Uncertainty in Fire History and Restoration of Ponderosa Pine Forests in the Western United States

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Abstract—*Fire-history data for ponderosa pine forests in the western U.S. have uncertainties and biases. Targeting multiple-scarred trees and using recorder trees when sampling for fire history may lead to incomplete records. For most of the western U.S., research is insufficient to conclude that high-severity fires did or did not occur in these forests prior to EuroAmerican settlement, because the needed data are not commonly collected. The composite fire interval is shown here to be misleading, but this can be remedied in part with interval estimates by fire size class. These problems mean that an assumption—that high surface-fire frequencies will restore and maintain the structure of these forests—lacks a foundation in reliable fire-history research.*

Introduction

Restoration of fire in ponderosa pine forests depends upon fire-history data that are potentially biased and more uncertain than generally recognized (Minnich et al. 2000, Baker and Ehle 2001). Problems include a lack of modern calibration, inappropriate measures, targeted sampling, absence of fire-severity evidence, and insufficient treatment of variability and uncertainty (table 1). Some of these problems may be resolved quickly, while others will require longer study or may never be resolved. Here we highlight a few of the problems, suggest some remedies, and provide some thoughts regarding restoration of fire, given these problems.

No Modern Calibration

A significant problem plaguing fire-history research is a lack of modern calibration. Pollen studies, fire-history studies, and other paleo-ecological studies require calibration to determine whether evidence is preferentially preserved or lost and how it can be interpreted. Little is known about how fires leave evidence in the landscape over time. There is no way of knowing, without observing actual fires over time, whether it is possible to accurately reconstruct parameters (e.g., mean fire interval) of the fire regime from fire scars, and, if so, how to sample to best accomplish this. Calibration may allow corrections to be derived that enable reasonably accurate reconstructions.

One calibration approach might be to use fire boundaries reconstructed using aerial photographs (e.g., Minnich et al. 2000) or use other historical records, such as atlases of past fires. This would be particularly valuable if multiple approaches to sampling on the ground were compared to aerial-photo

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Table 1—Some limitations, potential biases, and uncertainties in fire-history studies in ponderosa pine forests.

- No modern calibration
  - Only know that some historical fires can be detected
- Biases
  - Targeted sampling
    - Trees with multiple fire scars
    - Places with high fire-scar densities
    - Old trees or forests with long fire records; avoid young trees and forests
    - Trees with open scars
  - Fire severity unstudied, but assumed to be low
    - Necessary age-structure data not collected
  - Analysis and treatment of fire-scar data
    - Recorder trees-do they work?
    - Only scar-to-scar intervals included
    - Compositing is biased toward smaller fires
- Uncertainties
  - Fire perimeters unknown
  - Fire record is uncertain due to unrecorded fires and unburned area within fire perimeters
  - Variability in fire-intervals is large and seldom explicitly treated
  - Large variability means sample sizes provide insufficient power for comparisons
  - Bracketing and confidence intervals are warranted

or map estimates. However, photographs and historical sources also have limitations and biases. Small fires may be undetectable in typical aerial photographs, and dating to single years is usually not possible (Minnich et al. 2000). There is no research program at the present time to actually undertake this calibration work, but it is surely needed.

In lieu of calibration, all that can be done is to work with sampling designs, sample sizes, and analysis techniques to see how the sampling estimates vary relative to a more complete sample. Some of this relative comparison work has been underway (Baker and Ehle 2001), but even this work is in its infancy. New sampling designs are being proposed and studied (e.g., Arno et al. 1993, Heyerdahl et al. 2001). There are promising signs that in a few years we will know how to sample in the most efficient, unbiased manner.

Potential Biases and Uncertainties

Targeting Multiple-Scarred Trees

Fire-history researchers have seldom sampled randomly or in an unbiased manner. Instead, they typically and purposely seek trees containing multiple scars and places that contain high scar densities (table 1). These are assumed to increase the length of the record and maximize identification of the fires that burned a stand. However, no study has actually compared the fires identified through targeting with those on non-targeted trees, or examined the effects of targeting on estimates of fire intervals in ponderosa pine forests.

To compare how targeted and non-targeted trees record fires and fire intervals, we sampled all visible scars on trees in nine plots randomly placed within the ponderosa pine zone in Rocky Mountain National Park (Ehle and Baker, in press). A total of 137 scarred trees was sampled. All fire scars were visually crossdated using a master chronology. Most trees had a single fire scar, but six trees had four or more scars per tree (figure 1). Trees with four or more scars are those that typically would have been selected for sampling using a targeting approach, based on a review of ponderosa pine fire histories (Baker and Ehle 2001). These six trees contained a total of 35 fire scars. We randomly selected an equal sample of 35 scars from trees that would not have been

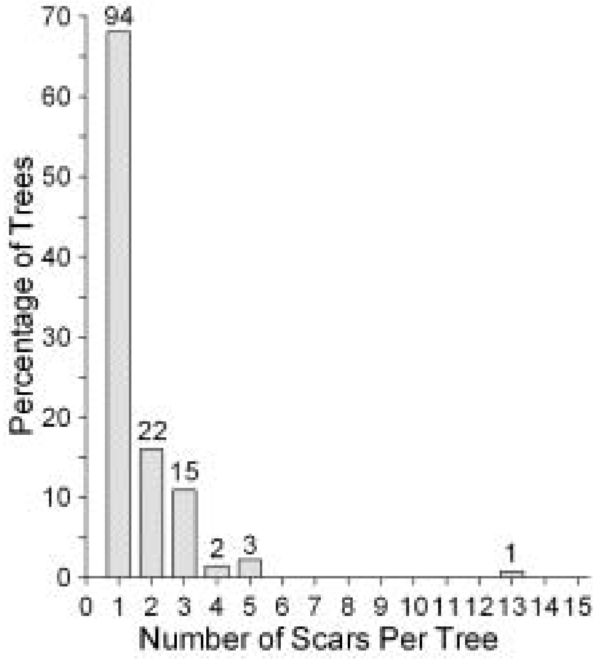

Figure 1–Percentage of sampled, fire-scarred trees (n=137) that have one or more than one scar per tree. The number of trees is listed above each bar.

targeted (trees containing £3 scars). A third sample of 35 scars was obtained from single-scarred trees. Individual trees did not occur in more than one of these samples.

Then, we separated the fires that were identified by these scars into five combined size and severity classes (figure 2; see also Ehle and Baker, in press). Low-severity fires leave numerous surviving trees, while mixed-severity fires leave only a few survivors in a plot, or are high-severity fires in part of a landscape and low-severity elsewhere (Ehle and Baker, in press). Small fires in this study scar more than one tree, and are not known to have spread beyond a 50 m X 50 m plot, but could have been as large as 1.2 km^2. Large fires burned >1.2 km^2.

The targeted sample identified more fires (n = 29) than did the single-scarred trees (n = 20) or the non-targeted sample (n = 16) even though the

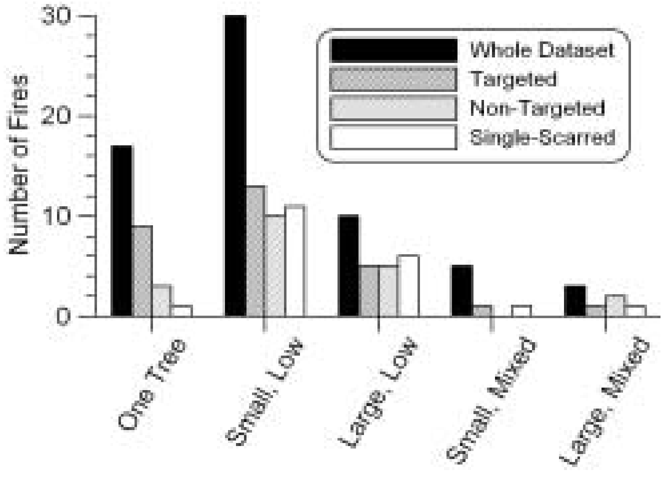

Figure 2–Effects of targeted sampling on the number of detected fires for fires of different sizes and severities. Small fires likely do not exceed the area of a sampling plot (50 m X 50 m), while large fires burn > 1.2 km^2.

number of scars was 35 in all cases. The fires identified by the samples can be compared to the total set of 60 fires identified by the 137 scarred trees in the nine sampled plots ("Whole Dataset" in figure 2). The targeted sample generally identified more of the small fires affecting only one tree and the small, low-severity fires, while the non-targeted sample and single-scarred trees identified few one-tree fires, but did as well or slightly better at identifying large, low-severity fires and mixed-severity fires (figure 2). Seventeen one-tree fires occurred in the nine plots (each of 0.25 ha) over a period of about 300 years, which is a rate of about one tree / ha scarred by fire every 40 years, an insignificant amount. If one-tree fires are ignored, there is not much difference among the samples in ability to detect fires of different size and severity.

However, an important difference is that the targeted sample comes from only six trees, while the single-scarred sample comes from 35 trees. Less effort is required to obtain the 35 scars from only six trees than from 35 single-scarred trees. However, 35 trees provide a much better spatial sample of where the fires burned, thus making it possible to more correctly identify fire size and severity (if age-structure data are also collected). If 35 trees can be sampled in either case, many more fires will be detected with a targeted sample of trees containing >4 scars than with a sample of single-scarred trees.

In our review (Baker and Ehle 2001), we expressed concern that fire intervals identified in a targeted sample might be much shorter on average than in a non-targeted sample. To test this, we used the same sets of samples from targeted, non-targeted, and single-scarred trees, each sample containing 35 fire scars. Then, we listed all the fires and fire intervals identified by each sample of 35 fire scars, and used an ANOVA (done using Minitab 12.1; Minitab, Inc. 1998) to test the null hypothesis that the mean fire interval for small, low-severity fires is equal regardless of sampling technique. While fire-interval data can have non-normal distributions, parametric statistical tests remain valid (Johnson 1995). We repeated the ANOVA for large, low-severity fires. Comparisons for mixed-severity fires are not possible due to small sample sizes (figure 2). The null hypothesis cannot be rejected for small, low-severity fires ($F = 0.21$, $p = 0.810$) or large, low-severity fires ($F = 0.00$, $p = 0.997$).

While the sample from multiple-scarred trees may not be biased in this regard, multiple-scarred trees alone will not identify all the fires in a stand. Three of the 60 fires were only found on single-scarred trees, five were only on double-scarred trees, and three were only on triple-scarred trees, all of which would be missed if trees containing four or more scars were targeted. Of these 11 fires (18% of the 60 fires), two were one-tree fires (figure 2), but eight were small, low-severity fires, while one was a significant high-severity fire. Three of these 11 fires occurred near or before AD 1700 and documented 30% of the 10 ancient fires found in the study area. Researchers seeking complete fire histories or long fire histories will miss important fires and ancient fires if only multiple-scarred trees are sampled, at least in this study area.

We conclude that targeting multiple-scarred trees in this case study does not produce a biased estimate of the fires that occurred in a larger sample or a biased estimate of the mean fire interval relative to that found with other samples. However, fire histories derived from targeted sampling may be incomplete, particularly missing some important fires and ancient fires.

However, this one small study is insufficient to draw strong conclusions about targeting. Fire intervals in this case study are quite variable, and the test, as a result, may not have much statistical power. Further testing is needed before these results are applied elsewhere. The other potentially significant targeting biases (Baker and Ehle 2001) also need testing. Moreover, until there is a modern calibration, the possibility remains that these sampling approaches simply produce equally biased estimates of fire intervals and other parameters of fire regimes.

Crown Fires and Mixed-Severity Fires Not Sampled in Ponderosa Pine Forests

If restoration of fire in ponderosa pine forests is to be successful, historical variability in fire severity must also be known. The evidence needed to determine fire severity is a combination of fire-scar data and age-structure data near each scar. Low-severity fires generally lead to low mortality of larger, established trees. High-severity fires can lead to pulses or a cohort of post-fire regeneration (Ehle and Baker, in press). A mixed-severity fire has a high-severity, crown-fire component and an associated low-severity component.

A fire scar alone, or even multiple fire scars across a landscape, reveal little about the severity of the fire. Fire scars indicate only that a fire was on the surface at the scarred tree itself. This tree could be a lone survivor of a fire that was in the crown of every other tree in the surrounding landscape. Scattered surviving trees are not uncommon in crown-fire landscapes (e.g., Kipfmueller and Baker 1998). The fire may have also have been mixed-severity, burning on the surface over a part of the landscape where the scar was found, and then crowning out in patches (e.g., Huckaby et al. 2001).

The idea that surface fires predominate in ponderosa pine forests has been so pervasive that fire-history researchers commonly study fires in these forests without collecting age-structure data, then erroneously conclude that it is known that surface fires predominate or that crown fires did not occur. Some researchers have even implied that, if fire-scars are present and ponderosa pine is present, this indicates that the fire regime sustained only low-severity surface fires (Heyerdahl et al. 2001). This is false, as crown fires in ponderosa pine forests can be followed within a few decades by surface fires as the stand develops (Ehle and Baker, in press).

Thirty-nine studies constitute nearly all the published scar-based fire-history research on pure ponderosa pine forests in the western United States (Baker and Ehle 2001). Only nine of the 39 collected the age-structure data needed to determine whether fire severity was low, medium, or high (table 2). Four other studies collected age structure, but not fire-scar data. These 13 studies with age-structure data reveal three general patterns. First, some studies of small areas or plots reveal an uneven age structure, often with apparent pulses of regeneration separated by gaps in regeneration, suggesting an absence of crown fires. Regeneration pulses in these plots are sometimes linked to variations in surface-fire frequency (Arno et al. 1995, 1997; Morrow 1986) or a combination of fire and climate (Cooper 1960), or they cannot presently be explained (Mast et al. 1999, White 1985). Second, some plots contain an even age structure, characterized by large pulses of regeneration commencing after a date identified on a nearby fire scar, suggesting a crown fire at the level of the plot (Arno et al. 1995, 1997; Mast et al. 1998). Brown and Sieg (1996) thought that ages of scarred trees in one plot were roughly synchronous, suggesting a possible crown fire or a climatic event. Age data (apparently collected but not presented) suggest that infrequent stand-replacing fires occurred in some parts of two study areas prior to EuroAmerican settlement (Barrett 1988, Swetnam and Baisan 1996b).

Third, more extensive landscape-scale studies that include multiple plots across an area of a few thousand hectares have revealed a mixed- or high-severity fire regime in the pre-EuroAmerican era. This was found in pure ponderosa pine landscapes of Rocky Mountain National Park, Colorado (Ehle

Table 2–Evidence of mixed-severity and high-severity (crown) fires in the pre-EuroAmerican period from studies of ponderosa pine fire history and age structure in the western United States.

	Age data[a]	Historical data[b]	Fire scar data	Comments on crown fires
Northwestern U.S.				
Bork 1984	No	No	Yes	No
Heyerdahl 1997	No	No	Yes	They did not occur because surface fires did occur.
Morrow 1986	Yes	No	Yes	No, uneven age structure with pulses of regeneration linked to low fire frequency
Sherman 1969	No	No	Yes	No
Soeriaatmadja 1966	No	No	Yes	Yes, they probably occurred on higher elevation, more moist sites
Weaver 1943	No	Yes	No	Yes, direct observation of even-aged stands suggesting past crown fires.
Northern Rockies				
Arno 1976	No	No	Yes	No
Arno and Petersen 1983	No	No	Yes	No
Arno et al. 1995	Yes	No	Yes	Yes, one stand of six dry-site stands and some wet-site stands
Arno et al. 1997	Yes	No	Yes	Some dry-site ponderosa pine forests must have experienced occasional stand replacement fires
Barrett 1988	Yes	No	Yes	Yes, infrequent stand-replacing fires are possible in upper elevations
Freedman and Habeck 1985	No	Yes	Yes	Yes, early historical observations suggest they occurred
Steele et al. 1986	No	No	Yes	Yes, hypothesizes that they occurred in the past during periods of drought and high winds.
Black Hills				
Brown and Sieg 1996	Scars	No	Yes	Yes, they were possible, but not verified; climate an alternative cause of regeneration events
Brown and Sieg 1999	No	No	Yes	No
Brown et al. 2000	No	No	Yes	No
Shinneman and Baker 1997	No	Yes	No	Historical records document large stand-replacing fires, particularly in the moister northern Black Hills
Southern Rockies				
Brown et al. 1999; Kaufmann et al. 2000; Huckaby et al. 2001	Yes	No	Yes	Yes, 71% of sampled polygons had stand-replacing fires
Brown et al. 2000	No	No	Yes	No
Ehle 2001; Ehle and Baker, in press	Yes	No	Yes	Yes, in 6 of 9 plots
Goldblum and Veblen 1992	No	No	Yes	Yes, but only in post-settlement
Laven et al. 1980	No	No	Yes	No
Mast et al. 1998	Yes	No	Yes	Even-aged cohorts and post-fire pulses of establishment, but linked to gaps or spot fires (crown fires)
Rowdabaugh 1978	No	No	Yes	No
Skinner and Laven 1982	No	No	Yes	No
Veblen and Lorenz 1986, 1991	Yes	Yes	No	Age structures and early photographs that show crown fires that occurred near or before EuroAmerican settlement
Veblen et al. 2000	No	Review	Yes	Yes, early photographs show them, and fire intervals are long enough to allow them at higher elevations
Southwestern U.S.				
Cooper 1960	Yes	Yes	No	No evidence of crown fires except possibly on a part of the Prescott National Forest
Dieterich 1980a	No	No	Yes	No
Dieterich 1980b	No	No	Yes	No
Dieterich and Hibbert 1990	No	No	Yes	No
Fule et al. 1997	No	No	Yes	No
Grissino-Mayer 1995	No	No	Yes	No
Madany and West 1980	No	No	Yes	No
Mast et al. 1999	Yes	No	No	Same site studied by White (1985); uneven age structure with pulses of regeneration not clearly linked to either climate or fire.
McBride and Jacobs 1980	No	No	Yes	No
McBride and Laven 1976	No	No	Yes	No
Morino 1996	No	No	Yes	No
Savage 1989; Savage and Swetnam 1990	No	No	Yes	No
Stein 1988	No	No	Yes	No
Swetnam and Baisan 1996a	No	No	Yes	No
Swetnam and Baisan 1996b	Yes	No	Yes	Yes, some evidence in dates of tree mortality and tree recruitment relative to fires synchronous over large areas
Swetnam and Dieterich 1985	No	No	Yes	No
Touchan et al. 1995	No	No	Yes	No
Touchan et al. 1996	No	No	Yes	No
White 1985	Yes	No	No	No, uneven age structure with pulses of regeneration

[a] Sufficient tree age data to be able to identify a crown fire in the pre-EuroAmerican period.
[b] Early photographs or historical observations from near or before settlement by EuroAmericans.

and Baker, in press) and in mixed-conifer landscapes with considerable ponderosa pine dominance at Cheesman Lake, Colorado (Brown et al. 1999, Kaufmann et al. 2000, Huckaby et al. 2001). In the Rocky Mountain National Park study, six of nine plots had stand-replacing fires and another plot had a stand-replacing event caused by an unidentified agent (Ehle and Baker, in press). In the Cheesman Lake study, 71% of sampled polygons had stand-replacing fires (Huckaby et al. 2001). Fires in both landscapes often were mixed-severity at the landscape scale, burning as surface fires in some areas and then crowning over other areas. Both studies reported that smaller parts of these landscapes contained uneven-aged stands with no evidence of crown fires for the past few hundred years.

Studies that use historical records or early photographs also found that crown fires occurred in some ponderosa pine forests, but not others, prior to EuroAmerican settlement (table 2). Shinneman and Baker (1997) reviewed historical evidence of extensive crown fires in the moister parts of the Black Hills, and Freedman and Habeck (1985) also noted historical evidence of crown fires prior to EuroAmerican settlement in a valley in western Montana. In early historical photographs Veblen and Lorenz (1991) could see ponderosa pine landscapes that were burned in stand-replacing fires some time before EuroAmerican settlement. Cooper (1960) reported that a review of early literature failed to find evidence of crown fires in ponderosa pine forests in Arizona before 1900, except on part of the Prescott National Forest. There is no further explanation of the Prescott case. Weaver (1943 p. 9), describing a broad region in the Pacific Northwest, simply stated that “extensive even-aged stands of ponderosa pine can probably be accounted for by the past occurrence of severe crown fires, by severe epidemics of tree-killing insects...or by the occurrence of extensive windthrows...” A more extensive review of early historical reports and photographs might reveal where stand-replacing fires had or had not occurred prior to EuroAmerican settlement.

For most of the ponderosa pine forests of the western United States there are no data at all that would allow a determination of whether crown fires or mixed-severity fires were present or absent before EuroAmerican settlement, or have increased or decreased. Where studies have been done or historical data were examined, crown fires or mixed-severity fires were sometimes found and sometimes not (table 2). There is a hint in these data that crown- or mixed-severity fires may occur on moister sites in the ponderosa pine zone.

No one, in any study anywhere in the West, has yet estimated how frequent crown- or mixed-severity fires were in ponderosa pine forests, how large these fires may have been, or what the fire rotation for these fires might have been prior to EuroAmerican settlement. The data are perhaps there to allow this estimation for study sites at Cheesman Lake, Colorado (Huckaby et al. 2001) and in Rocky Mountain National Park (Ehle and Baker, in press). These study areas, however, are small relative to the size of some recent fires (e.g., Hayman Fire, 2002). Larger areas have been logged or burned, destroying the evidence of past fires. It may be difficult or impossible to determine whether large, high-severity fires did or did not occur in ponderosa pine landscapes prior to EuroAmerican settlement.

Given the lack of data, there is little basis for the general perception that high- or mixed-severity fires, such as the 2000 fire that burned into Los Alamos, New Mexico, are not natural in ponderosa pine forests (Allen 2002). The conclusion that a particular fire is unnaturally severe is premature given the absence of the necessary data. For nearly all the ponderosa pine forests in the western United States it would also be premature to suggest that treatments that lower the probability of crown fire or high-severity fire or lower fire risk are “restoration.” For most of the range of ponderosa pine in the West it is not yet known whether these kinds of fires were or were not a part of the pre-EuroAmerican fire regime. Where crown fires occurred, thinning may be an inappropriate restoration technique, just as it is inappropriate in some pinyon-juniper woodlands (Romme et al., this volume). In some cases, restoration might even require reintroduction of high-severity fires, if they were unnaturally suppressed.

Analysis and Treatment of Fire-Scar Data

Recorder Trees—Do They Work?

It has long been thought that until a tree receives a fire scar, it is a poor recorder of fires. Thus, fire historians often do not consider a stand to be generally capable of recording the fires that occur in a stand until after some number of trees has received a first scar (e.g., 3; Grissino-Mayer 1995). The idea of a previously scarred “recorder tree” is that if there is an open scar, subsequent fires should be more effectively recorded than if fires must produce the first scar. If recorders work, fires should show up more often on recorder trees than as a first scar.

In our complete sample from 137 scarred trees, we found 60 fires. Nineteen of these fires (31.7%) show up only as first scars, while 17 fires (28.3%) show up only as scars after the first scar (i.e., on recorder trees). This result could occur if previously scarred trees are actually no better recorders or if different fires affected the recorder trees and the trees with first scars. However, 24 fires (40%) show up as a mixture of first scars and scars on recorder trees. Ninety-six of the 154 total scars (62%) documenting these 24 fires are first scars while only 58 of the 154 scars (38%) occur on recorder trees. A chi-square test leads to rejection of the null hypothesis that recorder trees and trees without scars are equal recorders of fires when fires show up on both ($\chi^2 = 4.761$, $p = 0.029$). In our study area, previously scarred trees are poorer recorders of fire than are unscarred trees. Previously scarred trees do not perform as commonly expected, perhaps because multiple factors influence whether a fire produces a scar. Smaller trees, for example, typically have thinner bark, which offers less resistance to scarring, perhaps making them better recorders than are larger trees. Our results suggest that if a complete history is desired, fire-history data should be collected and used whether a tree is or is not previously scarred. Fire-history studies that only use recorder trees may miss a significant part of the fire history.

Which Intervals Should Be Used?

Fire historians nearly always have focused on scar-to-scar (SS) intervals recorded on trees, omitting the interval between tree origin and the first scar (OS interval; Baker and Ehle 2001) as well as the interval between the last scar and tree death or the present. Yet, the OS interval estimates the real fire-free interval needed for trees to reach a size sufficient to survive surface fires (Baker and Ehle 2001). Since the OS interval does not necessarily begin with a fire, the real fire-free interval may be underestimated by the OS interval.

The OS interval is typically longer than the SS interval (Baker and Ehle 2001). In our sample of 137 fire-scarred trees from Rocky Mountain National Park’s ponderosa pine zone (figure 3), the pre-EuroAmerican OS interval on individual trees (n = 71) has a mean of 55.4 years and an estimated median of 51.5 years. The pre-EuroAmerican SS intervals on individual trees (n = 40), in

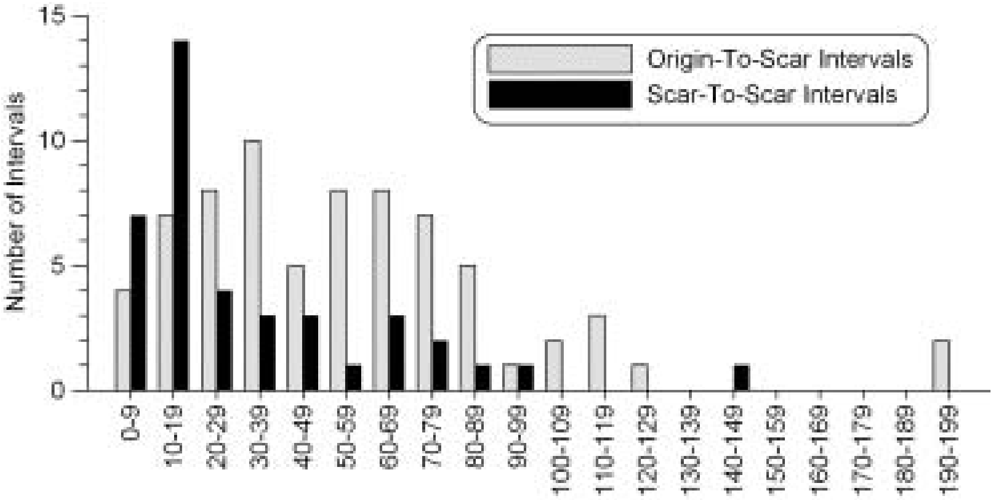

Figure 3–Distribution of pre-EuroAmerican fire-scar intervals for individual trees from a sample of 137 fire-scarred trees in ponderosa pine forests of Rocky Mountain National Park.

contrast, have a mean of 33.3 years and an estimated median of 28.5 years. The estimated difference in means is 22.1 ±13.2 years (95% confidence interval). The regression equation in Baker and Ehle (2001) for estimating the OS interval, if only the SS interval is known, suggests that the mean OS interval would be 53.5 years for a mean SS interval of 33.3 years, reasonably close to the 55.4 years actually found. The OS interval should be included as a real fire interval, and including it generally lengthens the estimated mean fire interval by about 1.6 times (Baker and Ehle 2001).

Compositing Biased Toward Small Fires

The mean “Composite Fire Interval” or CFI (Dieterich 1980a) is the traditional measure of central tendency in fire intervals, but this measure is flawed as a general measure of the fire regime (Baker and Ehle 2001). One problem is that the CFI pools fires of different extent and frequency. Regardless of the real mean fire interval in a landscape, the mean CFI decreases as the number of sampled fire-scarred trees and sampled area increase (Arno and Petersen 1983). The reason is that the numerous fires that scar only one tree (e.g., figure 2) are counted the same as an infrequent fire that scars many trees (Minnich et al. 2000, Baker and Ehle 2001). By adding sampling area or sampled trees, one quickly adds these apparently small fires. As a result, a CFI can be interpreted as mostly reflecting the frequency of small fires that affect little of the landscape.

A remedy for this shortcoming of a CFI is to analyze and report fire intervals separately for individual classes of fire size. Laven et al. (1980) may have been the first to use this approach for ponderosa pine forests when they reported separate intervals for small fires and large fires. Bork (1984) showed means and standard errors for fires varying in size from 1 plot to 5 plots (figure 4). Morino (1996) calculated separate fire-interval distributions and descriptive parameters (e.g., mean) for small fires, medium fires, and large fires. Mean fire intervals for larger fires in ponderosa pine forests are 41.7 years (Laven et al. 1980), 60-150 years (Bork 1985 and figure 4), and 24.4 years (Morino 1996), while the corresponding mean fire intervals for small fires in these studies are 20.9 years, 5.25 years, and 2.7 years, respectively. Thus, larger fires in these cases have mean intervals that are 2-10 times as long as are mean intervals for smaller fires. These estimates are imprecise, but illustrate that the mean fire interval for the fires that do most of the work in ponderosa pine forests is much longer than suggested by typical CFIs.

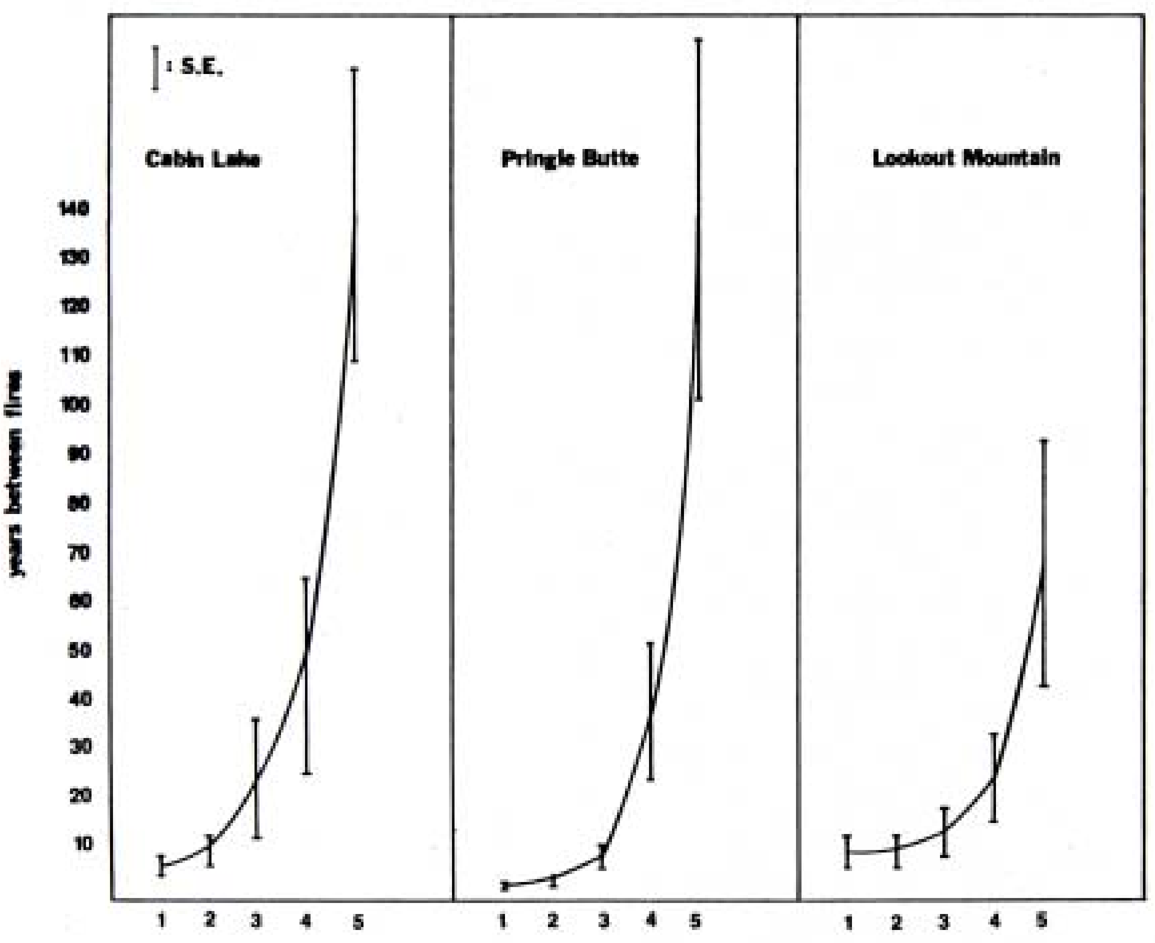

Figure 4–Mean return interval for fires of different size from three sites in eastern Oregon, estimated by proportion of plots having at least two fire-scarred trees. Reproduced from Bork (1985) Figure I-24 with permission from Joyce L. Bork.

Our review of 11 studies in the western United States show that about 50% of known fires are documented by a scar on only one tree (Baker and Ehle 2001). Given that these fires affect little land area, but dominate the CFI, we particularly suggest that the frequency of one-tree fires should be reported separately.

The idea that there is value in reporting intervals for fires of different sizes underlies the now-popular reporting of interval data for all fires compared to those that scar >10% or >25% of recorder trees (Grissino-Mayer 1995). However, it is not progressive restriction (sizes exceeding a certain size) that is needed, but separate reporting of intervals for each size class. Reporting a CFI for study areas of increasing size (e.g., Brown et al. 1999) is also not what is needed, as it is well known that CFIs decrease as study area size increases, even if the fire regime is the same across scales (Arno and Petersen 1983).

Separating fire-intervals by fire size also allows estimation of the fire rotation, a fundamental measure of the fire regime (Minnich et al. 2000, Baker and Ehle 2001). Data on the relative frequency and importance of fires of different sizes are invaluable for fire managers, as this information can be used directly in prescribed burning plans, regardless of the size of the management area. This is not the case for the traditional CFI, which is heavily dependent on the size of the study area in which the CFI was calculated (Arno and Petersen 1983, Baker and Ehle 2001).

What are appropriate fire size classes to use? Even reporting intervals based on number of affected plots (figure 4), or linear distances between plots, would be an improvement over a traditional CFI. Size classes used by the U.S. Forest Service and other agencies would be advantageous, as data from fire-history studies could then be compared to contemporary data from monitoring programs. Where fire-history data are insufficient to make fine distinctions in fire size, pooling of adjacent categories would still allow useful comparisons with modern data, particularly if small fires are segregated from large fires.

Unfortunately, it is difficult to estimate the size of surface fires using fire scars. Grid-based or random sampling methods are increasingly making it possible to approximate fire extent (Arno et al. 1993, Heyerdahl et al. 2001, Morino 1996). However, there is not yet a calibration to guide correction of size estimates from spatial sampling networks or sufficient study of appropriate spatial sampling designs for detecting fire sizes. Until this calibration and sampling design work is done, a method to bracket the potential uncertainty associated with assigning fires to size classes is needed.

Uncertainties

Fire intervals vary, and this variability is often large within a single tree and among all the intervals within a stand (e.g., figure 3). This variability suggests that fire intervals are not predictable results of the time for fuel to build up after a fire; fire intervals are shaped by the timing of weather that promotes fine-fuel accumulations and the timing of droughts (Veblen et al. 2000). This variability in fire intervals makes comparison of sets of fire intervals from different periods or different sites difficult, as sample sizes must be large to be able to detect even 50% or 100% differences in mean with adequate statistical power (Baker and Ehle 2001). However, few researchers have actually used statistical inference, instead simply presenting the sample data. Previous evidence that fire intervals have changed over time or differ among sites may not bear up under statistical analysis, except where the change is obvious, as when fires appear to virtually stop near or after settlement (e.g., Savage and Swetnam 1990).

Fire-interval data also have uncertainty that comes from at least two sources– unrecorded fires and unburned area within fire perimeters. There is presently no method to estimate the magnitude of these sources of uncertainty in a particular stand or area. Baker and Ehle (2001) thus suggest that all estimates of mean or median fire intervals should be bracketed using the restricted (>10% scarred) CFI and individual-tree mean fire intervals. However, if fire intervals are reported separately by fire size, as we recommend here, then the appropriate brackets for the estimate of mean fire interval for a stand are the unrestricted composite and individual-tree fire intervals.

Implications for Restoration

Fire-history research methods are in need of reassessment, as traditional measures are misleading or in error as sources of information useful for designing a program for restoring fire in ponderosa pine forests. The time that it took for fire to burn through these forests prior to EuroAmerican settlement is much longer than is implied by typical composite fire intervals, which have been reported to be between 2-25 years (Baker and Ehle 2001). The large fires, that actually account for most burned area, occur at intervals that are several times longer than reported composite fire intervals. Baker and Ehle argued that the population mean fire interval in western ponderosa pine forests is instead more likely to lie between 22-308 years. However, until there is a modern calibration and further testing of the potential biases and uncertainties we have identified, it would be premature to draw strong conclusions about what the fire intervals were in pre-EuroAmerican ponderosa pine forests.

Our analysis suggests that repeated prescribed burning of large areas of ponderosa pine forests at short intervals (e.g., less than 20 years) lacks a sound basis in science, and should not be done at the present time if the goal is restoration. In most parts of the western United States there is also insufficient evidence to support the idea that mixed- or high-severity fires were or were not absent or rare in the pre-EuroAmerican fire regime. Thus, programs to lower the risk of mixed- or high-severity fires in ponderosa pine forests (e.g., the National Fire Plan, Laverty and Williams 2000) have insufficient scientific basis if the goal is restoration.

Fire practitioners interested in restoration can certainly proceed with reintroducing fire into these forests on a limited basis, however. In many areas, fire has been excluded by livestock grazing or intentional suppression for a long period. We suggest that prescribed burning a large area once is not likely to push the ecosystem outside its historical range of variability. Reintroduction of small prescribed fires that burn a single tree or a few trees in a landscape is also appropriate, at least in our study area. However, prescribed burning of large land areas after short intervals (e.g., <20 years) has little scientific basis at the present time, if the goal is to restore the natural variability of the pre-EuroAmerican fire regime.

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