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Author(s): Mark A. Finney and Robert E. Martin

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SHORT FIRE INTERVALS RECORDED BY REDWOODS AT ANNADEL STATE PARK, CALIFORNIA

MARK A. FINNEY

Research Division, Sequoia National Park,
Three Rivers, CA 93271

ROBERT E. MARTIN

Department of Forestry and Resource Management,
University of California, Berkeley, CA 94720

ABSTRACT

Fire intervals were derived from analysis of fire scars on samples taken from 14 redwood (*Sequoia sempervirens* D. Don (Endl.)) stumps throughout Annadel State Park, California. Samples were obtained from small redwood groves that are isolated within other forest types. Dating before the mid-1800's, mean fire intervals between 6.2 and 23.0 years were found on individual stumps, with single intervals as low as 2 years. Although the sources of these fires are uncertain, fire usage by Native Americans is a plausible explanation given the archeological evidence at Annadel and sparse lightning activity in areas like Annadel near the coast.

The historical presence of fire among the oak woodland (Sawyer et al. 1977) and mixed evergreen forests (Griffin 1977; Wainwright and Barbour 1984) near the coast in northern California has been little studied. Records predating fire exclusion are scarce because most tree species in these forests are poor long-term recorders of fire scars. Nevertheless, several studies in similar vegetation types throughout northern California suggest substantial fire activity prior to the mid-1800's (Talley and Griffin 1980; Rice 1985; McClaran and Bartolome 1989; Wills 1991). This paper reports fire history evidence obtained from fire scars recorded on coast redwood trees which grow in isolated clumps within oak and mixed evergreen forests.

STUDY AREA

Annadel State Park is approximately 2000 hectares in size, located 3 km east of the city of Santa Rosa in Sonoma County, California (Fig. 1). Elevations range from approximately 90 meters to 550 meters at the summit of Bennett Mountain, the tallest point at Annadel. Much of the park is elevated several hundred meters above valley bottoms which surround the Park on the North (Melita and Rincon Valley), East (Valley of the Moon), and West (Bennett Valley and Santa Rosa).

Dominant vegetation cover includes Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) which forms closed stands throughout the

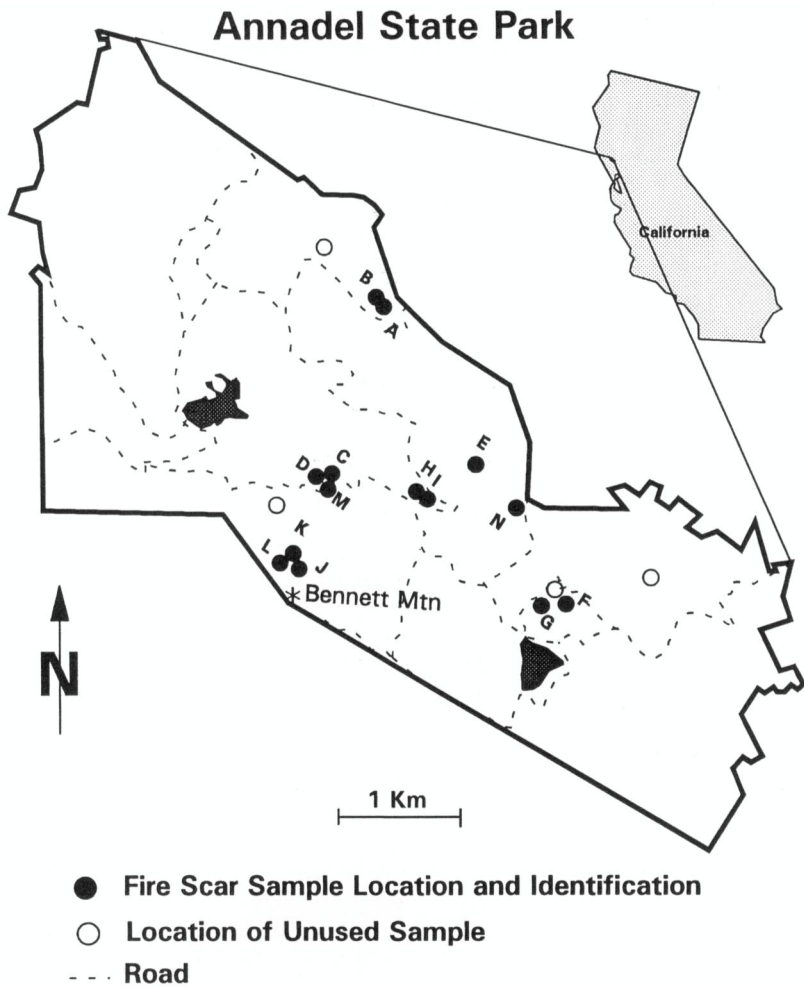


FIG. 1. Location of Annadel State Park and fire scar samples removed from redwood stumps.

area and is an obvious invader of the oak woodlands and oak savannahs (Barnhardt et al. 1987; Wainwright and Barbour 1984). Madrone (*Arbutus menziesii* Pursh), California laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.), and Douglas-fir comprise the mixed evergreen forests (Sawyer et al. 1977) which occupy much of the park. Oak woodlands contain various proportions of blue oak (*Quercus douglasii* Hook. & Arn.), black oak (*Q. kelloggii* Newb.), valley oak (*Q. lobata* Nee), or interior live oak (*Q. wislizenii* A. DC.). Coast redwood is found typically in small groves (<5 ha) on north-

erly aspects and as isolated clumps in drainages. Areas of chaparral, grassland, and various wetlands are interspersed throughout the forested areas of Annadel.

The coast redwood, in contrast to most co-occurring tree species, is renowned for its relative fire resistance, longevity, and resistance to heart-rot. Redwood is thus a potentially useful and important source of fire history information. To date, information on fire history obtained from redwood has been reported by Fritz (1931), Veirs (1981), Greenlee (1983), Jacobs et al. (1985), Stuart (1987), Swetnam (1987), Finney and Martin (1989), Brown (1989), and Finney (1990).

Evidence of fire specifically at Annadel has been restricted to written records (Amme 1987) which indicate only two lightning ignitions since 1939. No investigations at Annadel have quantified fire occurrence prior to these records. Land use by settlers began with cattle grazing in the 1830's, and by the 1870's logging and quarrying were initiated (Futini 1976).

METHODS

Following a reconnaissance of the redwood clumps in drainages and redwood stands growing along northerly aspects, samples were removed from any redwood stump showing fire history evidence (Fig. 1). Redwood was the only species from which fire scar evidence could be obtained, since Annadel State Park contains few other species that can or have survived to offer fire history information. Usable redwood evidence at Annadel was scarce because the long time since early logging has allowed natural deterioration (including insect damage and rot) of stumps and fire scar evidence. Stumps found in acceptable condition were sectioned with a chainsaw in order to locate the best recorded series of fire scars; up to three wedges or full slabs were removed to the laboratory from each stump.

At one stump in each grove, the largest individual stem among the youngest definite generation of redwood sprouts was selected for age determination. One increment core was extracted from that sprout as close to the base as possible (<30 cm). Redwood often sprouts when damage occurs to the above ground organs during fire or harvesting, with sprout growth sometimes exceeding two meters per year during the first few growing seasons (Olson et al. 1990). Post-harvest sprouts are usually distinguishable from older pre-harvest generations by 1) their size, 2) their relatively uniform sizes and arrangement around the stump, and 3) the usual absence of fire scarring at the juncture between sprout and the parent tree (stump). Scarring is often present at these locations on sprouts which survived previous fires. High fuel accumulations around redwood clumps and radiative heat exchange between sprouts contribute to inward-facing fire scars.

Fire scar samples were sanded to a smoothness of 400 grit. Fire scars were identified by the characteristic disruption and healing patterns of radial tree ring growth. Fires were assigned a tree ring based on the position of the fire-caused growth disruption relative to the pattern of earlywood and latewood production. A fire year was assigned to a given ring if the growth disruption appeared to precede termination of latewood formation during that growing season or if the callus healing tissue began with earlywood in the year (ring) following that ring. The latter assumes a late season fire which occurred after latewood production had ceased, rather than an early season fire before earlywood formed the following year.

Intervals between fire scars were obtained by counting rings using a binocular dissecting microscope. No attempts were made to cross-date for correcting ring dating problems common to redwood (see Swetnam 1987; Brown 1989). Annual rings were counted along radii with the widest increment; often this involved tracing individual rings from zones of narrow growth to those with wider increment. Scar dates were then assembled for each stump individually. Where multiple sample cross-sections existed from a given stump, fire scar dates were compiled from all sections as one chronology by matching fire intervals common between sections. Discrepancies between scar intervals on separate sections were resolved by recounting; where necessary the most complete count was used because missing rings are more common than false rings (Brown 1989). Mean fire intervals were calculated from all fire intervals found on individual stumps.

In the laboratory, increment cores were mounted in a groove cut in a wooden lath and sanded to a smoothness of 400 grit. Dates of sprout origination were obtained by counting growth rings on the increment cores and were used to estimate the date of harvest. Given the typically rapid height growth of sprouts, no correction was made for the time required for a redwood sprout to reach core height.

Redwood harvest dates were used as the upper bound on the time-period covering the fire scar chronologies. More precise estimates of fire dates were not possible because the sapwood, and recent heartwood on some samples, had rotted away.

RESULTS

A total of 18 redwood partial sections or whole slabs were removed from stumps in the Park (Fig. 1). Fire scar evidence on four samples was rendered unusable by rot. Increment cores were removed from trees belonging to 6 separate groves. Ring counts on increment cores from all groves suggested that ages of the dominant generation of redwood sprouts at the time of sampling were between 124 and 134 yr. This suggests that logging of the previous redwood trees occurred between 1856 and 1866.

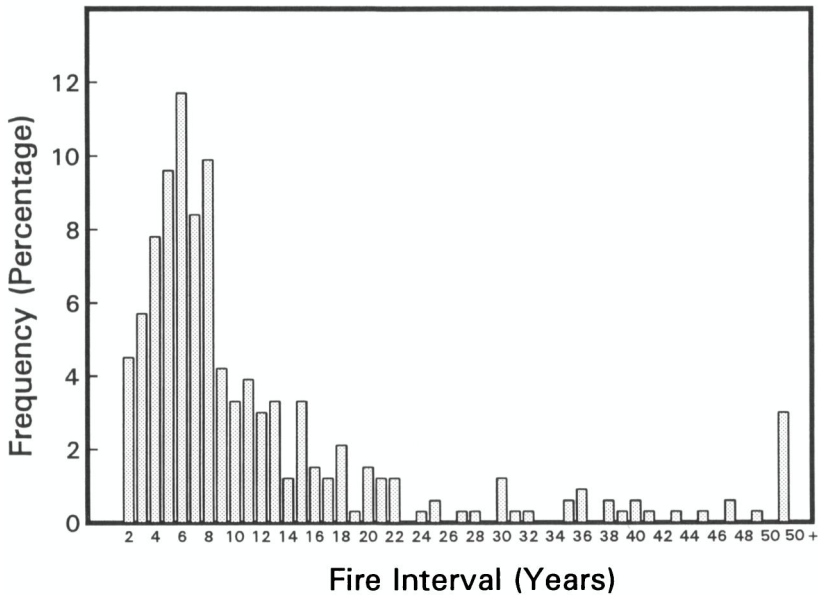


FIG. 2. Distribution of fire intervals from all samples combined. Fire intervals shorter than 10 years comprised 67.39% of all intervals.

Mean fire intervals among all individual stumps varied from 6.2 to 23.0 years (Table 1). All fire scars are believed to predate European settlement in the early 1800's. The most recent scar on each sample was typically older (by up to 106 yr) than the outermost ring (Table 1). Also, the most recent ring on each sample was actually several decades older than the harvest date because an unknown number of rings were contained in the decomposed sapwood. Fire intervals between 2 and 10 years comprised 67.39% of all intervals (Figs. 2 and 3), and often occurred in multiple sequences (Table 1, Fig. 4). Longer fire intervals (up to 131 yr) are evident on some samples. Summing the ring counts by sample suggests the earliest scar records date from about the 14th century (Table 1).

DISCUSSION

The short fire intervals found on many redwood samples at Anadel suggest a fire regime in sharp contrast to the modern era. Fires underburned redwood groves and probably the surrounding forests at intervals shorter than a decade throughout at least 4 centuries before settlement. Since the early 1900's fire suppression has limited the spread of both lightning and human caused fires.

The short fire intervals recorded in the isolated redwood groves

TABLE 1. FIRE INTERVAL DATA FROM REDWOOD STUMP SAMPLES. Intervals in parentheses are the number of rings between outermost ring and the most recent scar and were not included in calculating mean fire intervals. Other intervals represent the rings between fire scars.

Samples													
A	B	C	D	E	F	G	H	I	J	K	L	M	N
6.2	23.0	10.6	20.9	17.4	14.1	9.9	13.8	10.2	6.2	10.4	7.5	10.8	6.5
Means													
Intervals (most recent at the top)													
(13)	(75)	(47)	(35)	(106)	(30)	(53)	(35)	(67)	6	(36)	(71)	7	4
9	7	17	131	3	7	16	12	8	6	13	11	18	6
7	38	18	22	5	3	24	20	38	7	13	7	36	9
6	12	32	18	13	6	5	15	7	5	30	3	21	8
3	28	21	12	5	7	8	78	7	8	9	6	16	2
4	6	2	45	8	53	7	6	8	4	11	8	25	5
3	101	5	8	14	7	5	9	17	4	6	4	12	3
3	4	10	6	21	10	11	7	8	6	6	4	5	13
5	39	14	47	13	6	6	3	6	7	11	6	12	6
11	12	9	15	5	13	7	11	4	6	2	4	14	14
2	5	7	2	8	41	10	10	5	5	8	7	9	10
3	9	3	27	36	57	8	2	4	7	7	7	10	2
6	15	3	30	30	18	15	2	4	9	8	7	3	6
7		5	11	4	6	8	2	5		15	15	8	3
4		3	11	22	4	16	5			13	6	5	
16		5	9	40	9	19	8			8	9	7	
6		5	6	40	4	8	4			10	10	4	
6		2	6	10	4	8	8			2	3	6	
3		10	5	15	7	5	5			18	8	4	
3		4	8	43	6	3	3			15	5	8	
7		4	22	13	17	7	7			3	11	12	
5		4	13		5	4	4				10	2	
6		7	5		20	8	8				8	15	
9		8				20	20				5	12	

TABLE 1. CONTINUED

		Samples													
A	B	C	D	E	F	G	H	I	J	K	L	M	N		
6.2	23.0	10.6	20.9	17.4	14.1	9.9	13.8	10.2	6.2	10.4	7.5	10.8	6.5		
Means															
Intervals (most recent at the top)															
4		18									7		6		
15		8									2		16		
5		18									5		8		
4		4									7		6		
13		20									20		12		
6		11									2		5		
5		9									17		9		
6		6									6		11		
5		2									12		8		
8		49									6		5		
8		8									6		11		
4		11									6		22		
		5											8		
		6											6		
		15											31		
		25											21		
Totals															
230	351	460	494	454	340	281	215	179	80	244	319	484	91		



FIG. 3. A sample redwood cross-section from Annadel State Park that contains fire scars separated by 2 years.

at Annadel probably reflect the fire regimes of the surrounding vegetation types and fuels rather than the redwood forest type itself. Unlike the expansive forests of more coastal redwood study sites, the inland redwood groves at Annadel are presently isolated within more open forests (e.g., oak woodlands) which support considerable understory vegetation. Regrowth of grasses and herbaceous vegetation following fires in these forests can form continuous surface fuel cover sooner than forest litter and woody debris deposited beneath closed forest canopies.

The mean fire intervals from individual stumps at Annadel are somewhat shorter than mean fire intervals from wetter and more coastal redwood forests (Table 2), and the 10 to 15 year intervals from mixed evergreen forests of northern California (Rice 1985; Wills 1991). Direct comparisons between studies, however, are made difficult by the different methods used for obtaining fire dates and for computing mean fire intervals. The mean fire intervals computed for individual samples at Annadel are likely to be conservative because all fires may not scar a tree and scars may be destroyed by later fires, rot, and insects. Mean fire intervals computed from fire dates on more than one sample are generally shorter.

The impact of consistently short fire intervals as recorded at Annadel would have markedly influenced the vegetation. The distribution and composition of most plant communities have changed



FIG. 4. A sample redwood cross-section from Annadel State Park exhibiting a well preserved sequence of fire scars.

TABLE 2. SUMMARY OF MEAN FIRE INTERVALS FROM FIRE HISTORY STUDIES IN COAST REDWOOD FORESTS. Size of the sampling area is presented where mean fire intervals were computed using fire dates from more than one sample.

Location	Mean fire intervals (years)	Source
Humboldt Co. and Del Norte Co.	~25	Fritz (1931)
Marin Co.	22–27	Jacobs et al. (1985)
Humboldt Co.	11–44/190–430 ha	Stuart (1987)
Sonoma Co.	9–11/200 ha	Finney and Martin (1989)
Humboldt Co.	8–12/unknown	Brown (1989)
Marin Co.	5–15/5–10 ha	Finney (1990)

since settlement through conversion of chaparral to Douglas-fir forests, invasion of oak woodlands by Douglas-fir, and increasing canopy density of other forest types (Barnhardt et al. 1987). The boundaries of existing redwood groves, however, have apparently remained relatively static since settlement. No redwood evidence (stumps, sprouts, etc.) was found between extant groves to suggest a recently constricted distribution.

Without having direct evidence, the source(s) of the pre-settlement fires cannot be determined with certainty. Lightning, however, is unlikely to have been the primary cause of consistently short fire intervals given the modern record. In fact only two lightning ignitions at Annadel are recorded since 1939 (Amme 1987). Lightning ignitions surrounding the park were probably of similar frequency given the relatively low lightning densities of coastal California (Keeley 1982). Some fires, however, undoubtedly originated outside the present park boundaries.

Ignitions by Native Americans (intentional and accidental) could, however, account for the consistently short fire intervals recorded on redwoods. Aboriginal uses of fire throughout grassland and forested areas in northern California have been documented, often in association with acquiring food and other vegetal materials (Lewis 1973; Sugihara and Reed 1986; Reed and Sugihara 1987; Veirs 1987). Archeological evidence including bedrock milling stations, basalt metates, and obsidian quarries, suggests that Annadel had been used intensively for procuring food and stone implements (Parkman and McGuire 1981; Porter and Wilbur 1987). Prehistoric camp sites within the park suggest temporary or seasonal occupancy, and the largest of several nearby permanent village sites is within a few hundred meters of the park boundary (J. Charles Whatford personal communication).

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