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DO RULES OF THUMB MEASURE UP? CHARACTERISTICS OF FIRE-SCARRED TREES AND SAMPLES

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ABSTRACT

Dendrochronologists studying fire history must be strategic in their search for fire-scarred tree samples. Because it is desirable to extend the period of analysis in a site by looking for old scars, recent scars, and trees with large numbers of scars, researchers have developed rules of thumb regarding which trees are most likely to meet these goals as well as where fire scars are most likely to be found. To test our assumptions and quantify patterns about tree and sample characteristics, we analyzed a dataset of 2800 samples and 16,036 scars. On average, logs had the oldest scars and live trees had the most recent scars, although both very old and very recent scars were found on snags and stumps. Scars tended to be located on the uphill sides of trees, particularly on steeper slopes. The number of years between pith date and first fire scar ranged from 2 to 473 years, with a median of 52 and a mean of 67. The data confirm that searching for a variety of sample types and looking on the uphill sides of trees are useful methods for efficient sampling and extending a fire history record.

Keywords: dendrochronology, fire history, fire scars, number of scars, sample selection, sample type, scar age.

INTRODUCTION

Fire-scarred tree samples can provide valuable information about historical fire regimes over multiple centuries (Falk *et al*. 2011). Information from fire-scarred trees has been used to reconstruct fire regimes (*e.g.* Baisan and Swetnam 1990; Stephens *et al*. 2003), evaluate climate relationships with fire (*e.g.* Heyerdahl *et al*. 2002; Yocom *et al*. 2010), and infer human-fire dynamics (*e.g.* Niklasson and Granström 2000; Poulos *et al*. 2013). To extend the time period of analysis, researchers usually try to capture the longest-possible record of fire (Swetnam and Baisan 1996; Farris *et al*. 2013). This means dendrochronologists look for scars in what appears to be the oldest wood, usually stumps, logs (fallen trees), and snags (standing dead trees), as well as the most recent scars, which are considered to be most likely found on live trees.

Fire scars are most often found on the uphill sides of trees (Arno and Sneck 1977). This is because fires typically burn in an uphill direction, and fire scars are usually formed on the leeward side of a tree because the residence time of fire is longer and the temperatures are hotter there (Gutsell and Johnson 1996). In addition, fine fuels accumulate on the uphill side of trees. For these reasons, a common rule of thumb is that fire scars are more likely to be found on steeper slopes. Other rules of thumb when scouting for fire-scarred trees include (1) bigger trees are likely to have more scars because they tend to be older, (2) logs, snags, and stumps are likely to have the oldest scars (because they often contain the oldest wood in an area), and (3) live trees are likely to have the most recent scars (because they contain the newest wood). Additionally, researchers often choose to take samples from trees with multiple scars because they assume those trees contain a more complete and longer record of fire (*i.e.* earlier fire scars; Farris *et al*. 2013). Many of these rules of thumb are based on experience and anecdotal evidence rather than quantitative analysis. Our primary objective in the present study was to summarize the data from a large number of fire history studies carried out over several years in

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multiple sites to provide information that may help improve fire scar searching and sampling approaches.

We also analyzed the available data to test the idea that a fire-free interval of approximately 50 years is necessary for trees to regenerate, as proposed by Baker and Ehle (2001). To do this, we determined pith-to-first scar intervals on fire-scarred trees. Baker and Ehle (2001) used the term origin-to-scar intervals, but our dataset includes pith dates rather than origin dates (*i.e.* germination dates), which are not corrected for height-age relationships (Brown *et al.* 2008).

Based on experience and anecdotal evidence, we hypothesized that:

1. Mean scar dates are earliest in logs, intermediate in snags and stumps, and most recent in live trees;
2. More scars are found on steeper slopes;
3. More scars are found on the uphill sides of trees;
4. More scars are found on larger trees;
5. Samples with more scars tend to have older scars;
6. Field estimates of number of scars provide a good estimate of number of scars identified in the laboratory;
7. First fire scars form at least 50 years after pith dates.

METHODS

We analyzed data compiled from multiple fire history studies carried out by the Northern Arizona University School of Forestry and Ecological Restoration Institute. Samples were collected between 1995 and 2012, and were located in the southwestern United States (Arizona and New Mexico), Mexico, and Greece. The majority of trees sampled were in the genus *Pinus*, but a few samples were collected from other genera including *Abies*, *Juniperus*, *Pseudotsuga*, and *Quercus*. Although forest composition varied, all fire history studies were located in areas with frequent fire regimes. Information collected on sampled trees in the field included sample type (live, stump, snag, or log), slope and aspect, diameter, species, elevation, aspect of the scarred catface, height of sample on the tree bole, and a field estimate of the number of scars. Information noted in the laboratory, after sanding and crossdating the sections, included all fire scar dates (including first scar, last scar, and number of scars), inner date and a description of the innermost ring (pith or ring). Not all information was collected for all samples, so we included all available data for each analysis. Data analysis was performed using the statistical software SAS JMP Pro 10.0 and IBM SPSS Statistics Version 21.

RESULTS

The dataset included crossdated samples from 2800 fire-scarred trees, with a total of 16,036 fire scars. Dates of the fire scars ranged from A.D. 1422 through 2008. Elevation was recorded for 1122 samples, ranging from 1125 to 4257 m. Seven-thousand eighty-two scars (44%) were on stumps, 2871 (18%) were on snags, 983 (6%) were on logs, and 4556 (28%) were on living trees. The rest of the scars (3%) did not have sample type recorded.

The dates of all scars varied among logs, stumps, snags and live trees (median dates A.D. 1795, 1800, 1829, 1890, respectively, Figure 1), supporting our first hypothesis. The Welch's test for unequal means given unequal variance indicated significant differences in mean scar dates among the four groups ($p < 0.0001$). Post-hoc tests (Games-Howell) showed that means were significantly different in all pairwise comparisons ($p < 0.05$). However, the range of scar dates on each type of sample was large and the oldest scar in the database was found on a snag. Oldest scar dates for logs, stumps, snags and live trees were A.D. 1520, 1464, 1422, and 1516, respectively, and most recent scar dates were very similar at A.D. 1999, 2002, 2007, and 2008.

In the 2749 samples for which slope was recorded, there was no relationship between slope (%) and the number of scars that were recorded by each tree, meaning our second hypothesis was not supported. A set of 1834 samples were located on a slope ($\geq$1%) and had both the aspect of the slope and the aspect of the fire scars recorded. The scars faced uphill on 1284 (70%) of the samples,

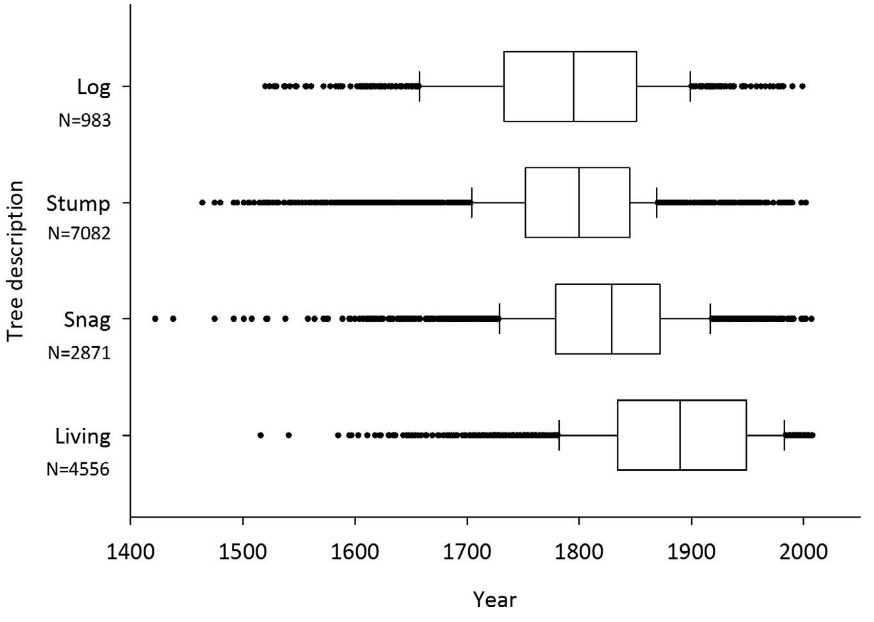

Figure 1. Scar dates found on logs, stumps, snags, and living trees. Box plots show medians, quartiles, error bars indicating 10th and 90th percentiles, and outliers.

exactly sideslope on 29 samples (2%), and downhill on 521 samples (28%). However, on steeper slopes (≥10%, N = 993), scars faced uphill on 857 (86%) of the samples (Figure 2). Our third hypothesis was supported.

There was a very weak but significant ($R^2 = 0.04$, $p < 0.05$, $N = 2668$) linear relationship in a regression between tree size and the number of scars that were recorded by each tree. There was also a weak but significant linear relationship between number of scars and the date of the oldest scar on each tree ($R^2 = 0.11$, $p < 0.05$, $N = 2800$). These results provide weak support for our fourth and fifth hypotheses.

A field estimate of number of scars on a sample was recorded for 2405 samples. Supporting the sixth hypothesis, correlation analysis showed a strong relationship between the field estimates and number of scars noted in the lab ($R^2 = 0.59$, $p < .0001$). Field estimates were correct

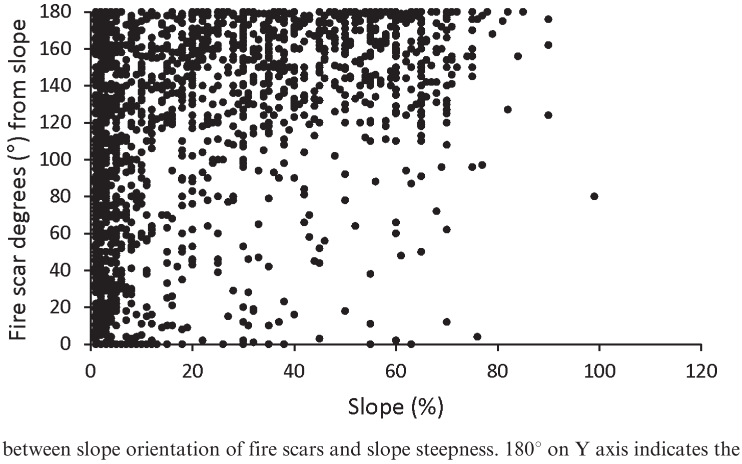

Figure 2. Relationship between slope orientation of fire scars and slope steepness. 180° on Y axis indicates the fire scar faces uphill, 0° on Y axis indicates the fire scar faces downhill.

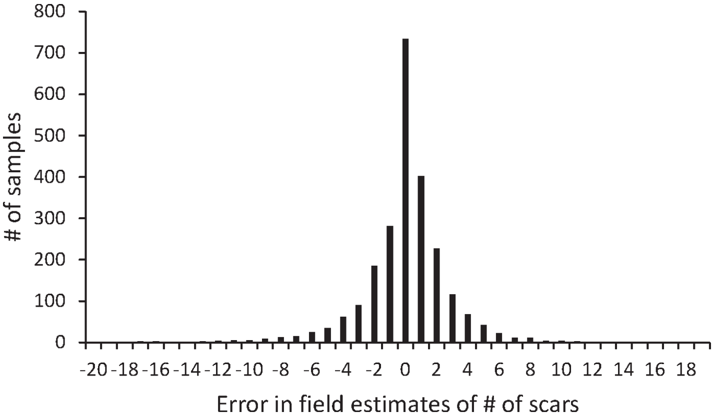

Figure 3. Differences between field-estimated number of scars per tree and lab-confirmed number of scars per tree (N = 2405). Negative numbers indicate fewer scars were estimated in the field than were dated in the lab, positive numbers indicate more scars were estimated in the field than were dated in the lab.

for 734 (31%) of the sampled trees, overestimated the number of scars for 923 (38%) of the sampled trees, and underestimated the number of scars for 748 (31%) of the sampled trees (Figure 3). The average difference between field estimates and lab numbers was 1.8 scars. The greatest difference between field estimates and lab-identified number of scars was 20: one sample was estimated to have 15 scars in the field but actually contained 35 fire scars.

Five-hundred and nineteen of the fire-scarred samples had pith dates. The number of years between the pith and the first scar on those samples ranged from 2 to 473 years. The mean number of years between the pith and the first scar was 67 years, the median was 52, and the highest number of pith-to-first scar intervals was in the 21- to 25-year bin (Figure 4).

DISCUSSION

Several of our hypotheses were validated by the data. Logs had the oldest average fire dates and live trees had the most recent fire scar dates, but very old scars were found on every type of sample. We did not find evidence that more scars are found on steeper slopes, but we did confirm that fire-scarred samples are generally found on the uphill sides of trees. However, this is not universal, as some scars were found on the downhill sides of trees, presumably because some fires burn in a downhill direction. There was a significant relationship between tree size and number of scars, but the predictive power of tree size was close to zero, indicating tree size is not a useful search criterion in the field. We confirmed that there is a weak relationship between the number of scars on a sample and the date of the

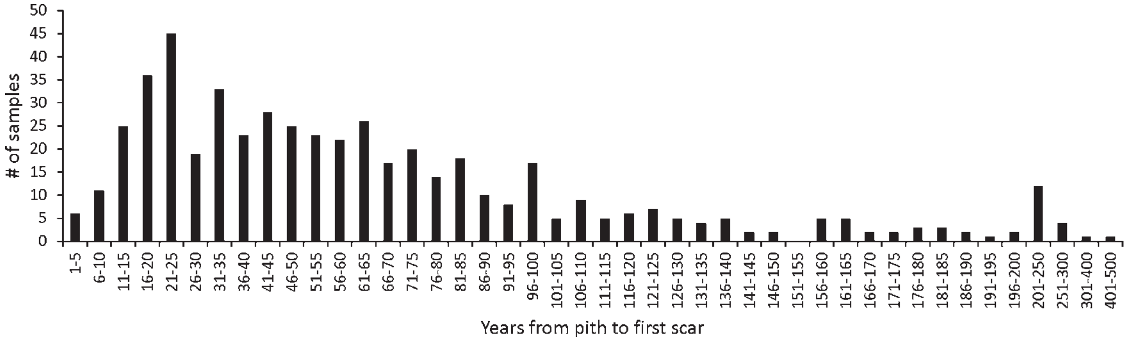

Figure 4. Years from pith to first scar, in 5-year bins (N = 519).

earliest sample, indicating that multiple-scar trees do tend to contain a longer fire record than trees with fewer scars (Swetnam and Baisan 1996). Finally, estimating the number of scars in the field is a useful practice because errors were generally low.

We rejected the hypothesis proposed by Baker and Ehle (2001) that a minimum fire-free period of 50 years was necessary before a young tree could survive a surface fire. The mean number of rings between pith dates and first fire scar dates was more than 50. However, half of the samples had 52 rings or less between the pith and the first fire scar (median = 52), and the highest number of samples fell in the 21–25 year bin. This is similar to the result that Brown *et al.* (2008) found in an analysis of 276 fire-scarred trees at Mount Rushmore in South Dakota. In that study, the mean pith-to-first scar interval was 51 years, but the mode was in the 16–20 year bin. It should be noted that the interval from the pith date to the first scar is not necessarily equivalent to tree age at the time of the first scar, because (1) earlier scars could have burned away in subsequent fires, and (2) most samples were not sampled at ground height, so pith dates on the samples are not the same as pith dates at ground level.

Analysis of a large, diverse dataset of fire-scarred trees showed empirical support for practices often carried out by dendrochronologists around the world. The data confirm that searching for a variety of sample types and looking on the uphill sides of trees are useful methods. As additional research is carried out beyond the well-studied forests of North America (Falk *et al.* 2011), these approaches should be useful for building strong datasets.

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