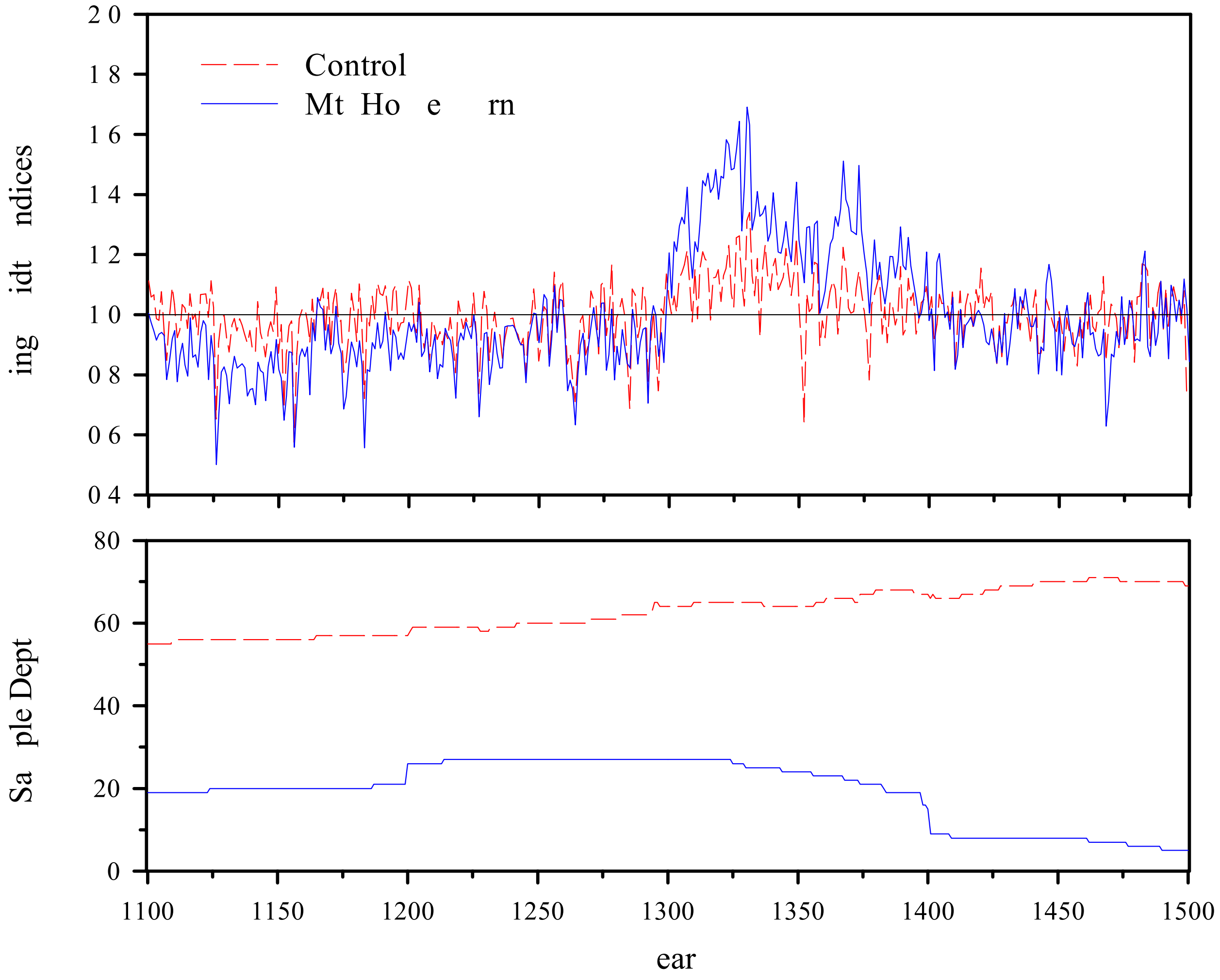

2 0
1 8
1 6
1 4
1 2
1 0
0 8
0 6
0 4
ing idt ndices
Control
Mt Ho e rn
80
60
40
20
0
Sa ple Dept
1100
1150
1200
1250
1300
1350
1400
1450
1500
ear

Figure 9.

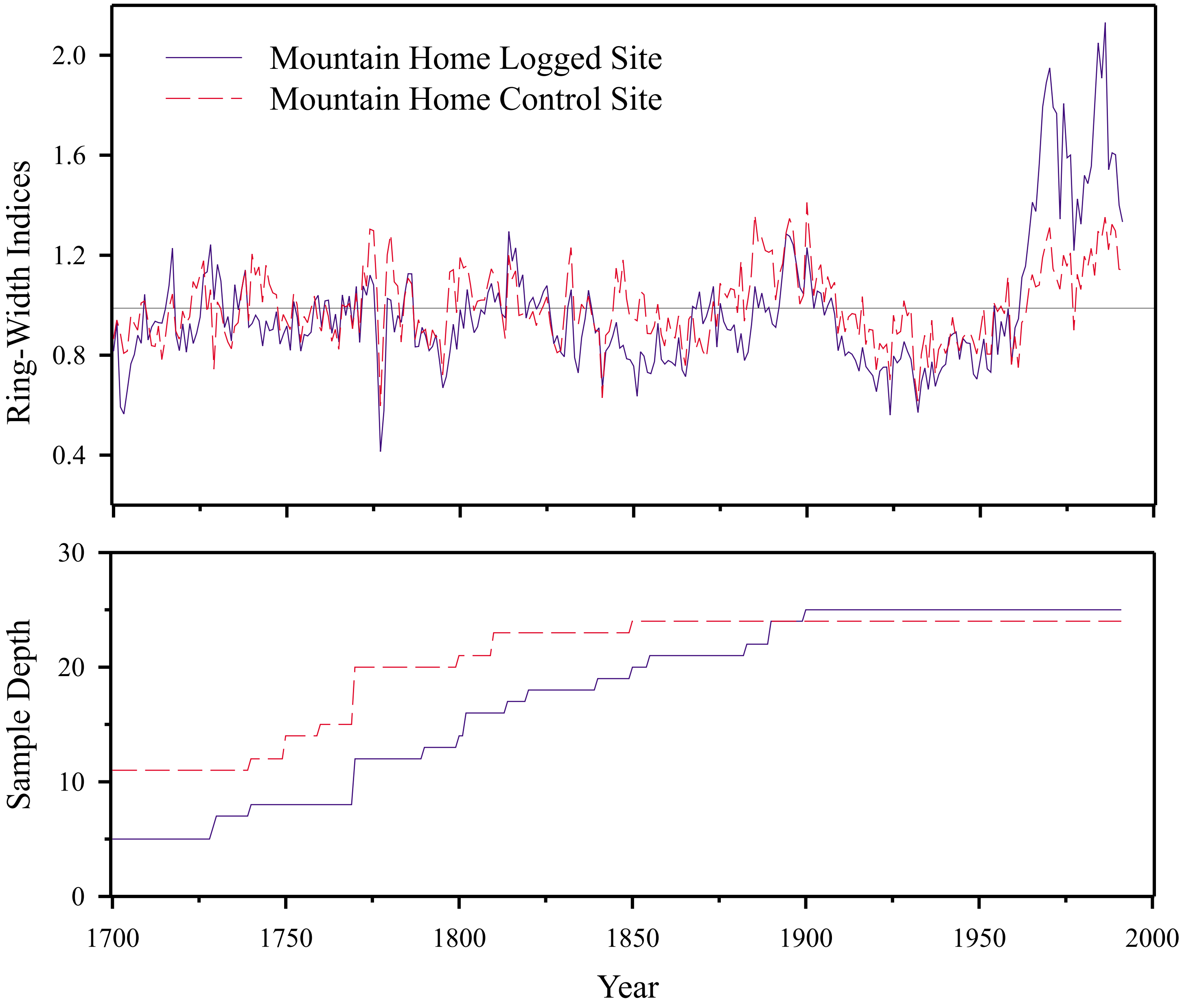

Mountain Home Logged Site
Mountain Home Control Site
Ring-Width Indices
2.0
1.6
1.2
0.8
0.4
Sample Depth
30
20
10
0
1700
1750
1800
1850
1900
1950
2000
Year

Figure 10.

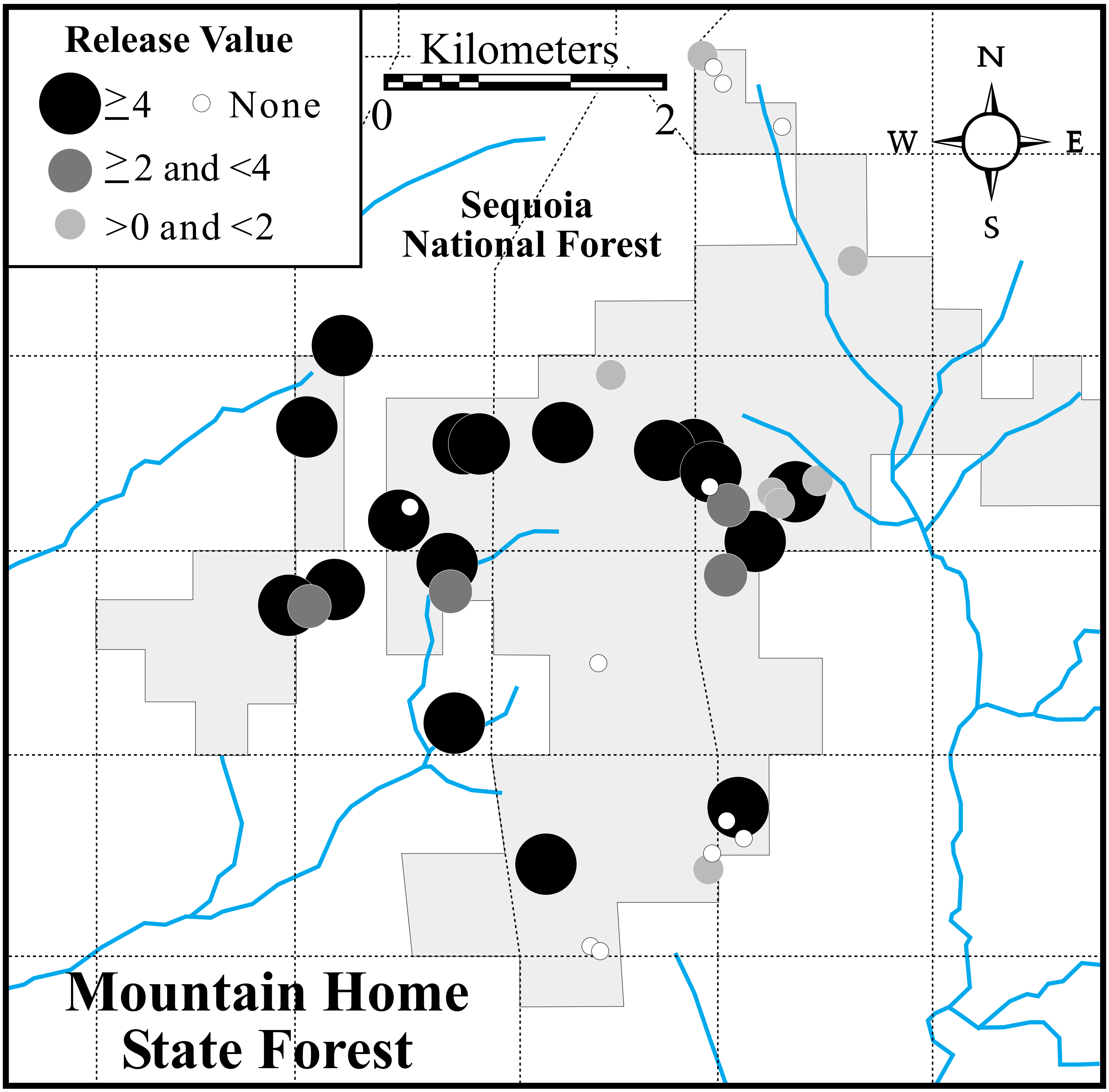

Release Value
≥4
None
≥2 and <4
>0 and <2
Kilometers
0
2
N
W
E
S
Sequoia National Forest
Mountain Home State Forest

Figure 11.

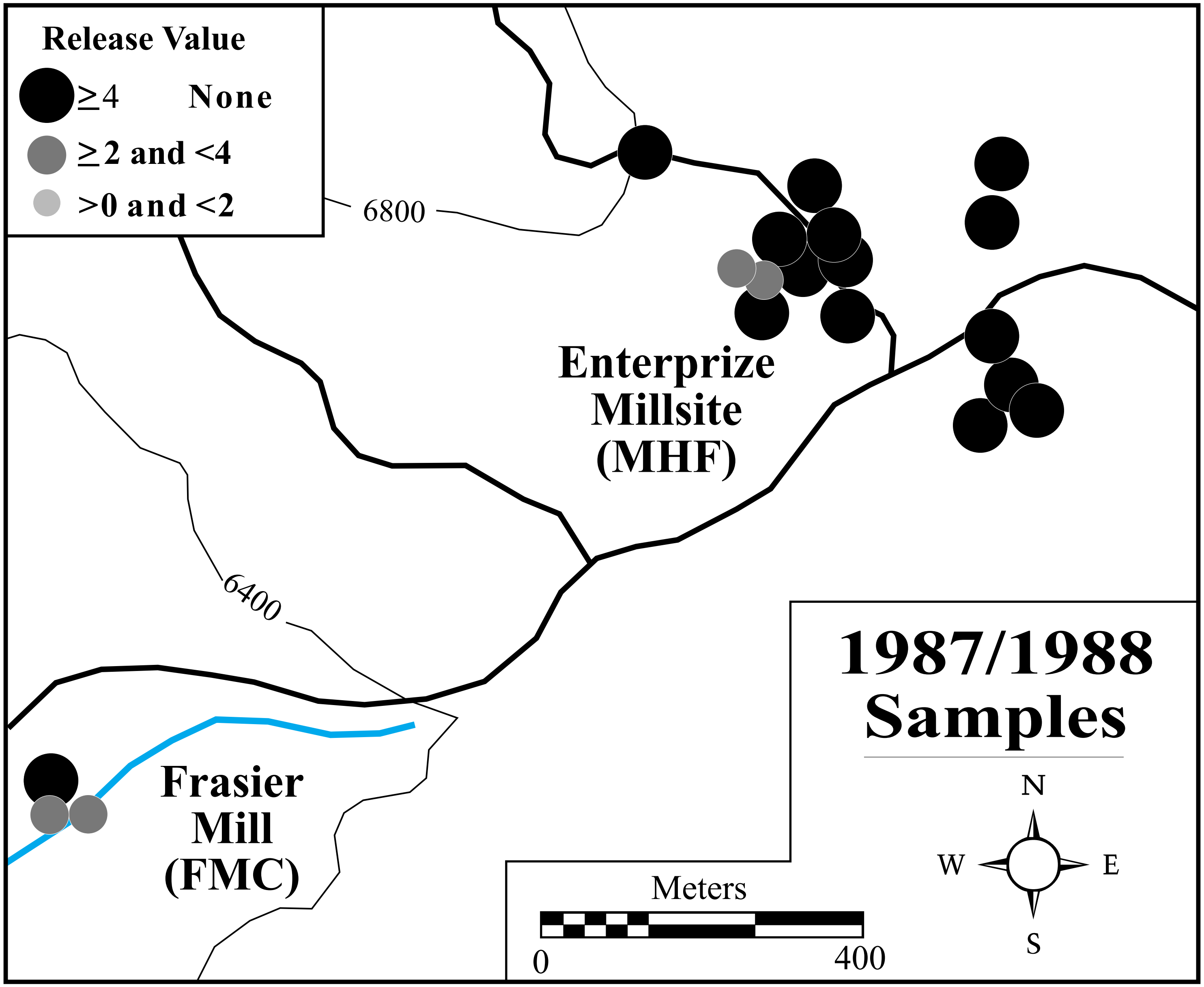

Release Value
● ≥4
None
● ≥2 and <4
● >0 and <2
6800
6400
Enterprize
Millsite
(MHF)
Frasier
Mill
(FMC)
1987/1988
Samples
Meters
0
400
N
W
E
S

Figure 12.

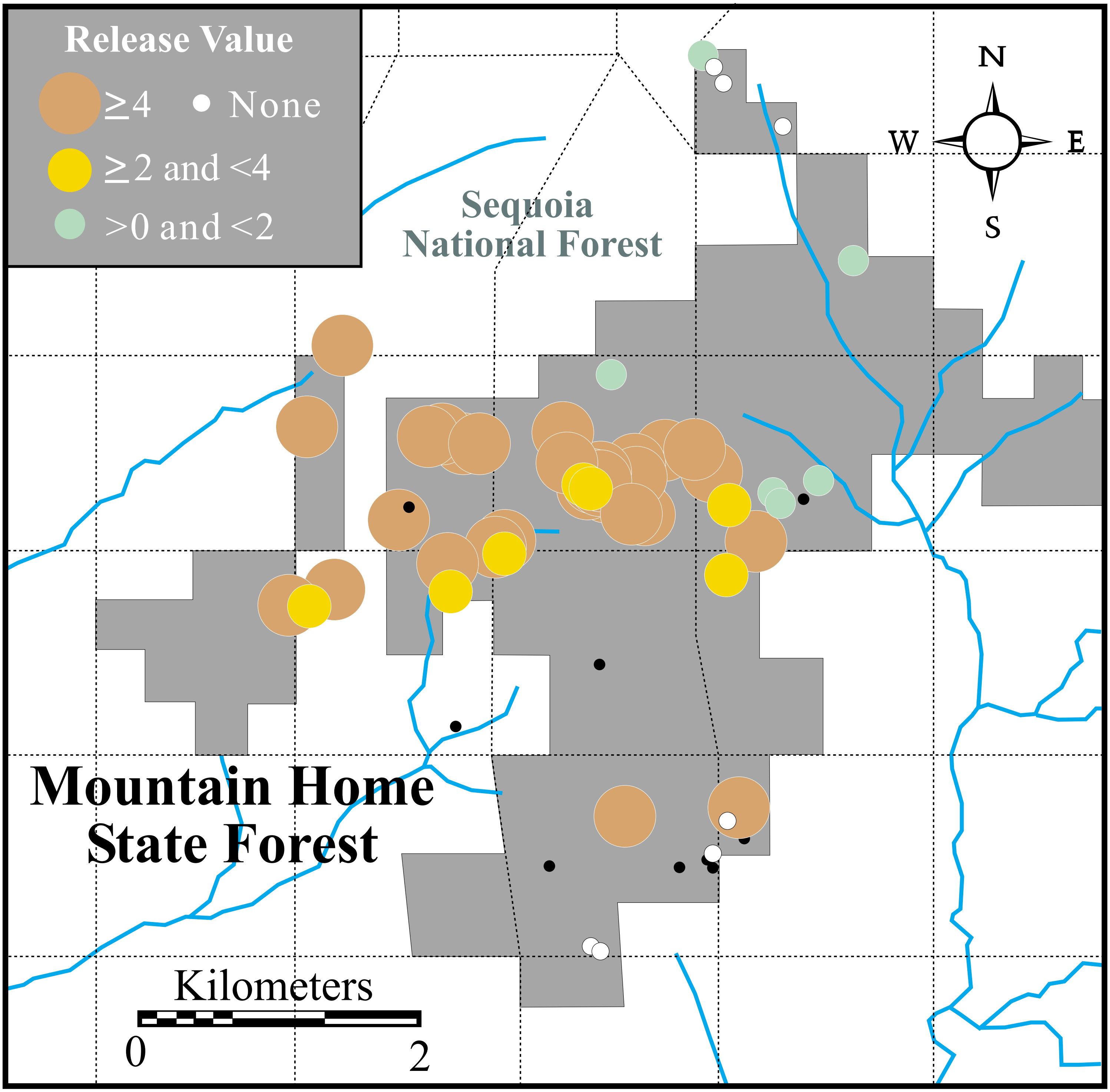

Release Value
≥4
None
≥2 and <4
>0 and <2
Sequoia
National Forest
N
W
E
S
Mountain Home
State Forest
Kilometers
0
2

Figure 13.

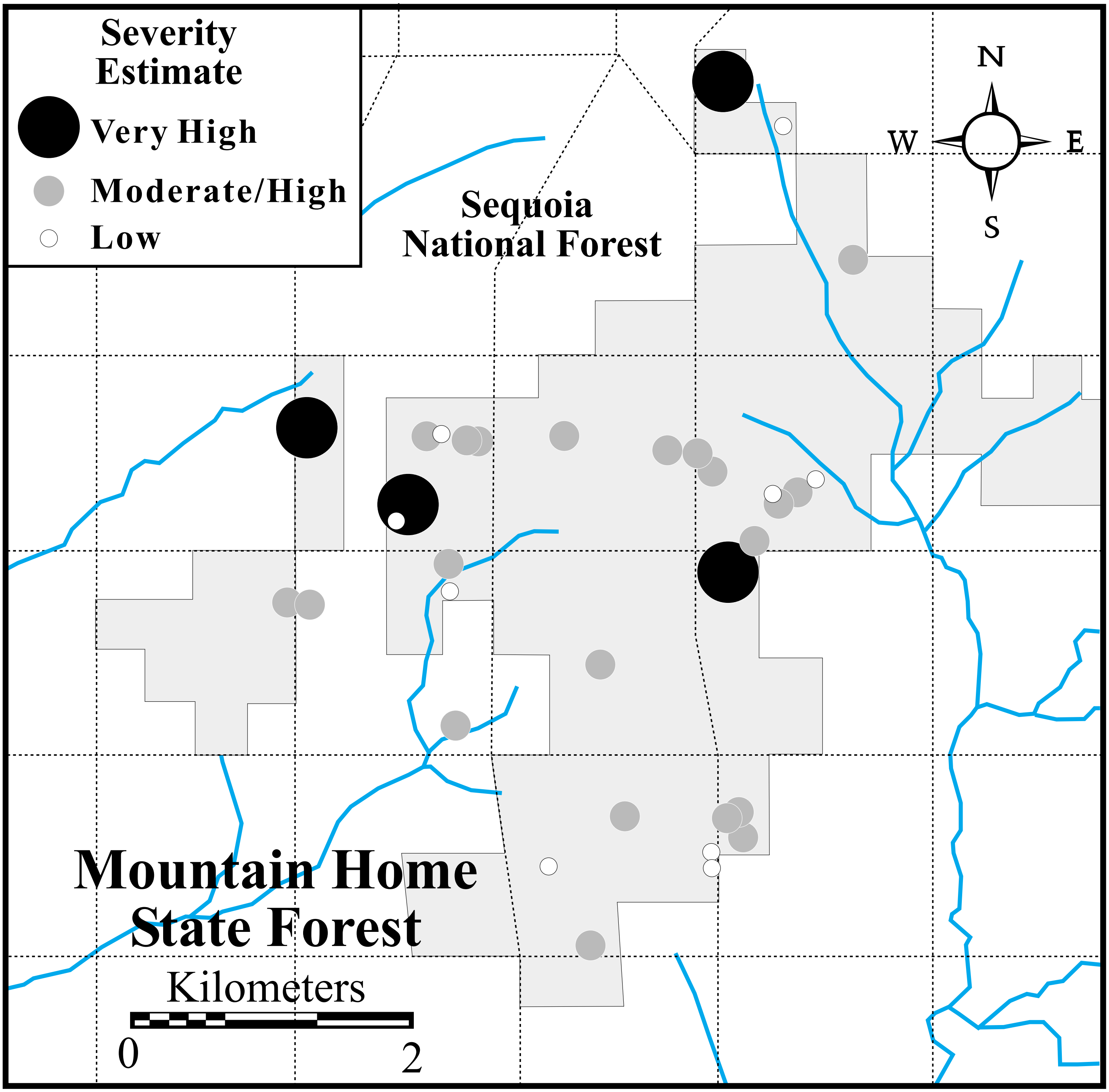
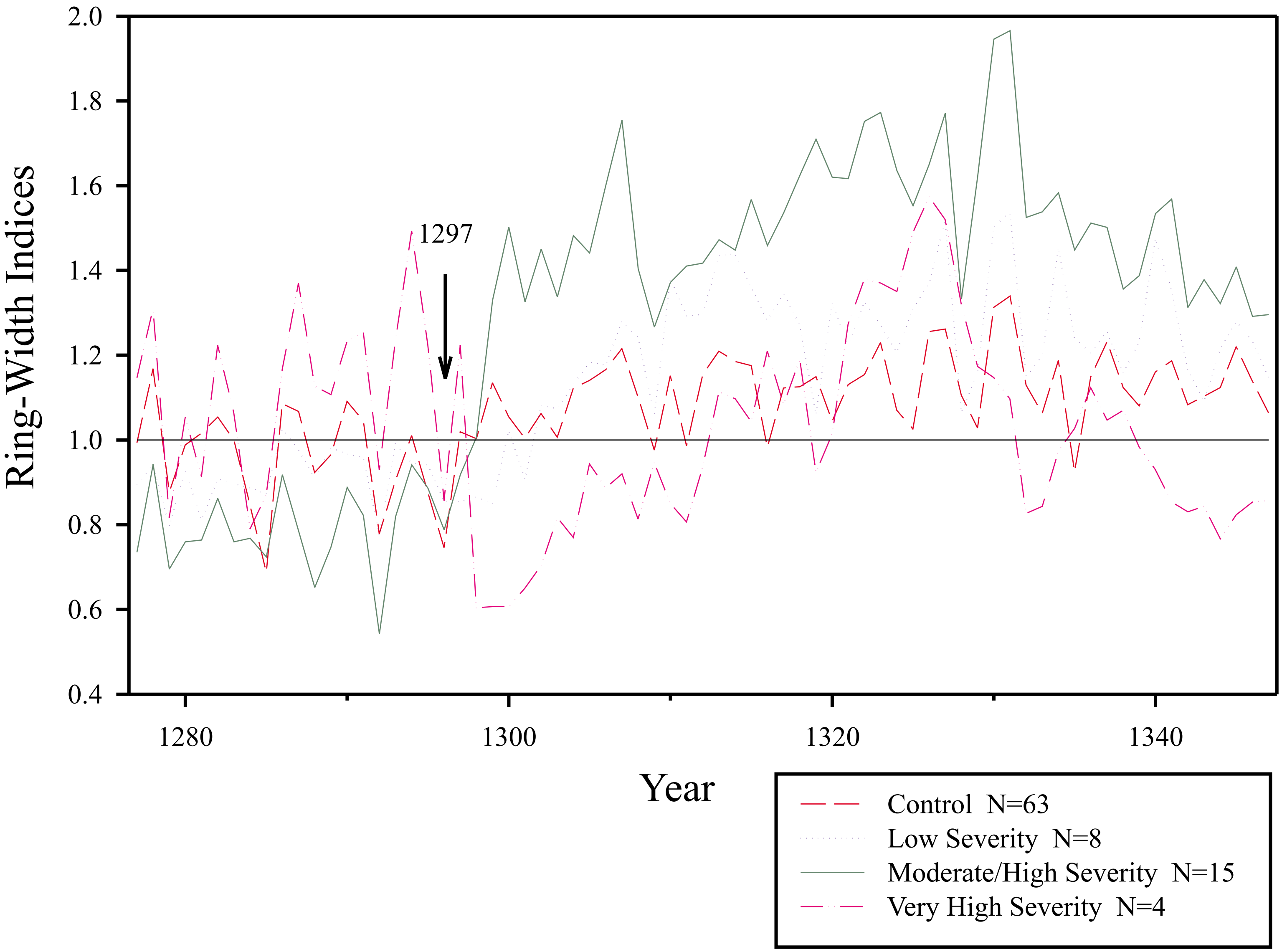
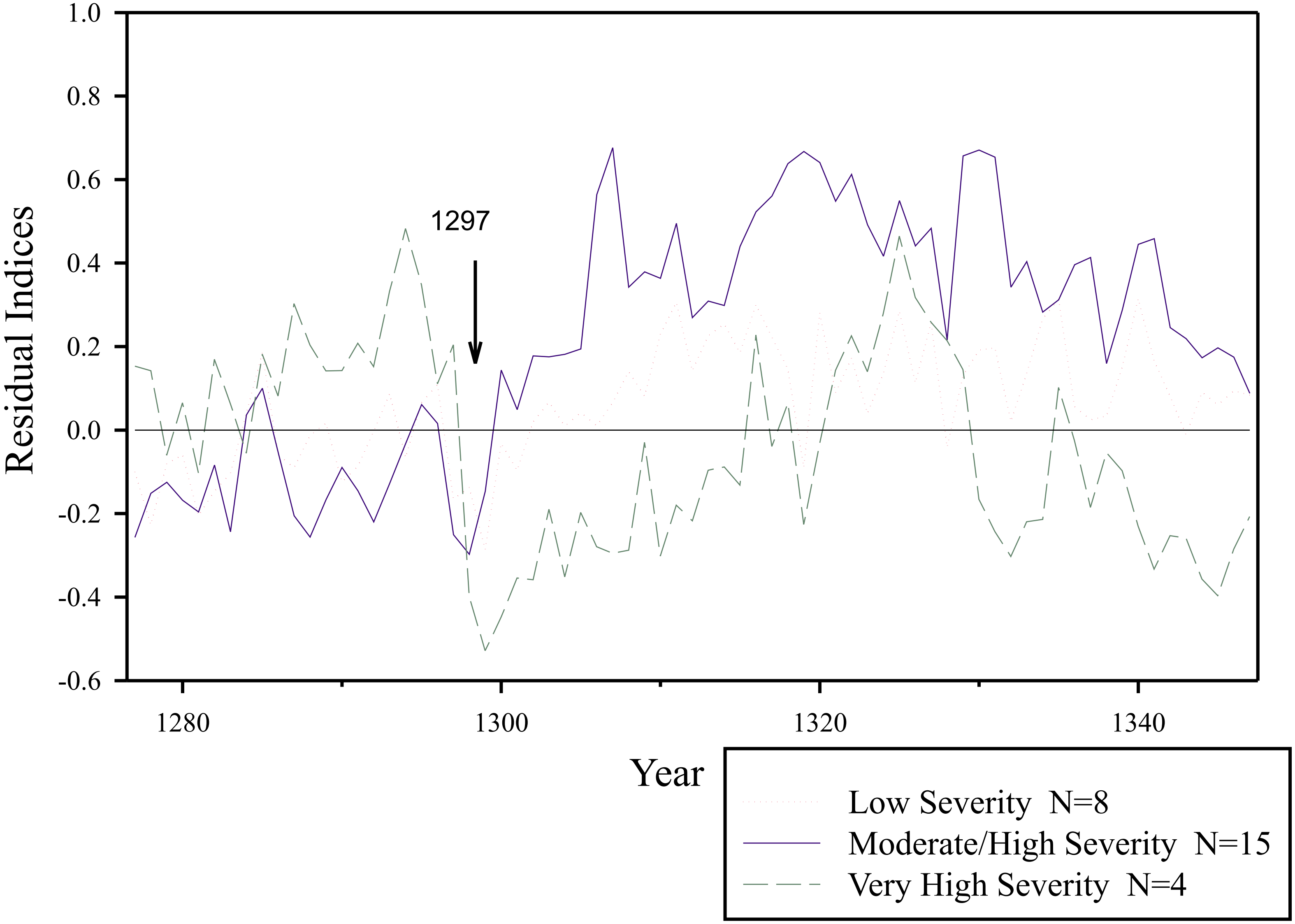

Severity Estimate
● Very High
● Moderate/High
○ Low
N
W
E
S
Sequoia National Forest
Mountain Home State Forest
Kilometers
0
2

Figure 14.



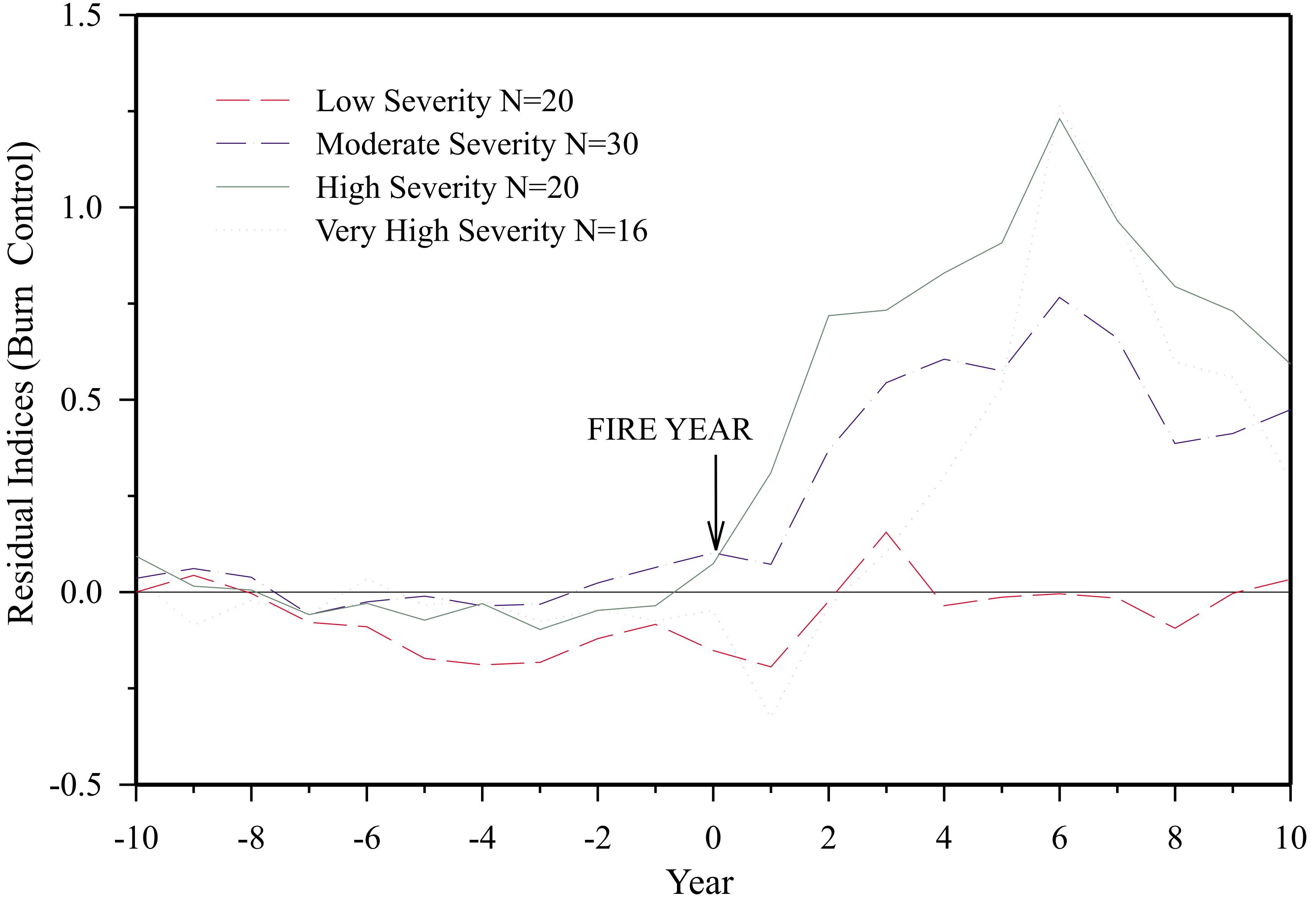
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Ring-Width Indices
1297
1280
1300
1320
1340
Year
Control N=63
Low Severity N=8
Moderate/High Severity N=15
Very High Severity N=4

Figure 15.



1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
Residual Indices
1297
1280
1300
1320
1340
Year
Low Severity N=8
Moderate/High Severity N=15
Very High Severity N=4

Figure 16.



Low Severity N=20
Moderate Severity N=30
High Severity N=20
Very High Severity N=16
FIRE YEAR
Residual Indices (Burn Control)
1.5
1.0
0.5
0.0
-0.5
-10
-8
-6
-4
-2
0
2
4
6
8
10
Year

Figure 17.

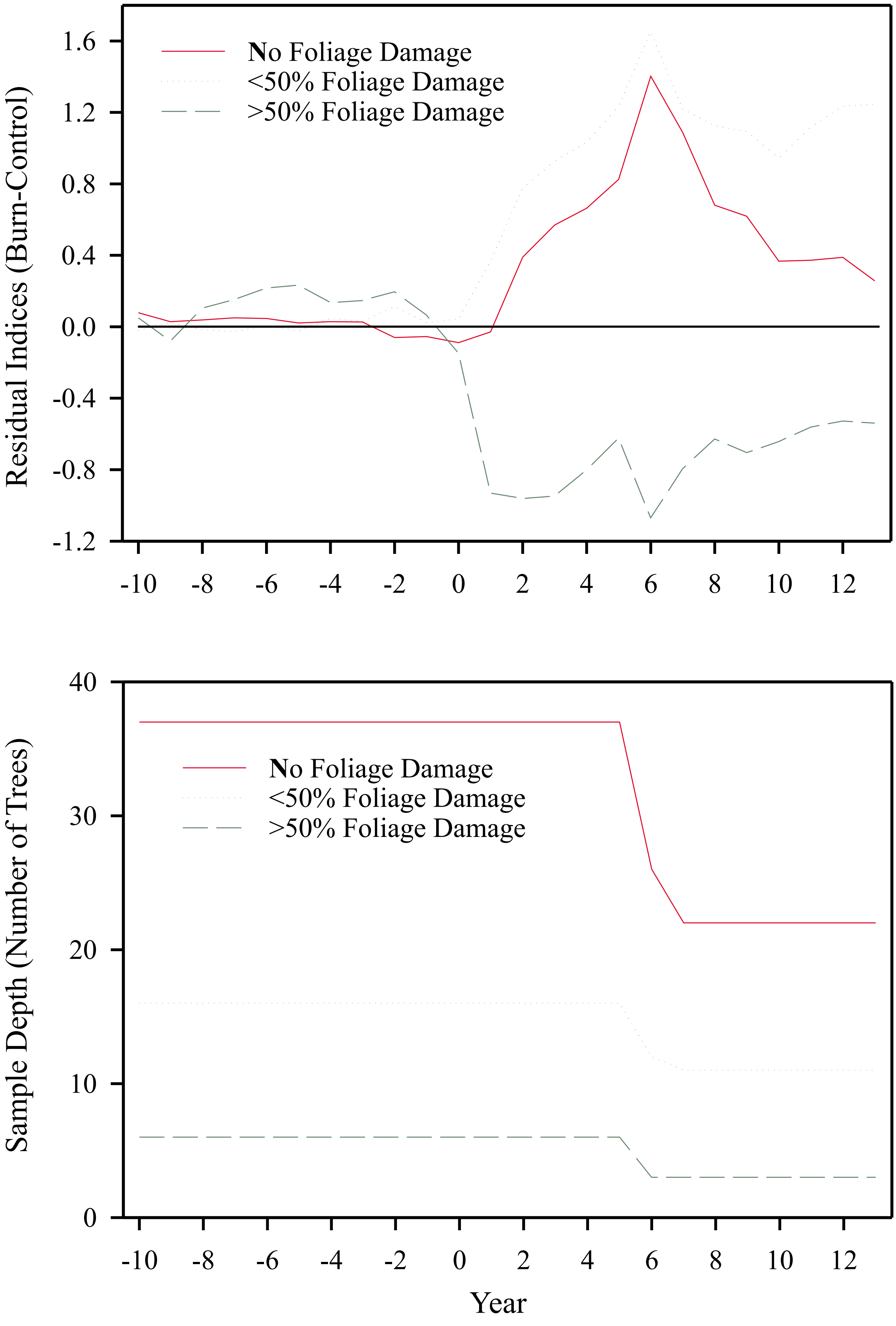

Residual Indices (Burn-Control)
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
No Foliage Damage
<50% Foliage Damage
>50% Foliage Damage
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
Sample Depth (Number of Trees)
40
30
20
10
0
No Foliage Damage
<50% Foliage Damage
>50% Foliage Damage
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
Year

Figure 18.

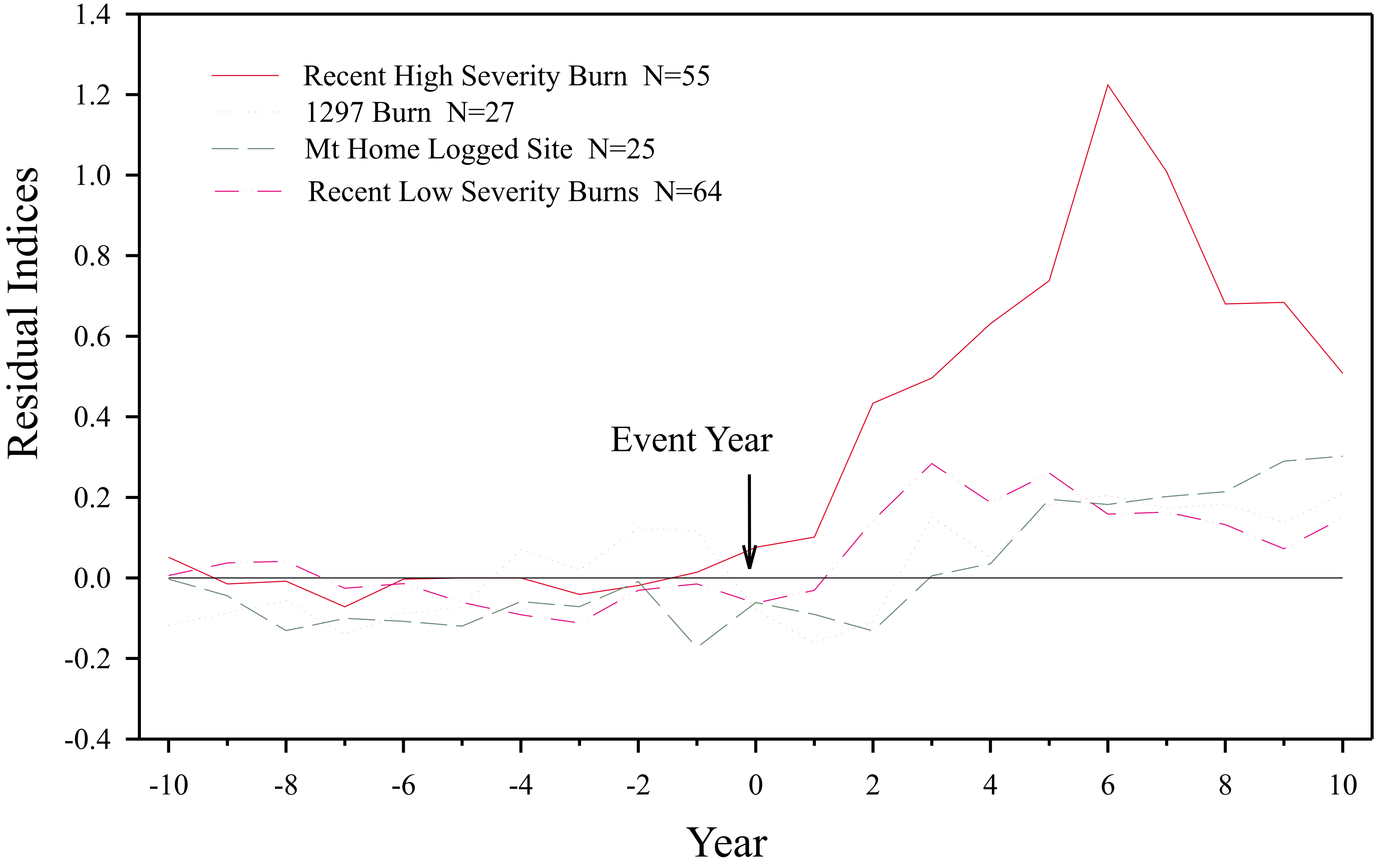
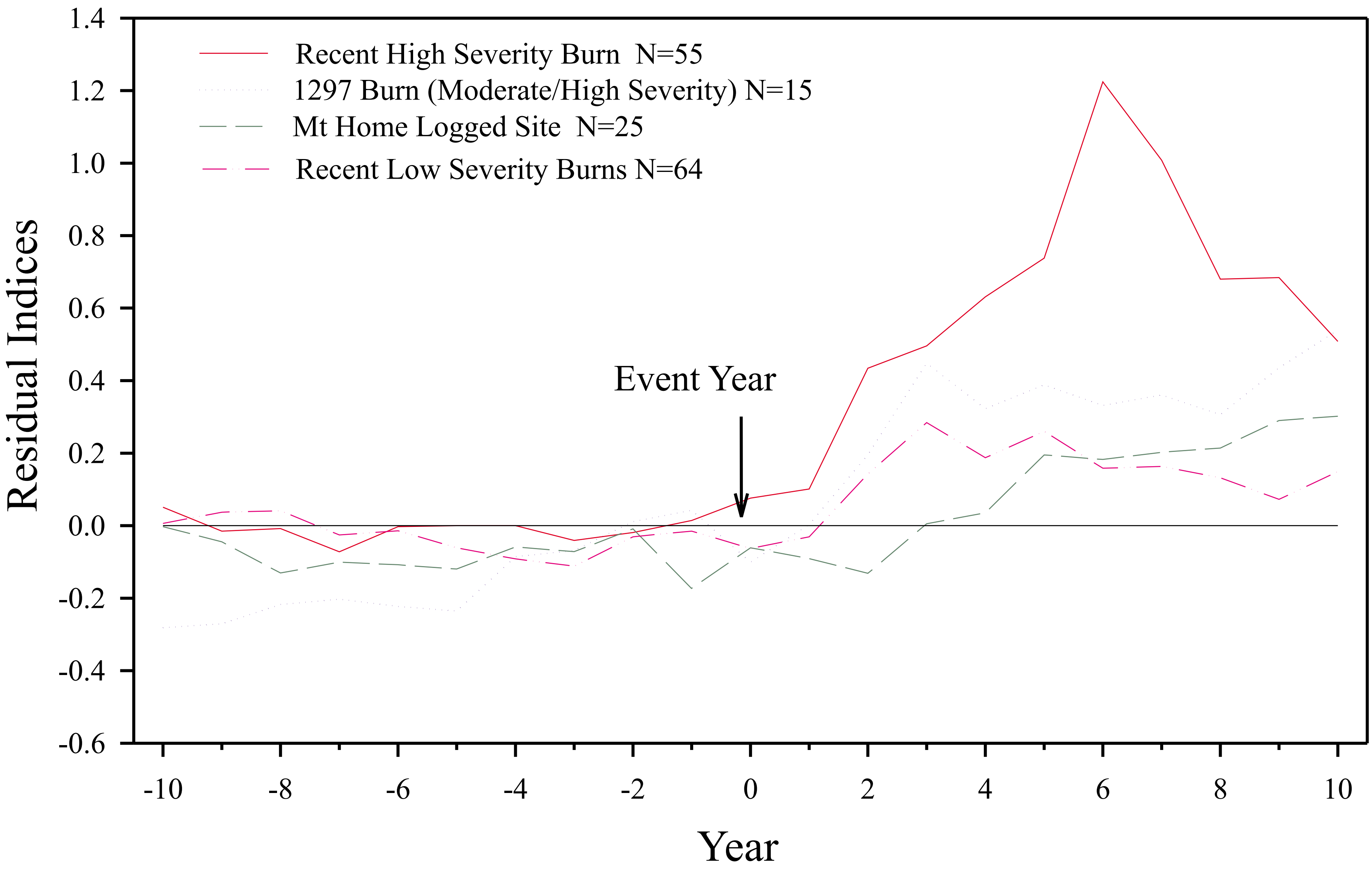

Recent High Severity Burn N=55
1297 Burn N=27
Mt Home Logged Site N=25
Recent Low Severity Burns N=64
Event Year
Residual Indices
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-10
-8
-6
-4
-2
0
2
4
6
8
10
Year

Figure 19.



Recent High Severity Burn N=55
1297 Burn (Moderate/High Severity) N=15
Mt Home Logged Site N=25
Recent Low Severity Burns N=64
Event Year
Residual Indices
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-10
-8
-6
-4
-2
0
2
4
6
8
10
Year

Figure 20.

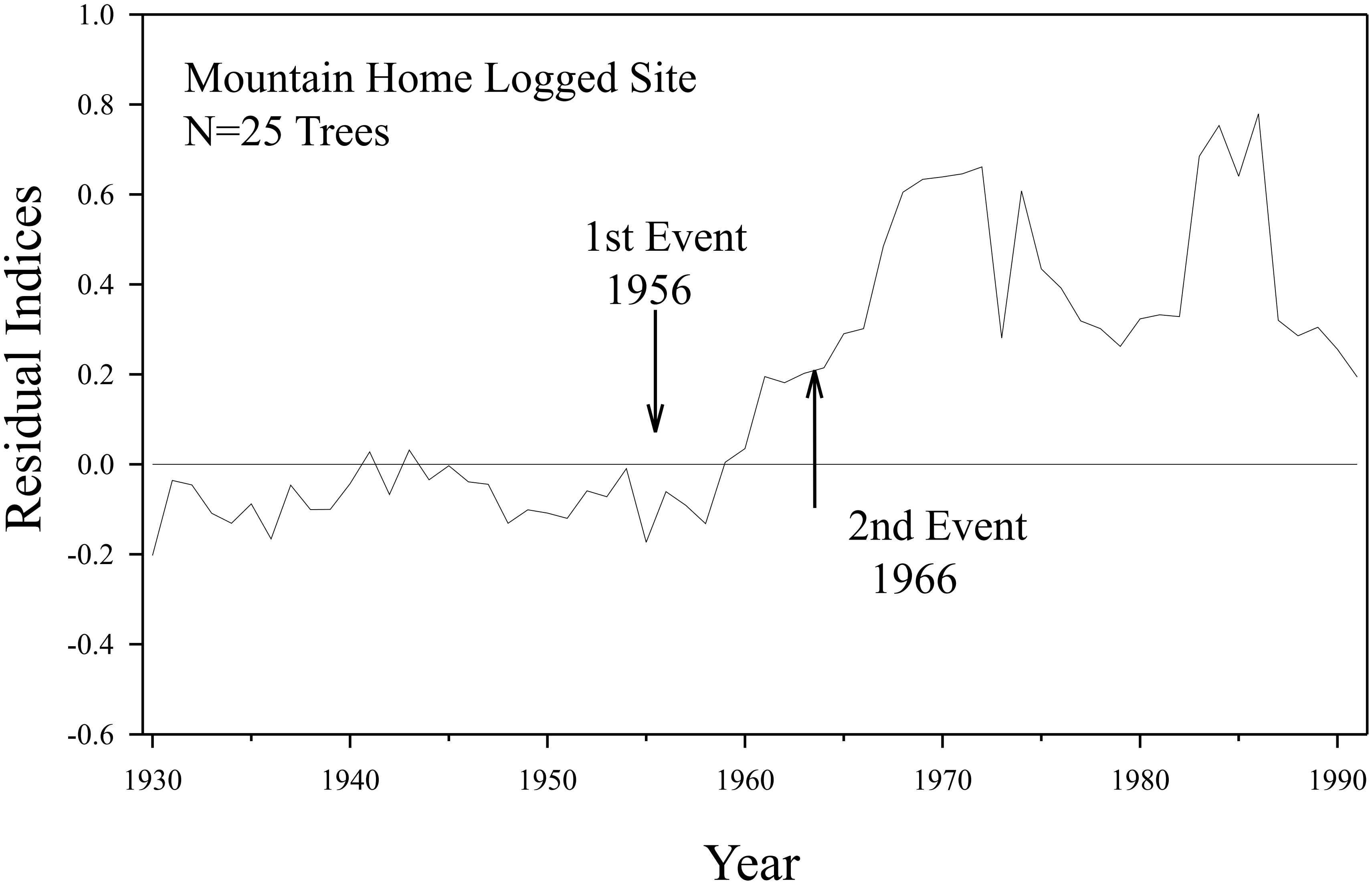

Mountain Home Logged Site
N=25 Trees
1st Event
1956
2nd Event
1966
Residual Indices
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1930
1940
1950
1960
1970
1980
1990
Year

Table 1. Sequoia chronology correlation matrix for the interval from 1100 to 1500 (401 years). All correlations are significant (P<0.05) and show the strong agreement among sequoia chronologies from throughout the region. The mean of the 15 correlations is 0.5429.

Ident.	BMG	CBR	CSX	GF	MHF	PPG
BMG	1.000					
CBR	0.537	1.000				
CSX	0.547	0.635	1.000			
GF	0.492	0.568	0.705	1.000		
MHF	0.330	0.543	0.715	0.586	1.000	
PPG	0.510	0.414	0.535	0.464	0.561	1.000
Mean	0.483	0.540	0.628	0.563	0.547	0.497

Table 2. Smallest 15 four-year running means (centered on last year) of reconstructed precipitation for the Giant Forest, sorted in ascending order, during the period from AD 1100 to 1500, based on reconstructions by Graumlich (1993) and Graybill (1993). Highlighted years show low mean values for the period between AD 1290 and 1300, indicating a strong persistent drought that lasted five years, 1292 through 1296. Average precipitation for the two reconstructions between AD 1100 and 1500 is 39.1 in. (993 mm) (Graumlich 1993) and 36.5 in. (927 mm) (Graybill 1993).

October to April Precip. (in.) (Graumlich 1993)		**November to April Precip. (in.) (Graybill 1993)**	
Year	**4-year Mean**	**Year**	**4-year Mean**
1292 - 1295	24.59"	1098 - 1101	22.70"
1293 - 1296	24.74	1425 - 1428	24.72
1458 - 1461	27.34	1292 - 1295	25.56
1294 - 1297	27.43	1150 - 1153	25.61
1170 - 1173	27.77	1149 - 1152	25.84
1140 - 1143	27.93	1153 - 1156	25.88
1335 - 1338	27.94	1358 - 1361	25.89
1295 - 1298	28.07	1183 - 1186	25.95
1251 - 1254	29.09	1295 - 1298	26.05
1250 - 1253	29.75	1262 - 1265	26.25
1315 - 1318	29.77	1182 - 1185	26.28
1336 - 1339	29.82	1293 - 1296	26.34
1296 - 1299	30.04	1350 - 1353	26.58
1472 - 1475	30.28	1294 - 1297	26.58
1471 - 1474	30.38	1215 - 1218	26.67

Table 3. List of all trees sampled in Mountain Home, location (tree identification corresponds to quarter-sections within townships except for the two RRJ trees), and post-1297 growth response that was noted or measured. Listed are the average ring-width for 10-years pre-1297, 10-years post 1297, the percent change, the severity rating, and the release value category. Tally of severity ratings and column means for each of the three severity ratings.

Tree Ident.	Before	After	%	Severity	Rel. Cat.
M1NW1*	0.805	1.523	189.19	M/H	4
M1SE1A*	1.016	1.113	109.55	L	0
M1SE3A*	0.944	1.042	110.38	L	1
M1SW1B	0.884	1	113.12	L	-
M1SW3B*	0.783	1.137	145.21	M/H	0
M1SW4*	0.923	0.978	105.96	L	0
M6NW1A	0.557	0.844	151.53	M/H	0
M6NW3B*	0.379	0.726	191.56	M/H	4
M6NW4*	0.429	0.446	103.96	L	0
M18SW1*	---	---	---	rejected	-
M18SW4*	1.354	1.045	77.18	VH	0
M18SW5*	1.016	1.03	101.38	L	0
M19SE2	0.835	1.552	185.87	M/H	2.5
M25NW1*	0.704	1.097	155.82	M/H	5
M25SE1*	0.811	1.432	176.57	M/H	4
M26-2A*	1.173	0.662	56.44	VH	0
M26NE1	1.059	1.062	100.28	L	4
M26NE2A*	0.779	1.209	155.2	M/H	4.5
M26NE5	0.469	0.623	132.84	M/H	4
M26NE6*	1.241	1.665	134.17	M/H	4
M26NW2A*	1.022	0.636	62.23	VH	4.5
M26SE4*	0.924	1.035	112.01	L	5
M30SW1C*	0.807	2.107	261.09	M/H	5
M30SW21*	1.15	1.268	110.26	L	3
M30SW3B*	1.038	1.202	115.8	L	2
M30SW4*	0.8	1.033	129.13	M/H	2
M30SW6*	0.69	1.179	170.87	M/H	4

Tree Ident.	Before	After	%	Severity	Rel. Cat.
M31NW1*	1.37	0.832	60.73	VH	2
M34NE1*	0.591	0.812	137.73	M/H	5
M35NE1A*	0.595	1.886	316.97	M/H	5
M35NE4	0.718	0.862	120.06	M/H	3
M35NW1U*	0.756	1.098	145.24	M/H	3
M35SE4A*	1.18	2.598	220.17	M/H	4
M36SW1*	0.773	1.155	149.42	M/H	0
RRJ 2	0.345	0.478	138.55	M/H	5
RRJ 6	0.488	0.962	197.13	M/H	4.5
Low	0.938	1.018	108.27	# = 10	1.67
Moderate/High	0.719	1.237	171.63	21	3.62
Very High	1.23	0.794	64.15	4	1.63
Column Mean	0.84	1.124	141.25	# = 35	2.90

* Trees used in developing the Mountain Home 1297 chronology.

Table 4. Results of IMPACT program. Mean growth indices are given for 5, 10, 20, 30, 40, and 50-year periods before and after 1297. The 1297 date is included in the "post-1297" period. The percent growth increase is the post-1297 mean as a percent of the pre-1297 mean.

Length of Period		Pre-1297	Post-1297	% Growth Increase
5-year	**Burn**	0.883	1.078	122.1
	Control	0.875	1.06	121.2
10-year	**Burn**	0.891	1.183	132.8
	Control	0.949	1.075	113.2
20-year	**Burn**	0.875	1.24	141.8
	Control	0.966	1.092	113.1
30-year	**Burn**	0.876	1.295	147.9
	Control	0.979	1.094	111.7
40-year	**Burn**	0.868	1.334	153.7
	Control	0.965	1.107	114.7
50-year	**Burn**	0.884	1.307	147.8
	Control	0.970	1.111	114.6

Table 5. Results of t-tests comparing the mean growth indices between Mountain Home burn and regional control chronologies for the 10-year pre-burn period and the 10-year post-burn period. Degrees of freedom were reduced in the post-burn period to account for unequal variances between groups.

Site Chronologies	Pre-Burn Period (1287-1296) Mean (SD)	Post-Burn Period (1298-1307) Mean (SD)
Mountain Home	0.92 (0.09)	1.19 (0.17)
Regional Control	0.94 (0.12)	1.09 (0.08)
	df=18, T=0.490, P>0.63	df=12, T=0.302, P>0.12

Table 6. Results of t-tests comparing the mean growth indices between Mountain Home burn and regional control chronologies for the 20-year pre-burn period and consecutive 20-year post-burn periods, up to 140 years post-burn. Sample sizes and degrees of freedom were not reduced to account for significant autocorrelation in the series. Asterisks indicate significantly different means (P<0.001).

Time Period	**Mean (SD)** **T-test results**
1277-1296 **Mountain Home** **Regional Control**	0.90 (0.09) 0.96 (0.13) df=38, T=1.514, P>0.14
1298-1317 **Mountain Home** **Regional Control**	1.26 (0.16)* 1.10 (0.08)* df=38, T=4.039, P<0.001
1318-1337 **Mountain Home** **Regional Control**	1.46 (0.12)* 1.15 (0.11)* df=38, T=8.646, P<0.001
1338-1357 **Mountain Home** **Regional Control**	1.26 (0.08)* 1.08 (0.13)* df=38, T=5.072, P<0.001
1358-1377 **Mountain Home** **Regional Control**	1.25 (0.14)* 1.03 (0.10)* df=38, T=5.564, P<0.001
1378-1397 **Mountain Home** **Regional Control**	1.14 (0.08)* 1.02 (0.07)* df=38, T=4.698, P<0.001
1398-1417 **Mountain Home** **Regional Control**	1.00 (0.11) 1.01 (0.07) df=38, T=0.214, P>0.83
1418-1437 **Mountain Home** **Regional Control**	0.96 (0.07) 1.01 (0.08) df=38, T=1.852, P>0.07

Table 7. Results of IMPACT program. Mean growth indices are given for the 10-year pre-disturbance period and the 10-year post-disturbance period for each burn (or logged) and control site comparison. The disturbance date is included in the "post-disturbance" period. The percent growth increase is the post-disturbance mean as a percent of the pre-disturbance mean. Both Moro and Grant burns are recent low to moderate severity burns and Partin burn is a high severity burn in Sequoia and Kings Canyon National Parks.

Disturbance Dates and Sites	Pre-Disturbance	Post-Disturbance	% Growth Increase
Burn Date 1979	**1969-1978**	**1979-1988**	
Moro Burn N=34	1.050	1.432	136.3
Giant Forest Control N=46	1.053	1.268	120.4
Burn Date 1979	**1969-1978**	**1979-1988**	
Grant Burn N=34	1.092	1.496	137.1
Grant Control N=41	1.136	1.436	126.3
Burn Date 1977	**1967-1976**	**1977-1986**	
Partin Burn N=57	1.189	1.845	155.2
Redwood Control N=53	1.202	1.240	103.1
Burn Date 1297	**1287-1296**	**1297-1306**	
Mt Home Burn N=26	0.891	1.183	132.8
Regional Control N=60	0.949	1.075	113.2
Logging Date 1956	**1946-55**	**1956-1965**	
Logged Site N=25	0.805	1.037	128.9
Control Site N=24	0.890	0.953	107.1

Table 8. Results of IMPACT program for Mountain Home logged site and control site. Mean growth indices are given for 5, 10, 20, and 30-year periods before and after the 1956 logging date. The 1956 date is included in the "post-1956" periods. The percent growth increase is the post-1956 mean as a percent of the pre-1956 mean.

Length of Period		Pre-1956	Post-1956	% Growth Increase
5-year	**Logged Site**	0.828	0.894	108
	Control Site	0.917	0.945	103.1
10-year	**Logged Site**	0.805	1.037	128.9
	Control Site	0.89	0.953	107.1
20-year	**Logged Site**	0.802	1.362	170
	Control Site	0.871	1.057	121.4
30-year	**Logged Site**	0.780	1.438	184.5
	Control Site	0.864	1.091	126.2

Table 9. Means of residual indices (disturbance indices minus control indices) for 10-year pre-disturbance and 10-year post-disturbance periods for all measured sequoias in the 1297 burn, for only the sequoias in the 1297 fire with the largest growth increases (believed to have sustained moderate to high severity fire), for a recent high severity burn (Partin--1977), for two recent low to moderate severity burns (Grant and Moro--1979), and for the Mountain Home logged site. Means of residual indices for 20- and 30-year post-disturbance periods are given for the logged site and the Mountain Home 1297 burn. The prescribed burns occurred too recently to permit evaluation for the longer periods.

Sites	N	**10-year pre-disturbance mean**	**10-year post-disturbance mean**	**20-year post-disturbance mean**	**30-year post-disturbance mean**
1297 Burn (All trees)	26	-0.023	0.102	0.163	0.230
1297 Burn (Subgroup with large increase)	15	-0.154	0.332	0.332	0.396
Logged Site	25	-0.086	0.121	0.329	0.377
Partin Burn	57	-0.009	0.650	--	--
Grant Burn	34	-0.055	0.100	--	--
Moro Burn	34	0.001	0.203	--	--