*Fire Ecology*, 1(1), 2005


# Fire History in Coast Redwood Stands in the Northeastern Santa Cruz Mountains, California

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## ABSTRACT

Fire regimes in coast redwood forests in the northeastern Santa Cruz Mountains were determined by ring counts from 48 coast redwood stumps, downed logs, and live trees. Degradation of remnant materials from post-harvest fires severely limited available fire scars in this region. The earliest recorded fire was recorded in approximately 1615 and the last fire recorded was in 1884. The Ohlone and early immigrants were probably the primary source of ignitions in this region. For all sites combined, the mean fire return interval (FRI) was 12.0 years; the median FRI was 10 years. There was no significant difference in FRI's between plot aspects but there was a significant difference in MFI between the four sampled sites. The grand mean FRI for single trees (point) was 16.3 years. Past fire scars occurred most frequently in the latewood portion of the annual ring or during the dormant period. It is probable that the number of fires recorded in coast redwood trees is a subset of those fires that burned in adjacent grasslands and oak savannahs. Continued development of old-growth and young-growth coast redwood forests toward prehistoric conditions may be dependent of a fire regime where prescribed burning substitutes for the now-absent aboriginal ignitions.

*Keywords:* Sequoia sempervirens, *fire intervals, dendrochronology, Native American burning*

## INTRODUCTION

Evidence of past fires is common in California's coast redwood (*Sequoia sempervirens* (D. Don) Endl.) forests. Redwood trees and stumps commonly exhibit fire scars in their annual growth rings, charred bark, and burned-out basal cavities. Early research on the role of fire in the redwood region advised managers to eliminate fire in old-growth forests and to be more careful when using it after logging operations, e.g. "The virgin redwood forest has been irreparably damaged by past fire; current fires aggravate the damage and on cut-over land they materially reduce the value of the land for new tree growth" (Fritz 1931). This early viewpoint was biased towards the utilization of redwood trees for lumber and is similar to that reported in the early 1900's for drier forests such as ponderosa pine (*Pinus ponderosa* Laws) in the Sierra Nevada of California (Show and Kotok 1924).

More recent research has documented the ecological role of fire in coast redwood forests (Jacobs et al. 1985, Stuart 1987, Finney and Martin 1989, 1992, Brown and Swetnam 1994, Brown et al. 1999, Brown and Baxter 2003). Fires perform many ecological functions in redwood forests including recycling woody and detritus fuels, preparing mineral seed beds, facilitating vegetative reproduction, and reducing understory vegetation.

Redwood trees produce thick bark at relatively young ages and they have the ability to resprout after being completely scorched by fire (Fritz 1931, Finney and Martin 1993). The ability to resprout after all needles have been killed by thermal injury is rare in coniferous trees. Coast redwood grows in a relatively mesic coastal area from central California to southern Oregon, a distance of approximately 800 km (Roy 1966). The distribution of coast redwood in the coastal mountains and valleys corresponds closely to the presence of oceanic fogs that reduce evapotranspiration stress during otherwise dry summer months (Dawson 1998). Redwood is probably limited in the northern portion of its range by the occurrence of freezing temperatures and in the southern portion by low winter rainfall (Lanner 1999).

Lightning ignited fires are rare in the coast redwood region because of modest topography and moist conditions that usually accompany lightning storms. The most common ignitions in this forest type were from Native Americans (Fritz 1931, Stuart 1987, Finney and Martin, 1989, 1992, Brown and Swetnam 1994, Brown et al. 1999, Brown and Baxter 2003). Fritz (1931) believed that Indians burned the forest occasionally but the specific purposes of the burning were unknown. Today we know Native Americans burned this region for diverse purposes including increasing the efficiency of food gathering, reducing acorn eating insects, to clear areas for travel, to produce high quality cordage materials, and to increase food production (Lewis 1973, Blackburn and Anderson 1993, Brown 2001). Early ranchers and farmers also burned this area during the 19th and early 20th centuries.

Fire history research in coast redwood has produced high variability in fire return intervals. Early research estimated very long fire return intervals of 50-250 years (Veirs 1982) whereas more recent work has produced very frequent intervals of 6-15 years (Finney and Martin, 1989, 1992, Brown and Swetnam 1994, Brown et al. 1999, Brown and Baxter 2003). Veirs (1982) hypothesized that coast redwood fire frequency varied from mesic coastal forests (200-250 years) to drier inland stands (50 years). Fire frequency in old-growth coast redwood forests has been reported to vary based on past land uses from relatively long intervals during the presettlement period, shorter fire intervals during the settlement period, and still shorter fire intervals during the post-settlement period (Stuart 1987). Fire frequency estimates in coast redwood are difficult to compare between studies owing to different methodologies and site characteristics (Finney and Martin 1989).

Only two studies (Brown and Swetnam 1994, Brown et al. 1999) have precisely dated fire scars using crossdating techniques (Stokes and Smiley 1977), all others have used less precise ring-counts. Coast redwood is very difficult to crossdate because of complacent annual ring patterns and discontinuous rings (Fritz and Averill 1924, Fritz 1931, Fritz 1940, Schulman 1940, Finney and Martin 1993, Brown and Swetnam 1994, Brown et al. 1999).

Ring discontinuities, where one or more rings wedge out along the trees circumference, are a fairly common feature in coast redwood (Fritz and Averill 1924, Fritz 1940, LaMarche and Wallace 1972). Indeed, Fritz (1940) noted differences in counts of up to 100 rings from different radii in a single, large coast redwood tree. It is also common for remnant materials (stumps and logs) to have extensive rotten wood and this further complicates crossdating (Finney and Martin 1992, Brown and Baxter 2003).

The objective of this study is to determine the fire history of 4 coast redwood stands in the northeastern Santa Cruz Mountains of California. Estimates of past fire frequency, seasonality, and if fire frequency was influenced by aspect are presented. The land-use history of the study area was also examined to aide in explaining past fire occurrence. This is only the second fire history study done using fire scars in the southern portion of the coast redwood range, the first (Greenlee 1983) was a small study that analyzed samples from only two stumps to estimate past fire frequency.

## METHODS

### *Study Area*

Fire scars were collected from the east-side of the northern Santa Cruz Mountains in San Mateo County, California. Three locations were included in this study, Stanford University's Jasper Ridge Biological Preserve (Jasper Ridge), and two San Mateo County Parks, Huddart and Wunderlich (Figure 1).

Climate in the study area is Mediterranean with mild, wet winters and cool, dry summers. Average summer and winter temperatures are 20°C and 10°C, respectively. Annual precipitation is approximately 62 centimeters primarily as rain with 72 percent falling during the winter months (December thru March). Soils in the redwood groves at Jasper Ridge Biological Preserve are classified in the Los Gatos series (mollisol) derived from sandstone and mudstone. Soil texture is a fine loam. Soils in Wunderlich and Huddart Parks are unclassified.

Jasper Ridge covers 481 hectares ha and includes grasslands, chaparral, oak and mixed evergreen woodlands, coast redwood forests, and wetlands at the south end of Searsville Lake. The current distribution of coast redwood within the Preserve covers only 1.5 hectares in three small isolated groves (100 meters elevation) upslope from San Francisquito Creek.

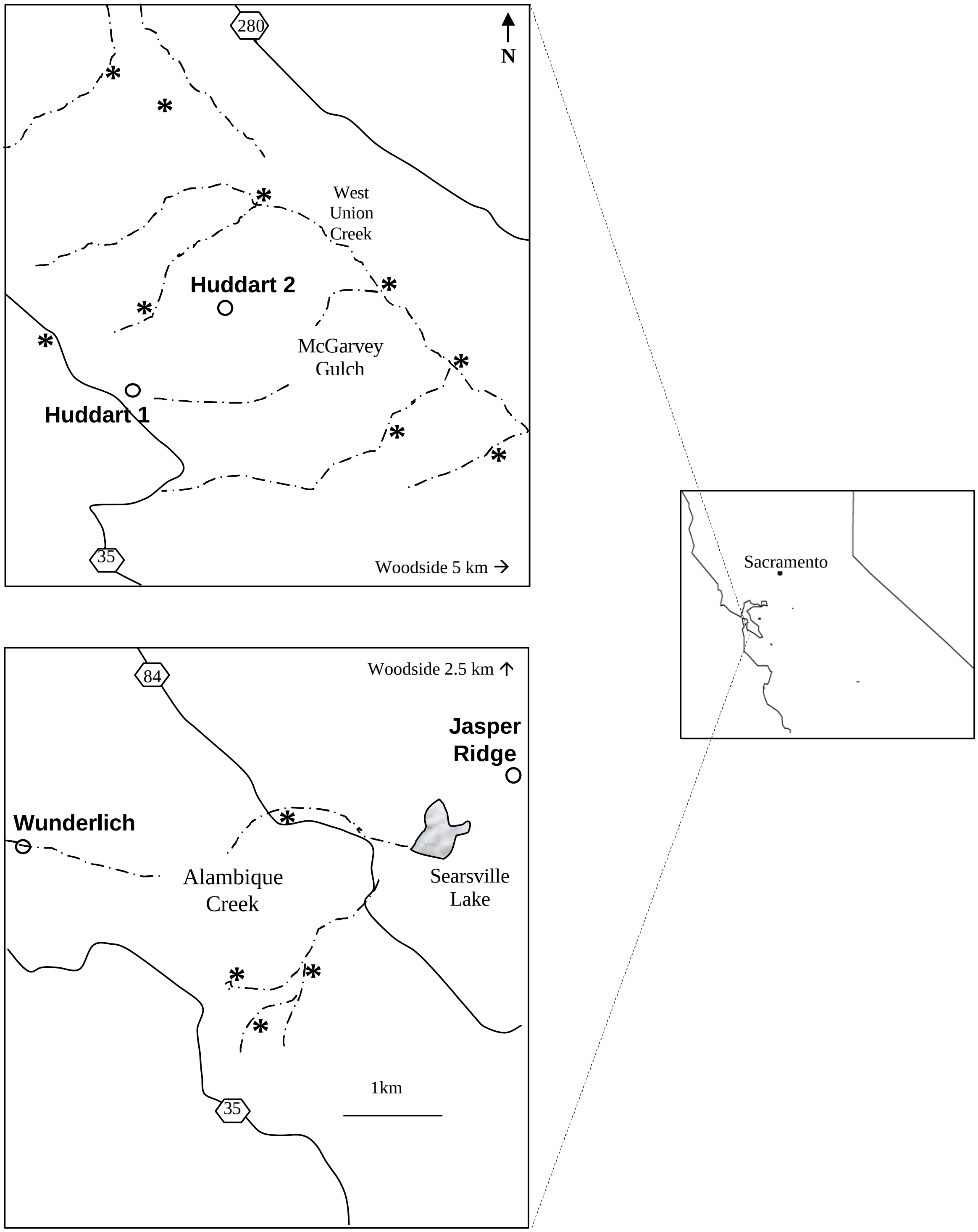
Wunderlich and Huddart Parks are located in Woodside approximately 3.5 km west and 7.5 km northwest of Jasper Ridge, respectively. Both parks include coast redwood forests, meadows, mixed evergreen forests, chaparral, and valley oak (*Quercus lobata* Nee) woodlands. Wunderlich and Huddart Parks are 377 and 389 ha in size, respectively, and elevation ranges from 100 to 610 m.

### *Land-use History*

The land-use history of this area is diverse. The Ohlone (Costanoan) Indians have lived in this region for thousands of years and they used fire as a management tool (Lewis 1973). The first recorded Spanish expedition entered this region on November 6, 1769, when the first Portola expedition camped in Portola Valley. Shortly after this expedition the number of European immigrants increased because of abundant natural resources and easy access from the San Francisco Bay.

Starting in 1849, the California Gold Rush brought thousands of people to San Francisco and the demand for lumber resulted in extensive logging operations in this area. By 1853, 10 sawmills in this region were producing 67,000 board feet of lumber daily (Stanger 1967). Near the present borders of Huddart Park, 5 sawmills operated between 1852 and 1860.

Figure 1. Coast redwood fire history study sites in southern San Mateo County.
(* identifies sawmill locations that were in operation from 1849-1860)



The historic Woodside Store was built in 1853 just below present day Huddart Park. This store was at the hub of activity during this early logging operations since about 15 sawmills were within 8 km of its location. The areas surrounding both Huddart Park sites was probably logged in the mid-1850's. Many early sawmills were stream powered and operated only seasonally. All sawmills were abandoned after the timber was harvested (Stanger 1967).

The Wunderlich and Jasper Ridge sites are located within 3 km of the Peninsula's first sawmill on Alambique Creek. This mill operated from 1849 to 1859 under several different owners and may have logged the entire Alambique valley (Stanger 1967), an area of approximately 3.5 $km^2$. The removal of the majority of the trees in this area in the mid 19th century prevented us from collecting tree demography data to complement our fire history information. Analysis of demography data could have determined if tree regeneration was continuous or episodic in these forests and could have allowed us to estimate past fire severity.

### *Fire History*

Our sampling strategy maximized the completeness of an inventory of fire dates within the study area over as a long time period as possible, while also collecting samples that were spatially dispersed throughout the areas (Swetnam and Baisan 2002). The three areas (Jasper Ridge, Wunderlich and Huddart Parks) were reconnoitered to determine where clusters with fire-scarred materials were located. Each cluster that contained a minimum of ten fire-scarred samples over an area = 5 ha was selected for sampling.

Following reconnaissance, three clusters were identified in the San Mateo County Parks, two on the northwestern end of Huddart in McGarvey Gulch (approximately 1 km apart) and one on the southern end of Wunderlich adjacent to Alambique Creek (Figure 1). One cluster was found in Jasper Ridge. Random selection of fire scar collection sites was not possible because of the extreme rarity of preserved fire scar data. As with other paleoecological data (e.g. pollen sequences, fossil assemblages), adequately preserved paleo-fire records are patchy and directed sampling had to be employed to derive a useful dataset (Brown and Baxter 2003).

Partial cross sections were cut with a chainsaw from all fire-scarred snags, downed logs, and live trees with visible fire scars within the four fire scar sampling areas. In some cases, several cuts were needed to obtain a sample with a maximum number of fire scars and a minimum of rotted wood. Live trees were not sampled more than twice and were sampled conservatively to reduce the probability of mechanical failure (Heyerdahl and McKay 2001, Stephens 2001). Each fire-scarred sample was sanded with a belt sander using a series of belts up to 400 grit. Fire scars were identified by the characteristic disruption and healing patterns of radial tree ring growth (McBride 1983).

To determine the fire return interval (FRI), annual rings between successive fire scars were counted for each sample. Some areas between fire scars were excessively burned and this probably eliminated some fire scars. These intervals were excluded from point and site FRI estimates (non-recording years). The position within the ring in which a scar occurred was noted as EE (early earlywood), ME (middle earlywood), LE (late earlywood), LW (latewood), D (dormant), or U (undetermined) to serve as an estimate of the season of fire occurrence (Ahlstrand 1980, Dieterich and Swetnam 1984).

We used a non-parametric Kruskal Wallis test to determine if a significant difference ($p < 0.05$) in mean fire return intervals (MFI's) existed between sampling sites and aspect. If a significant difference was detected then a non-parametric Tukey multiple comparison test (Nemenyi test) was done to determine if there were significant differences in MFI's among sites (Zar 1999). FRI frequency distributions were produced for each site and 2-sample Kolmogorov-Smirnov tests were used to test the null hypothesis that the distributions were not significantly different.

## RESULTS

A total of 48 coast redwood samples were collected from the four sites (Table 1). Fire intervals from two samples were not determined because of excessive rotten wood. The rot and degradation of stumps from post-harvest fires severely limited available fire scars in this region. A few samples had two fire scars and they provided only one fire return interval. Sites were on relatively steep terrain and varied in aspect (Table 1).

Table 1. Site characteristics for 4 coast redwood stands in southern San Mateo County, CA. SE = standard error of the mean.

| Grove | Number of samples | Average percent slope (SE) | General aspect |
|---|---|---|---|
| Huddart 1 | 13 | 46.1 (3.2) | NW-NE |
| Huddart 2 | 8 | 43.4 (7.8) | NE-S |
| Wunderlich | 13 | 41.5 (4.0) | NE-S |
| Jasper | 12 | 25.0 (5.0) | NW |

Three hundred fifty-five fire scars were identified on the 46 samples (Figure 2, Table 2).

Figure 2. Fire return interval frequency distributions for all 4 coast redwood fire history sites.

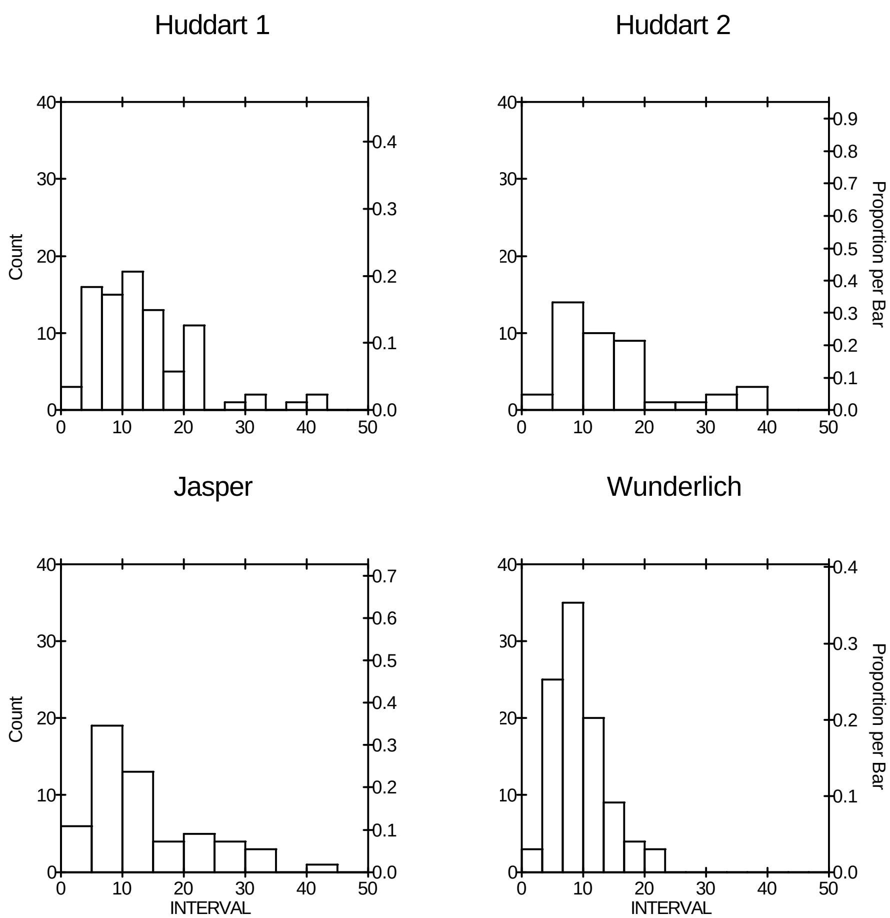


Table 2. Fire history statistics for 4 coast redwood forests. FRI statistics exclude intervals that were identified as non-recording (null) years. Mean values in a column followed by the same letter are not significantly different (*p*<0.05). SE = standard error of the mean.

| | Number of fire scars | Number of intervals | Average FRI (SE) | Median FRI (range) |
|---|---|---|---|---|
| Huddart 1 | 110 | 87 | 13.1[b] (0.9) | 11 (2-43) |
| Huddart 2 | 56 | 42 | 16.1[b] (1.9) | 11 (3-38) |
| Wunderlich | 115 | 99 | 9.3[a] (0.4) | 9 (3-21) |
| Jasper | 74 | 55 | 14.1[b] (1.4) | 10 (3-41) |

The approximate time period covered by the fire scar samples is 1650-1860 but the lack of crossdating does not allow us to precisely estimate this period. These redwood stands were harvested in the 1850's, which helped define the end point of the time period

The fire return intervals recorded from the redwood samples in this study were relatively frequent (Table 2). For all sites combined, mean FRI was 12.0 years (SEM = 0.5); the median FRI was 10 years. There was a significant difference in MFI between the four sites (K-W test statistic = 15.2, p = 0.002) (Table 2). The Wunderlich site had a significantly lower MFI than the other three sites. However, both of the Huddart sites and Jasper Ridge were not significantly different from each other. There was no significant difference in MFI's between aspects.

The grand mean FRI for single trees (point) was 16.3 years (range of means 6.2 – 45.3 years; SEM, 1.4). The grand median FRI (point) was 13.5 years. The mean number of fire scars on an individual sample was 6.4 (range 2-18 scars; SEM, 0.9). The grand mean FRI for single trees (point) was 12.4 years (range of means 6.2 - 26.4 years; SEM, 0.5) when the null years are excluded in the calculation.

FRI frequency distributions of for all four sites exhibited right skews (Figure 2). Using 2-sample Kolmogorov-Smirnov tests, Wunderlich was a significantly different distribution than the other three sites ($p < 0.05$). This distribution had the strongest skew with approximately 61 percent of the intervals less than 10 years. Huddart 2 had the lowest percentage of fire intervals less than 10 years (38 percent) and Huddart 1 and Jasper Ridge had 39 and 46 percent, respectively. Both the Huddart sites and Jasper Ridge interval frequency distributions were not significantly different ($p > 0.75$).

Only two live fire scarred coast redwood trees were found in the four plots. They were located in the Huddart 1 site and the samples were approximately seven meters apart. The earliest recorded fire was approximately in 1615 and the last fire recorded by both samples was in 1884 based from ring counts (Figure 3).

Figure 3. Live sample composite of fire activity from Huddart 2 coast redwood fire history site. Each horizontal line is a fire scar sample and each vertical tick is a fire scar.

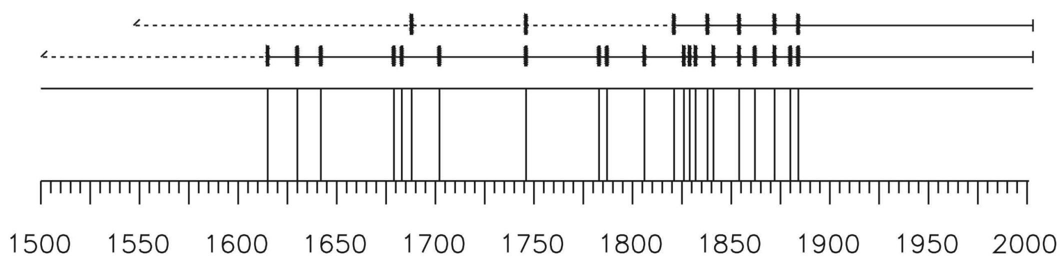
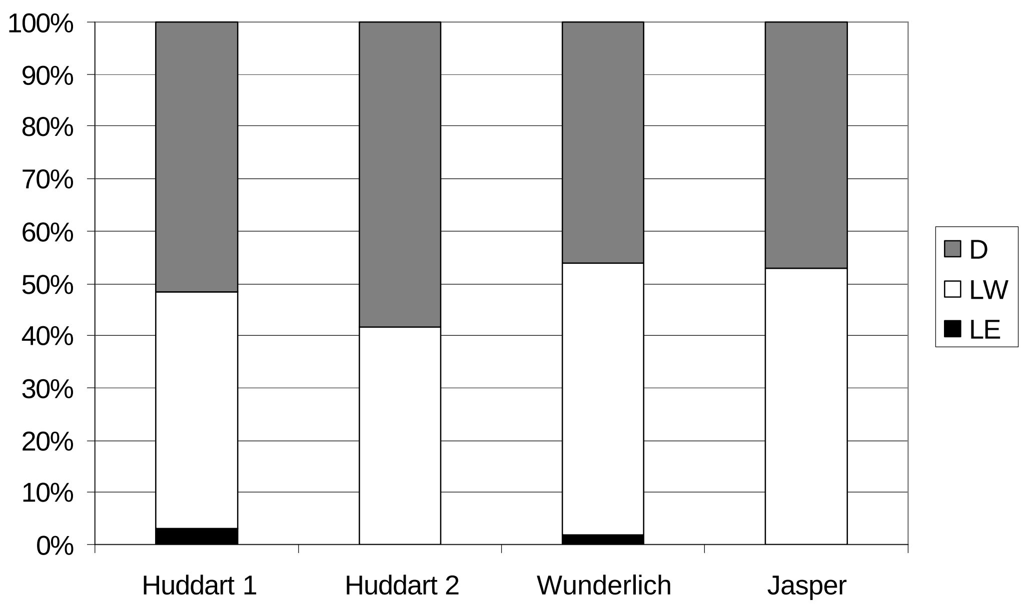



Figure 4. Percentage of redwood fire scar intraring positions by site in San Mateo County. D, dormant period; LW, latewood; LE, late earlywood.




Despite having several fire scar years coincident between the two samples, we do not consider these dates to be absolute.

The season of fire occurrence was determined for 50.3 percent of the fire scars. Past fire scars occurred most frequently in the latewood portion of the annual ring or during the dormant period (ninety-eight percent) (Figure 4).

Early growing season (earlywood) fires were very rare (1.7 percent). The three late-earlywood fire scars were recorded from the Huddart 1 and Wunderlich sites. No fire scars were found in the early or middle portion of the earlywood.

## DISCUSSION

Frequent surface fires were common in coast redwood forests in the northeastern Santa Cruz Mountains until the late 19th century. The first European immigrants entered this area in the late 1770's and they used fire for diverse purposes, before this period the Ohlone were the primary source of ignitions. Live fire scarred coast redwood trees are extremely rare in this area (only 4 percent of the sampled trees). Additional live tree samples are needed to more accurately estimate when frequent surface fires ended in these forests.

The interval data at Wunderlich (mean FRI and frequency distribution) was significantly different (shorter) than other sites sampled in this study. One possible reason for this difference is Wunderlich has experienced a more intensive land use history over the last two centuries. Farming, a fish pond, and orchard operations were located within this park which could have resulted in more human ignitions during the early Euro-American settlement period. The sampling area adjacent Alambique Creek has several relatively flat areas with evidence of past use that could have been used by the Ohlone or early immigrants. The only other site that had similar topography and access is Jasper Ridge.

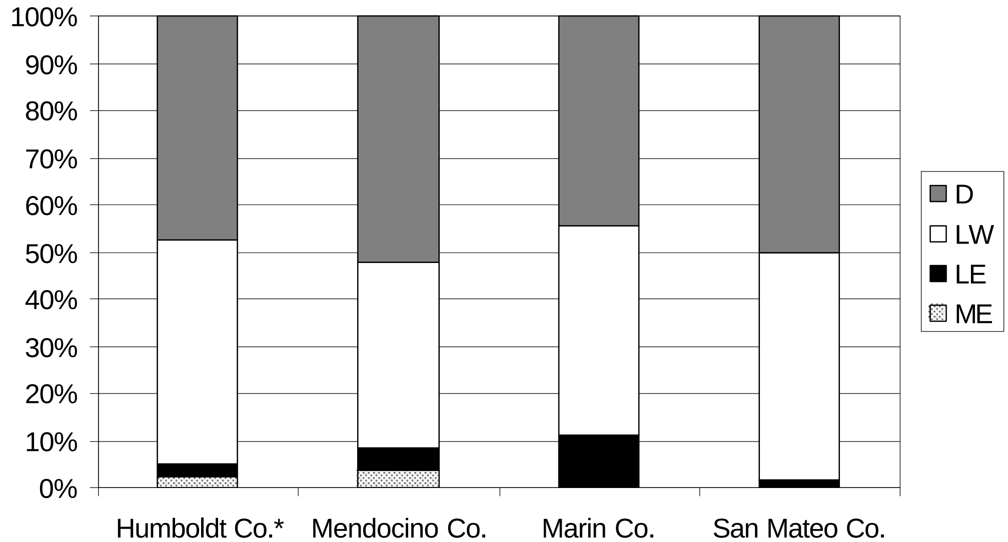
In this study, the grand mean FRI for single trees (point) was 12.4 years when null years are excluded in the calculation. Other research on coast redwood has reported generally higher mean FRI for single trees including 9.9 – 24.5 years (Brown and Baxter 2003), 20.5 – 29.0 years (Finney and Martin 1989), and 21.7 – 27.1 years (Jacobs et al. 1985) (Table 3). When null intervals are not removed from our calculation, the grand mean FRI for single trees (point) increases to 16.3 years (range 6.2-45.3; SEM, 1.4) which is similar to that reported earlier.

Comparison of fire frequency in coast redwood forests is confounded by several factors including differing methodologies (ring-count, crossdating, sprout aging), differences in the size of the sampled areas, and if MFI's are computed from intervals between fire scars or the actual differences in calendar dates between scars (Figure 6). Variations in environmental conditions between coast redwood forests could also influence past fire frequency (Veirs 1982, Stuart 1987, Finney and Martin 1989, Brown and Baxter 2003).

The season of past fires in coast redwood forests has been rarely reported. In this study, fires were recorded in the latewood and dormant periods and this agrees with four other published studies (Figure 5) (Brown and Swetnam 1994, Brown et al. 1999, Brown and Baxter 2003).

The growing season of coast redwood in Monterey County (95 km south of our fire history plots) approximates the period from April to October, but variations occur dependent upon individual site factors, the character of the seasons, and the condition of the tree (Haasis 1934).

Figure 5. Percentage of redwood fire scar intraring positions by site in Humboldt (Brown and Swetnam 1994), Mendocino (Brown and Baxter 2003), Marin (Brown et al. 1999), and San Mateo Counties (this work). D, dormant period; LW, latewood; LE, late earlywood; ME, middle earlywood. *Seasonality data in this paper was presented in 2 groups (latewood/dormant period and earlywood) and was divided here equally into the 4 groups for comparison.




It is probable that the number of fires recorded in the annual growth rings of coast redwood trees is a subset of those fires that burned in adjacent grasslands and oak savannahs. The Ohlone Indians burned primarily to enhance the growth and productivity of perennial grasses used for food and the majority of this burning was done in the fall (Chuck Striplen, personal communication, 2004). Fires also provided browse for high-value game species, restricted detrimental communities under high-value oak stands, and were used to enhance and create specific botanical products for baskets, cordage, clothing, tools, nets, and traps.

The early ranchers, loggers, and farmers continued burning but for different objectives. Ranchers burned in the fall to increase livestock forage and remove competing woody shrubs and trees from grasslands (Biswell 1989). Loggers used fire to consume large amount of slash that was left on site after harvesting and this occurred in the fall or early winter (Fritz 1931, Stuart 1987). Farmers used fire in the fall to consume unusable crop stubble, to prepare mineral soil seed beds, and to remove vegetation to increase the area that could be cultivated.

Most reported applications of fire-use in the coast redwood forest were targeted at grasslands or oak woodlands. These fires were intentionally ignited and certainly burned into the surrounding areas. Coast redwood forests have the highest canopy cover, height, and densities for any vegetation type in the Santa Cruz Mountains and such characteristics influence their local microclimate (Dawson 1998). Specific microclimate changes include increases in relative humidity, decreases in surface air temperatures, and reduction in ground level windspeeds. Surface and ground fuels would subsequently have higher moisture contents in coast redwood forests when compared to the surrounding grasslands and oak savannahs.

Some anthropogenic fires that were ignited in surrounding grasslands or oak savannahs would naturally extinguish themselves at the coast redwood ecotone because of the differing fire environments. This has been reported in the northern range of coast redwood where fires burning into remnant old-growth forests from pasturelands and slash fires were naturally extinguished because of a combination of lower temperatures, higher relative humidities, and high fuel moisture contents (Stuart 1987).

Experiences in prescribed burning in coast redwood forests further demonstrate the sensitivity of this forest type to changing weather conditions. A minimum relative humidity of 50 percent is needed to successfully burn redwood litter (Finney 1991). It is possible to burn under higher humidities into the early evening for approximately 30 minutes, but once relative humidity increased to 60 percent, burning is no longer possible (Mark Finney, personal communication, 2003). Redwood responds very quickly to relative humidity changes. With heavy fog in the morning, it is still possible to burn by two PM in the same afternoon.

Few agencies use prescribed burning in the management of coast redwood forests even though they once experienced fire at similar frequencies as Sierra Nevada mixed conifer forests (Caprio and Swetnam 1995, Stephens and Collins 2004). How our and other fire history data are used in management decisions is as much a societal as it is an ecological question (Brown and Baxter 2003). Should managers attempt to restore these forests to prehistorical conditions, or let them return to a fire regime that would likely been present in the absence of Native American influences? Continued development of old-growth and young-growth coast redwood forests toward prehistoric conditions may, therefore, be dependent of a fire regime where prescribed burning substitutes for lightning and now-absent aboriginal ignitions (Finney and Martin 1989). Any prescribed burning program designed to recreate pre-European man fire regimes should incorporate variable intervals and seasonality's.

## ACKNOWLEDGEMENTS

We especially thank Philippe Cohen and Priscilla Alvarez for assisting us with this project. We appreciate comments from Philippe Cohen and anonymous referees that improved this paper. Domenico Caramagno, Matt Smith, and Nikolai Barr-Cohol assisted with field sample collection. We thank Chuck Striplen for information on the Ohlone uses of fire and Mark Finney for information on coast redwood prescribed burning. This project was supported by USDA Agricultural Experiment Station funds from the University of California, Berkeley, and funds from Stanford University's Jasper Ridge Biological Preserve.

Table 3. Summary of fire history information from studies using annual growth rings conducted in coast redwood forests in California.

| Location | Data type | Fire interval (years) | Fire interval range (years) | Time period | Study size (ha) | Source |
|---|---|---|---|---|---|---|
| Northern Humboldt County | Composite | 8 | 2-22 | 1714-1881 | 0.25-3 | **1**)Brown & Swetnam 1994 |
| Southern Humboldt County | Composite | 11-44 | 8-87 | Pre1875 | 7 | **2**)Stuart 1987* |
| | Interval | 25 | -- | Pre1925 | 12 | **3**)Fritz 1931 |
| Western Mendocino County | Composite | 6-22 | 2-34 | 1700-1900 | 6-22 | **4**)Brown & Baxter 2003 |
| | Point | 10-25 | 2-43 | 1700-1900 | 6-22 | |
| Northern Sonoma County | Interval | 6-9 | 2-85 | 1650-1950 | 200 | **5**)Finney & Martin 1989 |
| | Point | 21-29 | 2-85 | 1650-1950 | 200 | |
| Southeastern Sonoma County | Point | 6-23 | 2-131 | Pre1850 | <5 | Finney & Martin 1992 |
| Western Marin County | Composite | 8-13 | 4-17 | 1840-1945 | -- | **6**)Brown et al. 1999 |
| | Point | 8-12 | 3-18 | Pre1850 | -- | |
| | Point | 8-22 | -- | 1450-1850 | 5-10 | Finney 1990 |
| Southern Marin County | Point | 22-27 | 2-98 | Pre1850 | 75 | Jacobs et al. 1985 |
| Southern San Mateo County | Interval | 9-16 | 2-58 | Pre1860 | 1-3 | **7**)This study |
| | Point | 12 | 2-58 | Pre1860 | 1-3 | |

*Composite data was derived from pith dates of post-fire resprouts surrounding sampled fire scarred stumps.

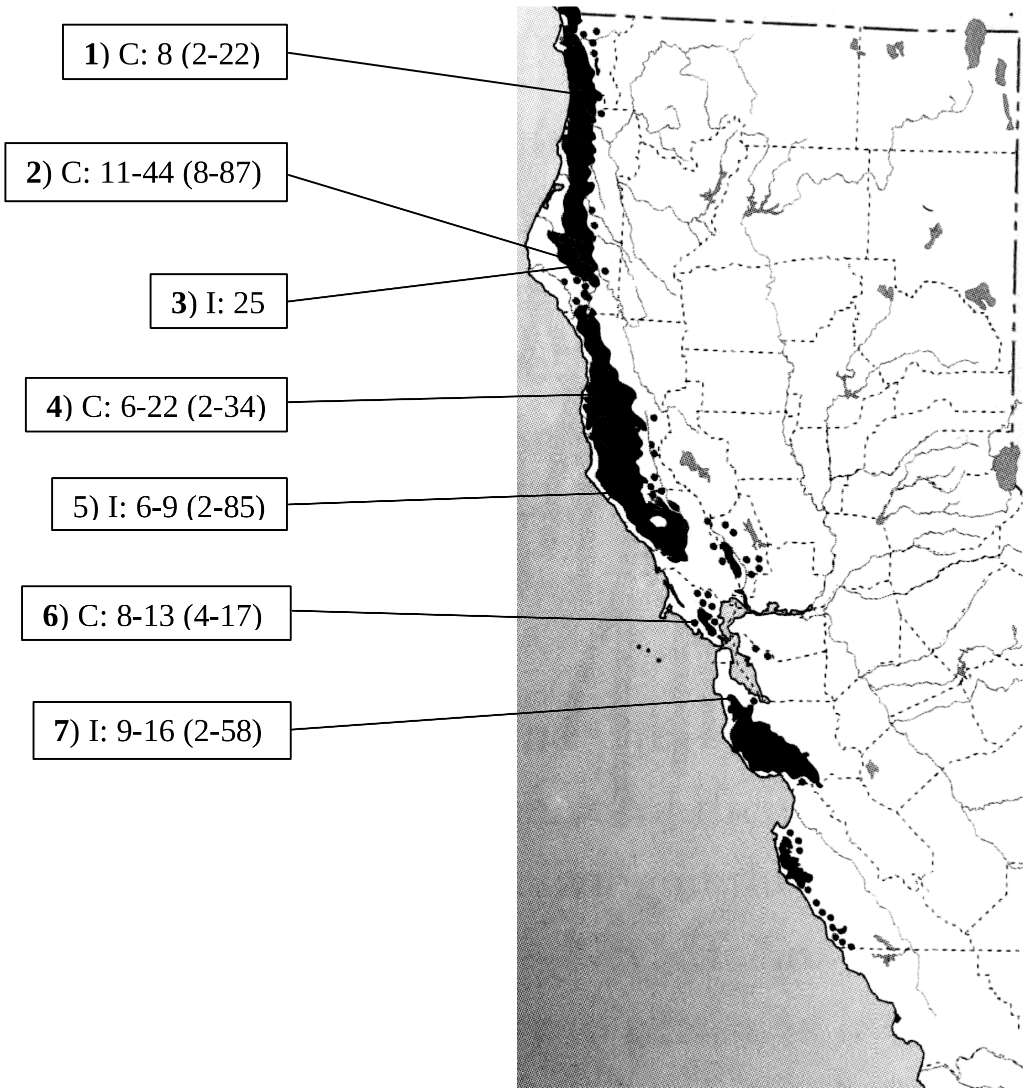



Figure 6. Summary of mean fire return intervals (range of intervals) from studies using annual growth rings conducted in coast redwood forests in California (See Table 3 for numbered references). C, composite data; I, interval data. Coast redwood distribution map from Griffin and Critchfield (1972).

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