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Fire History of White Fir Forests in the Coastal Mountains of Northwestern California

Abstract

Fire intervals are presented for white fir forests in the coastal mountains of northwestern California. Fire dates were derived from fire scars and tree establishment dates from 28 logged sampling sites spread across an area approximately 125 km by 30 km. Pre-suppression median fire intervals ranged from 12 to 161 years. The median fire interval for the pre-suppression period (27 years) was significantly shorter than for the suppression period (74 years). There were no significant differences in median fire intervals among vegetation series. There were also no significant regressions of median fire interval with distance from the ocean, latitude, or elevation. Most sampling sites were multi-aged and had experienced multiple surface fires. Some sites had experienced stand-replacing fires. Fire suppression has increased stand density, increased the density of shade tolerant tree species, and decreased the density of shade intolerant tree species.

Introduction

Fire history studies of California white fir (*Abies concolor* (Gordon & Glend.) Lindley var. *lowiana* (Gordon) Andr. Murray) indicate that low elevation sites have shorter mean fire intervals than high elevation sites (McNeil and Zobel 1980, Agee 1991). Low elevation sites have been found to have mean fire intervals between 9 and 25 years (Kilgore and Taylor 1979, McNeil and Zobel 1980, Bork 1985) and on high elevation sites mean fire intervals have been determined to be 40 to 64 years (McNeil and Zobel 1980, Agee 1991, Taylor and Halpern 1991). These differences have been attributed to the cooler and moister environments that are often present at higher elevations (Agee 1993). Previous studies of white fir fire history have been conducted in inland locations. Little is known of white fir fire history in the coastal mountains of northwestern California.

Pre-European settlement fire ignitions were thought to be a result of both Native American fires and lightning (Agee 1993). Native Americans burned regularly in the vicinity of white fir forests on the Six Rivers National Forest to maintain plants used in basketry and for food and clothing (Heffner 1984, Blackburn and Anderson 1993).

The objectives of this paper are to: 1) report fire intervals for white fir forests in the coastal mountains of northwestern California and to compare them with other fire history studies of Cali-

fornia white fir, 2) compare fire intervals among the different vegetation series containing white fir in the study area, 3) investigate whether elevation, latitude, or distance from the Pacific Ocean are associated with median fire intervals in these stands, and 4) infer the role fire and fire suppression have had on species composition and stand structure.

Study Area

This study was conducted within the Mad River and Orleans Ranger Districts on the Six Rivers National Forest. Study sites were located on a series of mountain ridges that separate the Six Rivers National Forest from the Klamath and Shasta-Trinity National Forests. In particular, sites were located on South Fork Mountain on the Mad River Ranger District and on ridges above Bluff Creek on the Orleans Ranger District (Figure 1). Sampling sites were found on all aspects and at elevations from 1,183 m to 1,646 m. The most southerly sampling sites were 127 km from the most northerly ones, and the most easterly sites were 31 km from the most westerly ones. The white fir forests on the Six Rivers National Forest are among the most westerly, occurring from 26 km to 81 km from the Pacific Ocean.

Annual precipitation varies from 175 cm on South Fork Mountain to 230 cm on the ridges above Bluff Creek (Miles and Roath 1993). Ninety-four

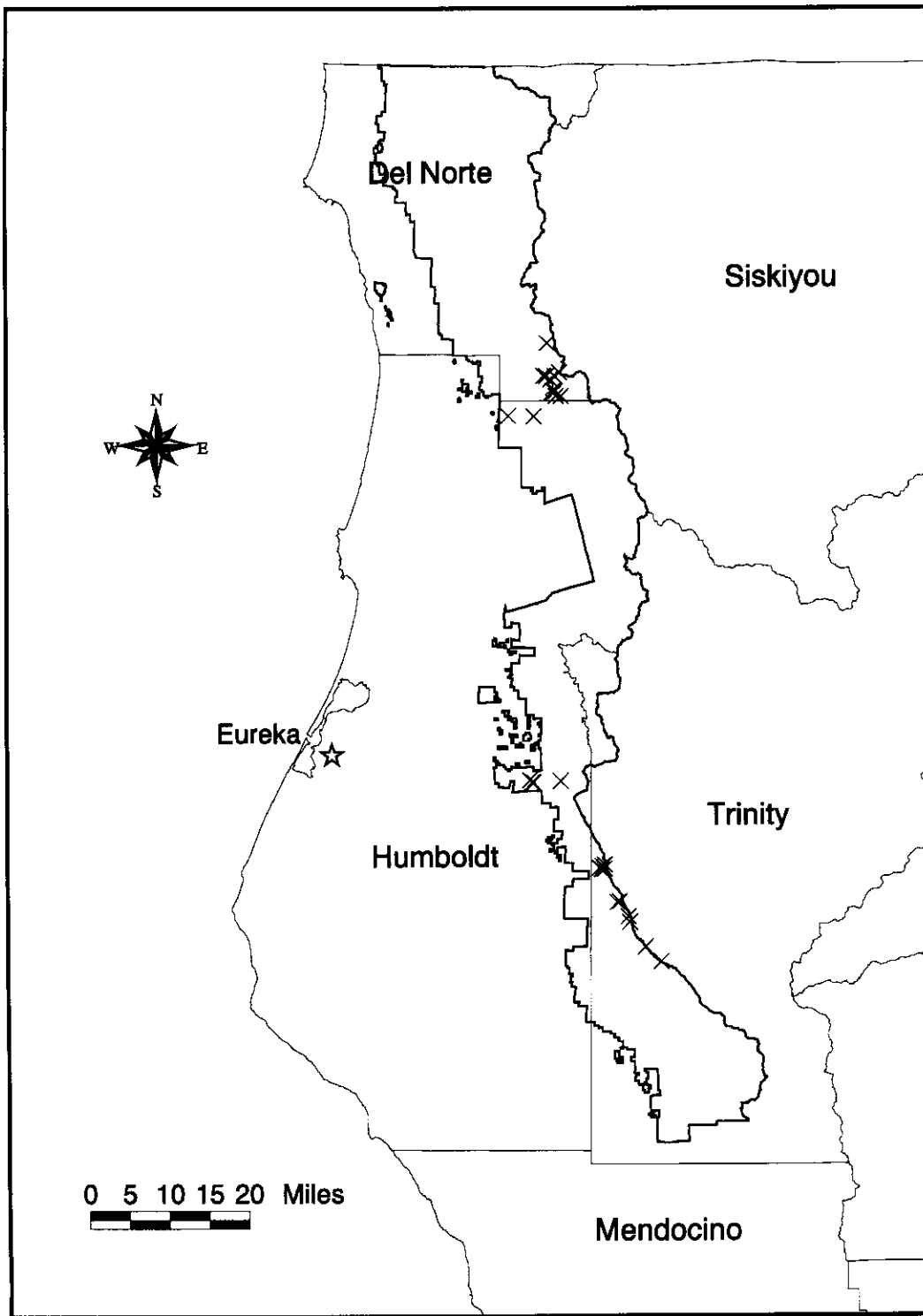


Figure 1. Location of sampling sites on the Six Rivers National Forest in northwestern California. Bolded lines are the national forest boundaries.

percent of the precipitation occurs during the months from October through May (Elford and McDonough 1964). Temperature and relative humidity are strongly moderated by the proximity of the Pacific Ocean. For a given elevation, winter temperatures are typically warmer and summer temperatures are cooler than more inland forests. The average July high temperature at Weitchpec, the closest weather station with similar weather to the study sites, is 28.6°C. The sampling sites, being at higher elevations, would be 5° to 8° cooler (Elford and McDonough 1964). In mid-summer, relative humidity averages 40 to 50% (Elford and McDonough 1964). East winds can dramatically reduce relative humidity and increase temperatures. During a 3-year period in Eureka, winds blew from the east 5% of the time, from the northeast 6% of the time, and from the southeast 17% of the time (Elford and McDonough 1964). Thunderstorms accompanied by lightning occasionally occur, but less often than in the Klamath Mountains, Cascades, or the Sierra Nevada (Automated lightning detection system April 1985–November 1997).

Study sites were located in forests with white fir either occurring as the dominant or co-dominant species. Other associated conifers included Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), incense-cedar (*Calocedrus decurrens* (Torrey) Florin), Port Orford-cedar (*Chamaecyparis lawsoniana* A. Murray), noble fir (*Abies procera* Rehder), and sugar pine (*Pinus lambertiana* Douglas). We classified each sampling site as belonging to one of three possible vegetation series: White fir, Douglas-fir, and Incense-cedar (Sawyer and Keeler-Wolf 1995).

Fire suppression records date to 1910 on the Six Rivers National Forest. Aggressive fire suppression and prevention of Native American and miner ignited fires in remote areas on the Six Rivers National Forest, however, did not begin until the end of World War II. Other studies from the Klamath Region found that fire frequency decreased in the 1940's (Agee 1991, Wills and Stuart 1994, Taylor and Skinner 1998), presumably because of more effective suppression efforts.

Methods

Twenty-eight sampling sites were located in logged areas that were dominated or co-dominated by white fir. Sampling sites ranged in size from 1.2

to 10.9 ha, with a mean size of 4.2 ha (s.d.=2.4 ha). The sampling sites were chosen to be coincident with logged areas to take advantage of readily available stumps. The sites, therefore, were not located without bias and may not reflect the variation found throughout the range of white fir in the broadly defined study area. We chose this sampling scheme because it was easier to find fire scars on stumps than on trees. Most trees in our area, as well as in other similar vegetation types in the Klamath Mountain region (Taylor 1993, Wills and Stuart 1994), have completely healed over fire wounds due to long fire-free intervals. Trees that did have open fire wounds were almost always rotten. Stumps from recently logged sites, in contrast, yielded good, sound wood.

Stem cross-sections were removed from all sound stumps having visible fire scars and were cut as close to the ground as possible, usually within 30 cm. Cross-sections were prepared with a power sander and sanded with successively finer grits of sandpaper whenever necessary to render an easily readable surface. Once prepared, the cross-sections were aged using a hand lens, and in some cases, a binocular microscope. Annual ring counts were made on one or more radii, depending on growth and ease of interpretability. Fire scar dates were recorded as well as tree age at the time of logging. Fire scars were recognized using criteria described by McBride (1983). Some trees had no fire scars but were aged as they presumably represented a cohort having been established following fire. Three years were added to the ages of trees at the time of logging to derive tree establishment dates after a reconnaissance sample determined the mean age of stump-high seedlings. Cross dating of tree rings (Stokes and Smiley 1968) was not possible with most specimens, presumably because competition influenced radial growth more than climate. Other studies have also found cross dating to be difficult in northwestern California (Brown and Swetnam 1994, Wills and Stuart 1994, Taylor and Skinner 1998).

A master fire chronology for each sampling site was prepared based on fire scar dates and years of establishment of even-aged cohorts. Fire scar dates that were uncertain were either discarded or adjusted using the techniques described by Arno and Sneek (1977). Only confirmed fire dates were used to calculate fire interval statistics. The Kruskal-Wallis H-test was selected to be used to detect significant differences in median fire

intervals between vegetation series and historic periods after the data were proven to be non-normal. Simple linear regression was used to assess whether median fire intervals had a statistically significant linear relationship with elevation, latitude, or distance from the Pacific Ocean.

Succession inferences for white fir forests on the Six Rivers National Forest were derived using data from Talbert (1996). Talbert (1996) demonstrated stand density and species changes using data collected in 1961-1963 on U.S. Forest Service Continuous Forest Inventory plots and then remeasured in 1993-1995. He used stand density index as a standardized density measure. Stand density index is based on the number of trees per 0.4 ha for trees 25 cm in diameter at breast height and is independent of age and site quality (Reineke 1933, Stage 1968). We reanalyzed Talbert's data after selecting for forests containing white fir.

Results and Discussion

A total of 126 fire-scarred stumps was found in the sampling areas. The number of fire-scarred stumps per sampling site varied from 0 to 11 with a mean of 4.5. These stumps produced an aggregate of 238 aged fire scars and an average of 8.5 aged fire scars per sampling site. Tree establishment dates were used as surrogates for fire dates on sampling sites without fire-scarred stumps and on sites with evident cohorts of white fir. A total of 112 trees was used to represent cohorts across all sampling sites.

Median fire intervals for all sampled sites ranged from 12 to 161 years. Fire intervals were highly variable within sampling sites with coefficients of variation ranging from 21 to 114%. Pre-suppression median fire intervals (27 years) were significantly shorter than the suppression period (74 years) ($P < 0.001$). Mean fire intervals, however, were longer for both the pre-suppression period (35 years) and the suppression period (83 years). The median and mean number of years since the last fire was 74 years and 78 years, respectively (Table 1). There were no significant differences in median fire intervals between vegetation series ($P = 0.284$) (Table 2). There were also no significant regressions of median fire interval as functions of distance from the Pacific Ocean ($r^2 = 0.001$, $P = 0.86$), latitude ($r^2 = 0.044$, $P = 0.29$), or elevation ($r^2 = 0.052$, $P = 0.25$).

TABLE 1. Fire intervals for the pre-suppression period, the suppression period, and since the last fire. Data are median fire intervals from the sampling sites. n = the number of sampling sites

	Pre-suppression period (1614-1944) ($n = 26$)	Suppression period (1945-1995) ($n = 28$)	Years since last fire (date of last fire: 1995) ($n = 28$)
Median	27	74	74
Mean	35	83	78
Standard deviation	30	34	39
Range	12-161	31-163	18-163

TABLE 2. Fire intervals (years) of vegetation series containing white fir. Data are median fire intervals from the sampling sites. n = the number of sampling sites within a vegetation series.

	White fir ($n=16$)	Douglas-fir ($n=9$)	Incense-cedar ($n=3$)
Median	40	26	16
Mean	49	31	45
Standard deviation	44	18	51
Range	12-82	16-161	15.5-104

The median and mean pre-suppression fire intervals (27 and 35 years, respectively) on our sampling sites were between fire intervals reported for inland low elevation and high elevation forests (9-25 years and 40-64 years, respectively) (McNeil and Zobel 1980, Agee 1991 Taylor and Halpern (1991). Our within and between site range in fire intervals are similar to those found in Douglas-fir dominated forests in the Klamath Mountains (Wills and Stuart 1994, Taylor and Skinner 1998), in Douglas-fir forests in the Cascades (Morrison and Swanson 1990), and in red fir forests in the southern Cascades (Taylor 1993). The somewhat longer fire intervals determined for our relatively low elevation sites are undoubtedly due to lower fire danger caused, in part, by the moist, cool climate of the Pacific Ocean. The summertime dome of cool, moist marine air usually extends to the first set of high ridges east of the ocean. East of these ridges, there are typically sharp summertime gradients of increasing high temperature and decreasing low relative humidity (Elford and McDonough 1964). Thunderstorms

and lightning are less frequent close to the coast than on inland sites (Elford and McDonough 1964, Automated lightning detection system April 1985–November 1997). Many fires, therefore, were probably ignited by Native Americans burning to culture basketry materials, food, and clothing (Heffner 1984, Blackburn and Anderson 1993).

Since the early 1960s, and presumably since fire suppression began, forests with white fir have become denser. Stand density indexes increased for all tree species combined, increased for tolerant tree species, and decreased for intolerant tree species (Table 3). Tolerant species were white fir, Douglas-fir, incense-cedar, and chinquapin (*Chrysolepis chrysophylla* (Hook.) Hjelmq). Intolerant species included California black oak (*Quercus kelloggii* Newb.), madrone (*Arbutus menziesii* Pursh), ponderosa pine (*Pinus ponderosa* Laws.), and sugar pine.

Changes in the proportional stand density index contributed by species over the sampling period revealed that white fir and chinquapin increased; incense-cedar contributed the same proportional amount to the overall stand density index; and Douglas-fir, ponderosa pine, sugar pine, Pacific madrone, and California black oak decreased (Table 3).

Most of the sampling sites were multi-aged and had experienced multiple surface fires. In most cases, there were more fire scar dates on a sampling site than there were cohorts of established trees. Most fires, presumably, were not severe enough to create sufficient growing space to reinitiate a cohort. Occasionally though, a surface fire was severe enough to allow tree re-establishment in gaps. On a few sampling sites there were dominant even-aged cohorts that presumably had become established following a stand replacing fire or wind event. These patterns are similar to those found in Douglas-fir/hardwood forests on the Klamath National Forest (Wills and Stuart 1994, Taylor and Skinner 1998), in mixed white fir forests in southern Oregon (Agee 1991), and in Douglas-fir forests from the central western Cascades of Oregon (Morrison and Swanson 1990). Fire has been the predominant stand replacing disturbance in these forests over the past several centuries and was presumably similarly predominant over the past few millennia.

TABLE 3. Thirty-two years of change in stand density indexes of major tree species occurring in white fir forests. Data are from Talbert (1996).

	1961-1963		1993-1995	
	Stand density index	Proportional stand density index	Stand density index	Proportional stand density index
all species	371.4	1.000	424.7	1.000
white fir	162.8	0.438	207.9	0.490
Douglas-fir	131.9	0.355	140.5	0.331
incense-cedar	14.9	0.040	16.8	0.040
chinquapin	2.3	0.006	2.9	0.007
California black oak	11.5	0.031	11.4	0.027
Pacific madrone	7.6	0.020	5.5	0.013
ponderosa pine	8.4	0.023	7.0	0.017
sugar pine	13.3	0.036	9.2	0.022
other species	18.7	0.050	23.5	0.055

Continued fire suppression in white fir forests on the Six Rivers National Forest should lead to further increases in total stand density, increases in stand density of tolerant species, and decreases in stand density of intolerant species. In particular, white fir should continue to increase in density and extend into previously unoccupied stands. The relative importance of Douglas-fir should continue to decrease relative to white fir in stands where they are co-dominant. Ponderosa pine, sugar pine, and California black oak should continue to decrease in density and will eventually be extirpated from more stands. These structural changes will increase live fuel loading and vertical fuel continuity.

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