Scaling Rules and Probability Models for Surface Fire Regimes in Ponderosa Pine Forests

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Abstract—*Statistical descriptors of the fire regime in ponderosa pine forests of the Jemez Mountains, New Mexico, are spatially scale-dependent. Thus, quantification of fire regimes must be undertaken in a spatially explicit framework. We apply a variety of analytical tests adapted from species-area relationships to demonstrate an analytical framework for understanding scaling of disturbance regimes. A new spatio-temporal scaling index, the slope of the event-area function, can provide a useful measure of the synchrony of events within watersheds (where fire spread regulates the distribution of events) as well as among mountain ranges. We propose two alternative mathematical models of fire interval distributions based on inherent properties of the fire record and the ecology of frequent-fire disturbance regimes; a discrete probability model, and a probabilistic application of the lognormal distribution. Because they involve distribution of energy and matter, these spatial and temporal scaling rules indicate more general disturbance event-area relationships that can facilitate the analysis of disturbance regimes in a broader ecological framework.*

Introduction

Many ecological processes scale in time and space in ways that are determined by underlying mechanistic or stochastic processes. For example, at the level of the individual organism, body size, growth and metabolic rates, and a variety of life history traits are related systematically and can be expressed as allometric or bioenergetic scaling rules (Wiens 1989; West, Brown, and Enquist 1997; Enquist et al. 1999). Recent work (Enquist and Niklas 2001; Niklas and Enquist 2001) has shown that these scaling proprieties can be extended to the structure, composition, mass, and productivity of complex ecological communities. The unifying force across these levels of biological organization is the efficiency of energy flow, which is a strong selective force in organismal evolution. Ostensibly emergent properties of communities and ecosystems can thus be related to fundamental biophysical processes.

Because they involve distribution and flows of energy and materials, disturbance processes similarly can be expected to follow scaling rules in space and time (Holling 1992; West, Brown, and Enquist 1997; Enquist, Brown, and West 1998; Ritchie and Olff 1999). In general, we may predict that ecosystem process will scale both spatially and temporally with the factors that regulate such events, and not simply as a function of geometry. Before we can assess scaling patterns in disturbances, however, we must be able to characterize disturbance events quantitatively and measurably.

Disturbances of a particular type are often grouped together under a "regime" (Pickett and White 1985; Agee 1993). While "regimes" are often discriminated qualitatively (e.g., "stand-replacing" *vs.* "surface fire" regimes), they are usefully defined by a set of quantitative descriptors (table 1). Because

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Table 1—Dimensions of fire regimes. Adapted and expanded from Agee (1993), Johnson (1992), Whelan (1995), White and Pickett (1985).

Dimension	Typical units or metrics
Temporal distribution:	
Frequency (f)	Number of events time^{-1} .
Interval (i)	Number of yrs between events; yr event^{-1} (= 1/f).
Interval variability (temporal heterogeneity)	Statistics of central tendency (mean, median, mode) and higher moments of the frequency distribution (variance, kurtosis, skewness).
Duration	Elapsed time of a single event over a defined area (from a point to entire extent).
Fire cycle	In a stand-replacing regime, mean age of a stand with a modeled age distribution.
Fire rotation	Mean number of years required for fires to burn a specified amount of area.
Seasonality	Intra-annual occurrence for a single event or group of events.
Spatial distribution:	
Extent	Total area covered (km^2).
Spatial heterogeneity	Proportion of burn area by intensity or severity class (%); patch size (ha) and aggregation, fractal dimension (D).
Intensity	Physical properties, e.g.: flame length (m), fireline intensity (kW m^{-1}), rate of spread (m hr^{-1}), energy output per unit time (BTU hr^{-1} m^{-2} or kJ m^2), peak temperature (°C.), residence time (min).
Severity	Effects on biotic and abiotic elements of the community, e.g.: mortality by species (%).

a disturbance regime involves multiple dimensions, disturbance regimes comprise multivariate space, not a single dimension (Agee 1993). By using multivariate space, we open the way for quantitative analyses, rather than verbal descriptors, to characterize the regime at a given place and time. Moreover, by describing the regime with a set of quantitative variables, each with associated measures and statistical characterization, we can evaluate the natural range of variability across locations and spatial scales and across time for any given spatial extent.

To illustrate these principles, we examine a 450-yr record of fire events in an old-growth New Mexico (USA) ponderosa pine forest, using tools of dendrochronology. Because fires in this ecosystem generally have low to moderate intensity of the flaming front with variable duration at the tree scale (Weaver 1951; Kilgore and Taylor 1979; Agee 1993; Allen 2001), mortality is size-dependent: most mature trees survive most fires, while most smaller and younger trees do not (i.e., mortality decreases with size). For fires above a threshold of temperature and exposure time, the cambium of mature trees will be killed locally at the locus of highest exposure (Keane et al. 2001). This dead cambium, and the tree growth response around it, creates a lesion that persists in the wood long after the event has passed. In tree species with growth rings that can be dated with annual or sub-annual precision, the year (and, in many cases, season) of individual fire events can be determined exactly (Arno and Sneck 1977; Kilgore and Taylor 1979; Dieterich 1980a; Romme 1980; McBride 1983; Swetnam and Dieterich 1985; Veblen et al. 1999). The spatial distribution of fire events in any given year can be assessed if samples are georeferenced and suitably distributed across the landscape (Niklasson and Granström 2000; Heyerdahl, Brubaker, and Agee 2002). With these tools a record of disturbance events is created, and their distribution in space and time becomes available for analysis.

Disturbance regimes are ultimately composed of events. Where these events are discrete, they can be mapped in space and time, and their distribution and scaling properties analyzed. In this paper we apply an analytical framework adapted from species-area relations and macroecology to study scaling effects in the disturbance regime. In effect, we substitute fire dates for species and then evaluate spatial and temporal scaling properties of the disturbance regime. We ask: Do quantitative descriptors of the fire regime scale in space and time? Is there an underlying probability distribution that can describe intervals between fire events? And finally, do these scaling relationships reflect governing biophysical processes, such as entrainment of the fire regime by climate?

Methods

Study Site

Monument Canyon Research Natural Area (MCN) is located in the western Jemez Mountains of north-central New Mexico, USA (figure 1). MCN was among the first Research Natural Areas in the United States, and includes stands of *Pinus ponderosa* var. *scopulorum* (ponderosa pine) and other conifers more than 420 years old (Touchan and Swetnam 1995; Touchan, Allen, and Swetnam 1996). At elevations of 2,438-2,560 m (8,000-8,400 ft), MCN is near the upper elevation limit for ponderosa pine dominance (Regional forest type 122.3, Petran Montane Conifer Forest) on mixed topography in northern New Mexico (Brown and Lowe 1980). As elevation increases above this level, forest communities transition to mixed-conifer types (121.3, Petran Subalpine Conifer Forest) regardless of aspect. In MCN, mixed conifer stands are found mostly on protected north-facing slopes and some small drainage bottoms. Soils are derived largely from tuff that formed the caldera of a large (10 km radius) Pleistocene volcano. The study area encompasses the entire 256 ha (1 mi^2) RNA, of which approximately 80% is relatively level mesa-top and 20% steep north-northeast slopes dominated by shade-tolerant conifers, including *Pseudotsuga menziesii* var. *glauca* (Rocky Mountain Douglas-fir), *Abies concolor* (white fir), and *Pinus flexilis* (limber pine).

Field Methods

We established a sampling grid with 200 m spacing across the study area, using GPS field-accurate to ± 7 m (figure 2). Each point was permanently marked with metal rebar and tagged for future relocation. At alternate points (400 m lateral spacing; N = 40), we located and sampled an average of four fire-scarred trees (min = 2, max = 12) showing evidence of the largest number of fire scars within a 40 m radius (approximately 0.5 ha) (Niklasson and Granström 2000; Heyerdahl, Brubaker, and Agee 2001). Further details of field sampling protocols are provided elsewhere (Falk 1999).

Specimen Preparation and Data Reduction

Fire-scar specimens (partial or full cross-sections) collected in the field were prepared and analyzed at the University of Arizona Laboratory of Tree-Ring Research (LTRR), using standard techniques in dendrochronology (Dieterich and Swetnam 1984; Fritts and Swetnam 1989). Each section was crossdated to a local master chronology, to ensure accuracy of dating trees with locally absent or missing rings. Once the entire ring sequence for each specimen was dated, we recorded the year of each visible fire lesion.

Data Analysis

Fire dates for each tree were entered into FHX2, a software program designed specifically for fire history analysis (Grissino-Mayer 2001). The resulting

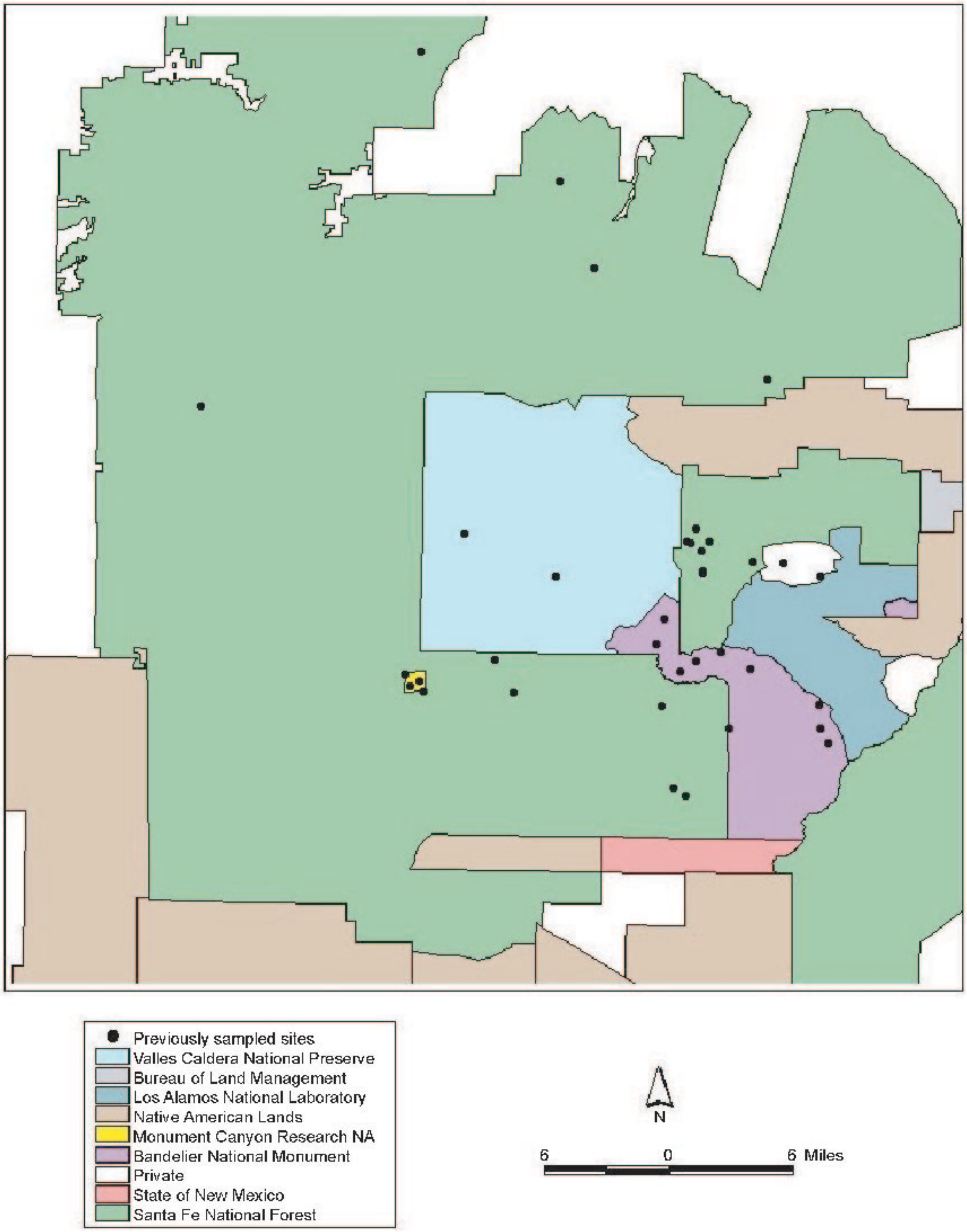

Figure 1—Site map of Jemez Mountains and Monument Canyon study area. Figure courtesy of K.L. Beeley (NPS) and C.D. Allen (USGS).

data set is a years × trees matrix, in which each cell is valued as 1 (fire recorded for that year) or 0 (no fire recorded). Because individual trees do not always record every fire event in their vicinity, we made a composite record for each grid point consisting of all fire dates recorded by any tree at that location (Dieterich 1980b). Thus, the grid-based 0.5 ha search area constituted our minimum resolution or Minimum Map Area (MMA) for reliable reconstruction of the fire record. For the same reason, fire occurrence is recorded only as presence (1) or absence (0), not relative abundance (e.g., proportion of trees recording a fire).

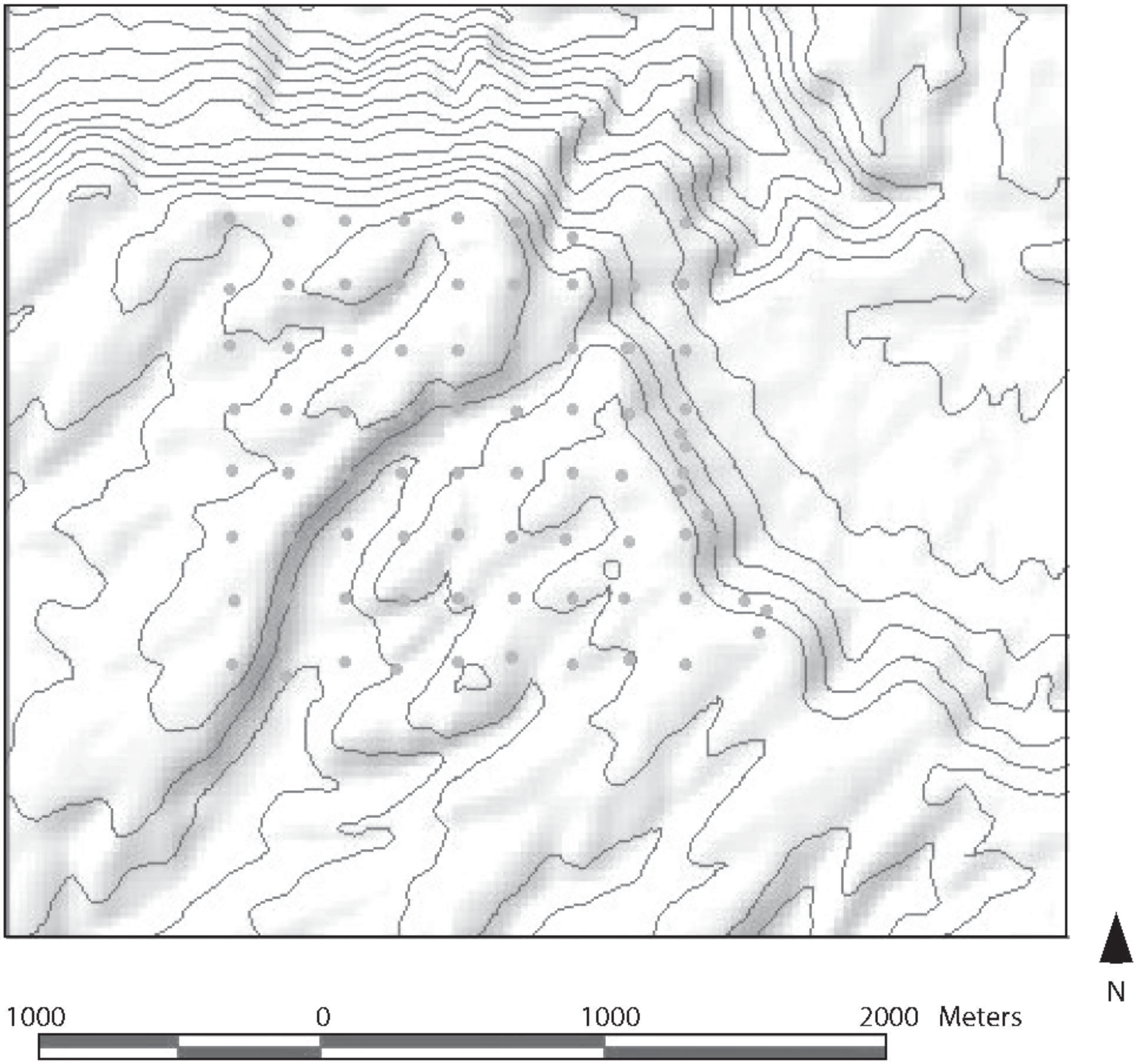

Figure 2—Sampling grid at Monument Canyon RNA.

Fire history metrics. For each grid-point composite, we calculated statistical measures of the fire regime (table 1), including total number of events detected, measures of central tendency (arithmetic mean, median, and mode) for fire intervals (yr event^{-1}), and higher moments (skewness and kurtosis).

Analytical tests. We applied a series of procedures commonly used in species-area relations to test for spatial and temporal scaling relationships in the statistical descriptors of the fire regime. We did so by substituting "fire years" for "species" in the 450-yr record of events. In a surface fire regime such as the one studied here, subsequent fires often do not eliminate the evidence of prior events. Thus, a given site can retain a record of individual fire events hundreds of years long, and individual trees with >20 scars are not uncommon. This contrasts with high-intensity, stand-replacing regimes where large, catastrophic fires destroy the tree record of prior fires on a given location (Heinselman 1981; Romme 1982). The retention of multiple fire records at a single point in space allows mapping the spatial extent of individual fires, given that not all trees near the perimeter of a fire may record, and that multiple independent fires within a single year could not be discriminated. Tests used included:

Accumulation functions ("collector's curves") for fire events. We tested for the effect of sample size (number of trees) on the number of fire events detected and mean fire interval, using a bootstrap resampling program (SSIZ) developed at the LTRR (Holmes 1995). SSIZ complies a list of fire dates and calculates the mean fire interval with confidence limits for randomly selected subsets of the original data set from 1… N trees. We ran 1,000 iterations of the resampling procedure without replacement.

Event-area relationships. The relationship between species richness and area of a sample or ecosystem is among the most widely studied patterns in species biogeography (Arrhenius 1921; MacArthur and Wilson 1967; Connor and McCoy 1979; Palmer and White 1994; Rosenzweig 1995). At small scales the accumulation ("collector's") curve dominates (Pielou 1977; Magurran 1988), but once sample size is sufficiently large, the number of species encountered increases as a power function of area, $s = cA^z$, where s is species richness, c a scaling constant that varies among organism groups, A is sample area, and z a rate constant that varies with ecosystem type and biogeographic scale (MacArthur and Wilson 1967; Rosenzweig 1995). With logarithmic transformation, the relationship is a linear function, $\log s = \log c + z \log A$. The value of s at the y-intercept (c or $\log c$) reflects "point" (alpha) diversity. Steeper values of the slope term z indicate faster accumulation of new species with increasing area. Because $z < 1$ (most published values are in the range 0.15 - .35), the rule says in effect that small areas are more species-rich per unit area than large areas.

In the current context, we can assess event-area relationships in two ways. First, we can count the number of fires (f) detected in a sample; this will stand as equivalent to species richness (S). Because fires are events in both space and time, we must define the sample temporally as well as spatially; this is conventionally done by calculating fire frequency, which is the number of fires per unit time, giving f units of fires time^{-1}. A related measure, fire interval, is the number of years between fire events, or $1/f$, with units of yr fire^{-1}. Both frequency and interval can be expressed statistically as mean, median, or modal values, and their higher moments calculated.

We tested for the effect of area by making spatially explicit subsets of the data set. Because the data are from known locations, we can create composite fire chronologies for any defined area within the study site. This can be accomplished by creating either nested series of samples beginning at any point, or non-nested samples of varying area centered on random points in the study site up to the full extent of the study (figure 3) (Palmer and White 1994). Although not reported here, sample size and sample area can be varied independently in our study design (Falk 2003 in prep.).

The interval-area relationship. The time interval between fires is of direct ecological interest because it represents the time between fire events. This interval is potentially important in forest demography because of size-dependent mortality: seedlings and saplings are unlikely to survive fires (Ryan and Reinhardt 1988; Peterson et al. 1994), so if the time interval between events is short, the probability increases that they will be exposed to a lethal event. By contrast, longer fire-free intervals allow young trees to attain size and morphology that makes their survival more likely (although fires occurring after very long intervals may be more intense, due to accumulation in the larger fuel sizes and changes in vertical fuel structure).

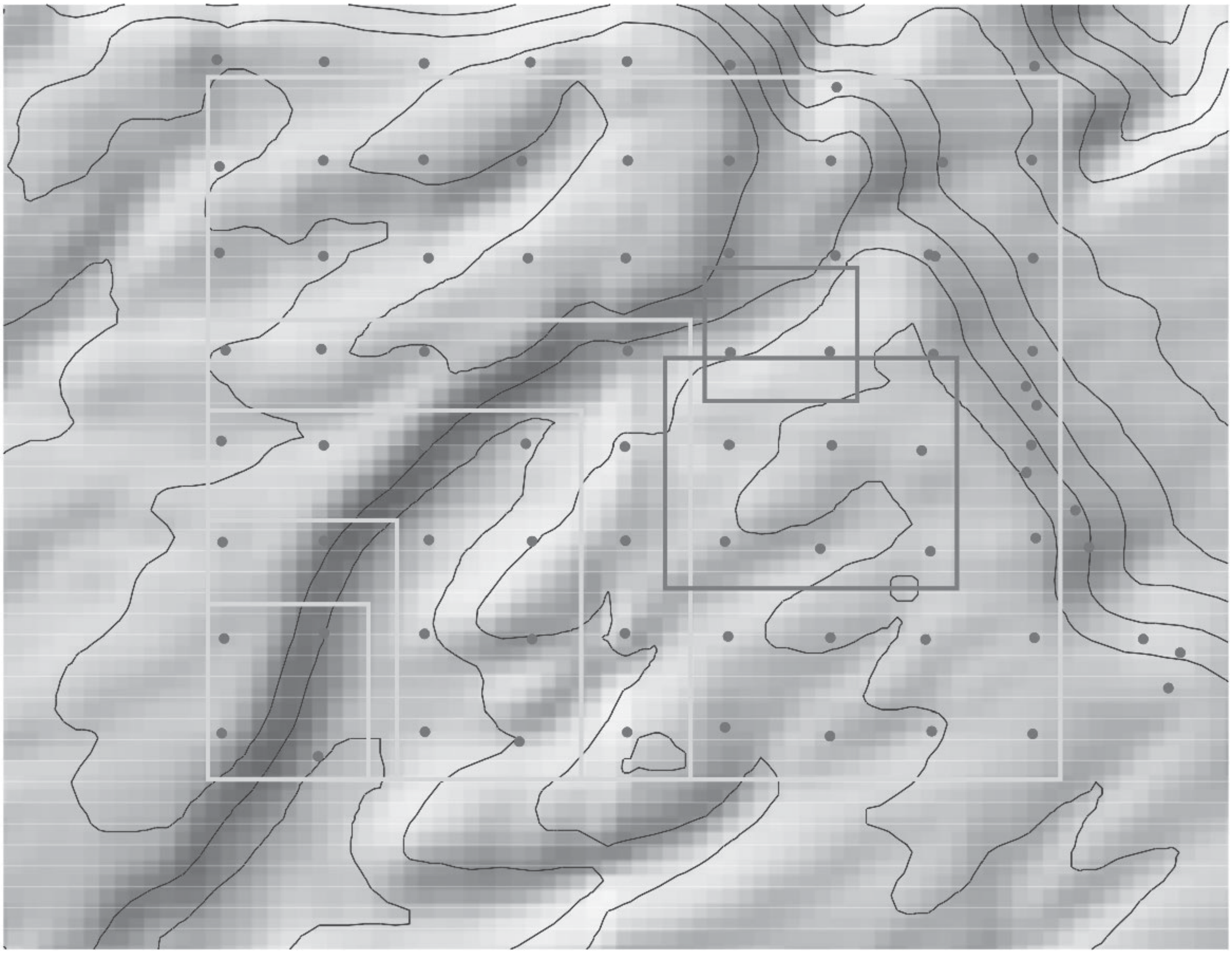

Figure 3—Nested and non-nested methods for creating simulated search areas for calculation of composite fire statistics. Fire dates are composited within each box to test for sample area effects.

Both f (fire frequency) and MFI (mean fire interval = $1/\bar{f}$) can be tested for area-dependence in a fashion similar to species richness. The predicted event-area function for frequency is a power law,

$$f = eA^{y}, \text{ hence } \log f = \log e + y \log A,\ y \geq 0$$

where e and y are scaling constants analogous to c and z in the species-area relationship. Similarly, the predicted interval-area relationship for mean fire interval over any defined period t is

$$\mathrm{MFI}_t = pA^{-y}, \text{ and } \log \mathrm{MFI}_t = \log p - y \log A,\ p = e^{-1}\ .$$

We expect $f(A)$ to have a positive slope (i.e., $y > 0$), since sampling larger areas across the landscape should encounter more fires in a patchy fire regime (Arno and Peterson 1983). Likewise, $\mathrm{MFI}_t(A)$ should be negatively sloped, because if larger area samples detect more fires, the denominator of the interval statistic increases. The decreasing fire interval statistic can also be interpreted as follows: as larger areas are sampled, the likelihood increases of a fire occurring somewhere in any given year.

Probability models for interval distributions. Fire interval probabilities have most commonly been modeled using 2- and 3-parameter versions of the Weibull distribution (Johnson and VanWagner 1985; Johnson 1992; Johnson and Gutsell 1994). Although alternative models have been inadequately explored, use of the Weibull to model fire interval probabilities has become widespread (Clark 1989; Johnson 1992; Agee 1993; Swetnam and Baisan 1996; Gardner, Romme, and Turner 1999; Grissino-Mayer 1999).

The Weibull distribution is a continuous probability model that describes the effects of stress accumulation, and hence is often used to model time to failure (e.g., metal fatigue, breaking points of materials, etc.) (Bain and Engelhart 1987; Johnson, Kotz, and Balakrishnan 1994). However, it is not clear that continuity is an appropriate assumption for fire regimes in the Southwest. Fire data in the dendroecological record are inherently annual in their resolution, as reflected in the record of annual fire dates derived from analysis of fire scars or establishment dates. One way of making this evident is by attempting to increase the resolution of the record, which should be possible in a truly continuous distribution. When we decrease the time interval to subannual patterns of fire occurrence, we are asking a different question (i.e., seasonality), not simply improving the precision (i.e., smaller units) of a fire interval estimate. Thus, the fire scar record is not infinitely divisible as is typically assumed for continuous data.

A related implication of a continuous distribution is that observations are unitary. For example, we do not interpret a temperature of 32° as the sum of two temperatures of 16°, nor a blood pressure of 120 mg as the sum of 80 mg and 40 mg. In fire history studies, the parallel assumption is that fire intervals of t years are a single event, which permits the use of a continuous frequency distribution.

Forest fires in ponderosa pine ecosystems may not conform to this unitary assumption. Both the fire record and fire events are composed inherently of a series of discrete, binary events. In southwestern forests, fire occurrence has a finite probability each year, with an outcome of fire or no fire. Thus, each year can be defined as a Bernoulli trial, where the outcome is one of two possible states (0,1) (Bain and Engelhart 1987). A fire interval of 10 yr is thus the accumulation of 10 separate no-fire years. In this respect, discrete probability models such as the negative binomial (years before the first success) may be more appropriate null model. An assumption of Bernoulli probability is that each trial is independent, whereas fire (or its absence) in year t-1 may have some effect on the probability of fire in year t.

Here we propose an alternative approach based on first principles in fire ecology and mathematical statistics. The capture of a fire scar in a sample is the result of a series of contingent events, each with its respective probability distribution (sufficient fuel, proper fuel moisture and wind, ignition source, tree species, age and size, prior scarring survival of the fire, capture in a sample). Thus, the eventual probability P_{tot} that a fire event will occur, be recorded by the tree, and sampled by a researcher is the contingent product of the probabilities of n constituent factors:

$$P_{\mathrm{tot}} = p_1 \times p_2 \times p_3 \times p_4 \times \ldots p_{\mathrm{n}} = \prod_{\mathrm{i=1}}^{\mathrm{n}} p_{\mathrm{i}} \,.$$

Taking the log of both sides gives:

$$\log P_{\text{tot}} = p_1 + p_2 + p_3 + p_4 + \ldots p_n = \sum_{i=1}^{n} p_i \, .$$

Sums of random variables approach normality under the central limit theorem, provided there are a sufficient number of factors (Montroll and Shlesinger 1982). The resulting distribution of log transformed variates is thus expected to approach normality. We therefore propose that fire intervals are lognormally distributed.

Results

Collections

For this analysis we used records from a preliminary sample of 53 fire-scarred trees at 16 grid points in the study area (figure 2). Most trees in the sample were *Pinus ponderosa*; other species included *Pseudotsuga menziesii* (Douglas-fir), *Abies concolor* (white fir), and *Pinus flexilis* (limber pine). We restricted our analyses to the period 1600-2000, for which there is sufficient sample size at all grid points.

Analytical Tests

Sample size accumulation function. The total number of events increased asymptotically with sample size (figure 4-a). The function is a classic "collector's curve," reflecting the capture of more fire events as sample size increases. Notably, very small samples appear unlikely to capture the full set of fire dates (although they probably record the most widespread events). The collector's curve is a saturating function, with a positive first and negative second derivative, and an asymptotic frequency of 9-10 events per century. The collector's curve in figure 4-a is for the full set of 53 trees across the sampled area. In a nested multi-scale analysis, each scale would have its own collector's curve reaching a characteristic asymptote (Palmer & White, 1994).

Event-area and interval-area relationships. Fire dates also accumulated in simulated samples of increasing area (figure 4-b). The lack of downward concavity suggests high patchiness in the fire regime: with increasing area, new events continue to be encountered at a high rate, although many of these events were small. This area effect appears to be independent of the accumulation of fire dates with increasing sample size (figure 4-a).

Mean fire interval was strongly scale-dependent (figure 5). Following the predicted power rule, the function is linear in log-linear space MFI $\approx 71.1 A^{-0.20}$, $r^2 = 0.68$. Individual plots (points in figure 5 along the y-axis) recorded fires at mean intervals ranging from 7-23 yr (mean = 12). Extrapolation to the tree scale (0.01-0.05 ha) suggests common intervals of 9-35 yr, although we consider this scale below the minimum reliable spatial resolution for field verification. As data from adjacent grid points were added together to form larger spatial composites, more fires were encountered and MFI decreased to 7 yr for 10-ha composite samples and 4 yr for sample areas of 100 ha.

Probability model. Lognormal functions provided as close a fit to the observed distribution of fire intervals as did the Weibull distribution for spatial composites of 1-16 grid points (figure 6). This suggests that the more

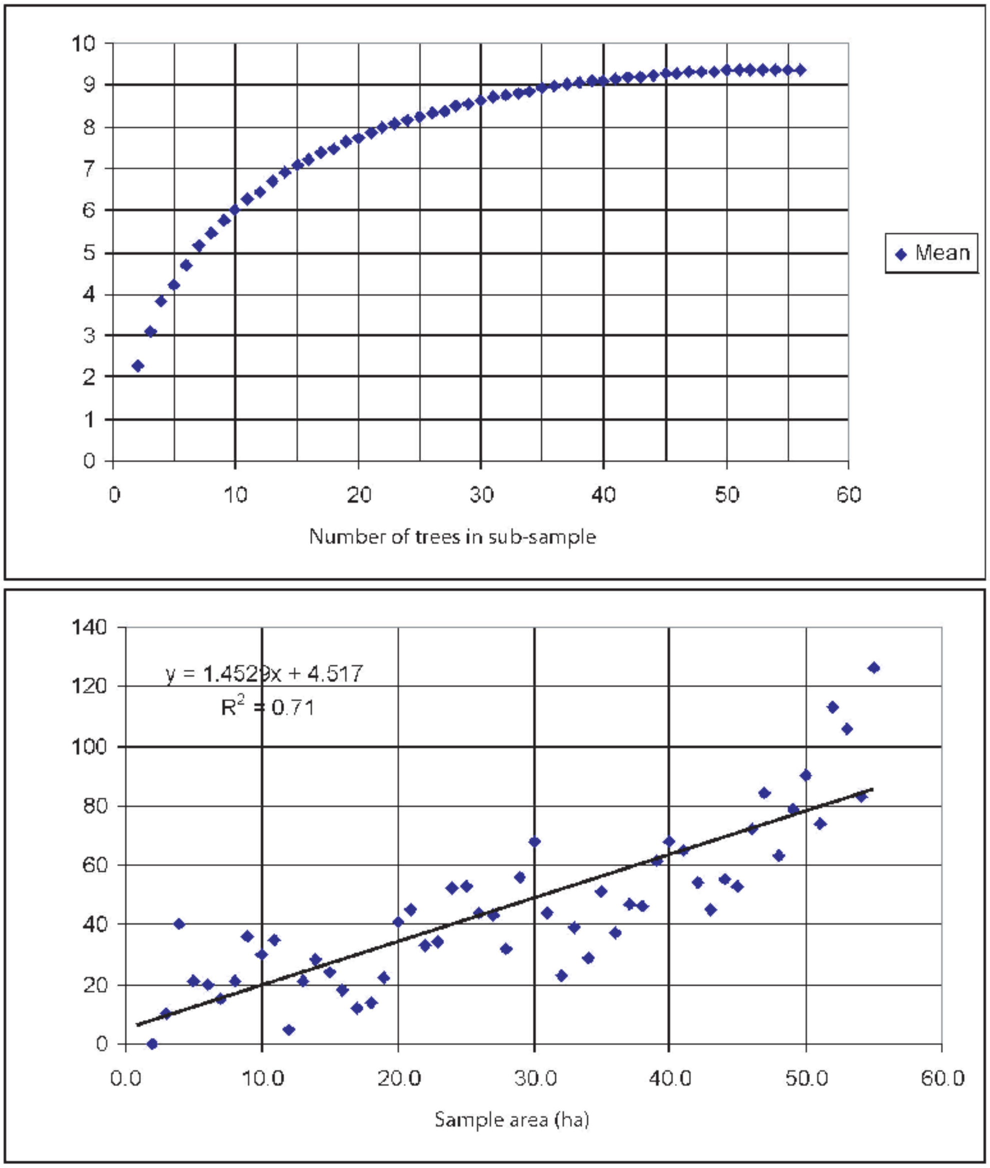

Figure 4—Accumulation functions ("collector's curves") for the number of fire events recorded as a function of (a) number of trees sampled and (b) sample area.

parsimonious and theoretically grounded lognormal distribution has potential application for modeling surface fire regimes. Interestingly, a comparison of the computed Weibull median probability interval (WMPI) with the simple arithmetic mean was highly correlated (i.e., little added information in the more complex model) (figure 7).

Conclusions, Discussion, and Future Research Directions

Scale dependence is demonstrated in the fire regime of an old-growth ponderosa pine forest. All measures of the fire regime tested appear sensitive to sample area; number of fires and mean interval were also found to be sensitive to sample size (number of trees). Thus, the notion of a unitary fire regime independent of scale is untenable; instead, we see that the fire regime is a scale-dependent characterization of an ecosystem.

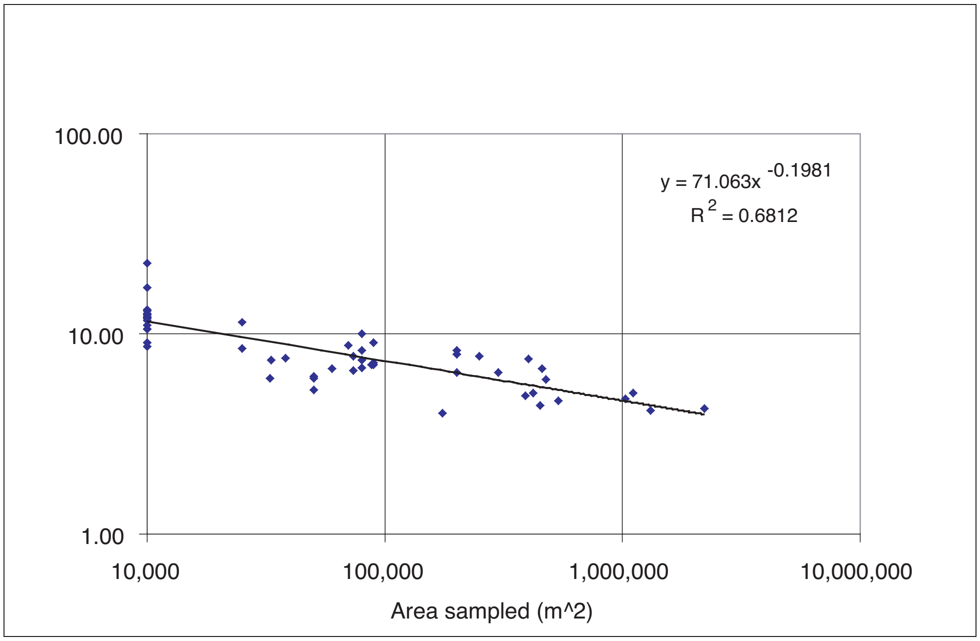

Figure 5—Dependence of mean fire interval on number of trees sampled. MFI (ordinate) decreases with increasing area sampled (abscissa, log scale). Data points are MFI for simulated sample areas of differing sizes.

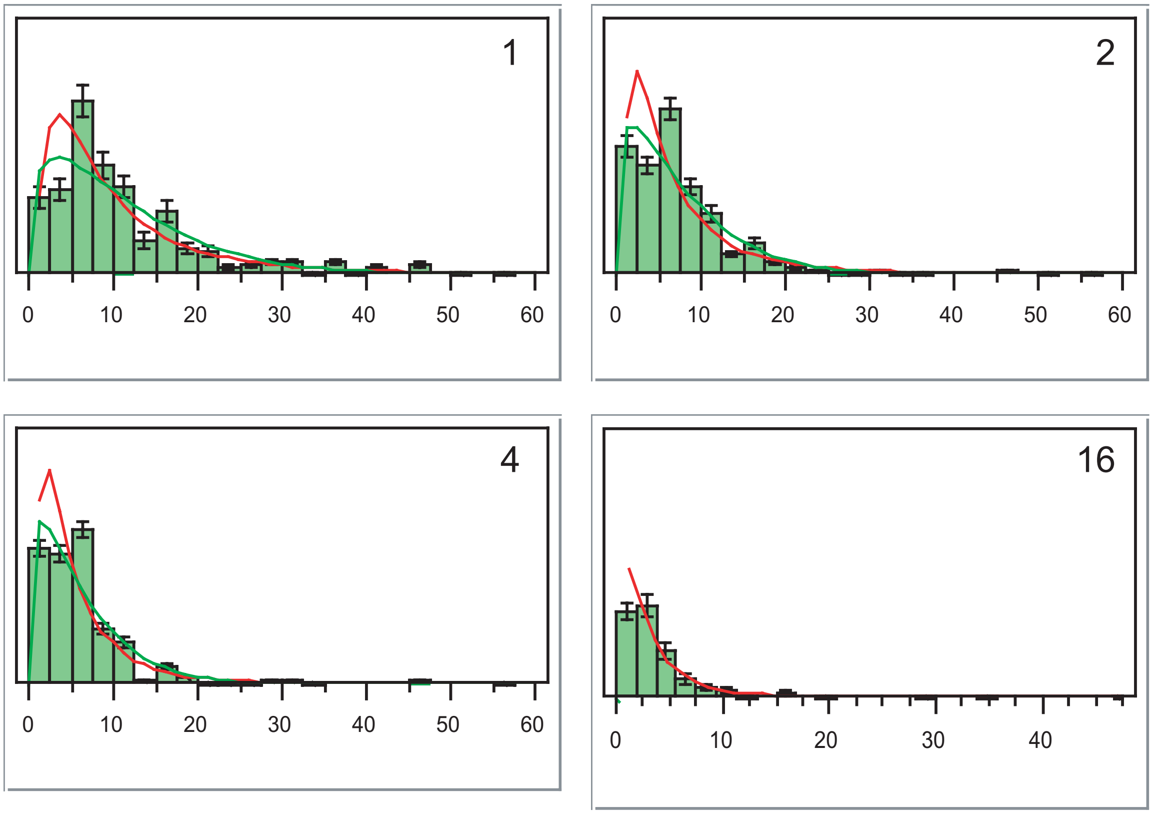

Figure 6—Scale dependence of the frequency distribution of fire intervals for nested spatial samples of 1-16 grid points, with fitted lognormal (green line) and Weibull (red line) distributions.

This preliminary analysis used approximately 20% of the eventual full data set of ≈275 trees at MCN. In addition to adding grid points (sampling locations), the full data set includes some sample points at closer intervals (200 m compared to 400 m in the present analysis), providing finer spatial resolution in the analysis. The present data set also covers approximately 150 ha; the full MCN data set will cover approximately 250 ha. Inclusion of samples from previous research efforts in adjacent areas of the Jemez Mountains (Morino,

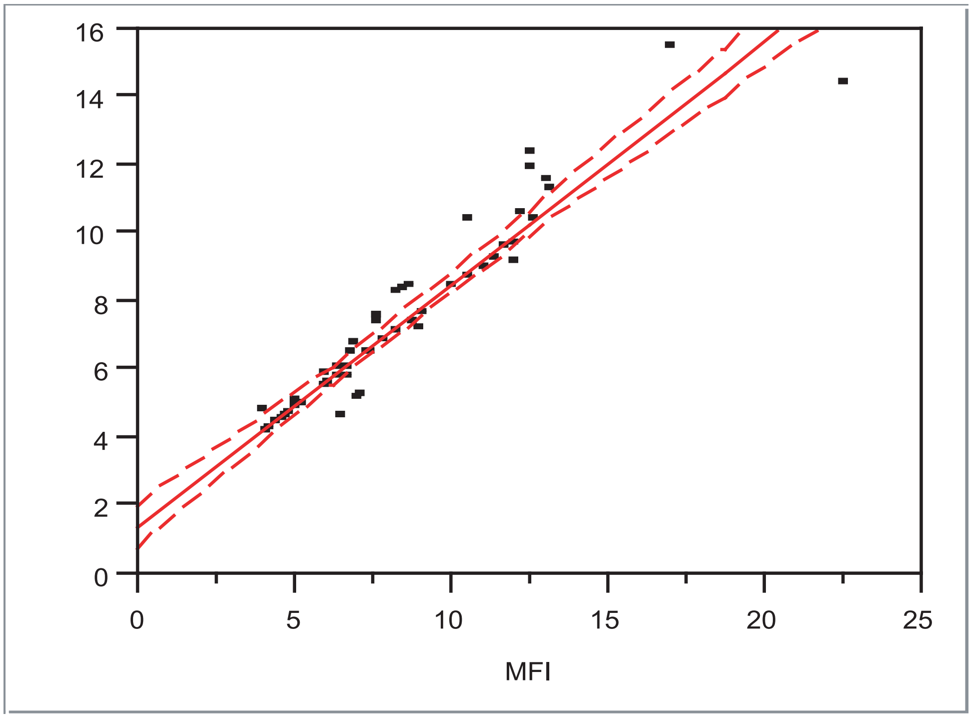

Figure 7—Correlation of mean and Weibull median probability interval (WMPI) for trees and composites at Monument Canyon (N = 53). WMPI = 1.37 + 0.71 MFI (r^2 adj. = 0.90).

Baisan, and Swetnam 1998; Allen 2002) will allow the tests used here to be applied across five orders of magnitude in spatial scale (5×10^{-1} - 10^4 ha). Several other recent fire history studies have used a spatial array of sampling points (Fulé, Covington, and Moore 1997; Brown, Kaufmann, and Shepperd 1999; Niklasson and Granström 2000; Skinner 2000; Veblen, Kitzberger, and Donnegan 2000; Heyerdahl, Brubaker, and Agee 2001). A meta-analysis of these studies may reveal even more general scaling rules.

Sample size and sample area are partly confounded in the results presented here. Distinguishing these two factors is important, for the same reasons as in species biogeography: the collector's curve can dominate the species- (event-) area function at small spatial scales (Palmer and White 1994). In the MCN case, the grid-based design allows sample size and sample area to be decomposed using a factorial procedure, assembling a composite data set for increasing sample size (say, 5-30 trees) selected at random from a series of increasing sample areas (5-250 ha). The resulting data can be tested by MANOVA, or used to generate Fisher's a statistic for increasing species (fire date) richness with increasing sample size. Stability in Fisher's α indicates that increased richness is attributable only to sampling more individuals, while an increasing Fisher's α indicates an increase in richness independent of sample size.

A filtering approach can also be used with fire history data to identify widespread fire years. For example, Swetnam & Baisan (1996) analyzed fire data from southwestern North America, selecting fire dates found respectively on $\geq$25%, $\geq$10%, or any recording tree within each site (the same approach can be applied at the site level, filtering out fire years recorded by only a few sites). Filtering removes fire dates found on only a few trees (or sites), and is thus useful for identifying widespread fire years. One difference with the present approach is that filtering is non-spatial. For example, in a sample of 100 trees, the filter does not discriminate between a fire year recorded by nine widely dispersed trees from a date recorded by nine trees in a cluster. Filtering would tend to reduce the number of fire years in a population, and thus decrease the upper asymptote of a collector's curve.

The event-area relationship has many potential applications in fire and forest management (Baker 1989). In ecology, scaling relationships have important implications for forest demography and stand dynamics. In southwestern pine forests, both mortality and scarring of survivors from fire events is strongly age- and size-dependent. Individual trees are affected only by fires that are proximate enough to generate the threshold values of exposure time and cambial temperature; fires that are too far away would have little effect. Thus, to understand the regulatory influence of fires of forest demography, we must evaluate fire occurrence (as well as fire-free intervals) at the "tree-scale." While much further research is required to define the radius of effect for fires on seedlings and saplings, the spatial domain of demographically effective surface fires is undoubtedly closer to 0.05 ha than to 500 ha. A fire occurring 1,500 m away probably has no demonstrable effect on the survival, growth, or reproduction of a target tree, whereas a fire within 50 m is likely to affect all three demographic parameters. Scale dependence in the fire regime is the key to understanding the spatial aspects of forest demography.

The event-area relationship can also be used as the basis for a measure of spatio-temporal synchrony of events. Independent fire events can be synchronized regionally by climate, particularly periodic events such as El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). (Swetnam and Betancourt 1990; Swetnam and Betancourt 1992; Grissino-Mayer and Swetnam 2000; Heyerdahl, Brubaker, and Agee 2002). When events are synchronous across the landscape, fires that occur anywhere occur everywhere, leading to a collector's curve that immediately reaches the asymptote. The corresponding MFI-area function will have a flat (approaching 0) slope, because as sample area increases, few events are encountered that have not already been detected. By contrast, during periods when fires are not synchronized regionally, the collector's curve rises more gradually, and the MFI-area function declines at a faster rate because the landscape is dotted with small, un-correlated events. We propose that the slope of the interval-area relationship may provide a statistical measure of regional entrainment of the fire regime by climate, and a potential indicator of regime shifts.

In terms of forest management, understanding the scaling relationships of the natural fire regime can be a powerful tool for restoring natural or prescribed fire intervals in fire management programs (Allen et al. 2002). In a simplistic example, fire intervals from data collected at the 100 ha scale (a common extent for fire history samples) might be applied uniformly across the landscape down to the level of individual tree clusters. The negative slope of the MFI-area relationship shows, however, that smaller areas experience fires less frequently than do larger areas. Scaling rules can help to make prescribed natural fire programs more realistic in their application.

The non-zero slope of the MFI-area function also suggests the importance of reporting search area as an integral element of fire interval statistics. Because the mean fire interval is non-stationary over area, sample area should be reported explicitly for a particular sample area (e.g., "7.5 yr for 100 ha"). The use of area-corrected units should become standard practice to avoid confusion in interpretation of interval data in research and management alike.

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