FHAES

Fire History Analysis and Exploration System

GPLv3 Free Software
Free as in Freedom

By Elaine Kennedy Sutherland, Peter W. Brewer, Donald A. Falk and M. Elena Velásquez.

For FHAES version 2.0.2

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Contents

Preface

FHAES (Fire History Analysis and Exploration System) is a tool used to analyze fire history based on fire scar chronologies developed from tree rings. FHAES has also been used to analyze chronologies of other disturbance events: any environmental event that results in a distinct anatomical marker in the rings. FHAES is a reimplementation and expansion of many functions of the FHX2 program (Grissino-Mayer, 2001). In FHAES the user can enter or revise fire event data (FHX files), evaluate sample size, summarize (compile) site files, create shapefiles, draw fire charts, perform statistical analysis, and evaluate the relationship between fire occurrence and presumed driving processes (e.g., climate conditions) using superposed epoch analysis.

FHAES is written in Java and builds on a variety of open source libraries. Downloads are available for several operating systems including Windows, OS X, Linux and UNIX. FHAES is open source software (see the details of the license on pages 47–51), so you are encouraged to inspect and edit the code. Please contact the authors if you'll like to find out how you can contribute to the FHAES project.

The development of FHAES is guided by the scientific steering committee: Elaine Kennedy Sutherland; Tom Swetnam; Donald Falk; Peter Brown; Henri Grissino-Mayer. FHAES is programmed by Peter Brewer and Elena Velásquez with support from Elaine Kennedy Sutherland and Donald Falk.

We acknowledge the contributions of NOAA's Paleoclimatic Division, Boulder, Colorado in early coordination and development of this project. We mention with gratitude the contributions of the late Michael Hartman who set up NOAA's International Multiproxy Paleofire Database, and worked to integrate this project with it. We also acknowledge the important role played by Wendy Gross, who programmed FHAES' original FHChart module and set up the original FHAES website on FRAMES. Thanks also to the late Richard Holmes for his pioneering work on many of the analytical routines that have been reimplemented in FHAES. Finally we'd like to thank the students of the University of Wisconsin-Platteville (especially Joshua Brogan) along with Evan Larson, Kun Tian and Omar Meqdadi for their work on the data entry and chart modules. An up-to-date list of all contributing programmers can be found in the 'About' dialog in the software.

We hope that you find FHAES useful and look forward to hearing your feedback.

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Chapter 1

Introduction

1.1 What is FHAES?

FHAES (Fire History Analysis and Exploration System) is a software tool to evaluate fire regime properties such as frequency, seasonality, extent, and fire/climate relationships from indicators of fire on trees. FHAES can also be used to calculate similar properties for other events that create unique signatures in a time series, like light rings from insect infestations or frost rings resulting from volcanic eruptions. FHAES accepts input data recording fire events in the Fire History Exchange (FHX) format similar to FHX2 (Grissino-Mayer, 2001). The techniques of fire history analysis that FHAES is built on assumes the user applied dendrochronological cross-dating methods to determine calendar year dates of annual tree rings and the characteristics of fire scars (Baisan and Swetnam, 1990; Dieterich and Swetnam, 1984; Fritts, 1976; Holmes, 1983; Stokes and Smiley, 1968).

1.2 Comparing FHAES and FHX2

FHX2 (Grissino-Mayer, 2001) has long been the standard for fire history analysis. Copyrighted by Henri D. Grissino-Mayer, it is a mix of Pascal and Fortran. It runs on Microsoft Windows operating systems, XP or earlier, and will run on other operating systems by using a DOS emulator.

FHAES is a comprehensive reimplementation of most of FHX2's functions. It is written as an open source, cross-platform, GUI application. FHAES will run on all modern operating systems (including 32 and 64 bit versions) and takes advantage of improvements in memory to analyze larger and longer datasets. In addition to reimplementing most functionality provided by FHX2, FHAES also includes additional features that you may find useful.

We hope that those of you familiar with FHX2 will find transitioning to FHAES quite simple. It is, however, important to understand that results produced by FHAES will not be identical in some cases to those produced by FHX2. For instance there are differences in the precision of floating point numbers (especially for provided numbers like π) between Pascal and Java. There are also different—yet equally valid—methods for performing certain calculations. For example, Henri Grissino-Mayer generously provided the source code from FHX2 for us to consult when we were coding FHAES. Unfortunately, the code for the Weibull function in FHX2 is a closed source binary (compiled Fortran code) so we had no way to determine its precise implementation. Within FHAES, however, all functions are open source and can be inspected by anyone interested in how the calculations are performed.

We are confident that the results produced by FHAES are identical, equivalent or more precise than those provided by FHX2. If, however, you feel that you have an example dataset which illustrates a degradation in the results produced by FHAES over FHX2, then we urge you to contact the authors so we can, with your assistance, investigate thoroughly.

Not every facet of FHX2 has been replicated in FHAES. While much of the output has been formatted as text and in spreadsheets, not all the earlier output tables are available at this time. That can change, with user input. There is no test for differences between two time periods or two subsamples of a site ("spatial differences"). If users express that some component of FHX2 was important to their work and is now missing from FHAES, please let us know and we'll do our best to redevelop it in FHAES (`fhaeshelp@gmail.com`).

1.3 Where can I get help?

This manual is the main source for information about FHAES and how to run it. The most up-to-date version of this manual is available from `http://help.fhaes.org`, or if you prefer to download a copy from `http://help.fhaes.org/pdf/`. If you would like a copy of the manual as it was at the release of a specific version of FHAES you can append the version number to the URL (e.g. `http://help.fhaes.org/2.0.0/` or `http://help.fhaes.org/2.0.0/pdf/`).

Please note that we intend to continue improving the manual over the coming months and years. Improvements will include better descriptions of the analyses and how to interpret them as well as documentation for future new features. Keep in mind if you choose to download a PDF version of the manual you will not be viewing the latest version. We therefore suggest you periodically check the URLs above - especially when you install a new release.

If you can't find the answer to your questions in the manual, you can email the developers at `fhaeshelp@gmail.com` or through the contact form on the FHAES website. Another source is the ITRDB forum mailing list, especially if your question is in regards to an academic issue (rather than FHAES itself) as many of the world's leading dendropyrologists are members.

1.4 How do I cite FHAES?

When you have used FHAES in your research please cite as you would any other academic publication. There are two distinct products that you can cite: the software itself; and this manual. When citing the software you should include the precise version of FHAES that you have used. Each official release of FHAES has it's own DOI number which can be found within the *Help* → *About* dialog. Depending on your citation style, a typical citation will be:

> Brewer, P.W., Velásquez, M.E., Sutherland, E.K. and Falk, D.A. (201X) Fire History Analysis and Exploration System (FHAES) version X.X [computer software]. http://www.fhaes.org. DOI:10.5281/zenodo.XXXXX.

The citation for this user manual should be:

> Sutherland, E.K., Brewer, P.W., Falk, D.A. and Velásquez, M.E. (2015) Fire History Analysis and Exploration System (FHAES) user manual. [compiled on 21/12/2017]. http://www.fhaes.org.

Chapter 2

Installation

2.1 Requirements

FHAES will run on any relatively modern operating system although testing is concentrated on the most recent releases. On Windows, FHAES will run on all versions back to XP. On OS X, FHAES will run on Lion (v10.7) and later, as well as 64-bit Macs running Snow Leopard (v10.6). On Ubuntu, FHAES will run on Precise Pangolin (v12.04) and later. On all other operating systems FHAES will run on anything that supports Java 7 or later, however, we highly recommend using Java 8 for FHAES (and for any other Java application) because Java 7 has passed its end-of-life and security updates are no longer released. Note that the Windows, OS X and Ubuntu packages come bundled with Java (or use the operating system's internal dependency manager) so there is no need to install Java separately.

2.2 How to install FHAES

Installation packages for FHAES are available for Windows, MacOS X, Linux and Unix. For users of other operating systems FHAES can be run from an executable JAR file.

First, download the relevant installation file for your operating system: `http://download.fhaes.org/`

- **Windows** – Run the installation program and follow the instructions[1].Once installed, FHAES can be launched via the Start menu.
- **Mac OS X** – Download then mount the DMG file, and then drag FHAES into your applications folder. Depending on your security settings OS X may block the launch of FHAES because it is not signed by an Apple-generated certificate. In this case you will need to go to *System Preferences* → *Security* and approve FHAES to be run.
- **Ubuntu Linux** – A Deb file is available which was designed for use on Ubuntu distributions but should work on any Debian based system. Install using your favorite package management system. On Ubuntu, the package will add a FHAES shortcut to your applications menu. Alternatively you can start FHAES from the command line by typing `fhaes`.
- **Unix** – This binary installer script is designed to run on most Unix and Linux distributions. Simply make the script executable and run from the command line. Note that this package does not include Java so you must ensure a suitable version of Java (Java 7 or later) is already installed.
- **Other operating systems** – Make sure you have Java 7 or later installed, then download the FHAES JAR file to your hard disk. You can run FHAES from the command line by typing:

```
java -jar fhaes.jar
```

.

[1] Some anti-virus programs may show warning messages that FHAES is not a widely known and may potentially be dangerous to install. Such messages are not the result of a detected flaw in the software but simply an indication that it hasn't been installed by thousands of users! You will, however, notice that the application is signed with a valid security certificate owned by the lead developer at the University of Arizona. This certificate shows the application hasn't been altered by anyone outside of the FHAES development team, therefore if you trust us you can ignore your anti-virus program's warnings.

2.3 How to uninstall FHAES

We understand that FHAES will never suit the requirements of all users, but as an open source product, we would really appreciate feedback as to why it didn't meet your needs. Without this feedback it is difficult to prioritize future development.

For Windows users, FHAES can be uninstalled using the standard add/remove programs feature in control panel. Mac users should simply delete the application from their applications folder. Linux users should use their prefered package management tool.

2.4 Source code and development

FHAES is open source and we warmly welcome contributions from members of the community. If you would like to inspect the source code or directly contribute to the development of FHAES please go to the FHAES Github page `https://github.com/petebrew/fhaes` for further information. The main readme file displayed there contains details of how to download the code into an Integrated Development Environment (IDE). The Github environment encourages you to fork the code, make changes in your own version of the repository and then send pull requests to the main development team. This is an easy and efficient way for new users to get aquainted with the code.

The Github pages also contain the issue system used to track bugs and feature requests, view progress towards the next milestone/release as well as recent code changes via the 'pulse' page.

If you would like to discuss how you can contribute to FHAES please contact the main FHAES developers at `fhaeshelp@gmail.com`.

Chapter 3

Getting started

If you have not yet done so, please install FHAES using the instructions on page 5 for your particular operating system. Once you launch FHAES you will be greeted by the FHAES home screen and 'quick-start' menu (figure 3.1). From here you can:

Create a new FHX file – Details about creating new FHX data files and general information about the structure of FHX files are in chapter 4. The data entry form is also accessible from the toolbar and file menu.

Load existing FHX file(s) – Load existing data files using the equivalent button on the toolbar or from the file menu[1]. Files can be loaded in the main screen by dragging and dropping them from your operating system's file manager. There is a routine in FHAES that checks FHX files for formatting errors and tells the user where in the file the format is wrong[2].

Run Superposed Epoch Analysis (SEA) – SEA analyses are performed in a separate window. Full details are in chapter 7.

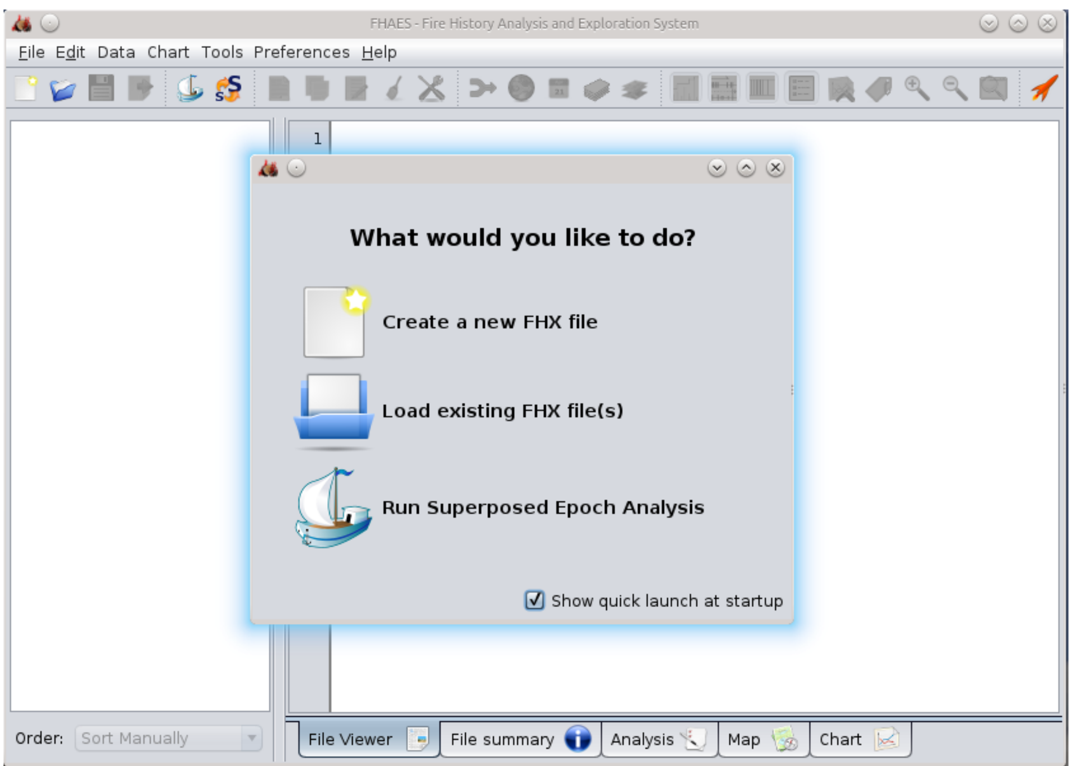


Figure 3.1: The FHAES home screen displayed on startup. Begin using FHAES by selecting either 'Create new FHX file' or 'Load existing FHX file(s)'.

[1] If you do not have any FHX data files but would like to test FHAES, use one of the sample files provided on the FHAES site or you can download data from NOAA's International Multiproxy Paleofire Database `http://www.ncdc.noaa.gov/paleo/impd/`

[2] If you come across problems with missing 'non-English' characters in FHX files loaded in FHAES see 4.7 for further assistance.

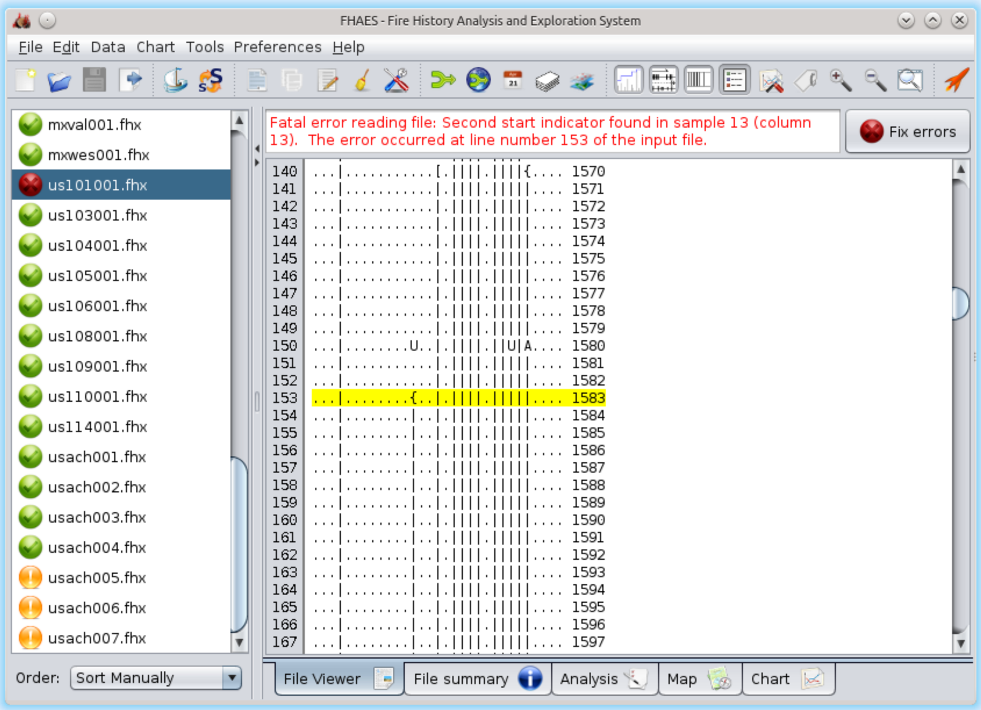


Figure 3.2: The left panel shows the FHX files currently loaded and the right tabbed panel shows details about the selected file. Note that the file list includes one file (us101001.fhx) that was checked and found to have formatting errors, and three files with no fire events. The 'File viewer' tab is open and shows a view of the erroneous file us101001.fhx. FHAES is highlighting the error in the file and is explaining the error in the message at the top of the screen.

3.1 Main screen

The main screen is divided into two main parts: the file list on the left and the main tab panels on the right. The file list on the left shows all the FHX files currently loaded in FHAES and the main data and analysis tab panels on the right show information about these files and the analyses performed.

FHAES uses the TRiCYCLE dendro converter library (Brewer et al., 2011) which makes use of the Tree Ring Data Standard (TRiDaS – Jansma et al., 2010) to load files you have chosen and checks they are valid. FHX files that are determined to be invalid are indicated by a red cross icon in the file list, while valid files are denoted by a green tick. Files marked with an amber exclamation mark are technically valid FHX files but contain no valid event data (FHX demography files for instance) and are therefore excluded from analyses although they can still be charted. Erroneous files can be corrected by double clicking the appropriate file in the list and then using the FHAES data entry screen to find and change the error(s), and re-save the file (see pages 13–18).

You can re-order the files using the drop down menu at the bottom of the left panel. The order of the files in the list will be reflected by the order of the analysis results.

3.2 Data and analysis tabs

In the following sections, we describe the processes available in the right panel's tabs of the main screen.

3.2.1 File viewer tab

The 'File viewer' tab displays the contents of the currently selected file in the file list (see figure 3.2). If this file is erroneous (i.e. it is marked by a red cross symbol) then a message is shown at the top of the screen. Where possible, FHAES will also highlight the line where the error exists. You can edit existing files by right clicking and choosing 'edit', or by using the equivalent toolbar or menu options.

3.2.2 File summary tab

The 'File summary' tab contains a report summarising the contents of the file currently selected in the file list. Note that only files with a green or amber marker will have a file summary. The summary includes details about: how many samples there are in the file; dates for the start and end of each sample; number of events; average number of years for each fire event etc. This text report is similar to the basic summary output produced by FHX2.

3.2.3 Analysis tab

The 'Analysis' tab shows the 'Analysis options' dialog where you define the parameters you'd like to use for your assessment of fire interval statistics and fire seasons, and for setting up numeric data matrices for further analyses outside of FHAES. Full details are in chapter 5.

3.2.4 Map tab

The 'Map' tab contains an interactive map displaying the latitude and longitude of sites in currently loaded files, if it was given in the header information. You can choose between a variety of background styles, zoom to the current map pins, and also turn the pin labels on or off using the buttons at the top of the page.

Please note that the latitude and longitude fields in FHX files are free-text and can therefore be in many formats. While FHAES will do its best to parse these fields to ascertain the coordinates, this may fail - in which case you will be warned. Please also note that in addition to lat/long fields, FHX-formatted files can contain location information in UTM and township/range fields. Because there is no field in FHX files to record the UTM zone (essential for the UTM easting and northing values to make sense), UTM information is disregarded by FHAES. Due to the huge potential variability of townshop/range data and the very limited use of these fields in FHX, they are also disregarded by FHAES. We strongly recommend using standardized WGS84 decimal latitude and longitude in your FHX files. Note you can use the FHAES data entry metadata tab to standardize coordinates.

FHAES uses the latitude and longitude fields in all spatial analyses. For further information see sections 3.3.4 and 3.3.5.

3.2.5 Chart tab

The 'Chart' tab displays a standard fire history chart for the currently selected file. There are many options for altering the content and style of the chart. See chapter 8 for a full description.

3.3 Data manipulation and tools

FHAES includes a number of tools for manipulating and processing your fire history data. These are available from various buttons on the toolbar and from the 'Data' and 'Tools' menus on the main screen. Because of their complexity, the Sample Size Analysis and tools are described in their own chapters (chapters 6 and 7 respectively). Descriptions and instructions for all other tools are provided below:

3.3.1 Merge selected files

The 'merge selected files' tool enables you to combine the data from two or more FHX files into a single file. It maintains all the samples from each input file as separate series within the output file. Note that because the tool requires two or more files, it will only be enabled once you select two or more files from the file list. When you launch the tool you will be asked whether to merge all years or just a subset of years. Once you have made your choice you will then be asked where you'd like to save the resulting FHX file, and whether you'd like to immediately add it to your existing project.

3.3.2 Create composite file

The 'create composite file' tool is similar to the merge tool, with the exception that all samples from a file are combined into a single series in the output. The output file therefore contains only one series per input file, labeled with the site code. Like the merge tool, a dialog will open asking whether the output file should be restricted to a specified range of years, or whether to include all years. However, you will also be asked to specify how the composite should be calculated. When creating a composite you might wish to only include broadly represented ("major") events in your datasets. The composite filter enables you to create a site composite composed using either a minimum number of events in a given year or the minimum percentage of series sharing the event in a given year for it to be included. For example, the filter for minimum number of events might be set at (for a given year) at least two fires among all the series indicate a fire to be included in the composite as a fire. Alternatively, the filter could be set at (for a given year) a minimum of 25% of the series indicate a fire to be included in the composite. The filter dialog also requires you to specify the minimum number of samples or recording samples in a year.

Note that events in composite files are always recorded as having an unknown seasonality because FHX files cannot represent events with multiple seasons within a single year.

3.3.3 Create event file

The 'create event file' tool produces a simple single column text file containing a list of years recording events. The file is typically used as an input to Superposed Epoch Analysis (see chapter 7) but may also be of use for other analyses. The tool is run on one or more selected files from the file list, and like the composite tool, it also asks the user to specify a year range, and options for how to filter the input files into a composite.

3.3.4 Spatial join on selected files

The ‘spatial join’ tool provides a method for creating event, composite and merge files based on location. It is only available when two or more files are selected in the file list. The tool works by clustering together files based upon the lat/long location fields provided in the FHX file header. It gives you the option to specify a threshold in kilometres lower than which sites are combined together. This is useful when doing regional analyses when you have multiple sites located close to each other recording similar fire histories. By combining these together you can simplify the comparison between these sites and those located further away.

When you specify your distance threshold, the tool will automatically create groups of sites list on the left of the dialog. You can click on each in turn to examine which sites have been included in each group. Files with no location information (or whose location information has not been successfully parsed) are located in a final miscellaneous group. By double clicking on the group names you can rename them to suit your needs. The tool also includes a separate map tab to show the spatial relationship between the groups. Each group is given a unique color.

The other parameter that needs to be set before continuing is what sort of output file you’d like to create: event; composite; or merge files. Once you’ve chosen your output file type and selected save you will be asked to chosen an output folder location. The files will be named according to the names you gave each group.

3.3.5 Create site summary shapefile

The ‘create site summary shapefile’ tool enables you to save the results of the ‘binary site summary’ table in Shapefile format for further visualization and analysis in GIS applications such as ArcGIS and QGIS. The resulting shapefile is typically viewed in conjunction with a temporal GIS plugin such as the Time Slider facility in ArcGIS or the Time Manager plugin to QGIS[3].

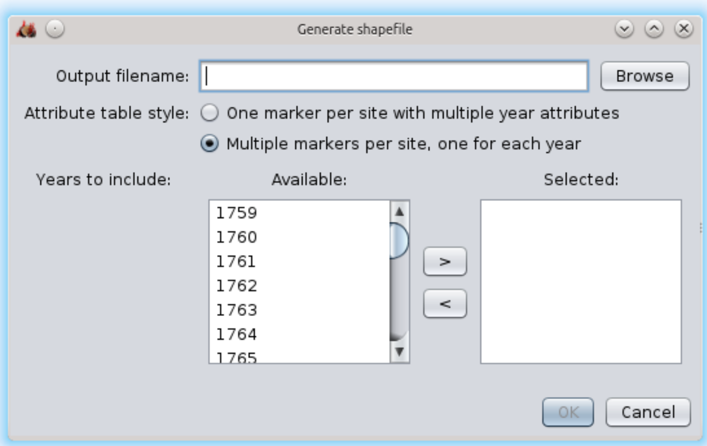


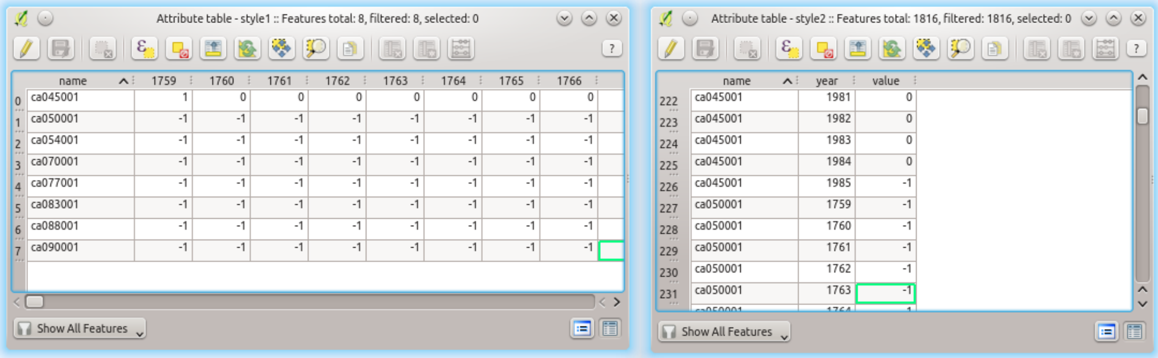
Figure 3.3: The screenshot of the export to shapefile dialog.

The export to shapefile dialog (figure 3.3) asks the user to provide an export filename, to specify the style of attribute table to use and to select the years you’d like to include. There are two attribute table styles, which you will find most convenient will depend on the GIS tool you are using.

The first creates a shapefile with just one map marker pin (row) per site but the associated attribute table contains multiple fields, one for each year requested. Because the shapefile format only supports a limited number of fields you can only include data for 255 years in your file. An example of the associated attribute table as displayed by QGIS is shown on the left in figure 3.4.

The second style creates multiple map markers (rows) for each site, one for each requested year. So if you select 200 years you will end up with a shapefile containing 200 markers in the same location for each site in your dataset. The associated attribute table will have just two fields, one containing the year and the other the data value. An illustration

[3] `http://anitagraser.com/projects/time-manager/`



	name	1759	1760	1761	1762	1763	1764	1765	1766
0	ca045001	1	0	0	0	0	0	0	0
1	ca050001	-1	-1	-1	-1	-1	-1	-1	-1
2	ca054001	-1	-1	-1	-1	-1	-1	-1	-1
3	ca070001	-1	-1	-1	-1	-1	-1	-1	-1
4	ca077001	-1	-1	-1	-1	-1	-1	-1	-1
5	ca083001	-1	-1	-1	-1	-1	-1	-1	-1
6	ca088001	-1	-1	-1	-1	-1	-1	-1	-1
7	ca090001	-1	-1	-1	-1	-1	-1	-1	-1

	name	year	value
222	ca045001	1981	0
223	ca045001	1982	0
224	ca045001	1983	0
225	ca045001	1984	0
226	ca045001	1985	-1
227	ca050001	1759	-1
228	ca050001	1760	-1
229	ca050001	1761	-1
230	ca050001	1762	-1
231	ca050001	1763	-1

Figure 3.4: Examples of the attribute tables associated with the shapefiles exported by FHAES. On the left is the table produced when the output style was set to 'one marker per site with multiple year attributes', whereas the right shows the output style when set to 'multiple markers per site, one for each year'.

of this is shown on the right in figure 3.4. There are no hard coded limits to the number of sites or years you can include using this style. However, if you do select a very large dataset you may find that your GIS becomes sluggish. In this case you would be best to import your data into a spatial database and ensure the relevant indexes have been configured.

Chapter 4

Data entry

4.1 Introduction to FHX (Fire History Exchange) data files

The FHX data format is the data standard used to archive fire-scar based fire history data in the International Multi-proxy Paleofire Database hosted by NOAA[1]. Although the file extensions are .fhx, they are actually text files formatted specifically for storing fire history information. While we recommend using the data entry tool in FHAES, with a good understanding of the format it is also possible to edit FHX files using standard text editing software.

The information recorded with FHX files includes an optional (yet highly recommended) header for storing metadata about the site and the samples, followed by the data (see figure 4.1 for an example data file). The data include the sample identification code and information regarding the beginning and ending year, years when the sample was and was not fire scar susceptible, and years when a fire scar or other indicator was recorded. The sample data are not numeric as is typical in dendrochronological data files, they are categorical and describe the status of each tree ring for the entire series. There are different characters for the beginning year depending on whether the sample included the pith (the true inside year). There are also different characters for the last year of the series, indicating whether the sample still had bark, or if the outside was bare wood that could potentially have eroded (and not included the last year of life). The position of a fire scar or other indicator in an annual ring relative to its earlywood or latewood is sometimes visible. This provides evidence of when the wildfire burned relative to the tree growth season.

An important concept in fire history analysis is "recording years" and in subsequent sections of this manual you will read many references to it. Whether particular rings are in recording status matters because it affects the analysis statistics, including mean, mode, variance, and many other descriptors. A recording year might be simply defined as a year when a tree could record a fire. Most analysts consider this to be the years after the first scar. After a tree is injured by a fire and the bark later falls away, the tree is considered "fire-susceptible," because wood is exposed and is in recording status. This biological response and physical condition translates into an FHX series being in non-recording status in pre-injury years and recording status in post-injury years. Once scarred, the tree is in recording status for the rest of its life, with some exceptions. There will be more about this issue in section A, below.

A complete list of the characters used for recording these data is shown in table 4.1.

The data for each sample are arranged by column, with each row corresponding to a year—beginning with the earliest year of any sample in the entire data set and ending with the latest year in the entire data set. This may seem unusual, but the nature of the data drives it. Fire scar data series can be several centuries or even millennia long. If the data format were reversed—that is, each year was represented by a column rather than a row—then there could be many hundreds of columns in a file. Viewing and managing many columns of data is far more unwieldy in most software compared to viewing and managing many rows of data.

Further information about the FHX file format can be found on the NOAA Paleoclimate website[2]

[1] http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/fire-history
[2] http://www.ncdc.noaa.gov/paleo/impd/tree_event_info.html

Header / Metadata

```
  1 Name of site   : Mesic mainland sites around Lake Duparquet
  2 Site code      : DMM
  3 Collection date: Summer 1985 and 1986
  4 Collectors     : Y. Bergeron, J. Brisson, D. Lemieux, F. Tetrault
  5 Crossdaters    : Y. Bergeron, J. Brisson, D. Lemieux, F. Tetrault, B. Suran
  6 Number samples : 45
  7 Species name   : Thuja occidentalis, Pinus banksiana, Pinus resinosa
  8 Common name    : Eastern white cedar, jack pine, red pine
  9 Habitat type   : Mesic shoreline
 10 Country        : Canada
 11 State          : Quebec
 12 County         : Abitibi-Temiscamingue
 13 Park/Monument  : L.Duparquet Research and Teaching Forest
 14 National Forest:
 15 Ranger district:
 16 Township       :
 17 Range          :
 18 Section        :
 19 Quarter section:
 20 UTM easting    : 630000m
 21 UTM northing   : 5370000m
 22 Latitude       : 48 28 N
 23 Longitude      : 79 17 W
 24 Topographic map: Rouyn-Noranda (32 D) 1:250 000
 25 Lowest elev    : 270m
 26 Highest elev   :
 27 Slope          :
 28 Aspect         :
 29 Area sampled   :
 30 Substrate type : Till, sandy clay, and silty sand
 31 Begin comments BELOW this line:
 32 Principal Investigator(s) Yves Bergeron, Jacques Brisson;
 33 End comments ABOVE this line.
 34
```

Data

```
 35 FHX2 FORMAT
 36 1573 45 3
 37 676382883011400066669996777758882299996366662
 38 026305112911677733332224877642225564455055559
 39 776076659523823145894561823989784518904367894
 40
 41 ...{......................................... 1573
 42 ............................................. 1574
291 ...............|...|.........{.....||||...... 1818
292 ...............|...|...............||||...... 1819
293 ...............|...|...............||||...... 1820
294 ...............|...|...............||||...... 1821
295 .....U.........|...|...E...U.......||||E..... 1822
296 .....|.........|...|...|...|.......|||||..... 1823
297 .....|...{.....|...|...|...|.......|||||..... 1824
298 .....|.........|...|...|U..|.......|||||..... 1825
299 .....|.........|...|...||..|.......|||||..... 1826
300 .....|.........|...|.E.||..|.......|||||..... 1827
301 .....|.........|...|.|.||..|.......|||||..... 1828
302 .....|.........|...|.|.||..|.......|||||..... 1829
303 .....|.........|...|.|.||..|.......|||||..... 1830
304 .....|.........|...|.|.||..|.......|||||..... 1831
305 .....|........[|...|.|.||..|.......|||||..... 1832
306 .....|.........|{..|.|.||..|.......|||||..... 1833
307 .....|.........|...|.|.||..|.......|||||..... 1834
308 .....|.........|...|.|.||..|.......|||||..... 1835
309 .....|.........|...|.|E||..|.......|||||..... 1836
310 .....|.........|...|.||||..|.......|||||..... 1837
311 .....|.........|...|.||||..|.......|||||..... 1838
312 .....|.........|...|.||||..|.......|||||..... 1839
313 .....|.........|...|.||||..|.......|||||..... 1840
314 .....|.........|...|.||||..|.......|||||..... 1841
315 .....|.........|...|.||||..|.......|||||..... 1842
316 .....|.........|...|.||||..|.......|||||..... 1843
317 .....|.........|...|.||||..|.......|||||..... 1844
318 .....|.........|...|.||||..|.......|||||..... 1845
319 .....|.........|...|.||||..|.......|||||...{. 1846
320 .....|.........|..E|.||||EU|.......|||||EEEE. 1847
321 .....|.........|..||.|||||||.......|||||||||. 1848
322 ...u.|..E......|..||.|||||||.......|||||||||. 1849
```

Figure 4.1: An example FHX data file with header/metadata at top followed by data section. Note the file has been split and truncated (indicated by the line numbers on the left) to show the detail of the most interesting part of the file.

Symbol	Described as	Interpreted as
.	Period or dot	(Can indicate two things:) - Space holder in data matrix before sample starts or after sample ends - Dated tree rings if sample is not recording for some period (typically before the first event in a series)
{	Left curly bracket	Beginning of sample's tree-ring series, if pith is not present
}	Right curly bracket	End of sample's tree-ring series, if no bark is present
[	Right bracket	Pith date of a sample; not always present
]	Left bracket	Bark date of a sample; not always present
|	Bar or Pipe	Recorder year. Tree is capable of recording fires but no fire was detected. Typically starts the year after the first fire event. See appendix A
D,d	Dormant season	The injury occurred between after cambial growth ceased or before it began; during the cambial "dormant" season
E,e	Early earlywood	The injury occurred during the first third of tree ring growth.
M,m	Middle earlywood	The injury occurred in the middle third of the tree ring growth.
L,l	Late earlywood	Cambium was injured late in earlywood development.
A,a	Latewood	The injury was apparent in the latest stage of cambial growth that year.
U,u	Undetermined	The position of the injury either was not or could not be determined.

Table 4.1: Symbols that indicate the status of each tree ring in a sample series. Brackets indicate beginning and ending years but are different depending on whether the pith or bark are present. Upper case letters designate years with fire scars, while lower case letters show years when indicators of fire other than scars–like resin ducts and growth releases–were present. Periods (dots) are used to fill the years before the tree was first scarred, or during periods when it is uncertain that the tree was recording fires (for example, a pocket of rot has obscured some rings).

4.2 Fire History Recorder

The purpose of the data entry module (FHRecorder) in FHAES is to create and edit FHX files. Please note that it is designed for editing standard data series files recording information about individual trees (as outlined above) and not for the very similarly formatted 'composite' files (see section 3.3.2) that represent data for multiple trees and/or sites. There should be no need for you to manually edit composite files and FHRecorder will warn you of this.

When creating a file we strongly advise you to record the metadata as fully as possible. If all the information is not available at first, fill out as much as possible and plan to obtain it and revise the file later. Because the original FHX metadata format did not provide a field to record UTM zone, if you have the UTM coordinates, record the zone used in the comment field and fill out the latitude and longitude field. We strongly recommend that you use the latitude and longitude fields as the primary means for recording locality information.

To create a new file you can click the icon on the toolbar, or by going to *File* → *New*. If you'd like to edit an existing file open it in FHAES as normal, then double click the entry in the file list, or select the file and click the edit button on the toolbar.

The main data entry screen has four tabs: data; metadata (see figure 4.2); summary; and graphs. These are described in detail in the following sections.

4.3 Metadata

The metadata tab provides a straightforward method for filling out the fields that make up the FHX header and at the bottom of the tab is space to enter comments. Next to each field is a help tip button which gives you a short description of the field and the sort of data you should be entering. This information is also provided below:

Township, Range, Section, Quarter Section – Township, range, section and quarter section fields have been used historically in the USA to record the locations using the Public Land Survey System. If used, the township and range fields are required at a minimum, with the section and quarter section values optionally used depending on

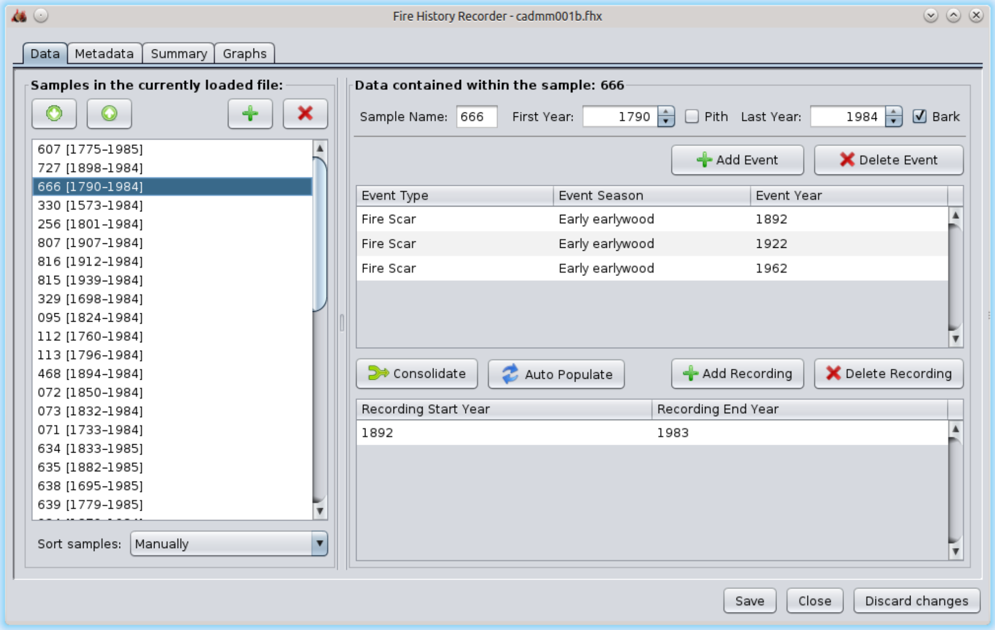


Figure 4.2: The main data entry dialog showing a file containing multiple series. The details of the selected series (666) are shown on the right. We can see it contains fire scars in the early earlywood portion of the 1892, 1922 and 1962 rings.

the precision and size of area being defined. These fields are not used by FHAES in spatial analysis, the latitude and longitude fields should be used instead.

Site name – Human readable name for the site. To be compatible with FHX2 this field should be no more than 70 characters long.

Site code – Short code used to identify the site. By convention and for use in FHX2, this should be 3 characters long, but can be longer if you only intend to use the file in FHAES.

Collection date – Date or dates when the samples included in this file were collected. It is best to use the ISO 8601 standard so that dates are recorded YYYY-MM-DD e.g. 2000-12-25.

Collector(s) name(s) – The name or names of those in the field that collected the samples represented in this file.

Dater(s) name(s) – Name or names of those who provided the dendrochronological placement for these samples.

Latin name(s) – Latin names of the trees from which these samples were taken. If more than one species is included in this file separate them with commas and then provide further information in the comments field.

Common name(s) – Common/vernacular names for the species in this file. As for latin names if more than one species is included then separate with commas.

Habitat type – Habitat type at this site. Please use standardized naming systems applicable to the region wherever possible.

Country – Country where this site is located.

State – State where this sample is located.

County – County where this sample is located.

Park – Park (e.g. National Park) where this site is located.

Forest – Name of forest where this site is located.

Ranger district – The Ranger district that covers this site.

UTM easting –*Warning Deprecated* – UTM easting value for the site. The FHX specification does not provide a facility for recording the UTM zone so UTM data is ignored by FHAES. The latitude and longitude fields should be used instead.

UTM northing –*Warning Deprecated* – UTM northing value for the site. The FHX specification does not provide a facility for recording the UTM zone so UTM data is ignored by FHAES. The latitude and longitude fields should be used instead.

Latitude – Latitude value for the location of this site. Although this is a free text field and any formatting is valid, we strongly recommend using decimal degrees. Existing free text values can be parsed and converted using the convert button.

Longitude – Longitude value for the location of this site. Although this is a free text field and any formatting is valid, we strongly recommend using decimal degrees. Existing free text values can be parsed and converted using the convert button.

Topographic map – Reference to the topographic map covering the site.

Highest elevation – Highest elevation of the site. Please also specify units.

Lowest elevation – Lowest elevation of the site. Please also specify units.

Slope angle – Angle of the slope of the site either as a description, or as a value in degrees.

Slope aspect – General aspect of the site, typically recorded as compass direction.

Area sampled – Total area sampled. Please also specify units. Should be 10 characters or less to remain compatible with FHX2.

Substrate – Description of the substrate at this site.

Sample count – This field is automatically set by FHAES depending on the number of samples entered in the data screen.

Note that all fields are free-text with no formatting restrictions (see section 4.8) but it is best to be consistent and standardize wherever possible . For example, we strongly suggest for the latitude and longitude fields you restrict yourself to using standard WGS84 decimal degrees. If you do have coordinates in other styles you may like to try the conversion buttons to standardize your data. It will successfully convert many commonly used styles of coordinates including those in degrees, minutes and seconds.

The metadata tab includes a checkbox to enforce original FHX2 field length requirements. The original FHX2 program included limits for the length of each field. Although FHAES does not have these same limitations (see section 4.7), if you intend to use the file in FHX2 as well as FHAES you should tick the checkbox here. Fields that do not meet the FHX2 specification are highlighted in red and a warning appears at the top of the screen. Note this checkbox enforces a length limit on sample names too.

4.4 Data

The main data tab is where you enter details about your samples and events. The panel on the left shows a list of series within the file. Series can be added and removed using the plus and cross buttons respectively. The order of the series can also be changed, either automatically by choosing sort criteria, or manually by using the up and down buttons. The order of the series in this list will be reflected in the order they appear in the FHX file, and therefore the order they will appear in analysis outputs and charts.

When you add a new series, you will be asked: to give the series a name; to specify the start and end years for the sequence; and to indicate whether the sample has pith and/or bark (see section 4.8 for an explanation of cases where pith/bark information is disregarded). In FHAES, the series name can be as long as the user wishes unless the 'Force FHX2 requirements' checkbox has been selected on the metadata page. In this case you will be restricted to eight characters to ensure the file can be successfully read in the original FHX2 program. See section 4.7 for more information.

4.4.1 Events

To add **events** to the series, first select the sample in the list. The panels on the right will show the details about the selected series and list any existing events currently associated with it. The series name, year range, pith and bark information are displayed and can be edited at the top of the screen. You can add events by clicking the add event button. In the event table you can then specify: whether the event is a fire or other injury; the year the event was recorded and what season it was recorded in. Note that events will automatically be ordered into chronological sequence.

Once the recording years table (described below) has been populated also note that you will not be able to add events that fall outside of the year range(s) that describe when the tree was 'recording'. For instance if you need to add an event prior to your first defined event you will need to extend the recording years backwards in time before the event table will accept the earlier year.

4.4.2 Recorder years

Once you have entered the events for your sample, you can then specify the **recorder years** (see appendix A) i.e. the years in which the tree was susceptible to fire (*sensu* Romme, 1980). Typically this will be from the first event until the end of the sample. If the recording years are not correct you can automatically re-populate the table using the button above the table. This option allows you to override the recording years to: from first event to the end of the sample; or from beginning to the end of the sample. The second case is used occasionally by some researchers when working with certain ecosystems and species where it is considered that trees record fires regardless of whether they have already sustained an injury or not.

In some samples there may be periods when the sample reverts to 'non-recording' status in the middle of the series. For instance in a tree injured by fire and therefore considered to be in 'recording' status the edges of the scar may close together until the cambium is reconnected. At this point the tree would be considered by many researchers to be in 'non-recording' status again until another cambium-injuring fire was to occur. In such cases you can add multiple ranges for 'recording' with gaps covering the 'non-recording' years to reflect this.

4.5 Summary and Graphs

The remaining two tabs in the data entry window provide an overview of the data file which can be helpful to verify that the data entry has been done correctly. The summary tab (figure 4.3) provides a table summarising the samples on a year-by-year basis. For each year the number of events, the number of samples and the percentage scarred samples are shown, along with the distribution of events by season. The final column of the table includes a color bar summarising the seasonality of the events recorded. The color bar can be customised with the button at the top of the screen. This enables the user to change colors as well as merge together seasons into a single color bar. This is done by dragging and dropping the seasons together into a single group.

The summary table can be exported to a CSV file using the relevant button at the top of the screen. It can also be copy and pasted into various spreadsheet applications.

The graph tab (figure 4.4) shows similar information in a graphical form. The color bar is replicated horizontally at the top of the screen, with the number of events and samples shown at the bottom. One good use for the bottom graph is to check for single events located immediately before or after a large number of events. This may be an indication that an event has been added a year too early or late.

4.6 Correcting erroneous files

If you edit an FHX file which includes one or more errors (i.e. is marked by a red icon), FHAES will display a file correction screen (see figure 4.5). This shows the original file on the left with the error highlighted, and then the same file on the right with the correction the FHAES suggests. Check that the correction suggested by FHAES is valid and if not you can manually edit the text. (It is helpful to have a copy of the original data nearby for reference.) When you are satisfied that the file is now valid, click save and the file will open in the standard data entry screen. If the changes you've made mean the file is still invalid, the file correction screen will refresh with the remaining errors highlighted.

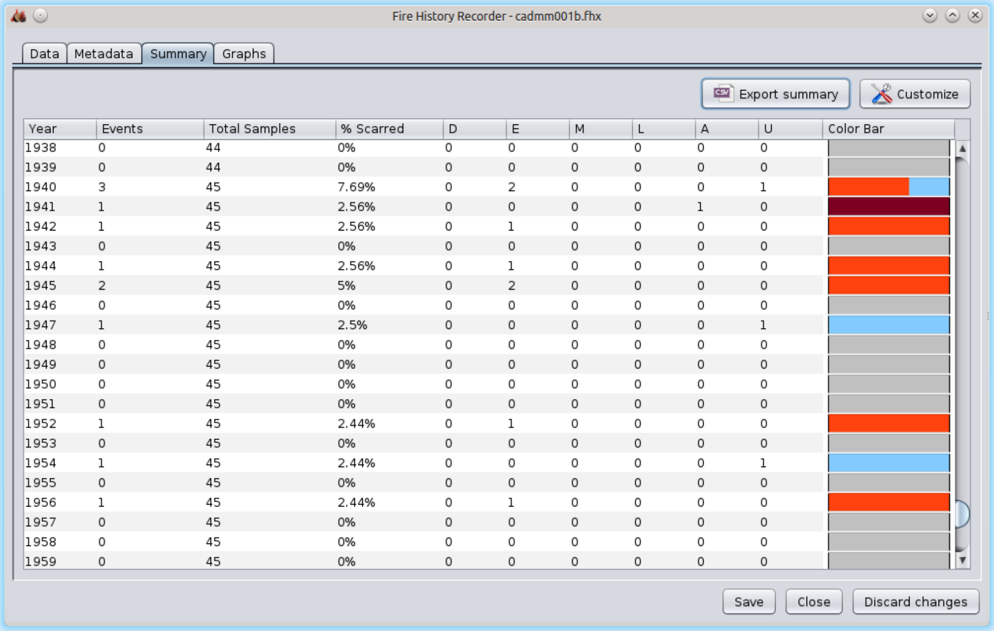


Figure 4.3: The FHRecorder summary tab summarises the information recorded in a data file on a year-by-year basis.

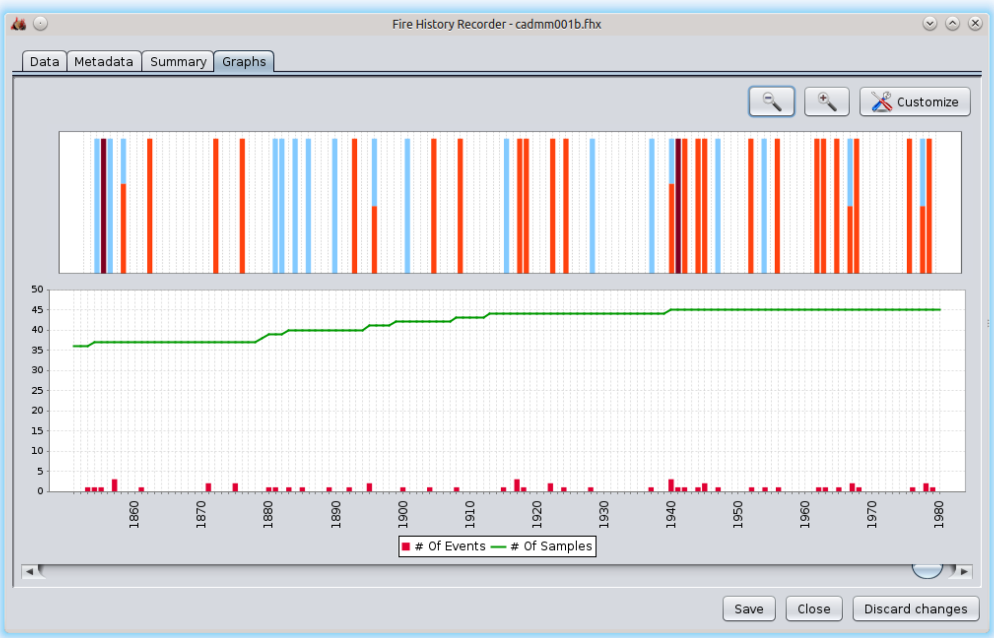


Figure 4.4: The FHRecorder graph tab illustrates similar information to that provided in the summary table (see figure 4.3) but in a graphical form.

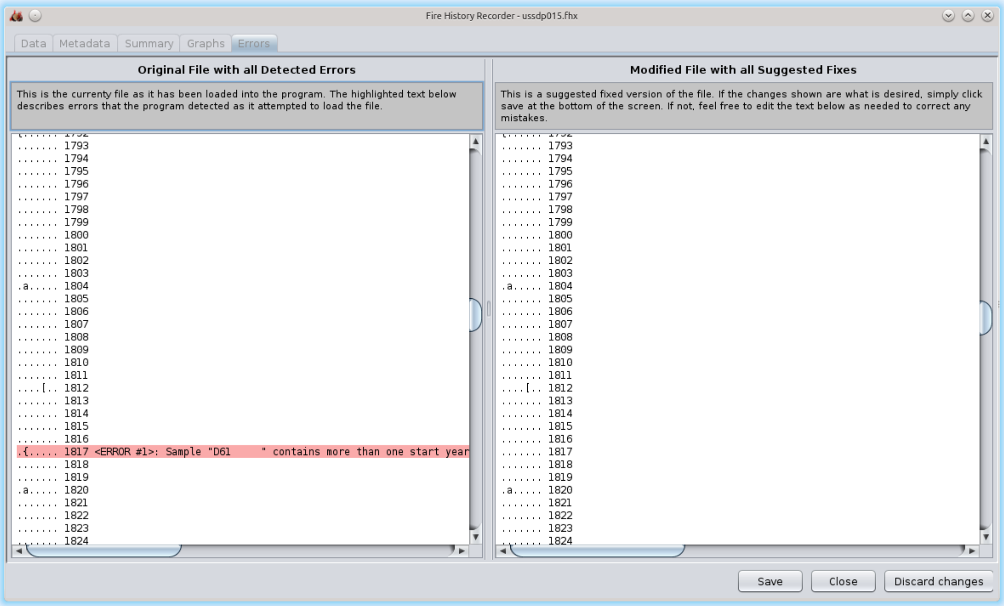


Figure 4.5: Screenshot of the file correction screen that is displayed when an erroneous FHX file is edited. Note the original file is shown on the left with the error highlighted and explained, while the right of the screen shows the same file with the suggested corrections.

4.7 FHX2 restrictions

The original FHX2 application enforces a number of limitations on field sizes and amount of data. This was in response to the relatively limited computer resources available at the time the program was originally written. Because modern computers have much more memory and speed, we didn't have such limitations when developing FHAES, and FHX files produced by FHAES can be slightly different than those produced by the original FHX2 application. While FHAES can read and edit all data files produced by FHX2, not all FHX data files produced by FHAES can be read by FHX2. Care must be taken if you intend to use files created by FHAES in FHX2. We have tried to make this easy: on the metadata page of FHRecorder there is a checkbox that instructs FHAES to enforce the original FHX2 format requirements. With this checked, the FHX2 field length limits are displayed and any fields exceeding these limits highlighted. Any fields not meeting the restrictions must be truncated before the file can be saved.

Here are some of the limitations in FHX2 that are not present in FHAES: the length of series names (limited to 8 characters); the number of series in a file (up to 254); and range of years (501BC-2020AD although earlier releases were 501BC-2006AD). It is also worth noting the difference in handling of BC dates in FHAES and FHX2. FHX2 uses the astronomical dating system which includes the year zero. This means that all year numbers prior to 1AD are offset by one e.g. 1AD=1; 1BC=0; 2BC=1 etc. FHAES on the other hand uses Gregorian year numbering, thus skipping the non-existent year 0. Care should therefore be taken when moving datasets containing BC data between the two programs.

A further limitation of FHX2 is only apparent when entering characters other than those used in English. FHX2 requires that data files use Extended ASCII (also known as Cp437, IBM437, ISO-8859-1 and others) character encoding with unsupported characters replaced by question marks. Even though FHX2 uses extended ASCII internally, the data entry interface only allows basic ASCII characters. A file saved with popular western accented characters (e.g. á è î ö etc) will display correctly in FHX2 but despite it not being possible to enter these characters manually in the program.

By contrast FHAES uses the UTF-8 character encoding which supports characters from virtually all languages. When the checkbox on the metadata page is set to force FHX2 compliance, FHAES will save to a file with ISO-8859-1, maintaining all characters supported by this older encoding. If unsupported characters are entered in the metadata the user is warned.

When loading FHX files in FHAES, the default behaviour is for FHAES to attempt to automatically detect the character encoding and use it accordingly. Unfortunately in some circumstances there is no way to definitively detect encodings without knowing the language and context of the text stored. In cases where FHAES incorrectly detects the encoding and you know the correct one, you can override the encoding used by using the *Preferences → Character encoding preferences* menu. We recommend editing and saving 'exotically' encoded files in FHAES to ensure they are saved in UTF-8 for ease of use and sharing.

4.8 Limitations of the FHX format

Even though the field and data length restrictions of FHX2 outlined in section 4.7 have been removed in FHAES, the FHX format still has a number of fundamental limitations for the accurate description of fire history data. The primary issues are outlined below:

- **No standardisation of metadata** – The metadata fields that are present in FHX files are all free text with no restrictions on how information should be added or formatted. The clearest example of this is the latitude and longitude fields. They can be written in a wide number of formats and styles: either decimal degrees; degrees minutes and seconds; degrees and decimal minutes; direction characters variably as +,-,N,S,E or W; space delimited; apostrophe delimited. The list is almost endless. To make use of this information in FHAES or in any other software, the coordinates, and other metadata fields must be interpretable without manual user intervention.
- **Single data point per sample per year** – The format only allows for only one data point (piece of information) to be recorded about each sample in any year. This causes problems, for instance when a tree begins or ends with an event as it means the pith/bark status cannot also be recorded[3]. Perhaps more importantly, it means that fire scars and other injuries cannot be coded in the same years which creates significant problems for those attempting to do analysis comparing, say, fire and insect outbreaks in the same stand.
- **Metadata applies to all series in the file** – The metadata header is limited by the fact that it applies to all series within the file. If the file contains data from different species there is no mechanism for for defining which species applies to a given series, although the user can list the species in the header or a comment line. There is a similar issue with coordinates as it's routine now to record each tree location with a GPS rather than more general coordinates for entire sites. Likewise for slope, aspect, collection date, substrate type etc, users may prefer to record these on a tree-by-tree rather than site-by-site basis. Having ready access to this data would be extremely useful for charting and spatial analysis.
- **Pre-defined categories of events with no flexibility** – The analytical routines within FHAES are agnostic with regards the type of events being processed. However, the pre-defined nature of the event categories in the FHX format means that users may find it difficult to adapt their data when using FHAES for novel analyses. As indicated elsewhere in this manual, the analyses performed in FHAES are not limited to fire histories but could be used for a wide variety of similar event types. These pre-defined event categories also do not allow for the recording of more general (textual) observations about particular rings.
- **Separation of dendro and fire history data** – Fire history research is often conducted alongside traditional dendrochronological research. The separation of ring-width and fire event data into different data files means duplicatation of metadata management. Combining all this data into a single file would be more efficient and would also facilitate analyses that combine ring-width and event data, for instance growth releases following fire events.
- **Dated and undated series** – Although fire history research is conducted overwhelmingly on trees that are absolutely dated via standard dendrochronological methods, it is conceivable that researchers may want to use FHAES on samples for which this is not the case. For example research may be carried out on wood sourced from archaeological or palaeoecological contexts. In these cases the samples may be dated within a relative dating framework; dated with uncertainty (e.g. via radiocarbon analysis); or not-dated at all. It would be preferable if this information was included alongside the fire history data.

To overcome these issues, the long-term aim is to support the Tree Ring Data Standard (Jansma et al., 2010) within FHAES while maintaining the ability to read existing FHX data files. In the meantime we recommend you maintain extensive notes to go with your FHX files. These can then be used to upgrade your existing FHX files in future once TRiDaS is fully supported.

[3] In cases like this the event information supersedes the pith/bark status so data series may in some circumstances begin and/or end with events rather than brackets. When this happens we must assume pith and/or bark are absent.

Chapter 5

Analyses

This chapter describes the analysis results tables presented on the 'Analysis' tab of the main window. The majority of these results tables are available only once the main analysis has been run. Some of the results also require two or more files to be loaded.

Most statistical calculations within FHAES are done using the standard Apache Commons Math library[1]. The main exceptions are the calculations associated with the Weibull distribution which are not available in any known open source libraries. These have been programmed within FHAES by Elena Velasquez. As with all the FHAES code, the code for these calculations can be inspected and scrutinized (see section 2.4 for further information).

Once files are loaded or created and you switch to the 'Analysis' tab you will be shown the 'Run Analysis' button. Clicking this will show the 'Analysis options' dialog where you can define the parameters you'd like to use for your analyses, after which FHAES will then perform the analyses.

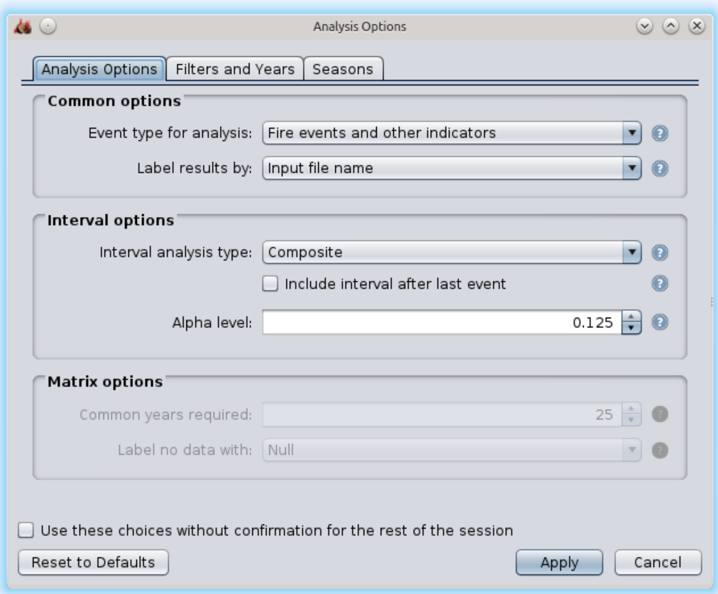


Figure 5.1: The analysis options dialog allows the user to define the parameters used when running fire history analyses. Note that options that have unavailable or not yet implemented are greyed out.

The dialog is split into three panels: analysis options; filters and years; and seasons. Each of the fields includes a help tip button to provide you with more information after what the parameter means and it's implications for the analysis. This information is also reproduced below:

Event type for analysis – Select whether to perform analyses on:

[1] https://commons.apache.org/proper/commons-math/

- only fire events (upper case letters in the input files)
- only other indicators (lower case letters)
- both fire events *and* other indicators

Note that choosing one of the first two options may remove one or more of your input files from the analyses if they do not contain enough of the specified event types.

Label results by – Select how you would like to label the input files in your results tables and charts. Note that FHAES will default to file name if you pick site name or code and a file is missing the relevant header information.

Interval analysis type – Select whether you want to perform analyses based separately upon each sample in your file or by combining samples within a file into a composite. Note if you select 'composite' then you may like to set composite filter options as well.

Include intervals after last event – Indicate whether you'd like to treat the time period from the final event marker until the end of the series as an interval in the interval analyses.

Alpha value – The alpha value or error is the maximum probability that a given return interval will be significantly short or long. The default alpha value for this two-tailed test is 0.125.

Year range – the default option is that the analyses are calculated across the entire range of years in your input files, or you may specify a more restricted time period.

Composite fire threshold – Specify how the composite of your samples should be filtered during analyses (number or percentage). If you choose 'number of fires' equals 1 for a given year then all fire events will be included in the composite; if number of fires is larger than one then only years with at least that many fires in a given year will be included in the composite. The 'percentage of fires' value ranges from 1 to 99. The larger the filter, the more that extensive events in the record are emphasized.

First season combination – In the seasons analysis, scar positions relative to the earlywood, latewood, or between growth rings (or grouped) are compared for differences based on some hypothesis. A common hypothesis would be that most fires occurred in the typical wildland fire season for the locale (first season combination) and rarely occurred in the second season combination.

Second season combination – The second season combination are scar positions being compared to the first season.

The analysis options dialog will open automatically each time you load FHX files. If you want to repeat analyses without confirming or changing options each time you can choose to use the same options without confirmation for the rest of the session. The next time you load FHAES it will remember your preferred analysis options, although you will be shown the options dialog and asked to confirm them again. Once you confirm your analysis options FHAES will perform the calculations and populate the tabs on the home screen (see figure 3.2).

Once the analyses have been performed, a categorized list shows all the available analysis results on the right, while the table on the left shows the currently selected result. Analyses not available will be greyed out (e.g. when only one FHX file was loaded and the listed analysis requires multiple files for comparison). There is a full description of each analysis in chapter 5 as well as through the online help system you can access by pressing the help button.

To view the analysis results simply select the analysis type from the categorical list on the right and they will be shown in the table on the left. You can copy and paste values from this table into your preferred spreadsheet or statistical package using the edit menu, toolbar buttons, or right-click popup menu. You can also save single tables by right- clicking the required table in the results tree on the right. Additionally, certain tables can be saved in other formats. For example the popup menu for 'Binary site summary' will allow you to save as a GIS Shapefile (see page 11 for more information).

To save all analysis results at once, you can go to *File* → *Save* → *Save analysis results* or use the save button on the toolbar. You have the option of specifying ZIP or XLSX format; the former will give you a ZIP file containing each table as a CSV text file and the latter will give you a single Microsoft Excel workbook with each table as a separate worksheet.

5.1 Descriptive summaries

The descriptive summaries provide basic summaries of either all the loaded files or the currently selected file depending of the analysis selected.

Series-by-series summary – This summary table has a row for each series found in each of the currently loaded files. It includes a number of columns of file-wise metadata extracted including: filename; site name and code; sampling date; latitude; longitude; state and country. It also includes series specific metadata including: series name; first year; last year; pith presence; and bark presence. The final two columns contain a summary of event years with and without associated seasonality information as a simple space delimited list.

Current file annual summary – The current file annual summary provides a basic descriptive summary by year of the currently selected file. It contains a row for each year present in the file and has columns for: sample depth; recording depth; number of events; percentage of recording trees with an event. The percentage of events column has a value of -99.0 as a 'nodata' value when there are no recording trees.

Current file event summary – The event summary table provides a summary of events in the currently selected file. The table has three columns: trees recording; number of years; and years. The table groups the years in which n trees record an event, and provides a count and sorted list of these years. It provides the user with a quick tool for seeing which fire years are most (and least) commonly represented in the file.

Note that the current file annual and file event summary tables are not saved to the analysis results file but this option may be available in a later version of FHAES. For the present we suggest performing a copy-and-paste of the current file tables to a text or spreadsheet file.

5.2 Interval analysis

The Interval analysis tables provide the results of several analyses for each data file. Interpretation of the results will depend on whether you chose to perform the interval analysis on the composite or by sample. If you specify "composite", FHAES creates a composite (summary) fire chronology for the site and calculates the intervals (and analyses) between fires for that composite chronology. Say the time period you are analyzing is 1600–1900, and the earliest fire scar was 1625 and the most recent was 1889. The results are interpreted as the mean (or median) intervals between fires occurring anywhere in the area sampled. If you specify "sample", FHAES calculates a set of fire interval statistics describing how often fire could be expected to return to each original point or sample. The composite chronology intervals are likely to be shorter than those of the sample intervals because fire will probably occur at least somewhere in the sample area more often than it will burn at each sampling point.

The fire interval statistics are given for two probability distributions, the normal and the Weibull. Often, sets of fire intervals have more short intervals than long ones and are better described by the Weibull distribution than the normal. A description and formula for each statistic or parameter are shown below.

5.2.1 Total intervals

This is the number of intervals between fires, notated as n. The number of intervals will be one less than the number of fires (so $n = F - 1$).

5.2.2 Mean fire interval

The mean fire interval $\bar{I}$ is the arithmetic mean of the intervals in a series, where I_j is the Jth interval in years. Fire intervals are in units of years/fire. Note that the mean of a distribution can be influenced by outliers (extreme small or large values) or asymmetrical distributions. Because fire interval distributions are often strongly right-skewed, $\bar{I}$ can be "pulled" to the right by occasional long intervals. The median fire interval (below) provides a potential solution to this issue.

$$\bar{I} = \frac{\sum_{j=1}^{n} I_j}{n} \tag{5.1}$$

5.2.3 Median fire interval

The median fire interval is the middle value of all intervals in a series when the intervals are rank ordered by size. When there is an even number of intervals, the median is calculated by convention as the arithmetic midpoint between the two adjacent middle values. Median fire intervals are often used as a measure of central tendency because the median is less sensitive than the arithmetic mean to outliers or highly skewed distributions.In fire history the median fire interval is considered a robust estimator of the fire regime.

5.2.4 Standard deviation

Standard deviation is the square root of the variance in a sample, and is used in calculating measures of departure from the mean, such as calculating confidence intervals. FHAES calculates the *sample standard deviation* (SD-sub-N), because the intervals evaluated are an unknown subset of the complete population of intervals.

$$\text{SD} = \sqrt{\frac{\sum_{j=1}^{n}(I_j - \bar{I})^2}{n-1}} \tag{5.2}$$

5.2.5 Fire frequency

Frequency in a discrete series is the number of events per unit time. In the case of fire history, frequency is the number of fires, F, divided by the total number of years in a series. Fire frequency is in units of fires per unit time (year, decade, century).

5.2.6 Coefficient of Variation

The coefficient of variation (CV) is the standard deviation of a sample normalized by (that is, divided by) the sample mean. The CV is useful for comparing the relative variation between samples that may have different means, since it provides the standard deviation as a proportion of the mean. The CV is unitless since the units divide out in the numerator and denominator. Here the denominator is the mean fire interval, $\bar{I}$.

$$CV = \frac{\text{SD}}{\bar{I}} \tag{5.3}$$

5.2.7 Skewness

Skewness is a measure of the symmetry of a distribution around the mean. A skewed distribution has more values below ("left-skewed") or above ("right-skewed") the modal value. Thus by definition, skewed distributions are asymmetric and thus are non-normally distributed. Fire interval distributions are commonly right-skewed, meaning that there are more long intervals above the mode than short intervals below the mode. In right-skewed distributions, the mean is higher than the mode or median. Skewness is hence an indicator of whether the mean fire interval is a robust indicator of central tendency. Skewness is the third moment of the frequency distribution, given as:

$$\gamma^2 = \frac{\sum(I_j - \bar{I})^3}{N} \tag{5.4}$$

5.2.8 Kurtosis

Kurtosis is sometimes referred to as the "fourth moment" of variation about the mean, which is how much of the data is in the tails of the distribution compared to centrally distributed. Distributions with high kurtosis are "heavy tailed" (i.e., more of the data are divergent from the mean) compares to a normal distribution. In fire history this could indicate a greater than expected prevalence of short or long intervals compared to a standard normal distribution.

$$\text{kurtosis} = \frac{\sum_{i=1}^{N}(Y_i - \bar{Y})^4/N}{s^4} \tag{5.5}$$

5.2.9 Minimum and maximum fire intervals

These are simply the shortest and longest fire intervals (in years) observed in the dataset. Note that these extreme values may not represent the distribution of all intervals well, because a single small or large value could be very divergent from the rest of the distribution.

5.2.10 Weibull Distribution

The Weibull function is a flexible probability distribution that can represent a wide range of non-normal data. Because of its flexibility and relative tractability, it has been extensively adapted for statistical analysis in fire history (Falk, 2004; Grissino-Mayer, 1995, 1999; Johnson, 1992; Johnson and Van Wagner, 1985) The Weibull distribution is a "stress accumulation" statistical model; thus, under some circumstances the probability of an event (e.g. a fire) increases with time as a result of some accumulating stress (e.g. fuels as a function of time since fire).

The underlying reason that the Weibull is used in fire history analysis is that many fire regime properties (e.g. fire intervals or frequency) are not normally distributed. For example, fire interval distributions are nearly universally right-tailed (i.e. skewed) with a heavy tail (i.e., data have occasional outliers of very long intervals), so they cannot be approximated by a normal curve (Falk, 2004; Grissino-Mayer, 1995, 1999). The Weibull distribution is used to model a set of empirical data (for example, a frequency distribution or histogram of fire intervals).Empirical distributions (e.g. from a fire history collection) may be "noisy", i.e. they may not be smoothly distributed. Fitting a modeled probability distribution to empirical data allows the data to be quantified and analyzed; this is the real strength of probability modeling in fire history.

There are several forms of the Weibull function. FHAES models the two-parameter Weibull distribution, with parameters for shape and scale respectively, by iteratively fitting the distribution to a set of empirical data such as fire intervals. The shape parameter (κ) regulates departures of the Weibull distribution from normality. When $\kappa > 1$, the Weibull probability distribution is modal and approximately normal at $\kappa = 3$; as κ becomes smaller, the mode of the distribution drifts toward 0, and the distribution becomes strongly right-skewed (i.e., a long right tail, typical of fire interval distributions). At $\kappa = 1$, the Weibull distribution reduces to a negative exponential, and for $\kappa < 1$, the Weibull approaches $\frac{1}{x}$, a rectangular hyperbola. Values of κ are non-negative, i.e.:

$$\kappa\epsilon(0, \infty) \tag{5.6}$$

For a Weibull distribution with a given shape parameter κ, the scale parameter (λ) stretches or compresses the distribution. Lower values of λ are more compressed about the mode, meaning that most of the values are close to the center. Distributions with high λ are more dispersed into the tails. λ is also a non-negative parameter:

$$\lambda\epsilon(0, \infty) \tag{5.7}$$

5.2.11 Weibull Mean

The mean of a fitted Weibull distribution can be calculated from the parameters κ and λ, which are estimated during the model fitting process. The Weibull mean is:

$$\lambda\Gamma(1 + \frac{1}{k}) \tag{5.8}$$

where Γ is the Gamma distribution evaluated for $(1 + \frac{1}{k})$. For fire intervals, the Weibull Mean Probability Interval is a modelled analogue to the mean fire interval calculated from empirical data.

5.2.12 Weibull Median

As noted above (Sec. 5.2.3), median values are used throughout statistics to represent central tendency in non-normal or asymmetric distributions. This holds true for fire history, where interval distributions are often right-skewed. The median of a Weibull distribution is defined as the value for which half of the probability distribution is below, and half above, that value.The Weibull median probability interval (I_{WM}) is considered a robust estimator of central tendency and can also be calculated as:

$$\lambda(\ln(2))^{\frac{1}{k}} \tag{5.9}$$

5.2.13 Weibull Mode

The mode of a distribution is defined as the most common value, for data that are integers or compiled into bins. For a modeled probability distribution, the mode represents the frequency peak in the probability density function (pdf). The mode would thus represent the most common (probable) range of values for data set. In fire history, this would represent the most common fire interval.

The mode of a Weibull distribution is calculated using the parameters κ and ϵ:

$$\begin{cases} \lambda(\frac{k-1}{k})^{\frac{1}{k}} & k > 1 \\ 0 & k = 1 \end{cases} \tag{5.10}$$

5.2.14 Weibull Standard Deviation

If needed, the standard deviation of a Weibull distribution can be estimated using the parameters κ and ϵ, and the gamma distribution:

$$\sqrt{\lambda^2 \left[\Gamma(1 + \frac{2}{k}) - (\Gamma(1 + \frac{1}{k}))^2 \right]} \tag{5.11}$$

Note that this formula takes into account the skewness and dispersion of the data, and is thus preferred to a standard deviation calculated with an assumption of normality.

5.2.15 Weibull Skewness

Similarly, the skewness of a fitted Weibull distribution is estimated using the model parameters:

$$\frac{\mathit{\Gamma}(1 + \frac{3}{k})\lambda^3 - 3\mu\sigma^2 - \mu^3}{\sigma^3} \tag{5.12}$$

5.2.16 Exceedance Intervals

Exceedence intervals are values of a distribution for which of a value smaller (or larger) than that value has a probability of *p*. For example, If the upper 95% exceedence value of a fire interval distrubiton is 75 years, this indicates that 95% of all fire intervals are less than 75 years, and only 5 percent larger. Exceedence intervals are widely used in hydrology and climatology, e.g. to estimate the probability of an event of a given magnitude. This statistic is also highly useful in fire regime analysis for indicating the probability of short or long intervals.

In FHAES, exceedence intervals are displayed in the output table as: lower exceedance interval; upper exceedance interval; significantly short interval upper bound; and significantly long interval lower bound. Exceedence intervals are estimated using the probability density function (pdf) of the fitted Weibull distribution.

5.3 Seasonality

Careful dating of fire scars often allows information about when fires burned relative to the growth of individual tree rings to be estimated in the laboratory. The edges of the scar—the scar margins—can occur between rings or extend into xylem cells of an annual ring. Ring position is only an approximate proxy for actual calendar seasonality, since the time of formation earlywood or latewood of a ring varies by species, location, and year. If the phenology of a sampled species is known, then ring position can be translated into an estimate (of unknown accuracy) of calendar seasonality.

In FHAES, seasonality analysis summarizes the ring position of each fire scar (if entred by the user), and then summary statistics for the frequency distribution of fire scars by ring position.

5.4 Binary summary matrices

Binary matrices are a convenient way to summarize the occurrence (or non-occurrence) of fire across multiple plots over a period of record. In essence, binary data condense a fire record into a presence/absence (1,0) matrix with dimensions of **years** (rows) x **plots or trees** (columns). Binary matrices can include all events, or the input data can be filtered to include only years or plots meeting certain criteria. Binary matrices are also a convenient way to tabulate fire occurrence over a study area.

In FHAES, the binary summary matrices provide summaries of presence or absence of events, including fire, other injuries, or both. If an event is recorded then the matrix for that plot or tree x year cell takes a value of 1, whereas if the event is not recorded despite the fact the trees were capable of recording then the matrix includes a value of 0. If there are no data for that particular year (as occurs if the tree-ring record doesn't extend to that particular year, or other non-recording years) then a value of -1 is recorded in the matrix.

FHAES produces three types of binary summary matrices:

Binary site summary – a single summary binary matrix for the entire file, with one column per file (in other words, a vector of **years** x **1**).

Binary tree summary – a binary summary of the fire record but divided into individual trees (columns). In addition to the normal header row containing the site name, code or filename, the matrix has a second header row containing the tree code. Thus the dimensions of this matrix is **years** x **trees**.

NTP matrix – the NTP matrix contains three columns per file: one for the number of fires; one for the number of trees; and a third for the percentage of trees that were scarred. The dimensions of the NTP matrix is **years** x **3**.

5.5 Binary comparison matrices

FHAES generates a set of matrices that compare the fire record at two or more sites. These comparison matrices are the foundation of similarity analysis in fire history.

For any pair of sites in a given year, there are four possible outcomes:

- Both sites record fire – this is referred to as the *a* case.
- Only one site records fire – these are the *b* or *c* cases, where *b* or *c* are assigned each to one of the sites.
- Neither site records fire, called the *d* case.

For every year common to the two sites, the number of *a*, *b*, *c*, and *d* cases is compiled, along with the number of years of common record. FHAES then outputs these results in a series of files that report the number of years with each of the four outcomes. If multiple sites are selected for analysis, the resulting triangular matrices will have the same number of rows and columns, which will correspond to the number of sites, but the analyses are only for each pairwise comparison. The FHAES matrix files are:

A – number of years in which both sites record fire (1,1)

B – number of years only one of the two sites record fire (1,0)

C – number of years in which only the other site records fire (0,1)

D – number of years in which neither site record fires (0,0)

L – number of common years between each pair of sites

5.6 Similarity and dissimilarity matrices

FHAES calculates indices of multivariate similarity using the five binary output files summarized above. The similarity index used in FHAES is the Jaccard index, a widely-used statistic in ecological analysis.Using the four cases in a binary comparison, **Jaccard similarity** is computed as:

SJ = [A / (A + B + C)]where *A*, *B*, and *C* are the number of cases compiled in the comparison files. The motivation of the Jaccard index is to calculate the number of times to sites both have fire in the same year (*A*), and then express that as a proportion of all years in which fire occurred in one or the other sites, or both (*A* + *B* + *C*). Note that Jaccard does not use the *D* case in which neither site records fire. This is a suitable property for fire history analysis, as even in high-frequency systems most years at a given location are non-fire years unless the "site" is a very large area.

The Jaccard index returns values from 0 to 1 inclusive: $J\epsilon(0, 1)$.

Jaccard dissimilarity (or "distance") is 1-SJ; in other words, when SJ = 1 two sites are completely different, and when SJ = 0 they are identical.

The general form for a probability-corrected similarity index is:

$$Sp = \frac{P(z) - P(e)}{1 - P(e)} \tag{5.13}$$

Where Sp is the pth index, $P(z)$ is the probability of agreement between two pairs, and $P(e)$ is the expected probability of agreement based on chance.

		Site j	
	Outcomes	1	0
Site i	1	a (1,1)	b (1,0)
	0	c (0,1)	d (0,0)

This method can be illustrated with Cohen's index (S_{COH}), in which both (1,1) and (0,0) cases a and d are considered 'agreement', $P(a) = \frac{a+d}{N}$, where $N = a + b + c + d$. $P(e)$ is computed as the joint probability of sites i and j having a '1'; hence,

$$P(1i) = \frac{a + b}{N}, \tag{5.14}$$

$$P(1j) = \frac{a + c}{N} \tag{5.15}$$

$$P(e) = P(1i) \times P(1j) \tag{5.16}$$

Consider a comparison between a pair of sampling units with the following outcome:

		Site j	
	Outcomes	1	0
Site i	1	8 (1,1)	4 (1,0)
	0	5 (0,1)	83 (0,0)

Hence $a = 8$, $b = 4$, $c = 5$, $d = 83$, and $N = 100$. Then:

$$P(z) = \frac{8+83}{100} = 0.920$$
$$P(1i) = \frac{8+4}{100} = 0.120$$
$$P(1j) = \frac{8+5}{100} = 0.130$$
$$P(e) = 0.12 \times 0.13 = 0.016$$
$$S_{COH} = \frac{0.920 - 0.016}{1 - 0.016} = 0.919$$

Note that similarity in this case is dominated by the d (0,0) case. This represents a common outcome for rare events where d $>>$ a.

In the previous example, when both the a and d cases are considered 'agreement', the index can be dominated by d case when events (a) are rare. An alternative approach for rare events is to calculate similarity based on the positive outcomes only, e.g. in our context, event years, the a (1,1), b(1,0), and c (0,1) cases. Let $R = (a + b + c)$, the union of event years; then pairwise similarity is calculated as:

$$Sp = \frac{P(a) - P(e*)}{1 - P(e*)} \tag{5.17}$$

Where $P(a) = \frac{a}{L}$, the probability of the a case given a fire in either site, $P(1*_i) = \frac{a+b}{R}$, $P(1*_j) = \frac{a+c}{R}$, and $P(e*) = P(1*_i) \times P(1*_j)$, the probability of joint 1s occurring by chance in an event year. In the example given:

$$L = a + b + c = 8 + 4 + 5 = 17$$
$$P(a) = \frac{8}{17} = 0.471$$
$$P(1*_i) = \frac{8+4}{17} = 0.706$$
$$P(1*_j) = \frac{8+5}{17} = 0.765$$
$$P(e) = 0.706 \times 0.765 = 0.540$$
$$S* = \frac{0.471 - 0.540}{1 - 0.540} = -0.15$$

This index reflects only the distribution of the event cases a, b, and c. The outcome is negative if $(b + c) > a$, and positive if $a > (b + c)$, which complicates interpretation. To avoid this outcome the index can be expressed as $1 + S$, which occurs on 0,1; in this case, $S* = 0.85$.

Chapter 6

Sample Size Analysis

6.1 Introduction

Like all areas of paleoecological research, fire history relies on analysis of remnant evidence. While such evidence can provide a long time perspective on ecological processes, individual evidence generally represents an incomplete picture of the events and conditions at the time of its creation. In the case of fire history, fire scar formation and retention reflect a combination of deterministic and stochastic processes. Fire is not necessarily the cause of cambial injury in every scarred tree, even where fires have burned. Fire intensity (heat output per unit area) can be highly variable within stands due to variation in fuel mass and continuity, as well as fine-scale variation in winds, humidity, and topography. Tree characteristics (such as diameter, bark thickness and rooting depth) can also vary within stands, making some trees more susceptible to scarring than others. Once scarred, a variety of contingent factors affect the retention and preservation of lesions, including subsequent burning, mechanical injury, wood decomposition, and mobilization of resin into xylem cells in a zone from the heartwood to the injured surface. The net result of these factors is that individual trees provide an incomplete record of fire occurrence, even at the stand scale.

To counteract the limitations of records provided by individual trees, fire historians and ecologists typically composite the records from multiple trees in a stand or other scale of interest. In most fire regimes, records from individual trees overlap to some extent; i.e., there are some fires in common among trees, whereas other events may be detected on some trees but not others. Thus, as the number of trees sampled increases, additional fire dates are usually detected, but at a decreasing rate (Falk, 2004). This pattern is formally analogous to the "collector's curve" used in estimating species richness from a number of sample plots. For a given area, the number of species detected (s) is a function of the number of samples (trees or plots). As n increases, s generally increases at a decreasing rate, causing the collector's curve to flatten out with additional samples.

The sample size analysis tool is designed to ask a similar question for characterization of fire history in a study area. Have we sampled enough trees to capture the main fire dates, and to characterize properties of the fire regime (frequency, interval distribution, etc.)? If our sample size is too small, can we estimate how many more samples would be required to provide a reliable estimate of the site fire history?

Although the sample size analysis tool is designed to explore the effect of sample size on the observation of fire frequency, it is equally capable of exploring other event data such as insect infestations. The tool calculates the mean number of events per century observed in an increasing sub-sample of series within a data file. Multiple simulations are run by randomly picking series from the file to simulate the accumulation of trees in the total sample.

The sample size analysis tool in FHAES is a reimplementation of the original SSIZ tool written by Richard Holmes under the direction of Tom Swetnam at the Laboratory of Tree Ring Research, University of Arizona. The FHAES implementation of SSIZ removes the limitations in simulation number, sample size, and time span imposed by the original SSIZ program while dramatically speeding up analyses.

6.2 Performing analysis

The sample size analysis tool is launched from the tools menu or via the equivalent button on the FHAES toolbar. The screen (figure 6.1) is split into two halves: the left containing the analysis parameters; and the right the analysis results. The parameters required by the tool are outlined below:

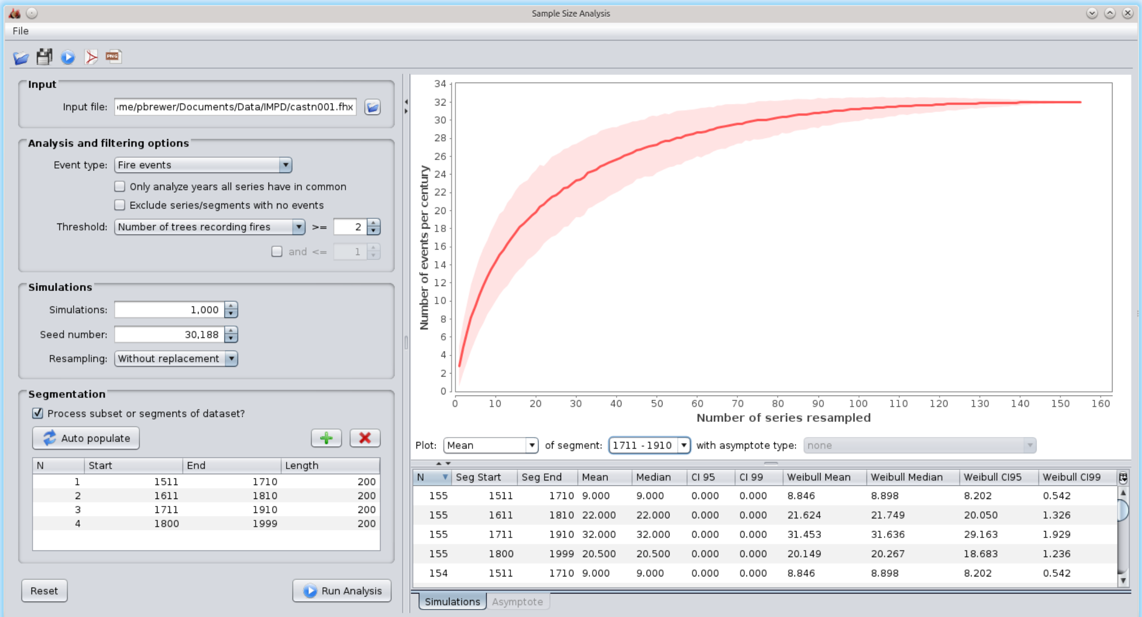


Figure 6.1: Screenshot of the sample size analysis tool. The screen includes the analysis parameters on the left and the results on the right.

Input file – provide an FHX format file containing the data you would like to analyse. If you would like to analyse data across multiple files you will need to use the 'Merge files' tool in FHAES first (see page 10).

Event type – you can choose to analyse: just fire events (in which case all lower case events are ignored in the FHX data file); just injuries (in which case upper case events are ignored); or fires and injuries together.

Simulations – here you specify the number of simulations or repetitions on the analysis you'd like to run for each stage of the analysis. The more simulations you run the smaller the confidence intervals, however the longer the analysis will take.

Seed number – the random selection of series is in fact pseudo-random. This means that when an analysis is done with the sample parameters and seed number the results will be identical[1]. The seed number should be a large integer and can be left as the default value unless you specifically want to generate results from a different randomised pool of series.

Resampling – FHAES supports resampling both with and without replacement. When 'sample with replacement' is chosen, each random selection of a series is done from the entire dataset which means that one series can be included multiple times. Conversely when sampling without replacement, each series can only appear in the random pool once.

Threshold – the threshold parameters determine how many times an event must be recorded in the file to be considered a true event for sample size analysis. The threshold can be determined either as an absolute number, or as a percentage within the dataset (either as a percentage of all trees or as a percentage of only those that are in recording status). If the threshold is set to $>= 1$ fire then all events within the dataset are used including those that are only represented by a single series. Often researchers prefer to exclude events recorded by just one tree as they can be indicative of very localised fires that have not played a significant role in the region. There is also the option of specifying an upper threshold to remove very large events from the dataset.

Common years – this option enables users to limit the analysis to only the years in common to all series within the file. This can be useful, for example, when a single series in the file extends beyond the temporal coverage of all the remaining series in the file. If all years are considered in such an analysis, then the events recorded by the long series may skew the analysis.

[1]This should be the case when run on different computers running the same major version number of Java; however it can only be guaranteed when run on exactly the same system.

Include series with no events – this option enables the user to choose whether to include or exclude series which do not include events. By excluding series with no events the user can interpret the result of the asymptote analysis as indicating the number of samples *with evidence of fires* required to adequately characterise the fire history of the study region. If non-event series are included, then the asymptote is indicative of the number of trees required to characterise the regime of the study area using samples from both scarred and non-scarred trees. This could be useful, for instance, if you are studying insect oubreaks where trees are sampled without any visible injury. Note that if you are running analyses on a subset of a series (either due to the common years option being enabled, or through segmentation) then a series will be excluded if there are no events within the time period being analysed, regardless of whether it has events elsewhere in the dataset.

Segmentation – segmentation parameters enable you to run sample size analysis on one or more time periods in the file. You can manually specify the start and end years for each segment by clicking the 'add' button and typing the values in the table. Alternatively you can use the 'auto populate' button to generate equally sized segments. The dialog asks for the first year you'd like analysed, the length of each segment and the lag between the start of each segment. For instance with a start year of 1600, a length of 100 and a lag of 50, the segments would run: 1600–1699; 1650–1749; 1700–1799 etc.

Plot variable – FHAES allows the user to select the output variable of interest, in units of centennial fire frequency (i.e., fires per 100 years). This variable is easily converted to other units (e.g. annual fire frequency, fire interval) as needed for analysis. FHAES provides fire frequency based on the (a) arithmetic mean, (b) arithmetic median, (c) fitted Weibull distribution mean, and (d) fitted Weibull distribution median. The dark red line is the central value of the variable; the shaded area indicates the 95th and 99th percentile confidence intervals (these are also provided in the output table).

Once you have entered your parameters, press the 'run analysis' button at the bottom of the screen or on the toolbar. Note that if you have chosen a very large number of simulations and have many series in your data file, the analysis may take several minutes to run.

6.3 Analysis results

The results of the analysis are shown in the tables and graph on the right hand side of the screen. Note that the plot variable can be changed even after the analysis is run, by using the "Plot" pull-down button.

The options on the chart enable you to visualise the the different measures calculated during the analysis. If you ran the analysis on multiple segments you can choose which segment to view. The chart can be exported to in both PNG and PDF formats by right clicking, and can also be copied and pasted into other applications. Some basic properties of the chart can be altered through the right click properties option.

> 💡 Once you have run your analysis you may prefer to hide the parameters panel by clicking the collapse button on the vertical divider in the middle of the screen. Likewise, the amount of space given to the chart and tables can be altered by dragging the horizontal divider.

Below the chart, the raw data produced by the analysis are shown in tables. These tables can be copied and pasted into other applications such as spreadsheet or statistical programs for further analysis. They can also be exported to tab delimited text files. Both options are accessed via a right click menu. Alternatively you can use the option in the file menu or the equivalent button on the toolbar to save the results to disk.

6.4 Interpreting results

FHAES calculates the response variable (fires per century) as if this were estimated from a single tree selected at random from the FHX file. The program then picks a second tree and re-calculates fire frequency, then a third, and so on until the number of trees sampled is equal to the total sample size in the file. If the user has chosen sampling with replacement, then any tree may be chosen more than once; Scheiner and Gurevitch (2001) and Legendre and Legendre (2012) are good guides on this issue.

The overall shape of the resampling curve is invariably a downwardly-inflected (that is, saturating) function, rising rapidly at low sample sizes and flattening out as sample size increases. This occurs because with small number of trees, the probability that any given tree will contribute a new event is high, but as numbers accumulate, the probability of a unique event declines. This “flattening” of the sample size curve is evidence that the study area has been adequately sampled, or in other words, the fire frequency of the study area has been accurately estimated. The different mathematical variables (mean, mean, fitted Weibull mean or median) generally have similar behavior, although the confidence intervals may vary.

Chapter 7

Superposed Epoch Analysis

7.1 Introduction

⚠ *Section in progress*

Superposed Epoch Analysis (SEA) is a statistical procedure used to evaluate the temporal relationships between the occurrence of key events and the high or low values in a time series of information related to the event (Prager and Hoenig, 1992). For example, Wilson et al. (2010) used SEA to evaluate how volcanic eruptions influenced annual climate indices for several years after eruptions. The most common application of SEA in dendrochronology has been to assess how climate variability (e.g., Palmer Drought Severity Index; Palmer, 1965) influenced fire occurrence in the years before and during fire; for example, Baisan and Swetnam (1997); Brown and Schoettle (2008); Flatley et al. (2013).

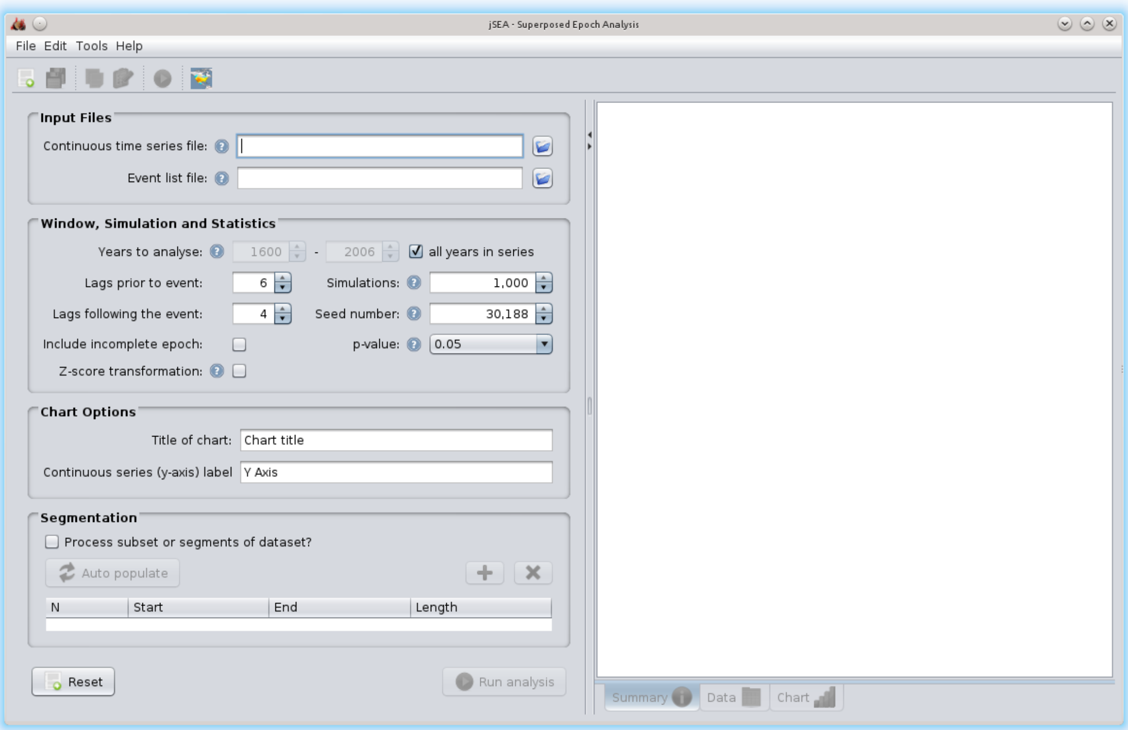


Figure 7.1: Screenshot of the jSEA analysis tool. The screen includes the analysis parameters on the left and the results on the right.

7.2 Input files

SEA requires two data files as input: a discrete time series and a list of key events. Both files should be provided as comma delimited (CSV) text files. Any header lines or comments should begin with an asterisk to ensure the comments are ignored by the input routine.

The key event list should be a simple single column of integer (whole numbers) years. You can create an event file from any FHX data file using the 'create event file' option in the Data menu of the main FHAES window. Alternatively you can use a text editor to create a comma delimited file of key event years. The year can be positive or negative, depending on its relative relationship to beginning of the Common Era (CE). The last line should end with an End Of Line character (EOL). FHAES does this automatically.

The time series file should contain two columns. The first column contains the year (as an integer) and the second the data value (as a decimal). The year and the data value can be positive or negative. The rows of the file should be in sequence, the oldest at the beginning and the most recent at the end. The separator between the year and value can be spaces, tabs, or commas. The last line should end in an EOL.

If you need to view or edit the files to ensure they meet these criteria, use a text editor.

7.3 Window, Simulation, and Statistics

The main parameters for the SEA are found in the 'Window, Simulations and Statistics' panel of the jSEA dialog (see figure 7.1). An explanation of each parameter is given below:

Years to analyse – Specify the time period over which the analysis should be performed. By default this will be all the years in the data file, but can be restricted to a subset if desired. Note this is separate to segmentation of the time periods handled in the segmentation panel.

Lags prior to event – Specify how many years prior to the event in question should be analysed.

Lags following the event – Specify how many years following the event in question should be analysed.

Include incomplete epoch – An incomplete epoch occurs when there is an event near the beginning or end of the time series. In this case, the window of analysis around the event overlaps the beginning or end of the series.

Simulations – Number of simulations to run. Increasing the number of simulations increases the analysis time.

Seed number – The analysis requires a pseudo-random component which is seeded with the seed number (a large integer value). Running analyses with the same seed number enables produces the same results. You can leave the seed as the default number unless you specifically want to generate results from a different randomised pool.

p-value – The cutoff value to use for statistical significance.

7.4 Segmentation

SEA can be performed independently on segments of the dataset. This is useful, for example, when comparing two time periods with different regimes.

You can manually specify the start and end years for each segment by clicking the 'add' button and typing the values in the table. Alternatively you can use the 'auto populate' button to generate equally sized segments. The dialog asks for the first year you'd like analysed, the length of each segment and the lag between the start of each segment. For instance with a start year of 1600, a length of 100 and a lag of 50, the segments would run: 1600–1699; 1650–1749; 1700–1799 etc.

7.5 Historical note

In dendrochronological research, SEA was originally calculated using the FORTRAN program EVENT written in 1994 by Richard Holmes at the direction of Thomas Swetnam (Laboratory of Tree-Ring Research, University of Arizona). The last version of EVENT (6.02) was released in 2001 and is available from the Dendro Program Library (DPL; Holmes, 1983). Superposed epoch analysis has been more commonly performed in the past 20 years using FHX2 (Grissino-Mayer, 2001). FHX2 performs SEA using a module called FHEVENT which until March, 2016 has been the original version of EVENT. This original version did not adjust the range of the series to match the range of the event series. If the series has a broader range than that of the events, numbers chosen during the Monte Carlo randomization procedure can include numbers outside the event range, introducing error. Later versions of EVENT (6.02) removes values outside the common ranges of the event and time series.

7.6 Analytical background

SEA compares the climate conditions during event years to the prevailing climate conditions during a defined period of time in which the events occur. SEA uses Monte Carlo randomization to establish confidence intervals of climate during analysis period. The mean and variance of climate in the event years is then compared to the climatic confidence interval.

SEA compiles values for the climate time series in each event year ($t = 0$), and then for any prior or subsequent years selected in the input screen. For example, an investigator interested in antecedent climate conditions to fire years might include 4 years prior to a fire year ($t =$ -1, -2...-4).

SEA compiles these event year and antecedent year values for each event, and creates a matrix in which the mean and variance in all event years is calculated, as is the mean and variance of antecedent years; this is the process of "superposition" which gives the procedure its name. In dendrochronology, we align multiple events of some kind, and then examine the temporal antecedent (and subsequent, if appropriate) conditions common to these events. FHAES plots histogram bars to indicate the mean climate values of the superposed event or antecedent years.

To determine the confidence intervals of the background climate series, SEA selects sets of years at random from the full time series. This procedure is iterated as directed by the user to establish 95th and 99th confidence intervals of the full climate time series. In practice, the variance in confidence intervals stabilizes at roughly 2x the length of the series, which can be used as a starting guide to the number of iterations required. Given the speed of modern computing systems, there is little cost to running a larger number of iterations for CI calculation.

SEA tests a null hypothesis of no difference between the climate values in the event years compared to a random draw of climate values in the overall climate series. In other words, SEA asks whether the association between a set of key events and an continuous variable is stronger than would be expected if events were located randomly in the time series. If values of the continuous series are significantly different in events years, H0 is rejected.

Chapter 8

Fire History Charts

FHAES includes the tools necessary to produce publication quality fire history charts. These charts provide a powerful method for illustrating the fire regime of a site or region.

Charts are produced on a file-by-file basis and are available on the 'chart' tab of the main screen.

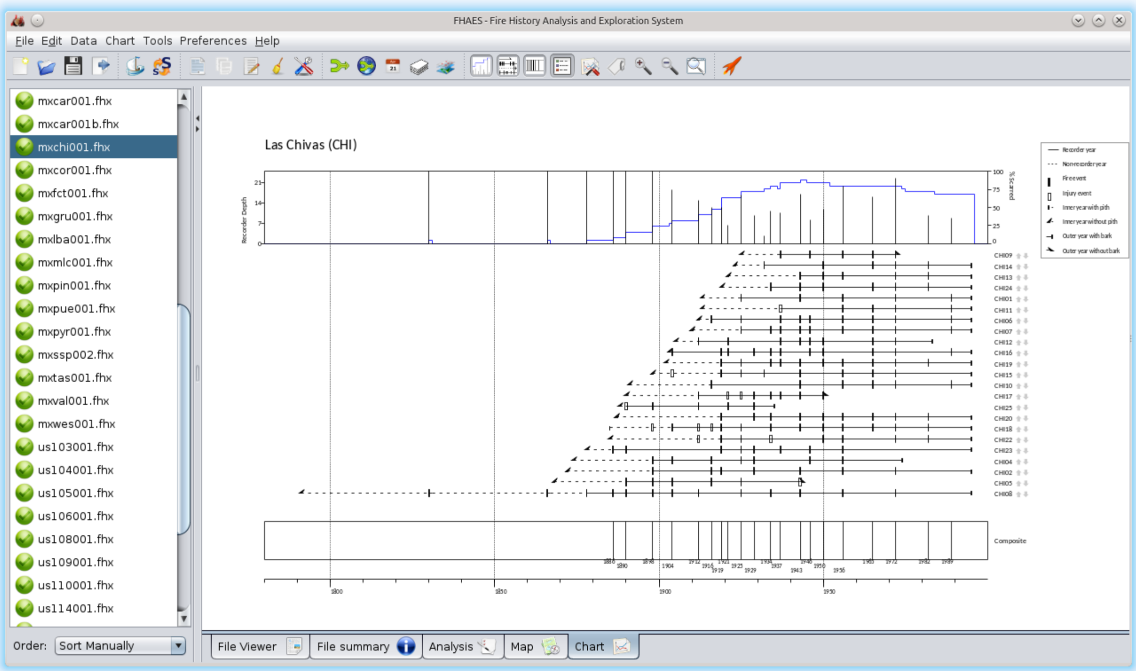


Figure 8.1: A typical fire history chart produced by FHAES. The chart has three optional components: fire index plot (top); fire chronology plot (middle); and fire composite plot (bottom).

8.1 Chart components

There are three components to a fire history chart, each or which can be included or removed as desired. The first (shown at the top of figure 8.1) is the **fire index plot**. This includes a histogram showing the sample depth for each year (i.e. how many trees are recording the fire history in each year) and a bar chart illustrating what percentage of these trees record a scar event.

The second component is the **fire chronology plot**. This shows a bar for each sample in the file illustrating the timeline for the tree e.g. the start and end year for each sample and all fire events. Through the use of various symbols the plot illustrates whether the tree is recording fire histories or not; when a tree records a fire scar or injury; and whether the sample starts and ends with pith and bark or not. Figure 8.2 shows the symbols used by this plot for each feature.

The third and final component is the **fire composite plot**. This shows whether the samples in the site or region as a whole record a fire event depending on certain threshold criteria set in the plot preferences. When the criteria are met, a line is marked on the plot for that year. The criteria can be set so that only years where greater than a specified percentage of trees record an event are marked. It is also possible to require a minimum number of samples so that events recorded by small number of trees when the sample depth is very low are not shown. These criteria are set by going to *Edit* ➔ *Filter Options* ➔ *Composite Axis Filters*.

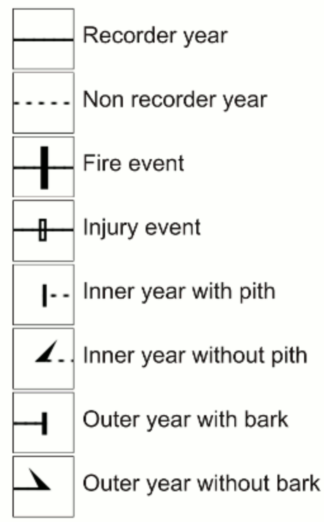


Figure 8.2: Legend for fire chronology plots.

Each of the chart components can be displayed or hidden by toggling them on and off using the toolbar buttons, through the chart menu, via the right click popup menu or via the chart properties dialog described below.

8.2 Modifying the chart

The main features of the chart can be altered through the chart properties dialog. This can be accessed through the toolbar, menu or by right-click popup menu. The dialog is split into four tabs: Generic options; Index plot; Chronology plot; and Composite plot (see figure 8.3). Options that alter the general appearance of the entire plot are located on the generic options tab, while the remaining tabs alter options specific to the three main parts of the chart.

The options specified in the chart properties dialog are remembered between sessions. If at any time you'd like to revert to the default settings you can press the 'revert to defaults' button at the bottom of the dialog.

8.2.1 Generic options

The top panel sets the font family to use throughout the chart, as well as whether to include a legend and title. The title can be styled and the title text itself can be overriden (the default coming from the metadata of the FHX file).

The next panel specifies details about the x-axis (timeline) primarily what time period the chart should cover. This defaults to the full extent of the data file. The font size for the timeline labels can also be altered.

The 'Ticks and Vertical Guides' panel allows the user to enable/disable these features as well as control their style. Major and minor ticks are the small graticule lines displayed on the timeline axis. Here the interval for each can be defined. Vertical guides are lines that are drawn across the entire chart to help align the reader. The interval is fixed to that of the major tick, and the style, width and color of the guide can be set.

The 'Highlighted Years' panel allows the user to annotate the chart with extra guide lines to help illustrate a year (or years) of interest. When enabled, years can be added and removed using the plus and cross buttons, and Like the standard periodic vertical guides, the highlighted year lines can also be styled.

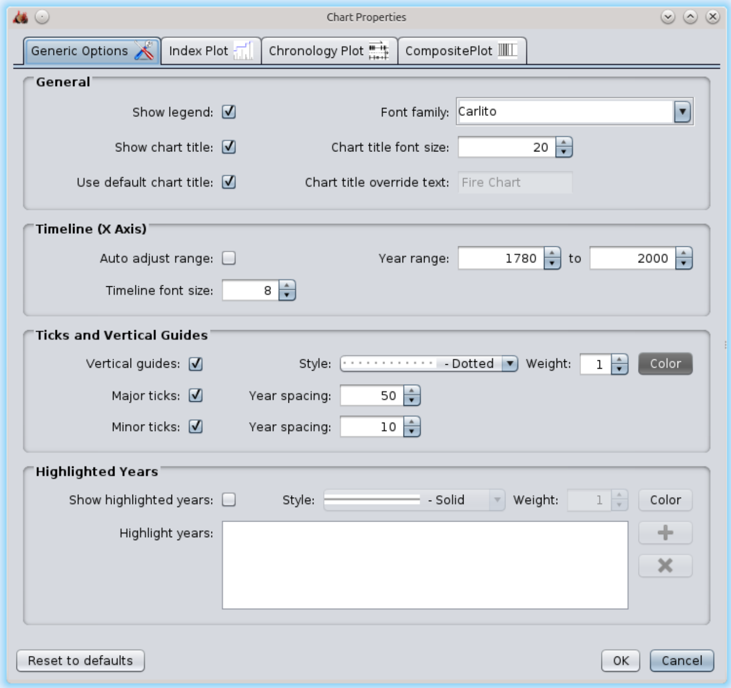


Figure 8.3: The chart properties dialog provides many options for modifying the content and style of fire history charts

8.2.2 Index plot options

The Index Plot tab provides options for tailoring the index plot panel at the top of the chart. The index plot can be enabled/disabled using the checkbox at the top of the panel and the height of the index plot panel can be set here too.

The 'Components' panel allows the user to specify what data values to include. Typically the index plot contains a histogram of sample depth and a line chart of percent scarred. In FHAES you have the option of specifying whether the sample depth histogram is based on complete sample depth or recording sample depth (i.e. only count samples that are in recording status). FHAES also has the option of adding a sample threshold line. This is a simple horizontal line at the specified sample depth. This is typically used to indicate the point at which the sample depth becomes significant, the value being derived from an sample size analysis (see chapter 6). The remaining panels enable the user to style the axis titles.

8.2.3 Chronology plot options

The chronology plot tab provides options of tailoring the central sample-by-sample fire history plot. The top panel gives options for showing/hiding and styling the labels as well as which series to plot.

The next panel provides options for showing/hiding different features. For instance if your data file has both fire and other injuries, but you are only interested in seeing fire events, the injury markers can be hidden.

The bottom panel provides the ability to style series categories. This panel is only relevant if you enable sorting by categories (see section 8.3).

8.2.4 Composite plot options

The final tab controls the style of the bottom composite plot. The top panel provides options for basic chart size and title label style while the next panel provides options for how the composite years are calculated. The composite filter used here is the same as that provided for the 'create composite file' tool described in section 3.3.2.

The bottom panel styles the year labels on the composite plot. Years can either be displayed in long (e.g. 1996) or short (e.g. '96) style, and can be displayed horizontally, vertically or angled depending on preference.

8.3 Categories and sorting

The series within the chronology plot are by default displayed in the order in which they are recorded in the file. There are a number of other options in the *Chart* ➔ *Sort series by* menu including: name (alphabetically); first fire year; start year; end year; category; and order in file. These options are also available in the Chart Properties dialog.

The sort by category option enables you to group series into defined categories e.g. species, slope aspect, sub-groups etc. Unfortunately the FHX file format does not provide for sample-by-sample metadata (see section 4.8 for further information) so there is no way to define these categories programmatically. To define these categories manually, go you *Chart* ➔ *Edit categories*. Click the 'add new category' button against each sample and enter the category name. When you are done, click the save button.

This category information is saved to a CSV text file next to your original FHX data file. The format of this file is very simple and self-explanatory so if you have your metadata stored in a structured format elsewhere (e.g. database or spreadsheet) you should be able to generate the category files for each of your FHX files quite easily.

8.4 Exporting charts

Once you are happy with your chart you can export to one of three image files for use in publications and reports. The PNG format is a raster image format which is suitable for inserting into word processing documents and basic reports. It is however not very suitable for high quality journal publications. In this case you should use either the PDF or SVG vector formats. The nature of these formats means that can be scaled to any size with not loss of quality. Both formats are widely supported by vector editing programs which provide you with the ability to further tailor the charts beyond what FHAES offers.

To export the current chart go to *File* ➔ *Export chart* ➔ *Export current chart as...* then in the file dialog specify the filename and the file format you'd like to use.

Alternatively you can export charts for all the files you currently have loaded by going to *File* ➔ *Export chart* ➔ *Bulk export to* choosing the format you would like to use. You then need to specify a folder where the exported charts should be saved. The charts will be named the same as the input FHX files but with the .pdf, .svg or .png extensions according to the format you specified.

8.5 Clarification of component widths

One aspect of the chart drawing that may cause confusion—especially for charts with few years—is the width of some of the chart components.

The width of the percentage scar columns, chronology event markers and composite plot columns are all fixed regardless of x-axis scale. This is to ensure a clear and uniform-looking chart whether it decades or millennia of data are drawn. These data points are plotted to coincide with the tick-marks on the x-axis. If two data points are shown in adjacent years, then there will be a small gap (depending on the scale of the x-axis) between them.

The horizontal lines for each sample in the chronology plot, as well as the blue sample/recorder depth line in the index plot are in contrast, drawn continuously with no gaps. This gives the sample/recorder depth line a 'saw-tooth' style plot.

Appendix A

Recorder Years

The issue of what constitutes a 'recorder year' is actually quite complex. Some researchers feel that a tree can only ever be in recording status after it has been injured by fire. Others feel that this is not necessarily the case depending on the species and ecosystem you are working with.

Within FHX data files the issue is confused by two factors. The first is that the design of the format means that only one character can be used per year for each sample. It is therefore not possible to explicity specify if a year in which there is an injury whether the tree was in recording status or not. Likewise you can't specify the recording status as well as indicating the inner/outer rings, or pith/bark. The second issue is that the dot symbol has multiple meanings depending on the context:

- Filler symbol before the first ring
- Filler symbol after the last ring
- A dateable ring prior to the first scar (i.e. prior to recording status)
- An eroded ring (or commonly a succession of such rings) before the intial scar when fire cannot be determined to be present or absent
- An eroded ring (or commonly a succession of such rings) after the intial scar when fire cannot be determined to be present or absent

The standard way to decide if a year is interpreted as 'recording' or not in FHAES is described in figure A.1. This flow chart assumes you are at the beginning or within a series (i.e. it doesn't describe handling the initial filler symbols). This method is the same as the convention used within FHX2. The chart assumes you the analysis is being carried out with the event type set to 'fires' or 'fires and injuries'. If the event type is set to 'injuries' then the case of the characters should be inverted.

The modular way in which FHAES has been developed has led to one portion of FHAES using a different, more simplistic method of determining whether a sample is 'recording' or not. The FHMatrix module used in the calculation of the binary comparison and similarity/dissimilarity matrices (see sections 5.5 and 5.6) relies upon this simpler method. This method does not consider any year prior to the first fire year as recording. All fire and injury events are considered recording years, but all dot, pith, bark, inner ring and outer ring symbols are regarded as non-recording. The method is more transparent than the standard method but may be at odds with some researchers concepts of a recording year given the departure from the traditional concept used in FHX2. It is therefore important to understand these differences when interpreting binary comparison and similarity/dissimilarity matrices, especially if your data files contain recording years before the first fire event.

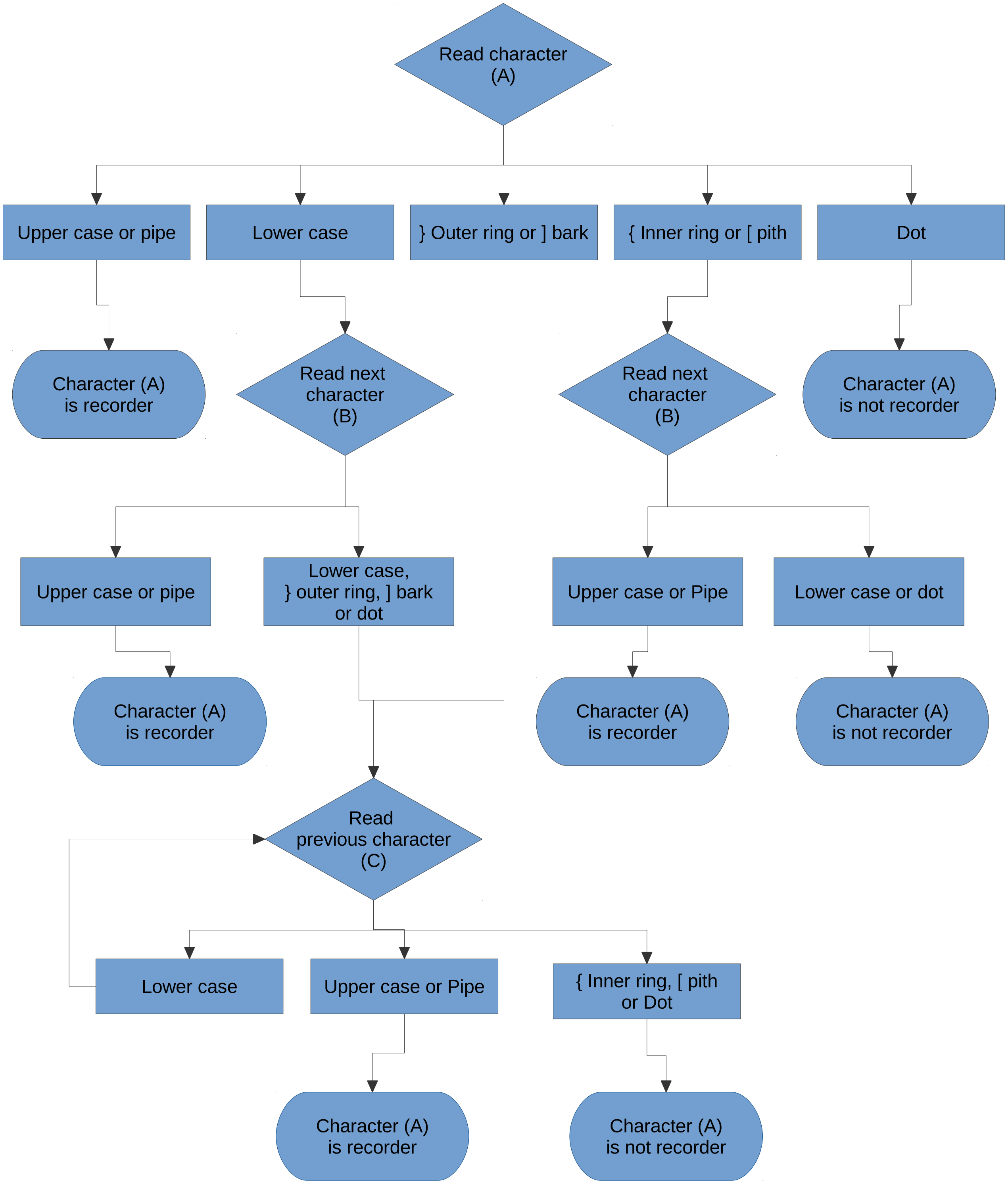


Figure A.1: A flow chart illustrating how FHAES (with the exception of the FHMatrix module) determines if a tree is in recording status or not. Note the chart assumes you are at the beginning or within a series and therefore does not describe the handling of the initial filler dot symbols. The chart is only applicable as drawn for analyses where the event type is set to 'fires' or 'fires and injuries'. If the event type is set to 'injuries' then the flow chart should be interpreted with the case of all characters inverted, i.e. replace 'Upper case' with 'Lower case' and vice versa.

Appendix B

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References

Baisan, C.H., Swetnam, T.W., 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, USA. Canadian Journal of Forest Research 20, 1559–1569.

Baisan, C.H., Swetnam, T.W., 1997. Interactions of fire regime and land-use history in the central Rio Grande Valley. US Department of Agriculture, Forest Service Research Paper RM-RP-330 .

Brewer, P.W., Murphy, D., Jansma, E., 2011. TRiCYCLE: a universal conversion tool for digital tree-ring data. Tree-Ring Research 67, 135–144.

Brown, P.M., Schoettle, A.W., 2008. Fire and stand history in two limber pine (*Pinus flexilis*) and Rocky Mountain bristlecone pine (*Pinus aristata*) stands in Colorado. International Journal of Wildland Fire 17, 339–347.

Dieterich, J.H., Swetnam, T.W., 1984. Notes: Dendrochronology of a fire-scarred ponderosa pine. Forest Science 30, 238–247.

Falk, D.A., 2004. Scaling rules for fire regimes. Ph.D. thesis. University of Arizona. Tucson, Arizona.

Flatley, W.T., Lafon, C.W., Grissino-Mayer, H.D., LaForest, L.B., 2013. Fire history, related to climate and land use in three southern appalachian landscapes in the eastern united states. Ecological Applications 23, 1250–1266.

Fritts, H.C., 1976. Tree rings and climate. Academic, San Diego, Calif.

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

Grissino-Mayer, H.D., 1999. Modeling fire interval data from the american southwest with the weibull distribution. International Journal of Wildland Fire 9, 37–50.

Grissino-Mayer, H.D., 2001. FHX2 - software for analyzing temporal and spatial patterns in fire regimes from tree rings. Tree-Ring Research 57, 115–124.

Holmes, R.L., 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin 43, 69–78.

Jansma, E., Brewer, P.W., Zandhuis, I., 2010. TRiDaS 1.1: The tree-ring data standard. Dendrochronologia 28, 99–130.

Johnson, E., 1992 .

Johnson, E., Van Wagner, C., 1985. The theory and use of two fire history models. Canadian Journal of Forest Research 15, 214–220.

Legendre, P., Legendre, L.F.J., 2012. Numerical ecology. Elsevier, Amsterdam, The Netherlands.

Palmer, W.C., 1965. Meteorological drought. volume 30. US Department of Commerce, Weather Bureau Washington, DC, USA.

Prager, M.H., Hoenig, J.M., 1992. Can we determine the significance of key-event effects on a recruitment time series?—a power study of superposed epoch analysis. Transactions of the American Fisheries Society 121, 123–131.

Romme, W., 1980. Fire history terminology: Report of the ad hoc committee., in: Stokes, M., JH, D. (Eds.), Proceedings of the Fire History Workshop, October 20-24, 1980, Tucson, Arizona, US Department of Agriculture General Technical Report RM -81. pp. 135–137.

Scheiner, S.M., Gurevitch, J., 2001. Design and analysis of ecological experiments. Chapman & Hall, New York.

Stokes, M.A., Smiley, T.L., 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago.

Wilson, R., Cook, E., D'Arrigo, R., Riedwyl, N., Evans, M.N., Tudhope, A., Allan, R., 2010. Reconstructing enso: the influence of method, proxy data, climate forcing and teleconnections. Journal of Quaternary Science 25, 62–78.

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