DEPARTMENTS

Technological Tools

Note: Dr. David Inouye is the editor of the **Technological Tools** section. Anyone wishing to contribute articles or reviews to this section should contact him at the Department of Zoology, University of Maryland, College Park, MD 20742, E-mail: di5@umail.umd.edu.

AN INTERACTIVE TUTORIAL ON FIRE FREQUENCY ANALYSIS (VERSION 3.0)

J. G. Fall and K. P. Lertzman.
School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C., Canada V5A 1S6. jfall@sfu.ca, lertzman@sfu.ca.

Fire plays a number of crucial roles in many forests (Johnson 1992, Agee 1993, Whelan 1995, Parminter 1998). Thus, a good understanding of historical fire regimes is an essential precondition for understanding fire–ecosystem interactions (Heinselman 1973, Madany and West 1983, Romme and Despain 1989, Johnson et al. 1990, Swetnam 1993), and for developing successful ecosystem-based management strategies (Agee and Johnson 1988, Baker 1989*b*, Hunter 1993, Swanson et al. 1993, Arno 1995, British Columbia Ministry of Forests 1995, Bunnell 1995, Johnson et al. 1995, DeLong and Tanner 1996, Fule et al. 1997, Lertzman et al. 1997). Fire frequency is an important parameter for characterizing fire regimes, but because the quantity and quality of evidence of historical fires is usually very limited, estimating the historical frequency of fire often requires fairly sophisticated data modeling and statistical analysis. In addition, the types of fire evidence available to a researcher differ between ecosystems, so various methods have been proposed and applied to this problem (Heinselman 1973, Arno and Sneck 1977, Van Wagner 1978, Dietrich 1980, Hemstrom and Franklin 1982, Arno and Petersen 1983, Baker 1989*a*, Clark 1989, Johnson and Gutsell 1994, Finney 1995, Grissino-Mayer 1995, Heyerdahl 1997, Reed et al. 1998). The variety and complexity of approaches taken in different studies can make it difficult to learn to correctly apply and interpret fire frequency analyses. Furthermore, the methods that are applied often make subtle or implicit assumptions that can easily lead to misunderstanding. It is important to address these problems because the historical frequency of fire is being used to guide forest management policies on the amount and pattern of forest harvest, and seral stage distributions required to meet biodiversity objectives (e.g., British Columbia Ministry of Forests 1995). In such cases, it is critical that nonspecialists be able to assess and interpret the models and methods used in reconstructions of historical fire frequency.

In this note, we describe an interactive tutorial on fire frequency analysis, composed of a set of hyperlinked spreadsheet documents, programmed in Excel for Windows. This format allows us to present complete working examples of how each method is applied, using a sample data set. The reader is given opportunities to interact with each example, and can directly access all the formulae that are used in each calculation. This presentation makes the application of the method to a data set more transparent. Many of the example spreadsheets may also be suitable as templates for analysis of other fire history data sets. These features help one to gain a more thorough understanding of the subject material than is possible from reading papers alone. The tutorial is available at <www.rem.sfu.ca/forestry/download/download.htm> (or contact the authors). Version 1.3 is still available; it runs under earlier versions of Excel (5.0 or later). However, the latest release, version 3.0, is recommended because it is substantially improved and has several additional modules. Version 3.0 requires Excel 97 or later.

Motivation and scope

We have three primary objectives for this tutorial:

- to review the published fire history literature and determine the methods, underlying models, and calculations commonly used to estimate historical fire frequency from tree-ring evidence;

• to identify the statistical and ecological assumptions and interpretations being made in these fire frequency reconstructions; and

• to synthesize and convey this material in a format that will help nonspecialists to understand what has been done, how it was done, and why it was done that way.

The scope of this tutorial is limited to the statistical analysis of fire occurrence data. Thus, the tutorial is not intended to equip people with all the tools they would require to *undertake* a fire frequency analysis. It is also important to note that this tutorial does not advocate any particular method, nor does it propose novel approaches to fire frequency reconstruction. It is a review of published material intended to aid comprehension of that material.

Overview of the interactive fire frequency tutorial

The tutorial begins with some basic definitions and an introduction to the concept of fire frequency. This portion of the tutorial is intended to give the reader a basic understanding of how the occurrence of fire over time translates into fire frequency. It covers the types of evidence typically employed in analyses of fire frequency, along with a description of how these data are used to build models of fire frequency. The introduction also includes a glossary of commonly used terminology and a bibliography, which serves as an introduction to the literature on fire frequency reconstruction. In addition, a complete "map" of the tutorial allows the reader to jump directly to any page (Fig. 1). The primary subject material is structured as a set of modules, each focusing on a particular model or method used in fire frequency analyses (e.g., Fig. 2).

The natural fire rotation

The first method module covers the Natural Fire Rotation (NFR) method, as presented by Heinselman (1973). Heinselman's data for the Boundary Waters Canoe Area are presented and used to demonstrate how the NFR is computed. The reader can manipulate the model parameters to compute the NFR over different time periods.

The Poisson model

The next module introduces a Poisson model of fire occurrence. It describes the underlying assumptions of the Poisson process and explains

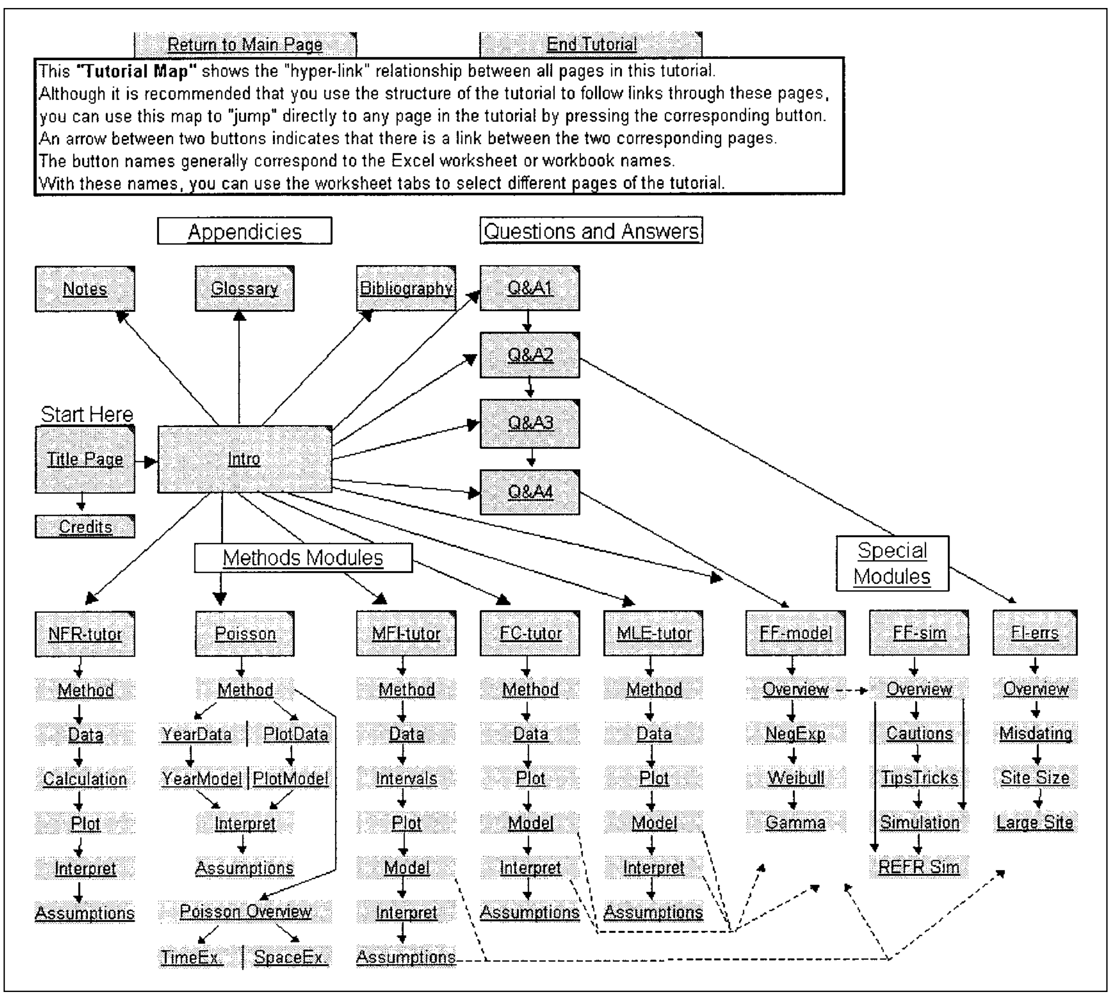

Fig. 1. The tutorial map. From this page, the reader can jump directly to any other page in the tutorial. (Although the figures are in gray-scale, the actual tutorial uses color to aid navigation.)

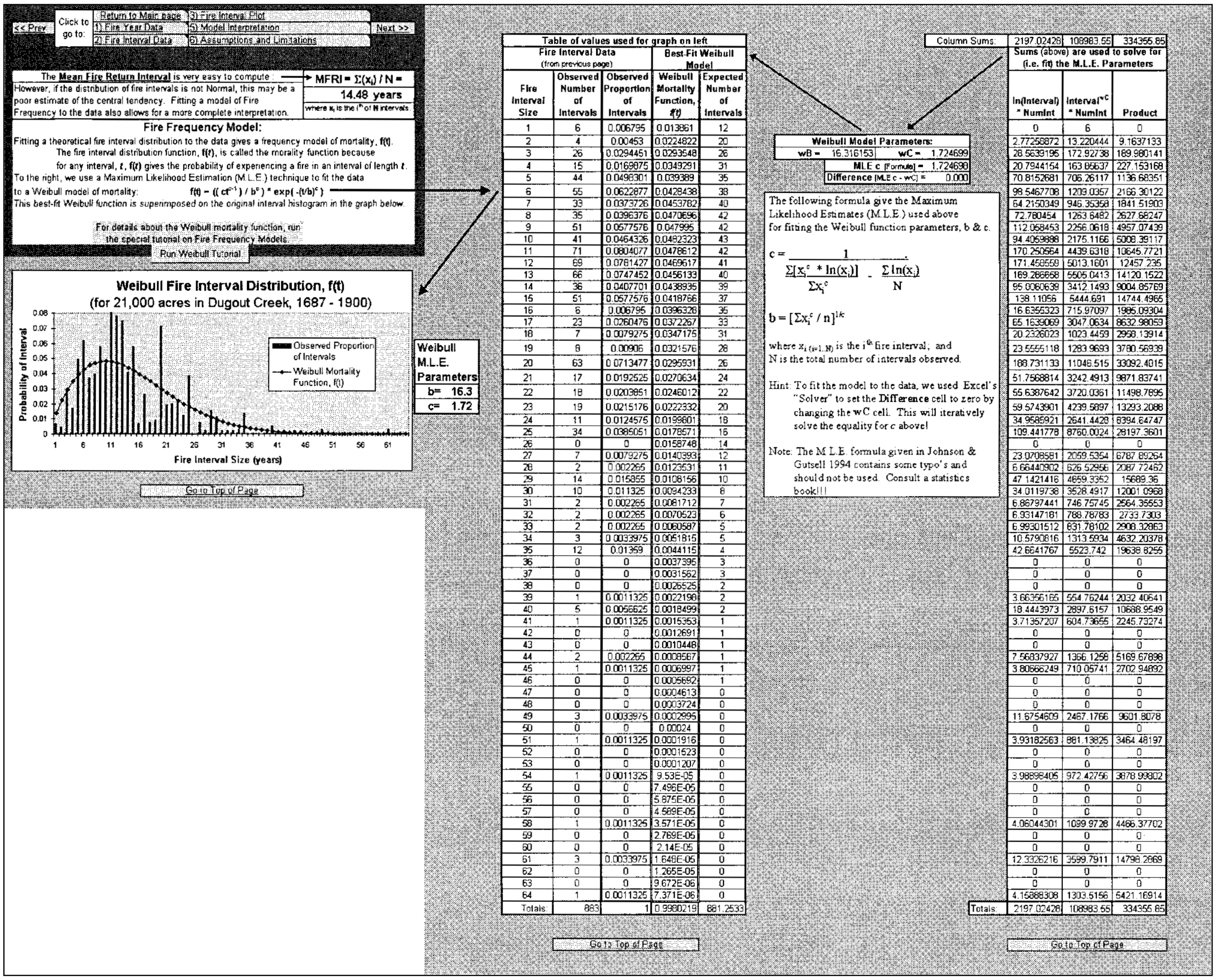

Fig. 2. The "model" page from the Fire Interval method module. This figure shows an example of the layout used to present a concept in the tutorial, in this case, fitting a fire frequency model to a fire interval distribution.

why this model is so important for fire frequency analysis. Two interactive pages allow the reader to manipulate a random Poisson process, which represents the occurrence of fire over space or time. These data are then transformed into a measure of frequency to demonstrate the relationship between the Poisson process as a model of fire occurrence, and the computation of fire frequency.

Fire frequency models

This module is a special tutorial on fire frequency models. It thoroughly investigates the negative exponential and Weibull models, including a general overview of these models, in addition to detailed sections that allow the reader to interact with the model equations and graphs to see the effect of changing the model parameters.

The mean fire interval

This module examines methods for computing fire frequency from fire interval data. We present and analyze a data set from Dugout Creek, Oregon (Heyerdahl 1997). A simple computation of the Mean Fire Return Interval is followed by a more sophisticated analysis of the fire interval distribution (Fig. 2). This module shows how two legitimate estimates of fire frequency can be derived from the same data set using different methods. This module includes a submodule that demonstrates the scale-dependent properties of fire interval data, and gives some advice on avoiding bias in analyses based on fire interval data.

The fire cycle

Two methods modules present fire cycle analyses using the negative exponential model on the same time-since-fire data set. The first of these covers the method developed by Van Wagner (1978) and refined by Johnson and Gutsell (1994). It fits a negative exponential model to the empirical cumulative time-since-fire distribution to estimate fire frequency. This module is presented to develop the underlying concept behind the analysis of time-since-fire data. However, the techniques used by this first method have been superseded by the more statistically rigorous method of Reed et al. (1998). This method is covered by the second fire cycle module, which presents all the calculations required to obtain maximum likelihood estimates and confidence intervals for fire frequency, along with a test to assess the statistical significance of temporal changes in fire frequency. This particular module is designed to be very flexible, and provides ample opportunity for users to interact with the data set, define different epochs, and change the data set to analyze other time-since-fire data sets. All methods modules contain a discussion of their assumptions and limitations.

A simulation modeling toolkit

Finally, a newly developed set of fire frequency simulation tools has been added to the tutorial. This package is included with version 3.0, and is also available separately. Two tools are provided for specifying and running a variety of simple, aspatial simulation models of fire frequency. These are very useful for extending the reader's understanding of statistical fire frequency models and exploring the consequences of various assumptions made by these models. The "Statistical Simulations" tool (Fig. 3) runs simulations of the type of statistical models of fire frequency reviewed by Johnson and Gutsell (1994). The Weibull model on this page is similar to the "fire cycle game" originally proposed by Van Wagner (1978). The "REFR Simulations" tool produces stochastic simulation models by using probability density functions to represent the distribution of fire sizes, and the timing between fire events. This tool can be used to produce aspatial versions of models similar to those employed by Baker (1989*a*), Lertzman et al. (1998), and Fall (1998). It includes a set of prepackaged model scenarios representing the ideas presented in these published studies, in addition to a flexible set of parameters that allow the user to create a customized simulation model for their own fire history data.

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Literature cited

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C., USA.

Agee, J. K., and D. R. Johnson, editors. 1988. Ecosystem management for parks and wilderness. University of Washington Press, Seattle, Washington, USA.

Arno, S. F. 1995. The seminal importance of fire in ecosystem management: impetus for this publication. Pages 3–5 *in* C. C. Hardy and S. F. Arno, editors. Proceedings: The Use of Fire in Forest Restoration. U.S. Forest Service Intermountain Research Station, Seattle, Washington, USA.

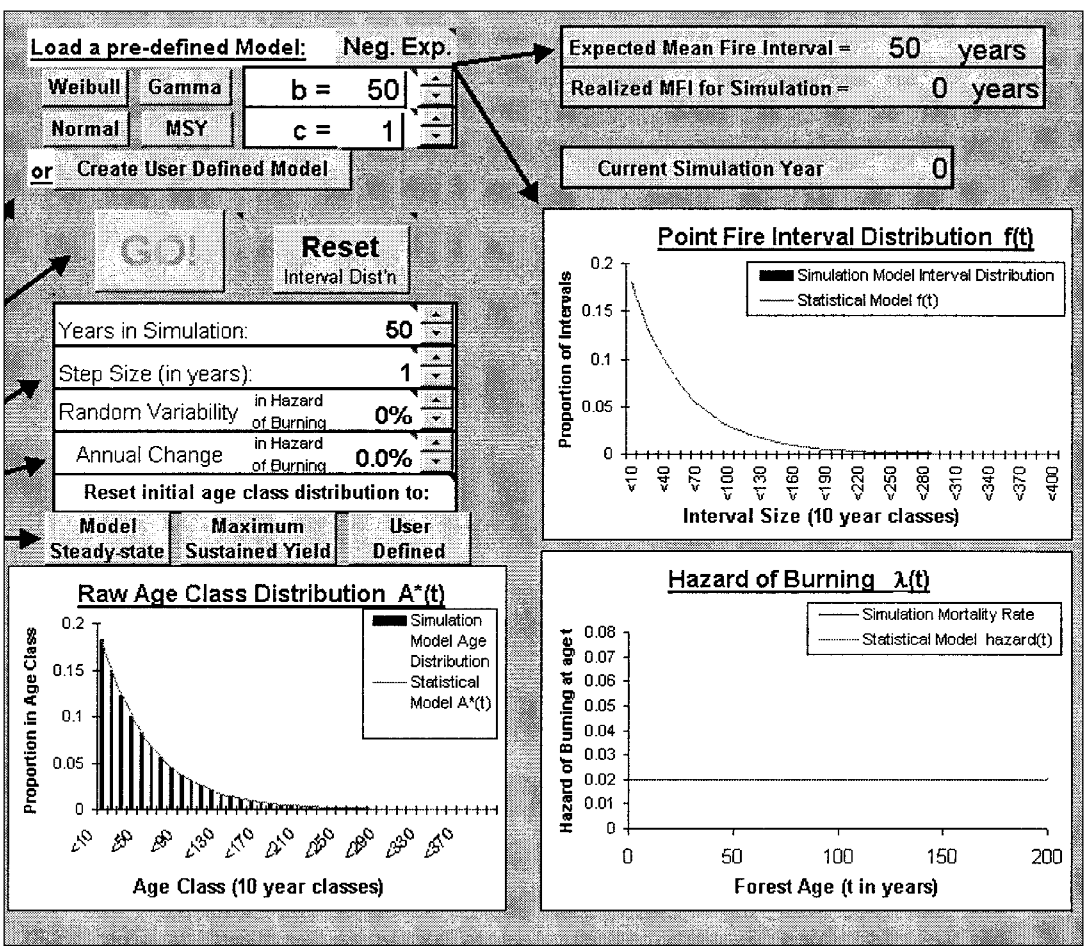

Fig. 3. The user interface for the Statistical Simulations tool.

Arno, S. F., and T. D. Petersen. 1983. Variation in estimates of fire intervals: a closer look at fire history on the Bitterroot National Forest. U.S. Forest Service Intermountain Forest and Range Experiment Station, Research Paper **INT-301**.

Arno, S. F., and K. M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain west. U.S. Forest Service Intermountain Forest and Range Experiment Station General Technical Report **INT-42**.

Baker, W. L. 1989*a*. Effect of scale and spatial heterogeneity on fire-interval distributions. Canadian Journal of Forest Research **19**:700–706.

———. 1989*b*. Landscape ecology and nature reserve design in the Boundary Waters Canoe Area, Minnesota. Ecology **70**:23–35.

British Columbia Ministry of Forests. 1995. Forest Practices Code of British Columbia: biodiversity guidebook. Queens Printer, Victoria, British Columbia, Canada.

Bunnell, F. L. 1995. Forest-dwelling vertebrate faunas and natural fire regimes in British Columbia. Conservation Biology **9**:636–644.

Clark, J. S. 1989. Ecological disturbance as a renewal process: theory and application to fire history. Oikos **56**:17–30.

DeLong, S. C., and D. Tanner. 1996. Managing the pattern of forest harvest: lessons from wildfire. Biodiversity and Conservation **5**:1191–1205.

Dietrich, J. H. 1980. The composite fire interval—a tool for more accurate interpretation of fire history. Pages 8–14 *in* M. A. Stokes and J. H. Dietrich, editors. Proceedings of the Fire History Workshop. U.S. Forest Service Rocky Mountain Forest and Range Experiment Station, Tucson, Arizona, USA.

Fall, J. 1998. Reconstructing the historical frequency of fire: a modeling approach to developing and testing methods. M.R.M. thesis. Simon Fraser University, Vancouver, British Columbia, Canada.

Finney, M. A. 1995. The missing tail and other considerations for the use of fire history models. International Journal of Wildland Fire **5**(4):197–202.

Fule, P. Z., W. W. Covington, and M. M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications **7**:895–908.

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

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research **3**:329–382.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research **18**:32–51.

Heyerdahl, E. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon and Washington: the influence of climate. Dissertation. University of Washington, Seattle, Washington, USA.

Hunter, M. L., Jr. 1993. Natural fire regimes as spatial models for managing boreal forests. Biological Conservation **65**:115–120.

Johnson, E. A. 1992. Fire and vegetation dynamics: studies from the North American boreal forest. Cambridge University Press, Cambridge, UK.

Johnson, E. A., G. I. Fryer, and M. J. Heathcott. 1990. The influence of man and climate on frequency of fire in the interior wet belt forest, British Columbia. Journal of Ecology **78**:403–412.

Johnson, E. A., and S. L. Gutsell. 1994. Fire frequency models, methods and interpretations. Advances in Ecological Research **25**:239–287.

Johnson, E. A., K. Miyanishi, and J. M. H. Weir. 1995. Old-growth, disturbance, and ecosystem management. Canadian Journal of Botany **73**:918–926.

Lertzman, K., J. Fall, and B. Dorner. 1998. Three kinds of heterogeneity in fire regimes: at the crossroads of fire history and landscape ecology. Northwest Science **72**:4–23.

Lertzman, K., T. Spies, and F. Swanson. 1997. From ecosystem dynamics to ecosystem management. Pages 361–382 *in* P. Schoonmaker, B. von Hagen, and E. Wolf, editors. The rainforests of home: profile of a North American bioregion. Island Press, Washington, D.C., USA.

Madany, M. H., and N. E. West. 1983. Livestock grazing–fire regime interactions within montane forests of Zion National Park, Utah. Ecology **64**:661–667.

Parminter, J. 1998. Natural disturbance ecology. Pages 3–41 *in* J. Voller and S. Harrison, editors. Conservation biology principles for forested landscapes. UBC Press, Vancouver, British Columbia, Canada.

Reed, W. J., C. P. S. Larsen, E. A. Johnson, and G. M. MacDonald. 1998. Estimation of temporal variations in historical fire frequency from time-since-fire map data. Forest Science **44**(3):465–475.

Romme, W. H., and D. G. Despain. 1989. The Yellowstone fires. Scientific American **261**(5):37–46.

Swanson, F. J., J. A. Jones, D. O. Wallin, and J. H. Cissel. 1993. Natural variability—implications for ecosystem management. Pages 89–104 *in* M. E. Jensen and P. S. Bourgeron, editors. Eastside forest ecosystem health assessment. Volume 2. Ecosystem management: principles and applications. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon, USA.

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

Van Wagner, C. E. 1978. Age-class distribution and the forest fire cycle. Canadian Journal of Forest Research **8**:220–227.

Whelan, R. J. 1995. The ecology of fire. Cambridge University Press, Cambridge, UK.