Peter M. Brown[1] and **Margot W. Kaye**[2], Rocky Mountain Tree-Ring Research, Inc., 2901 Moore Lane, Ft. Collins, Colorado 80526

Dan Buckley, Point Reyes National Seashore, Point Reyes, California 94956

Fire History in Douglas-fir and Coast Redwood Forests at Point Reyes National Seashore, California

Abstract

Historical variability in fire regimes and forest age structures is necessary reference information for management of vegetation and landscape patterns in naturally managed ecosystems. In this study, we reconstructed fire history and forest age structure at Point Reyes National Seashore on the central California coast to document changes in forest conditions over the past ca. two centuries. Surface fire history was reconstructed from dendrochronologically-crossdated fire-scarred trees in two stands of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) and one stand of coast redwood (*Sequoia sempervirens*). Age structure in an approximately 2000 ha area of Douglas-fir forest was examined for tree recruitment patterns. Reconstructed mean surface fire intervals and Weibull median probability intervals ranged from ~ 7 to ~13 years. Fires generally occurred late in the growing season or after growth had ceased for a year. Spatial patterns of historic fires and those reconstructed from the fire-scar record document often widespread fires in the central Olema Valley. Likely many, if not most, of the fires reconstructed from Point Reyes were ignited by humans given the long history of intensive use of this area, first by the Coast Miwok and later by European ranchers. Age structures of stands suggest that much of the Douglas-fir overstory is multiaged with little evidence of stand-replacing fire or other disturbance events. Ages of trees in Douglas-fir stands document increasing landscape coverage of Douglas-fir forest at Point Reyes and hardwood recruitment under older Douglas-fir canopies, and suggest that loss of surface fires is having cascading effects on landscape vegetation patterns, community relationships, and probably related ecosystem processes.

Introduction

Changes in fire regimes over the past century are well documented for many areas, especially in ecosystems that experienced frequent, episodic surface fires prior to widespread non-Native American settlement beginning in the western US in the 1800s (Agee 1993, Swetnam 1993, Covington and Moore 1994, Brown and Swetnam 1994, Swetnam and Baisan 1996, Barrett et al. 1997). Livestock grazing, geographical fragmentation caused by roads and fences, and fire suppression have resulted in the cessation of surface fires in these ecosystems. Cessation of surface fires has, in turn, led to often profound changes in forest and landscape vegetation patterns. Frequent surface fires killed tree seedlings and saplings before they could become established in a forest overstory or on grassland or shrubland margins. Increases in tree density or landscape coverage after fire exclusion have led to concurrent losses of understory biomass and species diversity and shifts in biogeochemical cycles and hydrological regimes (e.g., Mutch et al. 1993, Covington and Moore 1994). Shifts in forest structure and fuel loads also have led to feedbacks in fire regimes, and stand-destroying crown fires are today more prevalent in forests that experienced primarily surface fires (Covington and Moore 1994).

Here we describe historical patterns of fires and tree recruitment in stands of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) and coast redwood (*Sequoia sempervirens*) at Point Reyes National Seashore on the central California coast. Changes in fire regimes and forest patterns over the past ca. 2 centuries were reconstructed from fire scars recorded in dendrochronologically-crossdated tree-ring series and forest stand ages. We concentrated our study in Douglas-fir and coast redwood forests within the Seashore boundaries in an attempt to obtain the longest possible records of both fire scars and age structures. Bishop pine (*Pinus muricata*) forests also are extensive at Point Reyes, but Bishop pine trees are generally too young (< 100 to 120 years old) for reconstruction of long-term fire history (Sugnet 1984, and other data from this study). Results from this study provide information on historical variability in fire frequency, timing, spatial patterning, and seasonality at Point Reyes that is necessary for

[1]Corresponding Author: e-mail. pmb@rmtrr.org

[2]Present Address: Graduate Degree Program in Ecology, Colorado State University, Fort Collins, Colorado 80526

management of vegetation and landscape patterns in this naturally-managed area (Morgan et al. 1994, Kaufmann et al. 1994).

Methods

Study Area

The Point Reyes Peninsula is separated from the California mainland by the San Andreas rift zone that forms the Olema Valley (Figure 1). Point Reyes National Seashore covers most of the Peninsula west from the Olema Valley. Inverness Ridge runs northwest to southeast down the length of the Peninsula (Figure 1) and reaches a maximum height of 428 m at Mt. Wittenberg. Inverness Ridge drops steeply to the east in a series of drainages while descending more gradually to the west in rolling hills and valleys to the Pacific Ocean. The Peninsula is underlain by relatively young granites and shales in contrast to the sedimentary substrates of the Franciscan complex of the adjacent mainland (Galloway 1977).

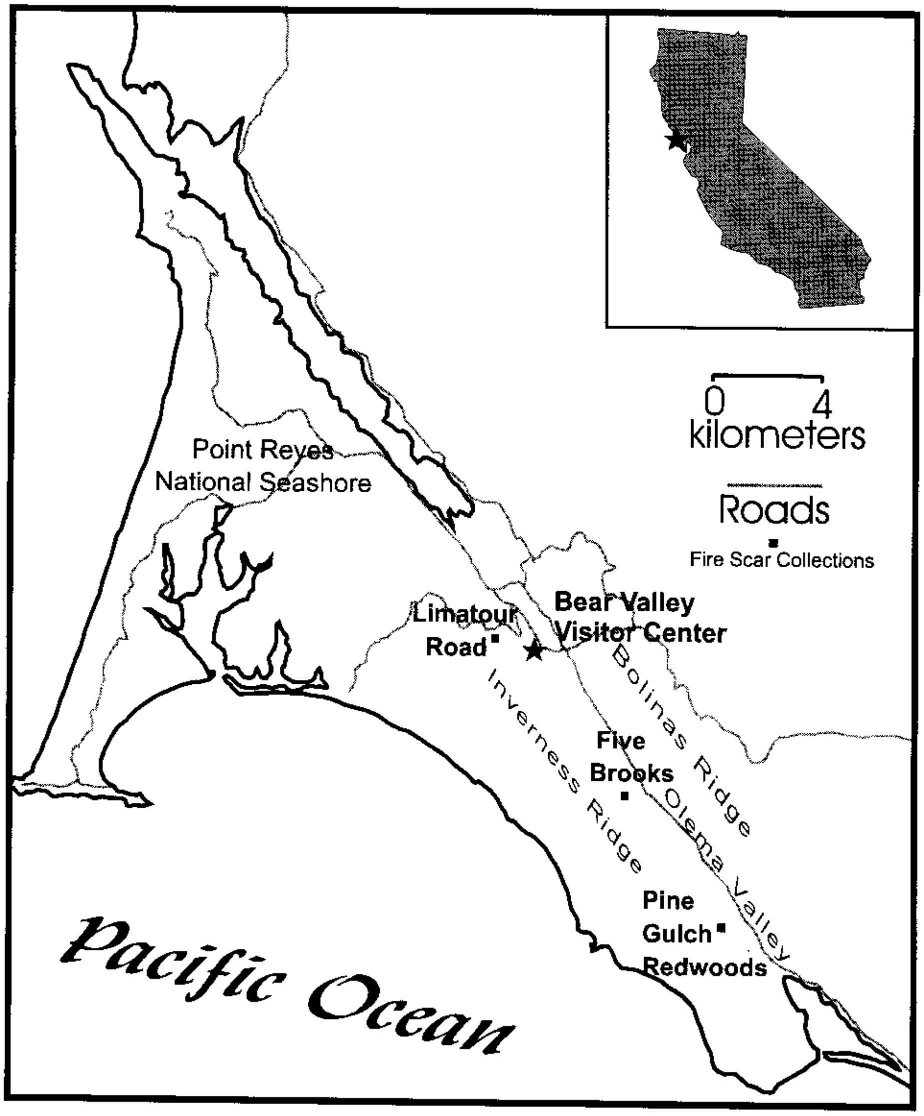

Figure 1. Locations of fire scar collections and place names mentioned in text.

A Mediterranean climate dominates, with wet winters and cool, dry summers. The coastal location and topography result in large variability in precipitation patterns. Average annual rainfall ranges from 460 mm on the western tip of the Peninsula to over 900 mm in the Olema Valley; over 80% falls from November through March. Coastal fogs during the summer contribute to increased soil moisture during otherwise dry summer months. Mean daily minimum and maximum temperatures range from 11° to 17°C in July and 6° to 13°C in January.

Inverness Ridge supports extensive coniferous forests while grasslands and coastal shrub or chaparral cover most of the rest of the Peninsula. Bishop pine forests dominate the north end of Inverness Ridge while predominately Douglas-fir forests are found in the south. Bishop pine is one of three species of relict closed-cone (serotinous) pine stands found in disjunct locations along the California coast (Duffield 1951, Critchfield 1966). Bishop pine generally occurs in pure, even-aged stands that established after crown fires (Wells 1962, Sugnet 1984). The Douglas-fir forest is usually considered to be a phase of the mixed evergreen forest of central California (Sawyer et al. 1977, Shuford and Timossi 1989) and often occurs with a sub-canopy layer of coast live oak (*Quercus agrifolia*) or California bay (*Umbellularia californica*) at Point Reyes. Most stands also have a dense shrub layer. A single stand of coast redwood is present on the southwest side of the Olema Valley in Pine Gulch (Galloway 1959), although more extensive stands are found on Bolinas Ridge (Figure 1) just to the east of the Seashore boundaries (Finney 1990). The coast redwood stands tend to have more open understories than the Douglas-fir forests, although they often have dense areas of shrubs, hardwoods, or occasionally abundant redwood regeneration from basal sprouts.

Human habitation of the Point Reyes area by the Coast Miwok began at least 5000 years ago (Treganza 1961, Duncan 1992). The earliest European contacts with the Coast Miwok were from Spanish and English voyages along the coast in the 16th century, the most famous of which was Sir Francis Drake in the *Golden Hinde* in 1579. Intensive Spanish influence in this area began in 1817 with establishment of a Franciscan mission at San Rafael, about 20 km southeast of the Seashore. After the Mexican revolution from Spain in 1821, the Point Reyes area was opened to land grant claims, the first of which was granted in 1836 in the Olema Valley (Toogood 1980). A long history of cattle and dairy ranching on the Peninsula began at that time (Livingston 1994, 1995). Cattle grazing is still present at Point Reyes, although grazing has not occurred within the forested areas since the 1960s and 1970s when the present Seashore boundaries were established.

Reconstruction of Fire History

Fire-scarred trees were opportunistically collected from three areas to reconstruct long-term patterns of surface fire events. Two areas, Limatour Ridge (LIM) and Five Brooks (5BR), are in the Douglas-fir forest and the third is in the coast redwood stand on the west side of Olema Valley (Pine Gulch Redwoods; PGR). In general, we searched for trees with sequences of fire scars that resulted from repeated fire events. These scar sequences are distinct from other injuries that may kill cambial tissues. We looked for fire-created "catfaces" from which we could remove partial circumference cross sections using chainsaws (Brown and Swetnam 1994). Catfaces are areas of open wood not covered with bark where cambial death occurred during fires or other injury events. However, owing to rapid growth exhibited by most trees at Point Reyes, living tissues on the margins of catfaces tended to grow over quickly and we found very few open catfaces on either living or remnant (logs or standing dead) trees. In an effort to obtain the most complete fire records for the Point Reyes area, we sampled extensively for hidden catfaces. This was accomplished on remnant trees by making "blind" cuts around a tree's base. Often we removed up to four partial circumference cross sections from different locations around a bole (Swetnam 1993, Brown and Swetnam 1994). All cross sections removed in this manner were from dead trees to minimize impacts on living trees in the National Seashore.

Tree-ring material was prepared and crossdated using standard dendrochronological methods (e.g., Swetnam et al. 1985). We developed a ring-width chronology from Point Reyes that aided in crossdating of remnant fire-scarred material. We assigned a position within the annual ring for fire scars or other injuries to assess possible seasonality of past fire events (Brown and Swetnam 1994). Dormant season scars (occurring between two rings) were assigned to the previous year (i.e., fall fires). Fire records from this area over the past century document that fires generally occurred from late August to November after radial growth had ceased (R. Moritz, Bolinas, California; unpublished data).

Composite fire chronologies were compiled for each cluster of fire-scarred trees using program FHX2 (Grissino-Mayer 1995). Fire frequency for each cluster was determined using three measures. Mean fire interval (MFI) is the average number of years between fire dates in a composite fire chronology and has been used widely to describe fire frequency (e.g., Romme 1980, Brown and Swetnam 1994, Grissino-Mayer 1995, Swetnam and Baisan 1996). Variability in fire intervals is described by the first standard deviation and range of intervals. Weibull median probability interval (WMPI) is the fire interval associated with the 50% exceedance probability of a modeled Weibull distribution of all fire intervals from a fire chronology and is considered to be a less-biased estimator of central tendencies in interval distribution (Grissino-Mayer 1995). Variability in fire data with the Weibull model is described by the 5% and 95% exceedance intervals (Grissino-Mayer 1995).

The third measure for fire frequency is determined as a regression slope fit through a cumulative sequence of fire dates (Brown et al. 1999). Piecewise linear regression procedures (Neter et al. 1989) were used to estimate the number of segments and break points in cumulative fire frequency through time (Brown et al. 1999).

Age Structure in Douglas-fir Stands

We examined maximum ages of overstory Douglas-fir trees to determine possible timing of establishment in the Douglas-fir forest on the east side of Inverness Ridge (Arno et al. 1995). Increment cores were collected using 50 cm increment borers from 10 dominant Douglas-fir trees in 24 plots located on a randomly-spaced grid laid out on the east side of Inverness Ridge. Total area covered by the grid was approximately 2000 ha. We measured diameter at breast height (DBH) of trees where cores did not reach pith or the vicinity of pith for later extrapolation of age. Larger-diameter (> 20 cm) sub-canopy hardwoods (oak and bay) were also sampled in plots where they occurred.

For ages of trees where sample cores did not reach pith, we estimated probable pith ages using either overlaid concentric circles or extrapolations based on measurements of ring widths. On cores where curvature of the inside rings was visible, we used overlaid circles to estimate the number of rings to possible pith locations (Arno et al. 1995). Pith ages were estimated to be from 1 to 22 rings with a majority (~75%) from 1 to 10 years from true pith locations using this method. For larger diameter trees, we used extrapolations of ring measurements to calculate number of rings to possible pith locations (Stephenson and Demetry 1995, Brown unpublished manuscript). Best-fit negative exponential or negative-slope linear equations were first determined for measured ring series from increment cores. These equations permitted us to account for wider rings towards tree centers. Equations were used to calculate backwards sums of ring widths until a probable radius was equaled. Radial distance was determined as 1/2 field-measured DBH for each tree and did not account for possible eccentricity in tree circumference. An average bark thickness of 3 cm was added to core lengths before extrapolations. The date of the inside ring at the point of equal radius was then used as pith age for the tree. Extrapolations from ring widths added from 15 to over 150 years to inside dates on increment cores from trees aged in this manner. We recognize that estimates of pith ages using this method are relatively crude but extrapolations based on ring widths were the only means available to estimate ages on trees that often exceeded 1 m and occasionally 2 m DBH (Stephenson and Demetry 1995).

Results and Discussion

Fire-Scar Records

Fire chronologies developed from fire-scarred trees at three sites on Inverness Ridge and in the Olema Valley are shown in Figure 2. Cross sections collected from Douglas-fir trees at Limatour Road (LIM) and Five Brooks (5BR) often recorded multiple fire scars (Figure 2). Fire-scarred cross sections from at least 20 other Douglas-fir trees were collected but could not be crossdated because of problems with either sample preservation or ring series that were too short to crossdate with the chronology for the area. Additionally,

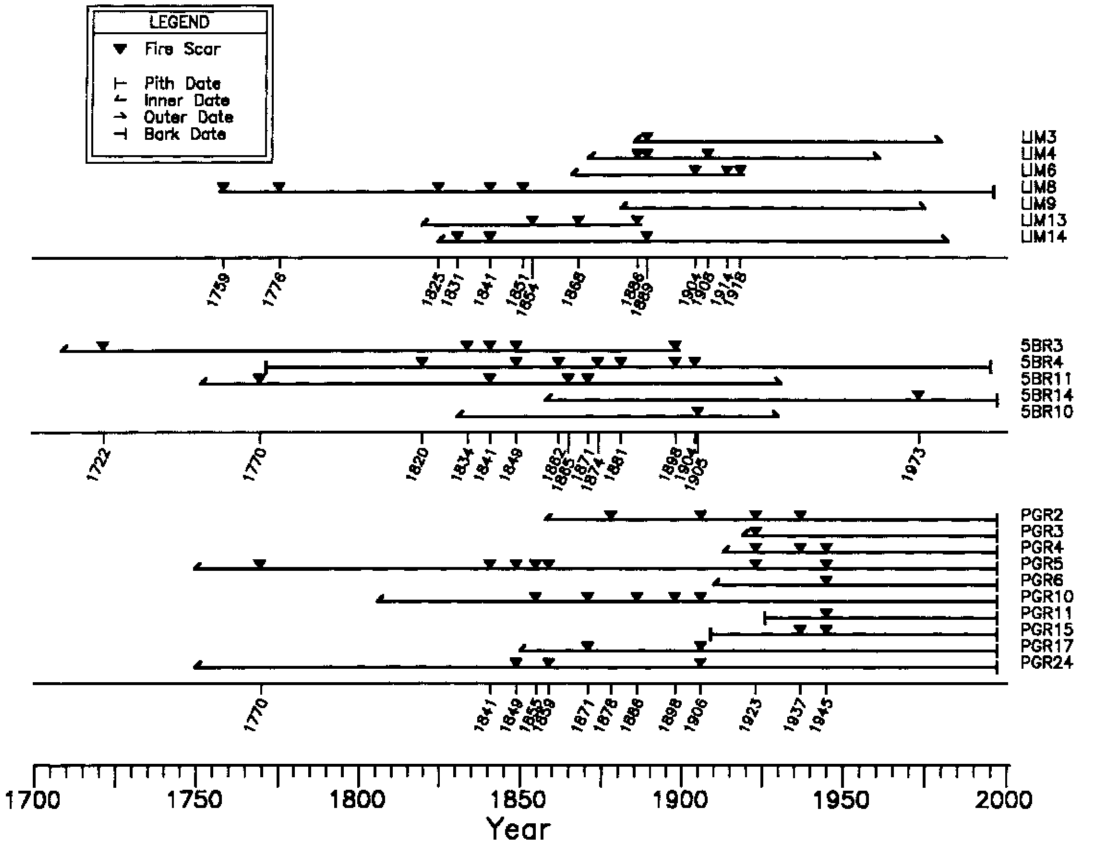

Figure 2. Fire chronologies for Point Reyes stands. Horizontal lines represent time spans of individual trees with inverted triangles at dates of fire scars.

ring widths in the Douglas-fir and coast redwood tended to be "complacent", with little variability in ring width, which made crossdating difficult on many trees. Most of the trees from sites 5BR and LIM were large diameter, 1 to 2 m DBH. However, because trees grow rapidly in this area (inside ring widths from 1 to 3 cm on many trees), most of the Douglas-fir sampled were not very old, and fire scar records did not extend much before the late 1700s. The oldest Douglas-fir tree (not fire-scarred) found in any of the areas sampled had an inside date of 1680.

Cross sections and increment cores were collected from 33 coast redwood trees at site PGR, although only 10 were successfully crossdated (Figure 2). The oldest trees on the northern California Coast are coast redwood, and they often contain long and well-preserved fire-scar records (Finney and Martin 1989, Finney 1990, Brown and Swetnam 1994). Large-diameter (> 2 m) stumps that grew prior to the 1800s were present at site PGR but were heavily decayed and burned from fires that occurred after this stand was logged. Toogood (1980) reports that logging of redwood stands in the lower Olema Valley and Bolinas Ridge began in the fall of 1849 and continued until 1858, with up to four lumber mills operating in the south end of the valley at the height of operations.

Coast redwood is an especially difficult species to crossdate because rings around tree circumferences are often incomplete (Finney and Martin 1989, Finney 1990, Brown and Swetnam 1994). We were not able to crossdate any of the pre-settlement trees from this stand. Most of the successfully crossdated tree were evidently basal sprouts that established after the original stand was logged or in response to fire events after logging (*sensu* Stuart 1987). In Figure 2, trees PGR 2 and 17 may have been sprouts that started after a fire in 1849, trees PGR 3, 4, 6, and 15 may have sprouted in response to fire in 1906, and tree PGR 11 likely was a sprout that started in response to fire in 1923.

Fire scars were found on trees at two or three sites in the Olema Valley during several fire years (Figure 2). Fires were recorded at both sites 5BR and PGR during 1770, 1841, 1849, 1871, and 1898. Trees at these two sites were collected from near the bottom of Inverness Ridge in the Olema Valley where there are few topographic breaks to limit fire spread between the stands. However, with the exception of 1841, fires recorded by trees at LIM were not recorded at either of the other two sites (Figure 2). Trees from LIM were collected from drainages on Inverness Ridge above the Olema Valley, and it is likely that topographic breaks (ridges and valleys) limited fire spread from the valley bottom.

Only one fire scar was recorded in sites LIM and 5BR after the early 1900s, in 1973 (Figure 2). Three fires were recorded at PGR during the 20th century (Figure 2), all of which also were recorded in historic records (R. Moritz, unpublished data). Historic records used to document fire occurrences include all California Department of Forestry fire records for the Point Reyes area. A widespread fire in October, 1906, reportedly burned most of the Olema Valley and closely followed an extensive fire that burned most of Bolinas Ridge in 1904 (Marin Journal, October 25th, 1906). Widespread fires were recorded throughout the Point Reyes area in 1923 and reported to have burned over 40,000 acres (16,200 ha). Extensive fire in 1945 was reported to have burned over 18,000 acres (7300 ha), much of it on the west side of Bolinas Ridge. No fires have been recorded in the Pine Gulch redwoods stand since 1945. In addition, most fire scars were recorded late in the growing season or as dormant scars (Figure 3), which fits well with historic records that document the majority of fires occurred in the period from August to November.

Surface Fire Frequency

Measures of surface fire frequency for the Douglas-fir (5BR and LIM) and coast redwood (PGR) sites are in Table 1. A period of analysis for fire frequency was determined for each site based upon piecewise regressions of cumulative fire dates (Figure 4). In Figure 4, all fire dates are plotted as cumulative data. However, dates before the early to middle 1800s from each site do not fit

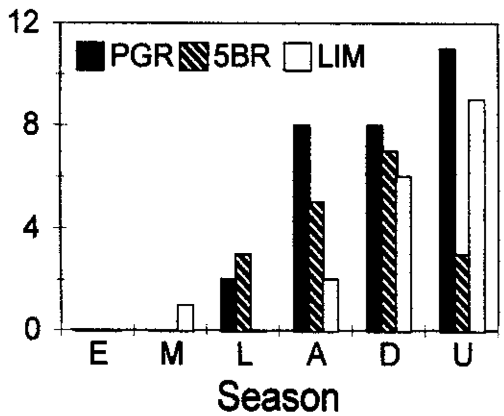

Figure 3. Positions of fire scars within annual rings for three sites at Point Reyes. E: within the first third of the earlywood band; M: middle third of earlywood; L: last third of earlywood; A: in the latewood band; D: dormant season; U: unknown position due to narrowness of rings, ring damage, or other factors. Dormant season scars were dated to the earlier year.

longer-term trends in cumulative events. It is probable that fire dates are missing from the fire scar records before this period. Fire frequency at site PGR was broken into two segments based on results from piecewise regression procedures. Regression slopes before and after 1906 were determined to be significantly different ($P > 0.10$) based on analysis of variance of regression results.

Measures of fire frequency from the early 1800s to early 1900s are consistent for all three stands (Table 1). Mean fire intervals (MFIs) ranged from 7.7 to 8.5 yrs while Weibull median probability intervals were slightly lower reflecting the generally positive skews in interval distributions. Variability in intervals as reflected by standard deviations, ranges, and Weibull 5% and 95% probability intervals also were consistent between stands. MFIs found by this study fit well with reconstructed fire frequency from coast redwood stands on Bolinas Ridge (Finney 1990). Finney found fire frequencies between 1850 and 1900 ranged from 6 to 33 years, with a mean of 14 years.

In addition to crossdated fire events on living coast redwood trees at site PGR, we collected fire scar sequences from five pre-settlement coast redwood stumps. Point fire intervals (i.e., average fire-scar intervals from individual trees) were calculated from these five trees using ring counts between fire scars (Table 2). These sequences of fire scars may be incomplete because fire scars

TABLE 1. Fire frequencies for Point Reyes sites. Fire frequency is calculated using intervals between all fire dates at each site for the period of analysis.

Site	Period of analysis	No. of intervals	MFI (± SD)[1]	Range of intervals [2]	WMPI [3]	5% to 95% prob. inter. [4]	Fire frequency (from fig. 4)[5]
PGR	1841 to 1906	8	8.1 ± 2.7	4 to 12	8.2	4.0 to 12.3	0.122
PGR	1906 to 1945	3	13.0 ± 4.6	8 to 17	13.2	6.0 to 22.7	0.075
PGR	1841 to 1945	11	9.5 ± 3.8	4 to 17	9.4	4.1 to 15.0	
5BR	1820 to 1905	11	7.7 ± 5.0	1 to 17	6.9	1.3 to 17.6	0.130
LIM	1825 to 1918	11	8.5 ± 5.3	3 to 18	7.8	2.1 to 16.0	0.107

[1] Mean fire interval and standard deviation of all intervals in composite fire chronology in years.

[2] In years.

[3] Weibull median (50% exceedance) probability interval in years.

[4] Weibull 5% and 95% exceedance probability intervals in years.

[5] Piecewise regression slopes calculated from cumulative fire dates (number of fires $year^{-1}$).

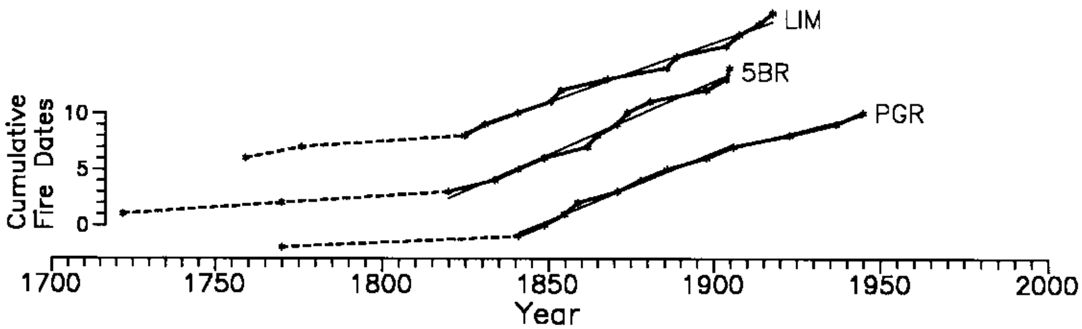

Figure 4. Fire frequency in stands determined from linear regressions fit through cumulative fire dates. Dashed lines are between fire dates not used in periods of analysis for fire frequency (see text). There is a significant difference in regression ($P > 0.10$) before and after 1906 at site PGR.

may not have been recorded in every fire event or fire scars may have been eroded or lost from a scar record. Missing rings between fire scars can be a common occurrence in coast redwood (Brown and Swetnam 1994) and may also bias mean intervals. However, averaging of fire intervals resulted in close agreement of point intervals between trees (Table 2). Unfortunately, without crossdated ring sequences, it is unknown what time period these fire frequencies may represent, only that they are from some time before logging of the stand in the 1850s. These "floating" fire scar sequences at least suggest that there have been relatively high fire frequencies in the Olema Valley during periods before the 19th century. Point fire intervals of 8 to 12 years on the PGR samples (Table 2) fit well with roughly-dated MFIs that ranged from 8 to 20 years from 1450 to 1850 found by Finney (1990) in coast redwood stands on Bolinas Ridge.

TABLE 2. Number of years, means and standard errors (in years) between fire scars in sequences recorded on undated pre-settlement coast redwood trees from Pine Gulch redwoods stand.

tree: intervals	mean ± SE.
PGR 18: 11, 16, 6	11.0 ± 5.0
PGR 22: 6, 11, 18, 5, 8, 11, 12	8.7 ± 5.5
PGR 28: 3, 11, 13, 6, 8, 16, 4, 7, 10, 3	8.1 ± 4.4
PGR 29: 7, 17	12.0 ± 7.1
PGR 30: 6, 6, 7, 8, 15	8.4 ± 3.8

Age Structure in Douglas-fir Stands

Ages of overstory Douglas-fir trees from 24 plots in the Bear Valley area of Limatour Ridge document an apparently multiaged forest with no evidence of even-aged forest structure over large areas (Figure 5). Although extrapolated pith ages based on ring measurements are only crude estimations

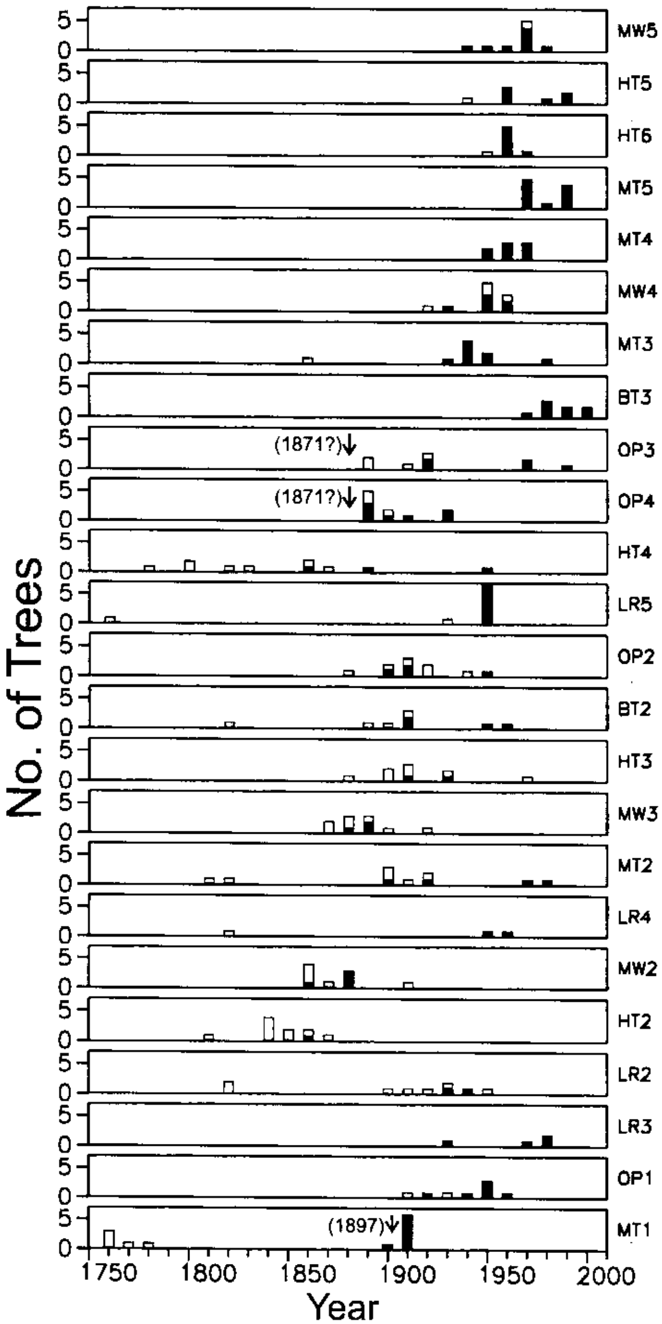

Figure 5. Estimated pith dates on overstory Douglas-fir trees from 24 plots in Bear Valley area of Inverness Ridge. Plots are arranged from bottom to top based on elevation from the bottom of Olema Valley to the top of Inverness Ridge. Solid portions of histograms are numbers of center dates determined from overlaid concentric circles where inside curvature of rings was visible on increment cores. Estimated number of rings from inside of core to probable piths ranged from 1 to 22, with a majority ≤10 rings. Open portions of histograms are numbers of pith dates determined from radial extrapolations of ring widths (see text). These dates may have larger errors owing to extrapolation procedure. Arrows mark possible stand-replacing fire dates in plots.

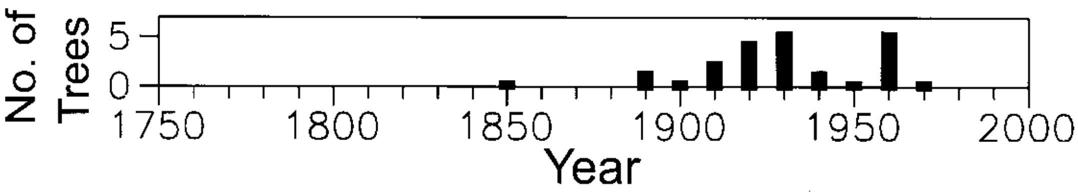

Figure 6. Numbers of understory oak and bay trees by center dates from all plots in the Bear Valley area.

of true ages, there is no clustering of dates over the approximately 2000 ha area where trees were sampled. Trees were young for the most part, with few trees in any plot over 200 years old. Ages of trees from plots near the top of Inverness Ridge were especially young (Figure 5). Several of the individual stands seem to have a maximum age cohort that may be related to stand-destroying events, such as catastrophic fires, logging, or unknown disturbances. The 1871 fire year was recorded as fire scars at sites 5BR and LIM, and trees at two plots (OP3 and OP4) did not have any trees that dated from before this year. A number of trees established at these two plots beginning in the late 1870s. Only 2 fire-scar dates were sampled on any trees in the plots. A fire scar was recorded on a single tree in plot BT2 in 1927. In plot MT1, fire scars were recorded on 2 trees in 1897. Five trees in the stand established in the early 1900s.

Understory hardwoods (bays and oaks) were younger than overstory Douglas-fir in all stands where hardwoods were collected (Figure 6). Abundant sub-canopy hardwood regeneration and little to no Douglas-fir regeneration was seen in many of the Douglas-fir stands. These patterns suggests that in the absence of Douglas-fir regeneration, hardwood trees may eventually replace Douglas-fir.

Implications of the Fire History for Vegetation Dynamics and Landscape Patterning

Results from this study document characteristics of the fire regime in Douglas-fir and coast redwood stands in the Olema Valley and on Inverness Ridge during the period from the middle 1800s to early 1900s. Average intervals between fires were similar between stands and ranged from 8 to 9 yrs. Fires were apparently variable in size, with most fire years recorded at only one site and fewer fires recorded at two or very rarely three sites (Figure 2). Historic records also document highly variable fire sizes from local stands to extensive landscape-scale events.

Longer-term fire history data from the Point Reyes area document relatively high surface fire frequency before the early 1800s. Floating fire scar sequences from pre-settlement coast redwood stumps in site PGR document point MFIs of 8 to 12 yrs prior to the middle 1800s (Table 2). Fire scars from Finney's (1990) study in coast redwood stands on Bolinas Ridge document comparable high fire frequency in this area at least back to the middle 1400s. The presence of charcoal layers in sediments from lakes in the south end of the Point Reyes Peninsula further support the regular occurrence of fire in forests of this area over the past several centuries (Russell 1983, Duncan 1992).

Surface fires ceased for the most part at all sites in the early to middle 20th century, with only one fire scar recorded at any stand after 1945 (Figure 2). Shifts in fire frequency from pre-settlement or early settlement periods to recent decades have important implications for assessing possible changes in landscape patterning and composition and structure of present-day forest stands. Frequent surface fires would have tended to maintain more open stands by killing young trees before they could become established in the overstory. Frequent fires on forest margins also would have tended to maintain the position of forest/grassland or forest/shrubland ecotones. Historical references and records of vegetation patterns on the California coast in the vicinity of Point Reyes document less forest on the coastal hills than at present. Viscaíno in 1602 described the coastal ranges north of Point Reyes as "places of *sierra* [hills] bare to the sea" (Aker 1965; quoted in Duncan 1992:213). In 1792, Vancouver noted that, "the verdure of the plain continued to a considerable height up the sides of the hills, the summits of which...one could see produced a few trees" (Vancouver 1967:10; Wilbur 1953:1). Von Kotzebue during an expedition in the 1810s described the Point Reyes area as "barren with few scattered trees on the higher elevations and patches of dwarf shrubs in the valleys" (Von Kotzebue 1967:48; quoted in Duncan 1992:242). Topographic and vegetation maps of the coast and a mile inland produced by the US Coast Survey from 1859 to 1862 show forested or shrub vegetation primarily in drainages on the east and west sides of Inverness Ridge but not on the ridge itself (maps on file at Point Reyes National Seashore). Historical photographs of Inverness Ridge and the Olema Valley taken in the late 19th and early 20th centuries (Livingston 1994, 1995) also document open hillsides and more extensive areas of grasslands prior to the middle 20th century than are present in these same areas today.

Age structures in Douglas-fir plots from Limatour Ridge show that large numbers of trees have established in these stands since the early 1900s (Figure 5). Most of the hardwoods in the stands also established after the early 1900s (Figure 6). Wills and Stuart (1994) found similar patterns of heavy recent regeneration in Douglas-fir/hardwood stands on the Klamath National Forest in northern California in the absence of surface fires. Age structures in stands from near the top of Inverness Ridge document encroachment of the Douglas-fir forest into these areas (Figure 5). Almost all trees from the plots near the top of the ridge established after the early to middle 1900s, and confirm shifts in landscape patterns of forest and grass or shrub communities.

Patterns in the fire regime at Point Reyes were most likely influenced by human activities. It is probable that some (if not most) of the fire events recorded by trees in Figure 2 were the result of human ignitions. References to Native American burning practices are extensive (e.g., Boyd 1999), and the Coast Miwok that occupied this area prior to the nineteenth century were known to have set fires for clearing brush, hunting, or accidentally (Treganza 1961, Duncan 1992). Intensive non-Native American settlement began in the early to middle 1800s. References in Livingston (1994, 1995) suggest that clearing of brush from grasslands was a frequent occupation of the early ranchers and dairy farmers on the Peninsula. While not often stated explicitly, setting fires to burn off the land would have been a possible means for clearing of brush.

The probable role of humans in historical fire regimes at Point Reyes leads to questions concerning the appropriate approach to management of ecosystems on the Peninsula. In the absence of human ignitions, it is likely that fires would not have been as common. Lightning ignitions are rare for this area, especially during the later summer/early fall period when grasses and herbaceous fuels cure and the majority of fires occurred. However, regardless of the source of ignitions in pre-settlement or early settlement fire regimes, forests of the Point Reyes Peninsula are not burning today with nearly the frequency they did in the past. Shifts from understory to overstory dominance, increases in fuel loads, and changes in forest structure (i.e., increases in "ladder fuels") may lead to increased incidence of overstory, stand-destroying fires that have been documented in other forests that experienced frequent surface fires prior to widespread non-Native American settlement (e.g., Covington et al. 1994). Conversion of grasslands to forest also will continue in the absence of fires. In addition, fires influence many ecosystem-level functions, such as nutrient cycling and energy flows, by rapid chemical and physical changes in both living and dead biomass. The loss of surface fires from forests of the Point Reyes Peninsula most likely has had and will continue to have cascading effects on landscape patterns and ecosystem processes (e.g., Covington and Moore 1994).

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Literature Cited

Agee, J.K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, D.C. 506 p.

Aker, R. 1965. The Cermeño Expedition at Drake's Bay, 1595: A research report to the Drake Navigator's Guild, Palo Alto. Manuscript on file, USDI National Park Service, Western Archaeological Center, Tucson.

Arno, S.F., J.H. Scott, and M.G. Hartwell. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. USDA Forest Service Research Paper INT-RP-481.

Barrett, S.W., S.F. Arno, and J.P. Menakis. 1997. Fire episodes in the inland northwest (1540-1940) based on fire history data. USDA Forest Service General Technical Report INT-42.

Boyd, R. (Editor). 1999. Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis. 320 p.

Brown, P.M., M.R. Kaufmann, and W.D. Shepperd. 1999. Long-term, landscape patterns of past fire events in a ponderosa pine forest of central Colorado. Landscape Ecology (in press).

Brown, P.M., and T.W. Swetnam. 1994. A cross-dated fire history from a stand of coast redwood near Redwood National Park, California. Canadian Journal of Forest Research 24:21-31.

Covington, W.W., R.L. Everett, R. Steele, L.L. Irwin, T.A. Daer, and A.N.D. Auclair. 1994. Historical and anticipated changes in forest ecosystems in the inland west of the United States. Journal of Sustainable Forestry 2:13-63.

Covington, W.W., and M.M. Moore. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry 92:39-47.

Critchfield, W.B. 1966. Crossability and relationships of the closed-cone pines. Silvae Genetica 16:89-97.

Duffield, J.W. 1951. Interrelationships of the California closecone pine with special reference to *Pinus muricata* D. Don. Ph.D. Dissertation, University of California, Berkeley.

Duncan, F.L. 1992. Botanical reflections of the *encuentro* and the contact period in southern Marin County, California. Ph.D. Dissertation, University of Arizona, Tucson.

Finney, M.A. 1990. Fire history from the redwood forests of Bolinas Ridge and Kent Lake Basin in the Marin Municipal Water District. *In*: Vegetation and Fire Management Baseline Studies: The Marin Municipal Water District and the Marin County Open Space District (Northridge Lands), Marin County, California. Leonard Charles and Associates and Wildland Resource Management, unpublished report (not paginated).

Finney, M.A., and R.E. Martin. 1989. Fire history in a *Sequoia sempervirens* forest at Salt Point State Park, California. Canadian Journal of Forest Research 19:1451-1457.

Galloway, A.J. 1959. Redwoods on Point Reyes Peninsula. Leaflets of Western Botany 9(4):66-67.

________. 1977. Geology of the Point Reyes Peninsula, Marin County, California. California Division of Mines and Geology Bulletin 202.

Grissino-Mayer, H.D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. Dissertation, University of Arizona, Tucson.

Kaufmann, M.R., R.T. Graham, D.A. Boyce, Jr., W.H. Moir, L. Perry, R.T. Reynolds, R.L. Bassett, P. Mehlhop, C.B. Edminster, W.M. Block, and P.S. Corn. 1994. An Ecological Basis for Ecosystem Management. USDA Forest Service General Technical Report RM-246. 22 p.

Livingston, D.S. 1994. Ranching on the Point Reyes Peninsula. A history of the dairy and beef ranches within Point Reyes National Seashore, 1834-1992. Historic resource study, National Park Service, Point Reyes National Seashore. 544 p.

________. 1995. A good life: Dairy farming in the Olema Valley. Historic resource study, National Park Service, Point Reyes National Seashore. 419 p.

Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, W. D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2:87-111.

Mutch, R.W., S. Arno, J. Brown, C. Carlson, C. Omar, and J. Peterson. 1993. Forest health in the Blue Mountains: A management strategy for fire-adapted ecosystems. USDA Forest Service General Technical Report PNW-310.

Neter, J., W. Wasserman, and M.H. Kutner. 1989. Applied Linear Regression Models. 2nd Ed. Irwin, Homewood, IL. 667 p.

Romme, W.R. 1980. Fire history terminology - report of the ad-hoc committee. *In*: M.A. Stokes and J.H. Dieterich (Technical Coordinators), Proceedings of the fire history workshop, October 20-24, 1980, Tucson, Arizona. USDA Forest Service General Technical Report RM-81:Pp. 8-14.

Russell, E.W.B. 1983. Pollen analysis of past vegetation at Point Reyes National Seashore, California. Madroño 30:1-11.

Sawyer, J.O., D.A. Thornburg, and J.R. Griffin. 1977. Mixed evergreen forest. In M.G. Barbour and J. Major (Editors.), Terrestrial Vegetation of California. John Wiley and Sons, NY: Pp. 359-381.

Shuford, W.D., and I.C. Timossi. 1989. Plant Communities of Marin County. California Native Plant Society, Sacramento; Special Publication No. 10.

Stephenson, N.L., and A. Demetry. 1995. Estimating ages of giant sequoias. Canadian Journal of Forest Research 25:223-233.

Stuart, J.D. 1987. Fire history of an old-growth *Sequoia sempervirens* (Taxodiaceae) forest in Humboldt Redwoods State Park, California. Madroño 34:128-141.

Sugnet, P.W. 1984. Fire history and post-fire stand dynamics of the Inverness Bishop pine population at Point Reyes National Seashore, California. MS Thesis, University of California, Berkeley.

Swetnam, T.W. 1993. Fire history and climate change in giant sequoia groves. Science 262:885-889.

Swetnam, T.W., and C.H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since 1700. *In*: C.D. Allen (Editor), Fire Effects in Southwestern Forests, Proceedings of the 2nd La Mesa Fire Symposium, March 29-31, 1994, Los Alamos, New Mexico. USDA Forest Service General Technical Report RM-GTR-286:Pp. 11-32.

Swetnam, T.W., M. A. Thompson, and E.K. Sutherland. 1985. Using dendrochronology to measure radial growth of defoliated trees. USDA Agricultural Handbook No. 639.

Toogood, A.C. 1980. Historic Resource Study: A Civil History of Golden Gate National Recreation Area and Point Reyes National Seashore, California. USDI, National Park Service, Historic Preservation Branch. Pacific Northwest/Western Team, Denver Service Center. 2 volumes.

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Treganza, R.E. 1961. The Indian story of Point Reyes. In Land Use Survey, Point Reyes. USDI, National Park Service.

Vancouver, G. 1967. A Voyage of Discovery to the North Pacific Ocean and Round the World, 1757-1798. Vols. 2 and 3, Portfolio Nos. 6 and 13. De Capo Press, NY.

Von Kotzebue, O. 1967. A Voyage of Discovery into the South and Bering Straits. Volumes. 1 and 3. Biblioteca Australiana, No. 17. N. Israel, Amsterdam.

Wells, P.W. 1962. Vegetation in relation to geological substratum and fire in the San Luis Obispo quadrangle, California. Ecological Monograph 32:79-103.

Wilbur, M.E. 1953. Vancouver in California, 1792-1794. Glen Dawson, Los Angeles.

Wills, R.D., and J.D. Stuart. 1994. Fire history and stand development of a Douglas-fir/hardwood forest in northern California. Northwest Science 68:205-211.