Fire-scar formation in Jeffrey pine – mixed conifer forests in the Sierra San Pedro Mártir, Mexico

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Abstract: Little is known about the probability of fire-scar formation. In this study, we examined all mixed conifer trees for fire-scar formation in a 16 ha watershed that burned as part of a 2003 wildfire in Sierra San Pedro Mártir National Park (SSPM), Mexico. In addition, we examine the probability of fire-scar formation in relation to the previous fire interval in forests in the SSPM and Sierra Nevada. Within the 16 ha SSPM watershed, 1647 trees were assessed (100% census) for new fire scars. The SSPM wildfire burned around the base of 78% of the trees, but only 8% developed a new fire scar. Although the years from tree germination to first fire scar could potentially represent a fire-free period, there is clear evidence from this study that the inclusion of this interval when computing fire statistics is not justified. When the time since previous fire was <10 years, 10–30 years, and >57 years, the probability of rescarring was approximately 0.05, 0.5, and 0.75, respectively. In areas where fires were frequent (<10 years), fire frequencies derived from fire scars will likely underestimate true fire frequency, at least in forests that are similar to those studied here.

Résumé : La probabilité qu'une cicatrice de feu se forme est peu connue. Dans cette étude, nous avons examiné la formation des cicatrices de feu chez toutes les tiges de conifères mélangés dans un bassin de 16 ha qui a brûlé lors d'un incendie de forêt en 2003 dans la Sierra San Pedro Mártir (SSPM), au Mexique. De plus, nous avons étudié la probabilité qu'une cicatrice de feu se forme en fonction du temps écoulé depuis l'incendie précédent dans les forêts de la SSPM et de la Sierra Nevada. Dans le bassin de 16 ha de la SSPM, la présence de nouvelles cicatrices de feu a été relevée sur 1647 arbres (recensement de 100 %). L'incendie de la SSPM a brûlé autour de la base de 78 % des arbres mais seulement 8 % des arbres avaient des cicatrices de feu. Alors que le nombre d'années entre le moment de la germination et l'apparition de la première cicatrice de feu pourrait correspondre à une période exempte d'incendies, cette étude démontre clairement que l'inclusion de cet intervalle dans la compilation des statistiques d'incendie n'est pas justifiée. Lorsque le temps écoulé depuis le dernier incendie était <10 ans, 10–30 ans et >57 ans, la probabilité qu'une nouvelle cicatrice de feu se forme était respectivement d'environ 0,05, 0,5 et 0,75. Dans les zones où les incendies étaient fréquents, (<10 ans), la fréquence des incendies dérivée des cicatrices de feu pourrait sous-estimer la vraie fréquence des incendies, du moins dans les forêts semblables à celles qui ont été étudiées ici.

[Traduit par la Rédaction]

Introduction

In forests where the fire regime is dominated by frequent, low- to moderate-severity fires, the physical evidence of fire occurrence can be found in the ring structure of individual trees, such as fire scars and (or) patterns of release in radial growth (Arno and Sneck 1977; Madany et al. 1982; McBride 1983; Swetnam et al. 1985; Ryan and Frandsen 1991). Current fire-history methods are probably biased towards underrepresenting fire occurrence because fires may have burned around many trees but failed to scar them. However, little is known about the probability of fire-scar formation in the field, and this is the focus of this paper.

Reconstructions of historical fire regimes are often used to inform management decisions to manipulate current forest structure and implement fire use (Swetnam et al. 1999; Collins and Stephens 2007*b*; Conedera et al. 2009). Such reconstructions can also aid in advancing our understanding of how future climates will affect forested ecosystems (Millar et al. 2007; Fulé 2008; Stephens et al. 2010). However, the uncertainty associated with fire-scar reconstructions has led to questioning not only the estimates of frequencies derived

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from these methods, but also the inferences about fire regimes drawn from such estimates (Johnson and Gutsell 1994; Minnich et al. 2000; Baker and Ehle 2001; Baker 2006).

Baker and Ehle (2001) contend that unrecorded fires (i.e., fires that do not show up in the fire-scar record) could lead to overestimation of the time between fires and the fire rotation. Unrecorded fires could be a product of insufficient fuel accumulation or consumption near the base of trees, as well as loss of previous fire scars due to consumption by subsequent fires. Ultimately, it is not entirely clear how to account for the uncertainties in the processes that lead to tree scarring over a landscape.

The origin-to-scar (OS) interval is the period between tree germination and the first fire scar (Baker 1989) and may be another source of uncertainty in reconstructions based on fire scars. Baker and Ehle (2001) proposed that this interval should be included in fire-scar statistics because they assumed that, for a tree to survive this period, it must not have experienced a fire. Two arguments have been made in the literature that attempted to explain why most trees are older than 50 years when they scar for the first time: (*i*) fires killed the young trees instead of scarring them, leaving no lasting evidence of the fire's presence, and (*ii*) fire was absent around seedlings and saplings during their establishment (Baker 1989; Gutsell and Johnson 1996; Keeley and Stephenson 2000; Baker and Ehle 2001). Although these are both possible explanations, a third possibility is that fire was present but failed to leave a scar (Fulé et al. 2003; Stephens et al. 2003; Van Horne and Fulé 2006). It is important to note that the OS interval only applies to trees that were fire scarred at some point during their life and not to the many trees that never scarred even though fires burned repeatedly through the stands in which they grew.

To assess different methodologies used in describing fire regimes, Fall (1998) constructed a series of computer simulations ("synthetic fire history") based on a fire-history study in Oregon's Blue Mountains (Heyerdahl and Agee 1996; Heyerdahl 1997). The probability that fires are recorded in the tree-ring record was found to be critically important for estimating the possible bias in a fire-history reconstruction (Fall 1998). The probability of a tree recording a fire for the first time (p_{ns}) may be different than the probability of a previously scarred tree rescarring (p_{ps}) because an open cavity is more susceptible to injury. However, little information currently exists on estimates of either of these fire scar characteristics.

Our study was initiated to further the understanding of fire-scar formation and how this process varies. Data for this study come primarily from an unmanaged mixed-conifer forest in Baja California (Stephens et al. 2003); however, we also include analysis of unpublished data from similar forests in the Sierra Nevada in California (B.M. Collins, unpublished data (2008)) to ascertain the interactions between fire and tree scarring more robustly. In contrast to much of the forested area in the western United States, fire regimes in Baja California's Sierra San Pedro Mártir (SSPM) were first modified by suppression in the early 1970s (Stephens et al. 2003). As such, the inferences that we draw may have applicability to historical fire – tree scarring interactions. Our study objectives were to (*i*) understand the burning patterns in a relatively intact old-growth forest watershed, i.e., is the absence of evidence (fire scars) actually evidence of the absence of fire? (P.M. Brown, Rocky Mountain Tree-Ring Research, Inc., Fort Collins, Colo., personal communication (2005)); (*ii*) determine what tree and fuel characteristics were associated with fire-scar formation; and (*iii*) determine if the probability of fire-scar formation on a previously scarred tree varies with the tree's previous burn interval.

Methods

Study area

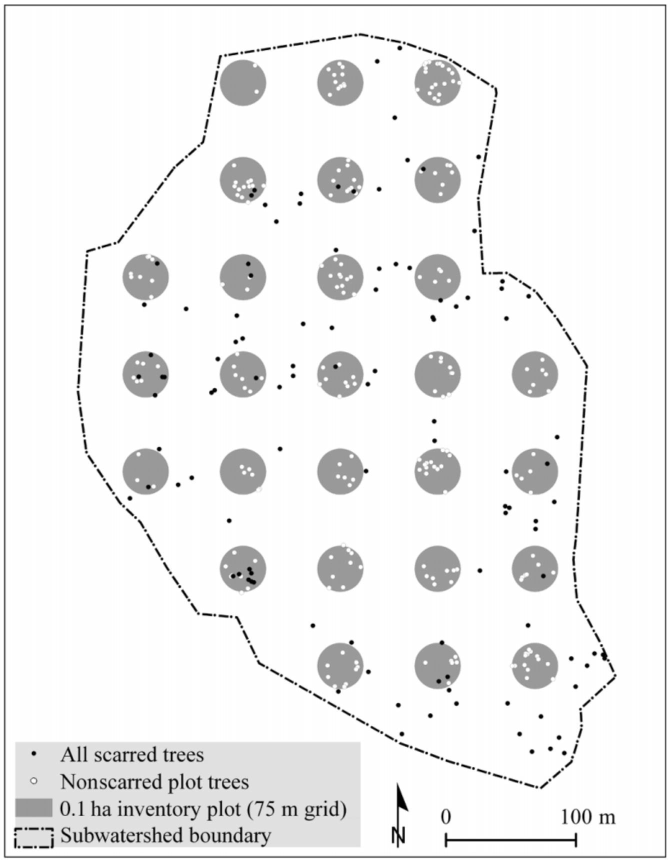
Fire-scar information was collected in forests in SSPM National Park (31°37′N, 115°59′W), which is approximately 120 km southeast of Ensenada, Mexico. The northern end of the range is located in the San Jacinto Mountains of southern California, which is approximately 350 km from the SSPM. Although there are no long-term weather data for the mountain's upper plateau, mean annual precipitation measured from 1989 to 1992 was 55 cm, and the climate is described as Mediterranean (Markham 1972; Pyke 1972; Minnich et al. 2000). However, Skinner et al. (2008) hypothesized that the preponderance of earlywood fire scars in the fire-history record suggests that climate is significantly influenced by the North American Monsoon System.

The SSPM's vegetation is composed of conifer forests of the Californian Floristic Province and cover approximately 40 655 ha of this range (Minnich et al. 1995, 1997, 2000; Minnich and Franco-Vizcaíno 1998). The forests are similar to those of portions of the eastern Sierra Nevada and southern California mountains with regard to geology, soil parent materials, fire frequency, and vegetation (Minnich et al. 1995; Potter 1998; Stephens 2001, 2004; Taylor 2004; Stephens and Gill 2005; Stephens et al. 2007; Everett 2008; Gill and Taylor 2009; North et al. 2009; Vaillant and Stephens 2009). The most common forest types are Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), Jeffrey pine – mixed conifer and mixed white fir (*Abies concolor* (Gord. & Glend.) Lindl.) forests, respectively (Minnich and Franco-Vizcaíno 1998). Although there are no ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in the SSPM, the relationship of Jeffrey pine to fire is usually considered to be similar to that of ponderosa pine (Habeck 1992; Stephens et al. 2003). The forests in the SSPM National Park have never been logged except for one 20 ha area that was selectively harvested. No harvesting has occurred in our study site.

Field sampling

In July 2003, a low-severity wildfire burned for approximately 6 days in the northern SSPM National Park, and all trees within a 16 ha watershed in the fire area were examined (100% census) in June 2004 for incipient fire-scar formation (see Stephens et al. 2008 for more details on the study site) (Fig. 1). Trees were measured for the following attributes: species, status (live or dead; snag class was based on decay characteristics; see Cline et al. 1980), diameter at breast height (DBH), bark char height, percentage of the tree base circumference charred, presence of a new fire scar, and dimensions of the fire scar (height and percentage of the tree base circumference scarred). The latter was estimated by finding the live or dead cambium boundary with a hatchet (Lentile et al. 2005). The locations of all trees with new fire

Fig. 1. Spatial locations of all trees (>2.5 cm diameter at breast height) in our 0.1 ha fixed-radius field plots within a 16 ha subwatershed; in addition, the locations of all fire-scarred trees outside the plots are identified. The watershed is located in Sierra San Pedro Mártir National Park, Mexico, and was burned by a July 2003 wildfire. Plots were installed on a 75 m grid. Plot trees without fire scars are shown as open circles, and fire-scarred trees are shown as solid circles throughout the watershed.



scars were mapped using a laser rangefinder referenced to monuments with high-resolution (differently corrected) global positioning system (GPS) coordinates.

Additionally, we searched the area surrounding each tree (1 m radius) for evidence of woody debris (>7.5 cm in diameter) that might have contributed to fire damage through radiation (Gill 1974; Johnson and Gutsell 1994). Evidence of coarse woody debris included charcoal, partially consumed wood, and changes to surface soil color. Although this assessment was done 11 months after the fire, we believe this evidence was still observable. Trees were resurveyed for live or dead status the third year postfire (2006) to reexamine the extent of cambium death.

Surface and ground fuels were measured on a grid of twenty-seven 0.1 ha circular plots installed in June 2004; the location of every tree within the plots was also recorded (Stephens et al. 2008) (Fig. 1). In each plot, fuels were measured using the line-intercept method (Brown 1974) on three randomly placed line transects. Fuel loads were calculated using equations developed for Californian forests (van Wagtendonk et al. 1996, 1998).

To assess the evidence of the 2003 fire, we collected fire-scarred wedges from Jeffrey pine trees and snags inside the watershed and within 100 m of its perimeter. The sampling strategy was intended to maximize the completeness of an inventory of fires while also collecting samples that were spatially dispersed in and near the watershed (Swetnam and Baisan 2003). Each sample had a minimum of five externally visible fire scars, and wedges were sanded to a high sheen and cross-dated using a local tree-ring chronology (Stokes et al. 1973) obtained from the International Tree-ring Data Bank using standard dendrochronological techniques (Stokes and Smiley 1968; Swetnam et al. 1985).

The season of occurrence for each fire scar was estimated by examining the intraring scar position. Scar locations were identified as EE (early earlywood), ME (middle earlywood), LE (late earlywood), LW (latewood), D (dormant or ring boundary), or undetermined (Caprio and Swetnam 1995). Fire-scar data were stored and analyzed using FHX2 software (Grissino-Mayer 2001). Sampling only multiple-scarred trees is an efficient method for detecting the maximum number of fire years with the least ecological damage and field and laboratory work (Brown and Wu 2005), which was important in the SSPM National Park.

Analysis

Two-sample t tests were used to assess the difference in tree size and percentage of the base circumference charred for trees that did or did not develop a new fire scar from the 2003 wildfire. The χ^2 test for association was used to assess fire-scar formation and the presence–absence of woody debris adjacent to the tree. This test measures the divergence between observations of two categorical variables that would be expected to be of no association under the null hypothesis. Differences in the above tests were considered significant if the p value was <0.05.

The spatial pattern of fire-scar formation was analyzed using the univariate Ripley's K function (Ripley 1981; Haase 1995). This function, expressed in the linear form $L(d)$ to stabilize variance, calculates the intensity of points within a circle centered on a point to describe two-dimensional distribution patterns of fire-scarred trees within the 16 ha watershed. This value is then compared with an expected K function for a random distribution, which is expected to equal πd^2, where d is the diameter of the circle. Upper and lower bounds of the 99% confidence limits for $L(d)$ (i.e., 99 simulation envelopes) were calculated on a randomly generated distribution of points (trees) within an area equal to the observed plot (Haase 1995). A value higher (lower) than the confidence limits implies a clustered (regular) distribution of trees.

We calculated the time since previous fire for each tree sampled for fire scars in both the SSPM and Sierra Nevada using previously published fire perimeters (Minnich et al. 2000 for the SSPM and Collins and Stephens 2007*a* for the Sierra Nevada). The probability of fire scarring was calculated based on comparisons from fire-scarred sections collected from trees known to be within the perimeter of a given fire from these previous studies (Minnich et al. 2000; Collins and Stephens 2007*a*).

Results

Plot and tree assessments

Within the 16 ha SSPM watershed, 1647 trees were assessed (100% census of all trees) in June 2004 (11 months after the wildfire), which included Jeffrey pine (90.5% of all trees), sugar pine (*Pinus lambertiana* Dougl.) (4.6%), white fir (4.7%), and incense-cedar (*Calocedrus decurrens* (Torr.) Floren.) (0.2%). DBH was 31.8 ± 0.6 cm (mean ± SE, median 25.3 cm) and ranged from 1.0 to 110.0 cm. In the June 2004 survey, a total of 199 snags (12.1% of total trees) were identified, and 44 of these had died before the 2003 wildfire (snag classes 2 and 3; see Stephens et al. 2008). An additional 139 trees had died by the subsequent survey in 2006 for a cumulative mortality of 20.5%.

The grid of 27 plots surveyed approximately 7.7% of the watershed (Fig. 1). Topography is diverse with plot slopes ranging from 5% to 60% (36% ± 2.7%), and all aspects were present in the 16 ha watershed (Stephens et al. 2008). Summary statistics for fuels measured after the wildfire are listed in Table 1. Area burned was patchy; within plots, a mean of 46% of the fuel transects intersected burned areas.

Probability of fire scar formation

Only a small number of trees in the SSPM study area developed new fire scars from the 2003 wildfire (141 trees, 8.3% of total), and 73% of these trees were scarred for the first time. Fire-damage characteristics by presence or absence of scar formation are summarized in Table 2. Mean DBH of trees scarred was significantly larger than the mean for trees that were not scarred (t test = –2.0, p = 0.046) (Fig. 2). For trees that were charred but did not develop a new fire scar, DBH was 33.6 ± 0.7 cm. The distribution of trees that were scarred was relatively uniform, differing from the classic inverse J distribution observed when all trees are included (Fig. 2). The percentage of tree-base circumference charred was 61% ± 1.0% (median 75.0%), and 22% of the trees had no evidence of fire at their base.

Trees in the 16 ha watershed that were scarred had significantly more of their basal circumference charred than trees that did not develop a new fire scar (t test = –7.7, p < 0.001). The χ^2 test indicated that there was a significant association between fire-scar formation and presence or absence of woody debris (Pearson χ^2 = 25.8, df = 1, p < 0.001). There was evidence of woody debris near 30% of the trees that developed new scars and 13.5% at trees that did not develop scars. Compared with a random spatial distribution, Ripley's K analysis indicated a clustered distribution of scarred trees from 0 to 50 m and from 80 to 125 m (Fig. 3).

In and adjacent to the 16 ha area sampled within the SSPM wildfire, a total of 94 fire scars were cross-dated (covering 1343–2005) from 13 Jeffrey pines. The intraannual ring position was identified for 72.3% of the scars. Of these scars, 92.7% were in the earlywood (EE, 47.1%; ME, 32.4%; LE, 13.2%) with 5.9% in latewood and only one ring-boundary scar. Six of the 13 samples (46%) were scarred in the July 2003 wildfire (Fig. 4): three in the ME and three in the LE. After 1750, fires scarred at least one-half the samples in 1777, 1877, 1928, 1946, and 2003. Previous fire-history research approximately 2 km east of the 16 ha watershed determined a mean FRI of <15 years based on >50 fire scar samples (Stephens et al. 2003).

The proportion of previously fire-scarred trees that were scarred by a given fire event varied substantially but increased with increasing time since previous fire in both the SSPM and Sierra Nevada (Fig. 5). When the times since previous fire were <10 years, 10–30 years, and >57 years, the probabilities of rescarring were approximately 0.05, 0.5, and 0.75, respectively.

Discussion

Although the 16 ha watershed that we studied was located entirely within the 2003 wildfire, evidence of burning was not uniformly present throughout (Fig. 1). The variability in the structure of the forest and surface fuels in this area likely led to a diversity of fire behavior and effects in this area (Stephens 2004; Stephens et al. 2008). Our finding that only 46% of fuel transects were in burned areas supports the patchy burn pattern. The higher proportion of trees with evidence of burning at their base (78%) was likely due to higher local fuel loads, both from cast needles and sloughed bark.

The spatial analysis of scarred trees indicating clustering at fairly small spatial scales (<50 m and 75–125 m) (Fig. 3) bears further discussion. Because we did not map all 1647 trees in the 16 ha watershed, it is difficult to ascertain whether the observed clustering is a real effect or simply a reflection of the underlying spatial patterns of trees. Observational evidence from this and other studies of fire-scarred trees (Stephens 2001; Skinner et al. 2008) suggests that it is common for scarred trees to be clumped. Perhaps future studies can provide more definitive results on the possible spatial patterns of tree scarring.

Most trees survived the 2003 fire without developing a fire scar, including the majority of small trees (Fig. 2). Small trees or clusters of small trees in open areas generally do not have high amounts of accumulated sloughed bark and needle litter near their base. As a result, residence time of the fire may be insufficient to kill portions of the cambium. An alternative explanation, which is equally plausible, is simply nonuniform consumption of fuel throughout the burn. Regardless of the mechanism responsible for such a high proportion of unscarred trees, our findings clearly demonstrate that analysis of fire scars will likely under estimate past fire occurrence. Thus, the unrecorded fire problem discussed by Baker and Ehle (2001) is likely to be an important source of uncertainty in fire-history reconstructions based on fire scars.

Fire evidence can never be recorded unless there was a fire (barring the misinterpretation of nonfire-related tissue damage), and many trees survive fires without developing fire scars. Thus, the physical evidence is biased towards underrepresenting the occurrence of fire, but the magnitude of that bias has received little study (Fall 1998). In the Jeffrey pine dominated forests of the SSPM and Sierra Nevada, the probability that a previously scarred tree will scar again during a given fire event is linked to the time elapsed since the previous fire (Fig. 5). Collins and Stephens (2007*a*) found that time since previous fire explained a substantial portion of the variance in tree scarring. Here, we demon-

Table 1. One year postwildfire fuel loads (t·ha^{-1}) in Jeffrey pine – mixed conifer forests in Sierra San Pedro Mártir National Park, Mexico (n = 27 plots).

Fuel type	Mean (SE)	Median	Minimum	Maximum
Duff	0.0 (–)	—	—	
Litter	8.6 (0.9)	7.9	2.9	21.7
1 h	0.0 (–)	0.0	0.0	0.3
10 h	0.6 (0.1)	0.5	0.0	3.5
100 h	1.2 (0.5)	0.6	0.0	11.0
1000 h sound	4.2 (2.1)	0.0	0.0	52.6
1000 h rotten	0.0 (–)	—	—	
Total dead and down woody fuels	6.0 (2.2)	1.5	0.0	52.9
Total load	19.4 (2.7)	14.4	4.8	72.0

Table 2. Comparison of tree and fire damage characteristics after the July 2003 wildfire in an old-growth Jeffrey pine – mixed conifer forest in Sierra San Pedro Mártir National Park, Mexico.

	Mean (SE)	Median	Minimum	Maximum
Trees scarred (n = 141)				
DBH (cm)*	34.7 (2.0)	30.5	1.5	98.0
% tree base circumference charred*	82.4 (2.7)	100.0	0.0	100.0
% tree base circumference dead	29.7 (1.3)	26.1	0.0	90.1
Scar height (cm)	4.0 (0.2)	3.4	0.0	16.0
Trees not scarred (n = 1506)				
DBH (cm)	31.5 (0.6)	24.8	1.0	110.0
% tree base circumference charred	59.9 (1.1)	70.0	0.0	100.0

*Measurements on scarred trees were significantly larger than on nonscarred trees ($p < 0.05$).

Fig. 2. Tree diameter frequency distribution of all trees (open bars), trees with bark char at their base (shaded bars), and trees with scars formed from the 2003 wildfire (solid bars) in a 16 ha watershed in Sierra San Pedro Mártir National Park, Mexico.

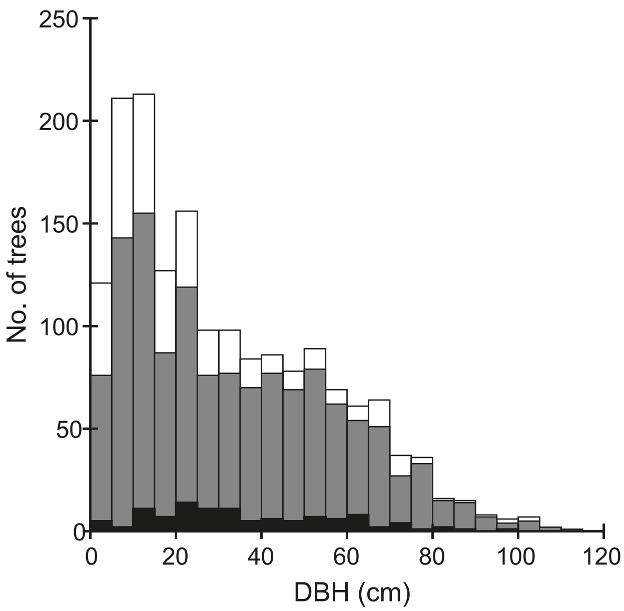
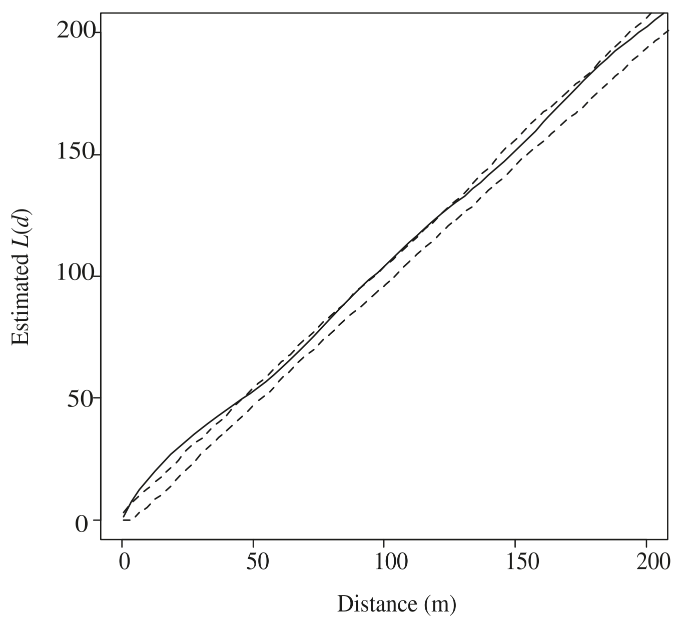


Fig. 3. Ripley's K function ($L(d)$) of scarred trees after the July 2003 wildfire in the 16 ha watershed in Sierra San Pedro Mártir National Park, Mexico. Broken lines are the upper and lower bounds (100 simulations envelope) of $L(d)$ based on a random spatial distribution.



strate that, when the time since previous fire was <10 years, the probability of rescarring was approximately 0.05 (Fig. 5). When the time since the previous fire increased to 10–30 years, the probability of rescarring was approximately 0.5 in the forests of both the Sierra Nevada and SSPM. Rescarring probabilities increased to approximately 0.75 when the time since previous fire was >57 years. This is likely because longer intervals between fires allows for greater accumulation and continuity of fuels at the base of trees (including large woody materials), thus leading to high probabilities of scarring.

Fig. 4. Composite fire activity collected from 13 Jeffrey pine trees in and adjacent to the 16 ha wildfire burn area in Sierra San Pedro Mártir National Park, Mexico. Recorder years are identified by solid horizontal lines and nonrecorder years (annual rings that were insufficient to identify fire scars) are identified by broken horizontal lines. Vertical lines show years where fire scars were recorded. The composite at the bottom is the occurrence of fires that scarred ≥25% of the recording trees.

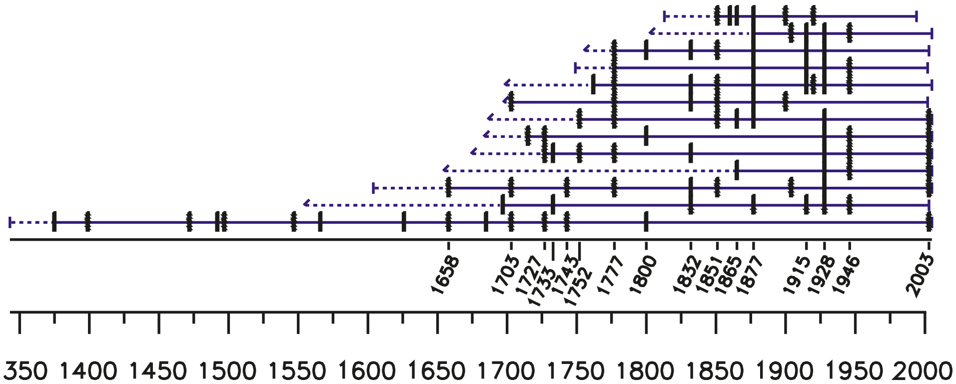
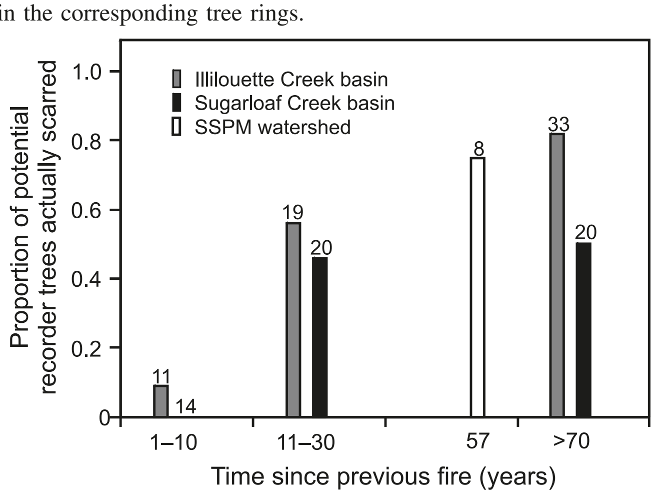


Fig. 5. Comparison of the proportion of previously fire-scarred trees that recorded a particular fire based on independently derived fire perimeters from our 16 ha watershed in Sierra San Pedro Mártir National Park (SSPM), Baja California, and the Illilouette and Sugarloaf areas in the Sierra Nevada, California. These proportions were based on fire-scarred sections collected from trees known to be within the perimeter of a given fire. The time since previous fire was calculated using previously published fire perimeters (Minnich et al. 2000 for the SSPM and Collins and Stephens 2007*a* for the Sierra Nevada) using fire atlases. The total numbers of samples used to calculate each proportion are shown above the bars. In the 1–10 year class, the Sugarloaf site had 14 samples that were located within fire perimeters, none of which recorded the respective fires in the corresponding tree rings.



Variable probabilities of recording fires complicates the interpretation of fire-history studies, at least in forests with similar composition, management histories, and burning conditions as those studied here. Although it is true that the OS period on any given tree could potentially represent a fire-free period, there is clear evidence from this study that most small trees experienced fire without scarring, and the inclusion of the OS interval when computing fire statistics is not justified. A similar conclusion regarding the possible inclusion of the first fire interval was found by Brown et al. (2008) in ponderosa pine forests in the Black Hills of South Dakota.

Fall (1998) determined that, from his simulations, the most significant source of bias and uncertainty in the empirical estimate of mean fire return intervals arose from the censoring of individual fire dates within the period of reliability. Although the probability of recording is primarily responsible for the censoring itself, the number of trees sampled at each plot is also important in determining the magnitude of this effect. Therefore, for any fire scar recording rate >0.5, a sample of at least two trees has a reasonable chance of detecting most fires. However, where recording rates are much lower (e.g., short fire return intervals <10 years), many more samples would be needed for reliable estimates. Because the number of fire scar samples is somewhat under the control of the researcher, multiple trees should always be sampled at each site if one wishes to reconstruct the history of fire with greater certainty.

Working with fire-history data from northeastern Oregon, Fall (1998) estimated that the fire-scar recording rate was 0.56. This is similar to our observed fire-scar recording rate (approximately 0.5) of previously scarred trees that had burned in the previous 10–30 years. It is important to note that Fall's simulations and our analysis of scarring probability over a range of times since previous fire both deal with trees that have been previously scarred. The 8.3% scarring rate that we report in the 16 ha watershed is for all trees, most of which had no visual evidence of previous scarring. Clearly, scarring probabilities are low for previously unscarred trees.

The 2003 wildfire in the SSPM burned during the first week of July. In the samples collected from this site, the intraring position of the fire scars was 50% in the ME and 50% in the LE. Intraring fire position of the other fires recorded in this area was approximately 50% EE and 30% ME. From these data, we deduced that the 2003 wildfire burned somewhat later in the year than most previous SSPM fires. In the SSPM, the occurrence of fires in the past was probably dominated by events in June. This intraring scar position (dominated by EE and ME) is corroborated by other studies in this region (Stephens et al. 2003; Evett et al. 2007; Skinner et al. 2008).

Conclusion

Our finding suggests that the "unrecorded fire problem" discussed by Baker and Ehle (2001) is a common occurrence when the time since previous fire is <10 years. This calls attention to a possible limitation of reconstructions based on fire scars where intervals between successive, overlapping fires are short (Collins and Stephens 2007*a*; Shapiro-Miller et al. 2007). In areas where these types of fires are common, fire frequencies derived from scarring will likely underestimate the true periodicity of fire, at least in forests that are similar to those studied here. However, the degree of underestimation will likely depend on the scale and intensity of fire-scar sampling, as well as bark thickness, the density of coarse woody debris, and rates of fuel accumulation within given forest types and (or) stands.

Regarding the question of whether the absence of evidence (fire scars) is actually evidence of the absence of fire, our results clearly demonstrate that the lack of fire scars should not be interpreted as the absence of fire. Fire-scarred trees were only a small subset of the actual number of trees that experienced fire (8.3%) in the 16 ha SSPM watershed.

Employing sampling techniques and sample densities discussed by Van Horne and Fulé (2006) in coniferous forests that once experienced frequent, low- to moderate-intensity fire regimes should result in accurate estimates of past fire frequency when intervals between fires are >10 years. It is not clear how widely applicable our results are across other forest types and regions; similar studies in other locations would assist in determining the frequency of fire-scar formation and the processes that lead to scarring.

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